NECA 417

Recommended Practice for Designing, Installing, Operating, and Maintaining Microgrids

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(This foreword is not a part of the standard)

Foreword

National Electrical Installation Standards™ (NEIS™) are designed to improve communication among specifiers, purchasers, and suppliers of electrical construction services. They define a minimum baseline of quality and workmanship for installing electrical products and systems. NEIS™ are intended to be referenced in contract documents for electrical construction projects. The following language is recommended:

> Microgrids should be designed, installed, operated, and maintained in accordance with NECA 417, *Recommended Practice for Designing, Installing, Operating, and Maintaining Microgrids* (ANSI).

Use of NEIS™ is voluntary, and the National Electrical Contractors Association (NECA) assumes no obligation or liability to users of this publication. Existence of a standard shall not preclude any member or non-member of NECA from specifying or using alternate construction methods permitted by applicable regulations.

This publication is not intended as a substitute for qualified design professionals. The design of microgrids and distributed energy resources, distributed generation and energy storage systems, requires the selection, sizing, and coordination of electrical power distribution system components, and should be performed under the supervision of qualified individuals, such as by qualified professional engineers.

This publication is intended to comply with the National Electrical Code (NEC). Because they are quality standards, NEIS may in some instances go beyond the minimum safety requirements of the NEC. It is the responsibility of users of this publication to comply with state and local electrical codes and Federal and state OSHA safety regulations as well as follow manufacturer installation instructions when installing electrical products and systems.

Suggestions for revisions and improvements to this standard are welcome. They should be addressed to:
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1. Scope

This Standard applies to microgrids and provides recommended practices for their design, installation, commissioning, operation, and maintenance.

1.1 Products and Applications Included

This Standard covers distributed energy resources, distributed generation and energy storage systems, and electrical power distribution system components and equipment associated with microgrids. This applies to:

- Microgrid Generation Systems
  - Solar photovoltaic Power Systems (NECA 412)
  - Wind Power Systems
  - Fuel Cells
  - Microturbines
  - Engine-Generators (NECA 404)
- Energy Storage Systems (See NECA 416)

Additionally, this Standard covers electrical power distribution system components and equipment associated with microgrids and energy storage systems. This applies to:

- Conductors
- Disconnecting Means
- Overcurrent Protection
- Grounding and Bonding

1.2 Products and Applications Excluded

This standard does not apply to:

- Distributed generation application process
- Interconnection agreements with electric utility providers
- Other sources of generation
- Sizing distributed energy resources or energy storage systems
- Remote power systems (microgrids that are not grid-connected due to physical isolation or other parameter without a connection to the electric utility grid)
- Electrical power distribution system planning and design (configuration)

1.3 Regulatory and Other Requirements

All information in this publication is intended to conform to the *National Electrical Code* (ANSI/NFPA 70). Installers shall follow the NEC, applicable state and local codes, manufacturer instructions, and contract documents when installing microgrids. Also, follow IEEE C2, National Electrical Safety Code (NESC)® for microgrid installations located on the utility side of the point of common coupling or where the electric utility provider is otherwise involved with microgrid installation, operation, or maintenance.

Only qualified persons as defined in the *National Electrical Code* familiar with the construction, installation, and operation of microgrids and distributed energy resources, distributed generation and energy storage systems, shall perform the technical work described in this publication. Administrative functions such as receiving, handling, and storing electrical power distribution system components and other tasks should be performed under the supervision of a qualified person. All work shall be performed in accordance with NFPA 70E, *Standard for Electrical Safety in the Workplace.*

General requirements for installing electrical products and systems are described in NECA 1, *Standard Practices for Good Workmanship in Electrical Construction (ANSI).* Other NEIS provide additional guidance for installing particular types of electrical products and systems. A complete list of NEIS is provided in Annex A.

1.4 Mandatory Requirements, Permissive Requirements, Quality and Performance Recommendations, Explanatory Material, and Informative Annexes

Mandatory requirements in manufacturer instructions, Codes, or other mandatory Standards that may or may not be adopted into law, are those that identify actions that are specifically required or prohibited and are characterized by the use of the terms “must” or “must not,” “shall” or “shall not,” or “may not,” or “are not permitted,” or “are required,” or by the use of positive phrasing of mandatory requirements. Examples of mandatory requirements may equally take the form of, “equipment must be protected . . .,” “equipment shall be protected . . .,” or “protect equipment . . .,” with the latter interpreted (understood) as “(it is necessary to) protect equipment . . .”

Permissive requirements of manufacturer instructions, Codes, or other mandatory Standards that may or may not be adopted into law, are those that identify actions that are allowed but not required, or are normally used to describe options or alternative means and methods, and are characterized in this Recommended Practice by the use of the terms “may,” or “are permitted,” or “are not required.”

Quality and performance recommendations identify actions that are recommended or not recommended to improve the overall quality or performance of the installation and are characterized in this Recommended Practice by the use of the terms “should” or “should not.”

Explanatory material, such as references to other Codes, Standards, documents, references to related sections of this Recommended Practice, information related to another Code, Standard, or document, and supplemental application and design information and data, is included throughout this Recommended Practice to expand the understanding of mandatory requirements, permissive requirements, and quality and performance recommendations. Such explanatory material is included for information only, and is identified by the use of the term “NOTE,” or by the use of italicized text.

Non-mandatory information and other reference Standards or documents relative to the application and use of materials, equipment, and systems covered by this Recommended Practice are provided in informative annexes. Informative annexes are not part of the enforceable requirements of this Recommended Practice, but are included for information purposes only.

2. Definitions

Closed Transition. The transfer of circuit(s) by paralleling two sources together for a period of time. Also known as a make-before-break transition, where the second source is connected in parallel with the first source, supplying the load(s), before the first source is disconnected.

Combined Heat and Power (CHP). Distributed energy resource which supplies both electricity and thermal energy to one or more loads.

Continuous Load. A load where the maximum power is expected to continue for 3 hours or more.

Distributed Energy Resource (DER). Generally, any form of decentralized generation, or energy storage capability.

Distributed Generation (DG). A small power plant located near an end-use customer, often interconnected with the utility distribution grid (versus the utility transmission system).

Electric Power Production and Distribution Network. Power production, distribution, and utilization equipment and facilities, such as electric utility systems that deliver electric power to the connected loads.

Energy Storage System (ESS). Equipment and systems capable of storing energy for use at a future time. ESSs include but are not limited to electrochemical storage devices (batteries), flow batteries, ultra-capacitors (or super-capacitors), and mechanical devices (flywheels, pumped hydro storage, and compressed air), among others, and also thermal devices (molten salt and others).

IEEE 1547. A set of industry standards for interconnecting distributed energy resources to electric utility systems. IEEE 1547 is being amended to accommodate microgrids and higher penetrations of DERs. See Annex A for additional information.

Interoperability. The capability of two or more networks, systems, devices, applications, or components to exchange and readily use information securely and effectively.

Islanding. The act of physically disconnecting a defined group of electric circuits from a utility system, and operating those circuits independently of the electric utility grid. Islanding capabilities are fundamental to the function of a microgrid.

Load Shedding. Intentional disconnection of a portion of the connected load in operation when the supplied load exceeds the connected energy resources capacity. Load shedding is typically performed in a prioritized order of less critical loads being disconnected first to preserve more critical loads in operation.

Microgrid. A group of interconnected loads and distributed energy resources (DERs), such as distributed generators, energy storage devices, or controllable loads, within clearly defined electrical boundaries that acts as a single controllable entity with respect to the electric utility grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

Open Transition. The transfer of one or more circuits from one source to another source which results in an interruption to the load(s) by disconnecting the first source and de-energizing the circuit(s) before connecting the second source and re-energize the circuit(s). Also known as a break-before-make transition.

Point of Common Coupling. The point at which the electric power production and distribution network (electric utility grid) and the customer interface occurs in a grid-connected system.

Renewable Energy Source. Any energy source that is naturally occurring and is replenished by natural process at a rate equal to or faster than the rate at which the resource is being consumed, such as solar (sunlight), biomass, biofuels, wind, rain, tides, waves, hydroelectric (stored potential energy), and geothermal, that is not derived from fossil fuel (such as coal, oil, or natural gas) or nuclear fuel, which are finite. Renewable energy sources cannot be exhausted and as such are constantly renewed after consumption.

Ride Through. The capability of electrical energy sources to stay connected to an electrical grid during short periods of lower electric grid voltage.

Solar photovoltaics (PV). Solar-electric energy cells in any of numerous forms and configurations.

Vehicle-to-Grid (V2G). A system in which electric utility grid operators have the ability via smart chargers to temporarily reverse the electric vehicle (EV) charging process to return stored energy from EV batteries to the grid. V2G energy storage can be used to release energy over a period of time ranging from seconds to a few hours.

3. Overview of Microgrids

3.1 General

Microgrids are an electrical distribution system or portion of a system that contains at least one distributed energy resource and associated controllable loads that can be operated in a controlled, coordinated way while either grid-connected or ~~while~~ not grid-connected (islanding) (see Figure 3.1). *NOTE: Distributed energy resources can be either distributed generation (DG) or distributed energy storage systems (ESS), both of which can be used to provide energy within a microgrid.* The loads and energy resources in a microgrid can be disconnected from, and reconnected to, the electric utility grid with minimal disruption.

[Insert Figure 3.1 here]

Figure 3.1 Elements of a Microgrid

Microgrids that operate both distributed energy resources and loads in a coordinated manner can offer benefits to both the customer and the local electric utility. Microgrids can provide improved electric service reliability, including supporting critical loads during natural or man-made disasters, and better power quality to end customers.

During an electric utility power interruption, whether scheduled, such as for maintenance or testing, or unscheduled, such as for a storm-related outage, microgrids operate in island mode, and their distributed energy resources maintain customer loads in operation when the customer loads would otherwise experience an outage.

Utility benefits of microgrids include the ability to address overload problems using distributed energy resources, or by removing customer loads from the utility system, and the ability to perform maintenance on the utility system while customer loads remain in service with the microgrid operating in island mode.

When a microgrid is operating grid-connected, the electric utility establishes the electrical operating parameters for the microgrid, such as voltage magnitude and frequency. Microgrid distributed energy resources typically operate in parallel with the electric utility with both the utility and microgrid energy sources supplying a portion of the power consumed by the loads within the microgrid. The result is that microgrid distributed energy resources reduce loading on utility system distribution circuits, and provide voltage support by supplying at least a portion of the loads within the microgrid.

When a microgrid is operating in island mode, the microgrid distributed energy resources (generation and/or storage), establish the electrical operating parameters for the microgrid independently of the electric utility. Microgrid energy sources must be at least equal to, or, preferably, greater than, the connected microgrid loads to maintain electrical system operation. Consequently, for microgrids where the capacity of distributed generation is less than the peak load demand supplied by the electric utility grid, the microgrid control system must disconnect loads in excess of connected energy resources (load shed), or use energy storage systems to compensate for the energy shortfall from insufficient connected generation. As a result, properly sizing microgrid energy resources, both generation and energy storage, is essential.

NOTE: Microgrid energy sources must be capable of providing in-rush currents for transformer and motor starting, and must also be capable of supplying the reactive power consumed by induction machines, motors and transformers, during non-grid-connected operation (islanding).

Microgrid generation may be comprised of renewable sources, such as solar photovoltaic power systems and wind generation, or conventional energy sources, such as fuel cells, microturbines, and engine-generators, or any combination. See Section 3.3.

Energy storage may be used to provide ride-through capability for generation that is sized less than the peak load demand of the microgrid when operating in island mode. During times of light loading, energy storage is charged either by microgrid generation systems or by the electric utility. Energy storage can also improve power quality when operating in grid-connected mode by providing voltage stability and ride-through capability for momentary utility fluctuations.

When disconnected from the electric utility and operating in island mode, either unexpectedly or when planned, energy storage can be used to supply that portion of the connected load demand in excess of connected microgrid generation.

The microgrid control system is used to monitor electrical power distribution system operating parameters in real time, to dispatch energy resources and control their respective outputs, including disconnecting and reconnecting to the electrical utility grid, as needed, and to control loads, such as load shedding, when needed to preserve the microgrid electrical system when islanding.

3.2 Microgrids and the Electric Utility

Microgrids are beneficial for both the customer and the electric utility:

- Locating distributed energy resources (generation and energy storage) closer to loads, which reduces transmission and distribution loading and losses, and improves voltage control and the security of the electrical supply system.
- Installing additional distributed energy resources within microgrids, which can reduce the environmental impact of electrical power by delaying the construction of large-scale bulk power plants, and which can increase customer-owned renewable energy sources such as solar photovoltaic and wind power.
- Sectionalizing the electric power distribution network into self-sustaining microgrids, which improves the reliability of the electricity supply.

From the utility standpoint, microgrids, and distributed energy resources in general, present safety concerns due to backfeeds. Utility repair crews may encounter equipment and conductors that are unexpectedly energized by distributed energy resources while working on utility-owned equipment. Additionally, the transition of a microgrid from grid-connected to island and back, if not controlled, can result in fault-level currents to flow in the system if microgrid distributed energy resources are not synchronized at the time switches/circuit breakers are closed, paralleling the sources (switching from islanded to grid-connected mode), or when switches/circuit breakers are open (when switching from grid-connected to islanded mode). Finally, if the electrical operating parameters (voltage, frequency, and phase angle) are significantly different between grid-connected and island operation, end-user equipment can be damaged.

Consequently, microgrids must be designed, constructed, commissioned, operated, and maintained in accordance with requirements of the electric utility connected to the microgrid to ensure safe, reliable operation. To ensure compliance, follow the application process established by the electric utility connected to the microgrid when installing distributed energy resources for microgrid applications.

3.3 Microgrid Generation Sources

Distributed generation, when applied in a microgrid, must be capable of operating in parallel with the electric utility grid (grid-connected operation), and be capable of independently supplying the connected load when the microgrid is disconnected from the electric utility grid (islanding, or island mode operation).

Grid-connected distributed generation systems rely on the electric utility grid to establish the system operating voltage and frequency. When distributed generation systems are islanding, they no longer can rely on the electric utility grid to establish and maintain the electrical operating parameters of the system. Consequently, microgrid distributed generation systems must be capable of independently establishing and regulating their operating voltage and frequency, and supplying or sinking reactive power to the loads of the microgrid when operating as an island.

Distributed generation sources typically applied in microgrid applications include solar photovoltaic (PV), wind, fuel cells, microturbines, and reciprocating internal combustion engine-generators. Each distributed generation technology has limitations in its application and operation that makes it more or less suitable to meet the various goals of microgrid distributed generation. For instance, solar photovoltaic power and fuel cells typically generate DC power, and low-speed wind turbines and microturbines typically generate AC power of some frequency other than 60 Hertz, which is the operating frequency of the electric utility grid in the United States. Power from these sources must be converted into an AC waveform with voltage magnitude and frequency that is compatible with the electrical operating parameters of the electric utility grid.

3.3.1 Solar photovoltaic (PV) Power Systems

NOTE: See NECA 412 for additional information.

Solar photovoltaic (PV) power is electrical power that is generated from sunlight (see Figure 3.3.1). Solar cells convert light energy to a DC voltage. The DC voltage created by PV power systems must be converted into an AC waveform and connected to the electric utility grid using an inverter, which regulates power delivered from the PV power system to the electrical utility grid.

[Insert Figure 3.3.1 here]

Figure 3.3.1 Solar Photovoltaic (PV) Array

PV power is a passive generation technology in that power production is solely dependent upon the amount and duration of sunlight. In short, it is not possible to control (increase or decrease) PV power production in response to system loading, with the exception of covering solar panels to stop PV power production. *NOTE: Due to longer daylight hours, more energy is generated by PV systems during summer months than winter months*.

3.3.2 Wind Power Generation Systems

Wind power is electrical power that is generated from the wind (see Figure 3.3.2). In a wind turbine, wind pushes against fan blades that are connected to the shaft of an electrical generator. Wind turbines typically generate AC power with a variable magnitude and frequency of AC voltage.

[Insert Figure 3.3.2 here]

Figure 3.3.2 Wind Turbines

Similar to PV power, wind power is a passive generation source. Wind power output is solely dependent upon the wind blowing, and is mutually exclusive of system loading. In short, it is not possible to control (increase or decrease) wind power production in response to system loading, with the exception of applying a brake to stop the wind turbine rotor from turning. Moreover, wind power systems do not generate power when the windspeed is below the cut-in wind speed (the minimum wind speed at which the specific wind turbine can generate power) or above the cut-out wind speed (the maximum wind speed at which the wind turbine can safely generate power).

NOTE: Due to stronger, more sustained air currents and colder, more dense air, more energy is generated by wind power systems during winter months than summer months.

3.3.3 Fuel Cells

Fuel cells are electro-chemical devices that convert external supplies of oxygen and hydrogen into DC electricity, heat, and water with virtually no emissions (see Figure 3.3.3). Fuel cells operate on a variety of fuels, are modular, and can be operated in parallel to meet virtually any power requirement. Fuel cells can have extremely high operating temperatures and are particularly suited to combined heat and power (CHP) applications where waste heat from the fuel cell is recovered and used for one or more heating applications.

[Insert Figure 3.3.3 here]

Figure 3.3.3 Elements of a Fuel Cell

NOTE: While CHP applications use both thermal and electrical energy available from the generation technology, many times the primary purpose of fuel cell applications is thermal energy recovery from the fuel cell, with electrical energy production being a secondary benefit.

3.3.4 Microturbines

Microturbines are small, single-staged combustion turbines that consist of a compressor, combustion chamber, turbine, generator, recuperator, and power controller (see Figure 3.3.4). Microturbines typically generate AC power of some frequency other than 60 Hertz that must be converted into an AC waveform that is compatible with the voltage magnitude and operational frequency of the electric utility grid.

[Insert Figure 3.3.4 here]

Figure 3.3.4 Block Elements of a Microturbine

Microturbines operate on a variety of fuels, are modular, and can be operated in parallel to meet virtually any power requirement. Similar to fuel cells, microturbines have high operating temperatures and are particularly well suited to CHP applications.

3.3.5 Engine-Generators

NOTE: See NECA 404 for additional information.

Engine-generators are typically synchronous generators that are driven by an internal combustion engine powered by any of a variety of gaseous or liquid fuels (see Figure 3.3.5). Engine-generators are available in most single- and three-phase voltage configurations, including low-voltage (1000V or less) or high-voltage (above 1000V), with individual power ratings in excess of 2,000 kilo-Watts (kW). Engine-generators are modular and can be operated in parallel to meet any power requirement. Engine-generators can be physically located virtually anywhere, with fuel storage and emissions being the primary operating and environmental considerations.

[Insert Figure 3.3.5 here – use front page image from NECA 404]

Figure 3.3.5 Engine-Generator

3.4 Microgrid Energy Storage Systems

NOTE: See NECA 416 for additional information regarding Energy Storage Systems (ESS).

3.4.1 Overview

Microgrid energy storage systems (ESSs) provides advantages for short-duration applications, such as improved power quality and frequency regulation, and for longer-duration applications, such as support for renewable generation, operating or spinning reserves, and energy management:

- Power Quality: Energy storage can be used to improve power quality on a short-term or instantaneous basis, such as providing energy capacity and voltage support "ride-through" for momentary outages, reducing harmonic distortion, eliminating voltage sags, and reducing the impact of voltage surges.
- Frequency Regulation: Energy storage can be used to maintain the balance between energy supply and load demand to provide constant frequency on the grid.
- Renewables Support: Energy storage can facilitate or speed up the integration of renewable power production by storing energy produced during times of light loading, and releasing energy during times of peak loading.
- Operating or Spinning Reserve: Energy storage can be used to increase microgrid stability by releasing energy within a short period of time to meet unexpected increases in demand or reductions in supply, such as during generation or utility outages, or during equipment failures, and by providing bridging power during the transition between grid-connected and island operation.
- Energy Management: Energy storage can be used for load leveling, peak shaving, and arbitrage (storing energy at one time, such as during non-peak loading, to release it at another time, such as during peak loading) to improve efficiency and to reduce energy costs.

Typical ESS technologies employed for microgrid applications include:

- Battery Systems
- Flywheels
- Ultra-Capacitors or Super Capacitors
- Smart Charger Vehicle-to-Grid (V2G)

NOTE: Large-scale ESS that is not covered by this Recommended Practice includes Compressed Air Energy Storage (CAES), Pumped Hydro Storage (PHS), Thermal Energy Storage (TES), and Superconducting Magnetic Energy Storage (SMES). Additionally, stored hydrogen, such as from separating water molecules into oxygen and hydrogen atoms by electrolysis using renewable energy sources, is considered to be a fuel and not an ESS, and is not covered by this Recommended Practice.

3.4.2 Battery Systems

Battery ESS are interconnected battery strings, battery charge controllers, rectifiers, inverters, and associated protection and controls that are used to convert electricity into stored chemical energy for later release.

Batteries may be connected in series, in parallel, or both, to provide the required operating voltage, current, and power levels, and minimum discharge time required by the application(s) being supported by the battery system. Battery systems can provide large scale energy storage with the capacity to release energy over a period of time from seconds to hours.

Utility-scale battery technologies used for ESS applications include lead-acid, and advanced lead-acid batteries, large format Lithium-Ion battery systems, flow batteries, sodium batteries, and others depending upon the applications.

3.4.3 Flywheels

Flywheels store kinetic energy in a disk or cylinder with a large mass rotating at high speed. Flywheels are typically connected to the electrical power distribution system through a motor/generator that is used to spin the flywheel up to its rated speed using power from the electric utility grid. The kinetic energy stored in the rotating mass is returned to the electrical power distribution system when system frequency drops below the electrical frequency at which the flywheel is rotating and the flywheel slows, such as when load demand exceeds the connected microgrid generation during island operation.

Flywheels can charge and discharge energy quickly and frequently, while operating with high efficiency. Additionally, flywheels operate at system frequency in real time, providing an instantaneous response, making them well-suited for power quality applications, such as frequency regulation and voltage support. Flywheels provide energy storage with the capacity to release energy over a period of time from seconds to hours.

3.4.4 Ultra-Capacitors or Super Capacitors

Ultra-capacitors (also known as super-capacitors) store energy in an electric field supplemented by chemical energy storage. Ultra-capacitors have among the fastest response time of any energy storage device, and are typically used in power quality applications such as providing transient voltage stability.

Ultra-capacitors are capable of operating with a short recycle time, and are especially well-suited to being discharged quite rapidly, to deliver a significant amount of energy over a short period of time, such as for high-power applications that require short or very short discharge durations. Ultra-capacitors can be sized to release energy over a period of time ranging from seconds to hours.

3.4.5 Smart Charger Vehicle-to-Grid (V2G)

Electric vehicles (EVs) connected to the electric utility grid via smart chargers provide a source of stored energy available to microgrid operators who can temporarily reverse the EV charging process in response to a critical need in real time to partially discharge EVs connected to the microgrid (a process known as vehicle-to-grid or V2G). V2G energy storage can be used to release energy over a period of time ranging from seconds to a few hours.

3.5 Microgrid Control Systems

The microgrid control system must be designed to safely operate the system for grid-connected operation with distributed energy resources, generation, energy storage, or both, operating in parallel with the electric utility grid, and in island mode with distributed energy resources, generation, energy storage, or both, supplying the microgrid loads independently of the electric utility grid.

The microgrid control system architecture may be based on a central controller, or may be imbedded as autonomous parts of each distributed energy resource.

When the microgrid is operating in island mode, the control system must independently regulate system voltage and frequency, monitor and regulate real and reactive power generation in response to consumption within the microgrid, and protect equipment and components within the microgrid, while monitoring the electric utility grid in preparation for reconnecting upon restoration of reliable utility power.

When the microgrid is operating in grid-connected mode, the control system associated with the microgrid must control the voltage and frequency associated with the microgrid, the power output of distributed generation sources, and monitor and regulate the bidirectional power flow within the microgrid, with surplus power produced by microgrid generation sources potentially backfeeding microgrid ESSs and/or the electric utility grid.

4. Microgrid Operation

4.1 Microgrid Modes of Operation

Microgrids essentially have two steady-state modes of operation, namely grid-connected operation and island operation. The transition of the microgrid between grid-connected and island operation, and back, must also be carefully considered in the operation and control of the microgrid.

4.1.1 Steady-State Grid-Connected Mode

In grid-connected mode, the microgrid relies on the electric utility grid to establish the system operating voltage and frequency. Microgrid distributed energy resources, generation, energy storage, or both, individually synchronize to the reference source of the electric utility grid, which also acts as a buffer to operating anomalies for the microgrid distributed energy resources.

In grid-connected mode, microgrid generation sources deliver real (and perhaps reactive) power to the microgrid. If the microgrid generation power production is less than the operating loads of the microgrid, the electric utility grid delivers the balance of power required by the microgrid operating loads across the point of common coupling. If the microgrid generation power production exceeds the operating loads of the microgrid, power is delivered either to microgrid energy storage systems (ESSs), if installed, or to the electric utility grid through the point of common coupling.

In grid-connected mode, microgrid ESSs, if installed, are charged when power is delivered to the ESS from the electric utility grid or from microgrid generation sources. Microgrid ESSs can also be discharged by microgrid operators as needed to regulate power flow within the microgrid and to buffer operating anomalies for microgrid distributed energy resources, similarly to the electric utility grid.

4.1.2 Transition from Grid-Connected to Island Mode

The transition from grid-connected to island mode may be a planned event, such as preparing for scheduled electric utility maintenance, or may be unexpected, such as for a storm-related electric utility outage.

For a closed-transition, when the microgrid load remains in operation without interruption during the transition from grid-connected to island mode, the capacity of the microgrid distributed energy resources (generation and/or energy storage) in operation must at least be equal to (or preferably exceed) the aggregate operating microgrid loads. Alternatively, a subset of the operating microgrid loads must be disconnected (typically automatic load shedding) to ensure that the operating distributed energy resources are at least equal to or exceed the operating loads.

For an open transition from grid-connected to island mode of operation, the microgrid loads are interrupted (shut off). The microgrid control system must be capable of staging ~~both~~ distributed energy resources, generation, energy storage, or both, onto the microgrid electrical distribution system, along with staging loads less than or equal to the generating capacity of the connected energy resources.

4.1.3 Steady-State Island Mode

For steady-state island operation, microgrid distributed energy resources (generation, ESS, or both) must have both the ability to independently establish and regulate system voltage and frequency, and the ability to meet the real power and the reactive power requirements of the dynamic load in real time, including block loading (large, sudden increase in load) and motor starting.

Microgrid distributed energy resources (and any additional distribution system equipment) must be controlled in real time to maintain system operating voltage and frequency, and to supply/absorb reactive power as needed to maintain the microgrid electrical system in operation. Distributed energy resources must maintain voltage stability and have a highly responsive dynamic reactive capability, such as when starting large motors. Similarly, transient stability must be maintained for load steps, any distributed energy resource outage, and for any faults within the island.

If, at any time, the aggregate operating microgrid loads exceed the capacity of the microgrid distributed energy resources (generation and/or energy storage), the system voltage and frequency collapse, resulting in an outage of the microgrid. Load shedding can be used to reduce the operating load of the microgrid to within the capacity of the connected distributed energy resources when operating in island mode. Some distributed generation sources (such as fuel cells and microturbines) must be completely shut down on a temporary basis to enable controls to independently establish and regulate operating voltage and frequency. ESS can be used to provide system ride-through capability as specific types of generation (fuel cells and microturbines) are shut down and restarted to enable island operation.

Alternatively, synchronous engine-generators with the capability of establishing and regulating system operating voltage and frequency can be used to provide the reference voltage source for other types of distributed generation to individually continue operation in “grid-connected” mode, provided that the capacity of the synchronous machines to deliver reactive power is not exceeded. Distribution system equipment with additional reactive power capability, such as capacitors and synchronous motors, may be required to be paralleled with the microgrid distributed energy resources to meet the reactive power requirements of the loads.

4.1.4 Transition from Island to Grid-Connected Mode

Upon restoration of the electric utility source, and after an appropriate time delay, the microgrid transitions back from island mode to a grid-connected mode of operation.

For a closed transition, synchronizing the microgrid to the electric utility grid is permitted to be active, or passive.

Active synchronization is where the prime mover (if applicable) voltage and frequency controls of the microgrid distributed energy resources (generation and/or ESS) actively match the operating voltage, frequency, and phase angle of the islanded system to the electric utility grid as the reference voltage.

Synchronization is also permitted to be passive. Passive synchronization is the periodic, random occurrence of when the electrical parameters of two or more sources operating at slightly different frequencies are within acceptable tolerances for circuit closure.

Once the electrical parameters are within acceptable tolerances, either using active or passive synchronization, the microgrid automatically connects to (parallels with) the electric utility grid at the point(s) of common coupling.

For an open transition, the microgrid is essentially shut down. The distributed energy resources are disconnected from the microgrid electrical distribution system. The microgrid loads are interrupted, after which the disconnecting means at the point of common coupling is closed, re-energizing the microgrid electrical distribution system from the electric utility grid. The microgrid loads are restarted, and the microgrid distributed energy resources are synchronized and paralleled to the electric utility grid, either automatically or manually.

5. Interconnection Requirements

NOTE: The IEEE Standard 1547 family of documents governs the application of distributed energy resources, both distributed generation and ESS, in microgrid applications. During normal parallel operation with the utility, the distributed energy resources operate in accordance with IEEE Standard 1547. IEEE Standard 1547.4 covers key consideration for planning and operating microgrids. IEEE Standard 2030 provides additional guidance for ESS applications.

5.1 Point of Common Coupling

The point of common coupling is the interconnection between the electric utility grid and the microgrid. Electrical characteristics are monitored on both the utility side and the microgrid side of the disconnecting means at the point of common coupling. The disconnecting means, whether switch, circuit breaker, other power electronic interface, or some combination of devices, along with appropriate controls, is designed to meet grid interconnection standards, such as IEEE 1547 and UL 1741, to ensure suitability for the purpose.

5.2 Requirements for Grid-Connected Operation (IEEE 1547)

The IEEE Standard 1547 family of documents establishes uniform technical requirements for safely and reliably connecting distributed energy resources, both distributed generation and ESS, to the electric utility grid for microgrid applications. These technical requirements include voltage regulation, power monitoring, grounding, synchronization, connection to network distribution systems, backfeeds, disconnecting means, coordinated equipment ratings, abnormal operating conditions, power quality, and islanding.

NOTE: IEEE 1547 is not generally intended to address distributed generation with capacity in excess of 10 MVA ~~or more~~, generation sources of other than 60 Hertz operation, protection, control, or operating requirements of generation sources, or automatic transfer schemes with momentary (100 ms or less) closed-transition (make-before-break) operation.

5.2.1 Voltage Regulation

IEEE 1547 does not permit distributed energy resources to actively regulate voltage at the point of common coupling with the electric utility grid.

The electric utility typically maintains voltage throughout the electrical power distribution system within +/–5% of the nominal system voltage in accordance with regulatory standards. The unique strategy used by an electric utility company to maintain the voltage profile of individual distribution circuits typically evolves over time, and may include voltage regulation equipment such as load tap-changing transformers, and static or switched capacitor banks.

Distributed energy resources can negatively impact the distribution system voltage profile and the utility's approach to voltage regulation in several ways:

- Reduced load current in distribution circuits, which reduces voltage drop across the electrical power distribution system.
- Cycling of distributed energy resources, such as intermittent generation sources (solar photovoltaic (PV) power and wind power), can create can wide swings in power supplied by the electric utility to the microgrid.
- Inability of certain distributed energy resource technologies to generate reactive power, which could cause the microgrid to present itself as a low power factor load or generator to the utility.
- Significant single-phase distributed energy resources can create voltage imbalances in three-phase systems.

5.2.2 Power Monitoring

In accordance with IEEE 1547, individual and aggregate distributed generation sources rated 250 kVA and greater at the point of common coupling must be provided with the following monitoring provisions:

- Connection status of the distributed generation sources, whether connected to the electric utility grid or not.
- Real power output of distributed generation sources.
- Reactive power output of distributed generation sources.
- Operating voltage at the point of common coupling.

The purpose of power monitoring is to mitigate safety and operating concerns with distributed generation sources backfeeding the electric utility grid. Power monitoring may be waived by the electric utility company if the distributed generation sources are relatively small in comparison to system loading, or if system interlocks or protective relaying prevents distributed generation sources from backfeeding the electric utility grid, such as reverse power relaying that would prevent exporting power to the utility, and listed utility-interactive power inverters that prevent energy sources from supplying power to the system with no reference voltage waveform at the inverter input terminals.

5.2.3 Grounding

In accordance with IEEE 1547, the grounding scheme of microgrid distributed energy resources, both generation and energy storage, must limit equipment and system voltage to within equipment ratings during faults and during operation in island mode. Additionally, the grounding scheme for microgrid distributed energy resources must not interfere with the coordination of the utility ground-fault protection scheme.

Consequently, microgrid distributed energy resources must be carefully designed so that the grounding system is effective for both grid-connected and islanding modes of operation. The microgrid grounding scheme must be approved by the local electric utility company.

Microgrid systems connected to multi-point grounded-neutral electric utility systems must be effectively grounded, or must incorporate protective relaying to detect ground-fault overvoltage on the electric utility and disconnect from the grid.

Microgrid systems connected to ungrounded electric utility systems must not contain any continuous, conductive (metallic) path to ground from the primary feeder, with the exception of properly-rated surge protective devices (lightning arrestors) and/or high-impedance ground-fault-detection devices.

5.2.4 Synchronization

Synchronizing distributed energy resources, generation and energy storage, requires matching frequency, voltage magnitude, phase angle, and phase rotation within close electrical tolerances prior to connecting the generation sources together for parallel operation.

In accordance with IEEE 1547, microgrids require synchronization techniques and controls that closely match frequency, voltage magnitude, and phase angle during either automatic or manual synchronization that will maintain the system operating voltage at an acceptable level at the instant the microgrid is connected to the electric utility grid. Paralleling energy resources together when not synchronized can result in high levels of real and/or reactive power (and high currents) flowing in the electrical power distribution system, along with voltage fluctuations outside of the permitted operating range at the point of common coupling.

5.2.5 Connection to Network Distribution Systems

NOTE: In a network distribution system or secondary spot network, the load is supplied simultaneously from two or more sources that are synchronized, that operate in parallel, and that share the load under steady state conditions. Network distribution systems and network transformers are protected and controlled by secondary (low-voltage) network protectors, which are an assembly of a circuit breaker and *relaying and control equipment which monitors synchronization and permits automatic operation and control of the network distribution system. Network protectors disconnect network transformers under abnormal operating conditions, such as phase-loss and reverse power. Network protectors are highly sensitive to electrical parameters necessary to synchronize sources together, such as voltage and frequency, and to the directional flow of power. Consequently, many electric utilities do not permit distributed energy resources to parallel with network distribution systems.*

In accordance with IEEE 1547, network protectors used to protect or control a network distribution system with connected distributed energy resources must be rated and tested for such an application. Network distribution system equipment withstand ratings must not be exceeded when distributed energy resources are installed on the system.

In accordance with IEEE 1547, distributed energy resources can only connect to the microgrid in grid-connected mode when the utility network is being supplied by more than 50% of the installed network protectors. Finally, distributed energy resources cannot cause the operation or prevent the reclosing of any network protector installed on the network, and cannot cause any cycling (repeated opening and reclosing) of network protectors.

5.2.6 Backfeeds

In accordance with IEEE 1547, distributed energy resources must not backfeed the electric utility grid during a utility outage. Automatic relaying and controls must be installed at the disconnecting means located at the point(s) of common coupling to disconnect the microgrid from the electric utility grid upon the loss of the utility outage.

Additionally, manual disconnect switches are required at the point(s) of common coupling to be operated by electric utility company personnel to provide a visible disconnecting means to ensure that distributed energy resources do not backfeed the electric utility grid while utility company personnel are working on the system. See Section 5.2.7.

5.2.7 Disconnecting Means

A disconnecting means is a device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply. The purpose of disconnecting means is to ensure safety. In general, disconnecting means are required to de-energize and isolate equipment for maintenance, testing, and repairs at the location where the work is to be performed.

In general, distributed energy resources are required to have disconnecting means that simultaneously disconnect all ungrounded or phase conductors of the energy resource from all other conductors. For equipment that is energized from both the distributed energy resource and the electric utility, such as a utility-interactive power inverter or a transformer, disconnecting means are required to de-energize and isolate equipment between those sources from both the distributed energy resource supply conductors and the electric utility source supply conductors.

Disconnecting means are usually installed in circuits with a one-way flow of electricity from the electric utility source toward the load. Because microgrid distributed energy resources, both generation and energy storage, are supplying power to (backfeeding) the microgrid at all times they are in operation, disconnecting means for microgrid energy resources have special requirements.

In accordance with IEEE 1547, distributed generation sources must have readily accessible, lockable, visible disconnecting means between the electric utility grid and the distributed energy resources when required by the electric utility company that:

- Provide isolation of distributed energy resources from the electric utility grid.
- Prevent inadvertent energization (backfeed) of the electric utility grid when utility workers are present.
- Be an external, visible, gang-operated disconnecting switch readily accessible for operation and locking by electric utility personnel at all times.
- Be externally operable without exposing the operator to contact with live parts. If power operable, be manually operable in the event of a power supply failure.
- Be located between distributed energy resources and the point of common coupling with the electric utility grid within 3 meters (10 feet) of the point of common coupling. Alternatively, a laminated, weatherproof map indicating the location(s) of disconnecting means must be mounted adjacent to the point of common coupling.
- Be rated for the voltage and current requirements of the installation.
- Comply with applicable UL, ANSI, and IEEE standards, and be installed in accordance with all applicable local, state and federal codes.
- Be clearly, permanently marked “Distributed Generation Disconnect Switch,” with letters 10 mm (3/8 inch) or larger.
- Indicate backfed devices labeled with a warning that all contacts may be energized.

Verify the specific installation requirements for microgrid distributed energy resource technologies with the local electrical utility companies, which may have additional requirements.

NOTE: The NEC and NESC have additional requirements for disconnecting means for generation sources and energy storage systems.

5.2.8 Coordinated Equipment Ratings

In accordance with IEEE 1547, distributed generation system equipment must have sufficient ratings to withstand voltage and current surges which may be caused by lightning or switching transients on the system, and to withstand standing waves created by high-order harmonics from Pulse Width Modulation (PWM)-based power inverters that are reflected from termination points and are additive in conductors.

For systems with voltage and current surges from standing waves, the operating frequency of the power inverter must be changed, or capacitors, inductors, or filters must be added to the system to eliminate standing waves. Lightning and switching transients must be modeled, and the system must be designed for survivability and continued operation in the event of surges.

Distributed energy resources must have an interrupting device that will disconnect the energy source from the electric utility grid during fault conditions. As a minimum, the interrupting device must have sufficient capacity to interrupt the maximum available fault current at its location. This device must be sized to meet all applicable ANSI and IEEE Standards, and be installed in accordance with all local, state, and federal codes. *NOTE: In addition, depending upon the location, territorial and tribal codes may be enforced. Check with the local Authority Having Jurisdiction (AHJ) for guidance.*

Finally, distributed generation interconnection paralleling devices must be capable of sustaining 220% of the interconnection system rated voltage across the open contacts of the device. *NOTE: The maximum permissible operating voltage of the electric utility grid is 110% of the nominal system voltage. When actively synchronizing, the distributed generation source will attempt to match the voltage magnitude, frequency, and phase angle of the electric utility grid, within tolerances. Circumstances can occur when the electric utility grid and the distributed generation source are both operating for an extended period with the interconnection paralleling device in an open position, with the maximum voltage across the open contacts occurring when the distributed generation source and the electric utility grid are 180 electrical degrees out of phase.*

5.2.9 Abnormal Operating Conditions

In accordance with IEEE 1547, all frequency and voltage parameters for abnormal operating conditions must be monitored at the point of interconnection of distributed generation. These requirements provide guidance for frequency and voltage relay and timing settings to ensure that:

- Distributed generation protective relaying continuously monitors voltage magnitude (either on each phase-to-phase or each phase-to-neutral, depending upon circuit configuration) and frequency of the voltage waveform.
- Distributed generation protective relaying disconnects distributed generation sources from the electric utility grid within specified times for specified fluctuations in voltage waveform or system frequency.
- Distributed generation sources disconnect from the electric utility grid prior to electric utility recloser operation. *NOTE: Disconnection is required to prevent out-of-phase closure of the utility to the microgrid in the event that distributed energy resources are not synchronized to the utility source at the time of recloser operation.*
- Distributed generation sources do not backfeed the electric utility grid when the electric utility grid is faulted.
- Distributed generation does not reconnect to the electric utility grid after a fault or significant fluctuation in voltage or frequency until the voltage and frequency of the electric utility grid are restored to acceptable levels for an adjustable period of at least five minutes.

5.2.10 Power Quality

In accordance with IEEE 1547, distributed energy resources must maintain the power quality of the electric utility grid. Distributed energy resources may not create objectionable flicker to other customers, and may not contribute DC current or harmonic current to the electric utility grid in excess of limits defined in IEEE 1547.

5.2.11 Islanding

In accordance with IEEE 1547, distributed generation must disconnect from the electric utility grid within two seconds when an "unintentional island" is created and distributed generation sources energize a portion of the electric utility grid which is separated from the rest of the grid (island). *NOTE: Disconnecting within two seconds is sufficient time for distributed generation sources to disconnect from* *the circuit before utility reclosers operate. Islanding may also be prevented by limiting the capacity of distributed generation sources with respect to the connected load.*

NOTE: In accordance with IEEE Standard 1547.4, an intentional island is the result of "intentional events for which the time and duration of the planned island are agreed upon by all parties involved." A microgrid operating in island mode, therefore, is considered an intentional island, and distributed generation sources are not required to disconnect from the microgrid when the microgrid is operating in island mode. The intent of IEEE 1547 to prevent distributed energy resources from backfeeding the electric utility grid during a utility outage is met when the microgrid, operating in island mode, disconnects from the utility grid, thus preventing the microgrid from backfeeding the utility grid.

In accordance with IEEE 1547.4, voltage disturbances must be quickly damped, and protection schemes both within the microgrid and for the electric utility grid must not be affected during the transition from grid-connected to island operation.

Additionally, in accordance with IEEE 1547.4, the microgrid, while operating in island mode, must have sufficient distributed energy resources, either generation, ESS, or both, to ensure that loads are powered with adequate power quality. Microgrid control systems must have sufficient controls to be able to regulate both voltage and frequency within acceptable operating ranges independently of the electric utility grid.

6. Sizing Conductors

Conductors for microgrid distributed energy resources, generation and energy storage, must be sized to safely carry current considering minimum circuit ampacity, voltage drop, and conductor insulation and termination temperature ratings and limitations. *NOTE: A discussion of voltage drop is beyond the scope of this Standard.*

Both ungrounded, or phase, and grounded, or neutral, current-carrying conductors of distributed generation supply circuits have requirements for sizing based upon the type of technology. Calculating minimum circuit ampacity for generation supply conductors is determined from the continuous output current rating of the source, adjusted by any Code-required multipliers for the specific type of generation.

6.1 Sizing Ungrounded or Phase Conductors

The size of ungrounded or phase conductors (which deliver supply energy to equipment) is determined from the maximum circuit current, which includes multipliers such as for continuous loading, where applicable, and applying adjustment factors, correction factors, or both, in accordance with the NEC (see Section 6.4).

6.1.1 Utility-Interactive Power Inverters

NOTE: The input of a utility-interactive power inverter is typically a DC power source, such as from a solar photovoltaic power system.

The ampacities of utility-interactive conductors are based on the input and output current ratings of the inverter. Because inverter system currents are considered continuous, the ampacity of conductors for inverter systems must be sized to carry not less than 125% of the inverter continuous input and output current ratings.

NOTE: For an inverter supplied from a source with a variable voltage output, such as a solar photovoltaic power system operating in less than full sunlight, the continuous input current rating of the inverter occurs when producing rated power at the lowest rated source input voltage.

6.1.2 Solar Photovoltaic Power Systems

The ampacity of solar photovoltaic source circuits is based on the maximum current for individual modules, or based on the sum of parallel module rated short-circuit currents for modules connected in series. The maximum current for parallel source circuits is the sum of the parallel source circuit maximum currents. Solar photovoltaic power system circuits are considered continuous, and circuit conductors must be sized to carry not less than 125% of the maximum circuit currents.

6.1.3 Wind Turbines

The ampacity of output conductors from low-speed and DC wind turbine output circuits is based on utility-interactive power inverter requirements (see Section 6.1.1). The ampacity of output conductors from high-speed wind turbine output circuits is based on generator requirements (see Section 6.1.6).

6.1.4 Fuel Cells

The ampacity of the feeder circuit conductors from fuel cell systems to the premises wiring system must not be less than the greater of the nameplate rated circuit current or the rating of the fuel cell system overcurrent protective devices.

6.1.5 Microturbines

The ampacity of output conductors from microturbines is based on the requirements for utility-interactive power inverters (see Section 6.1.1). *NOTE: NFPA 37 Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines, requires that all wiring for microturbines be protected from arcing and shorting, and that all conductors, with the exception of ignition or microprocessor wiring and thermocouples, must be stranded annealed copper.*

6.1.6 Engine-Generators

The ampacity of the conductors from the generator terminals to the first overcurrent protective device must be not less than 115% of the nameplate current of the generator. Where the design and operation of the generator prevents overloading, the ampacity of the conductors must not be less than 100% of the nameplate current rating of the generator.

6.1.7 Energy Storage Systems (ESS)

See NECA 416, Recommended Practice for Installing Energy Storage Systems (ESS) for guidance in sizing conductors for energy storage systems.

Determine conductor ampacity for ESS in accordance with NEC Article 310.

Calculate maximum circuit current for specific circuits in accordance with the following:

- Nameplate(s) rated circuit current is the rated current indicated on the ESS nameplate or system listing when the system is a pre-packaged self-contained system or is a pre-engineered system of matched components intended for field assembly as a system. The rated circuit current for other systems is determined by the system designer or installer in accordance with acceptable engineering practice.
- The maximum output current of an inverter is the inverter continuous output current rating.
- The maximum current of a standalone inverter input circuit current is the continuous inverter input current rating when the inverter is producing rated power at the lowest input voltage.
- The maximum DC-to-DC converter output current is the DC-to-DC converter continuous output current rating.

The ampacity of feeder circuit conductors from ESS to the wiring system serving the loads to be serviced by the system must not be less than the greater of the nameplate rated circuit current or the rating of the ESS overcurrent protective device(s).

If interactive single-phase, 2-wire ESS outputs are connected to the grounded or neutral conductor and a single ungrounded conductor of a 3-wire system or of a 3-phase, 4-wire, wye-connected system, the maximum unbalanced neutral load current plus the ESS output rating must not exceed the ampacity of the grounded or neutral conductor.

6.2 Sizing Grounded or Neutral Conductors

NOTE: The grounded or neutral conductor is an intentionally grounded (at the source only) current-carrying circuit conductor. For single-phase circuits, the grounded conductor carries return current from each phase conductor. For three-phase, four-wire circuits, the grounded conductor carries the unbalanced current from the vector summation of all of the ungrounded or phase conductor currents.

The grounded conductor is permitted to be increased in size proportionately to the ungrounded conductors when the ungrounded conductors are increased in size in accordance with the cross-sectional area to compensate for heating effects from continuous loading, more than three current-carrying conductors in a common raceway, roof-top heating effects, and/or high ambient temperature (see Section 6.4).

6.2.1 Utility-Interactive Power Inverters

In general, the grounded or neutral conductors of utility-interactive power inverters should be the same size as the ungrounded conductors. In all cases, the output current of an inverter must not exceed the ampacity of the grounded conductor.

NOTE: The ampacity requirements for grounded or neutral conductors for solar photovoltaic power systems, low-speed and DC wind turbines, fuel cells, and microturbines are based on the ampacity requirements of utility-interactive power inverters.

6.2.2 Solar Photovoltaic Power Systems

The ampacity of the grounded (or reference) conductor of a bipolar solar photovoltaic array should be the same as the ungrounded conductors. *NOTE: A bipolar solar photovoltaic array is a solar photovoltaic array that has two outputs, each having opposite polarity to a common reference point or center tap.*

For a solar photovoltaic power source that has multiple output circuit voltages and employs a common-return conductor, the ampacity of the common-return conductor must be sized not be less than the sum of the ampere ratings of the overcurrent devices of the individual output circuits.

6.2.3 Wind Turbines

Grounded or neutral conductors of DC wind turbine generators that must carry ground-fault currents must not be smaller than the minimum required ampacity of the largest ungrounded or phase conductor. The requirements for the grounded or neutral conductors for high-speed wind turbines are based on generator requirements (see Section 6.2.4).

6.2.4 Engine-Generators

Where a change occurs in the ampacity of an ungrounded or phase conductor to compensate for heating effects from continuous loading, more than three current-carrying conductors in a common raceway, roof-top heating effects, or high ambient temperature, the grounded conductor should be increased in size proportionately to the ungrounded conductors.

Where the grounded conductor of a generator must carry ground-fault currents (three-phase, four-wire with no equipment grounding conductor), the grounded or neutral conductor must not be smaller than NEC requirements, such as when a generator output circuit of three-phase, four-wires supplies more than one building, where no equipment grounding conductor is included in the generator output circuit, and where the grounded conductor is bonded to the grounding electrode system at each building similarly to service entrance conductors.

While not recommended, the NEC permits the grounded or neutral conductor of a generator that is not intended to carry ground-fault current (three-phase, four-wire plus ground) to be derated (downsized) from the size of the ungrounded conductors.

6.3 Sizing Equipment Grounding Conductors

Equipment grounding conductors are sized in accordance with NEC Section 250.122, including Table 250.122, Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment. In general, equipment grounding conductor sizing is based on the rating or setting of the next upstream automatic overcurrent protective device that protects the ungrounded or phase conductors of the circuit.

Equipment grounding conductors must be increased in size proportionately (according to circular mil area) to the increase in size of ungrounded or phase conductors (of the same circuit) when current-carrying conductors are increased in size from the minimum size that has sufficient ampacity for the intended installation. See Section 6.4.

6.4 Ampacity Adjustment and Correction Factors

After determining conductor ampacity based upon specific generation technology, including any energy storage systems installed, conductor ampacity is adjusted for the number of current-carrying conductors within a raceway and for rooftop installations, and corrected for the ambient temperature of the surroundings. *NOTE: The application of NEC ampacity adjustment and correction factors is generally well understood. As such, an in-depth treatment of applying ampacity adjustment factors, correction factors, or both to conductors is beyond the scope of this Standard, but is briefly discussed below.*

In general, the limiting factor in sizing electrical conductors is temperature. Heat breaks down electrical insulation. Electrical conductors that run hotter have a shorter life expectancy than conductors that run cooler. Consequently, the NEC requires that conductors be selected and coordinated so that the conductor operating temperature does not exceed the lowest temperature rating of any termination, conductor, or device in accordance with NEC 110.14.

Consequently, the ampacity (or current-carrying capacity) of conductors must be derated in accordance with the NEC by applying adjustment factors for the number of current-carrying conductors in a single raceway, and correction factors for deviations in ambient temperature, including an adjustment factor for rooftop installations where the distance above the roof to the bottom of the raceway or cable is less than 23 mm (7⁄8 inch), all of which affect the ability of conductors to dissipate heat.

7. Overcurrent Protection

The purpose of overcurrent protection is to protect conductors, conductor insulation, terminations, connections, and equipment from excessive temperatures that occur when current levels rise to a point that may cause damage. Overcurrent is any current in excess of the rated current of the equipment or the ampacity of a conductor caused by abnormal operating condition, such as overloads, short-circuits, and ground-faults.

Overcurrent protection is the automatic protective devices (e.g., fuses and circuit breakers) that act to protect equipment and conductors by disconnecting the supply conductors of a circuit when an overcurrent is detected. Overcurrent protective devices are selected to provide normal equipment operation while closely protecting conductors and equipment from abnormal operating conditions.

7.1 Overcurrent Protection for Conductors

Conductors are required to be protected against overcurrent in accordance with their ampacities. When conductor ampacity does not correspond to a standard ampere rating of a fuse or circuit breaker, the next higher standard overcurrent protective device is permitted to be used to protect the conductors.

For overcurrent protective devices rated over 800 amperes, the ampacity of the conductors must be equal to or greater than the overcurrent protective device. Standard ampere ratings for fuses and inverse time circuit breakers are listed in NEC 240.6(A). The maximum possible setting should be used to determine the rating of adjustable-trip circuit breakers.

7.1.1 Ungrounded or Phase Conductors

Overcurrent protection is required to be connected in series with each ungrounded or phase circuit conductor, and is typically required at the point where the circuit conductors receive their supply (source). Circuit breakers must be gang operated (e.g., three-pole circuit breakers used for three-phase circuits), and are required to open all ungrounded conductors of a circuit.

7.1.2 Grounded or Neutral Conductors

Overcurrent protection is prohibited in series with any intentionally grounded current-carrying conductor (grounded or neutral conductor). The exception to this rule is when the overcurrent protective device opens all conductors in the circuit, including the grounded conductor, such as installing a four-pole device for a three-phase, four-wire circuit that opens all three ungrounded or phase conductors along with the grounded or neutral conductor, and is designed so that no pole can operate independently (gang-operated).

7.2 Interrupting Ratings

The interrupting rating is the maximum level of fault current that the overcurrent protective device can safely interrupt at the nominal voltage of the circuit. The maximum level of fault current is dependent upon the available fault current from:

- The electric utility grid
- Any interconnected distributed energy resources, generation and/or energy storage
- Contribution from onsite motors running at the time of the fault

All sources of fault current must be considered when selecting interrupting ratings of overcurrent protective devices and related equipment installed in microgrid applications.

An overcurrent protective device may fail when attempting to open a faulted circuit when the available fault current exceeds the interrupting rating of the device. For this reason, overcurrent protective devices must have an interrupting rating higher than the fault current available at the terminals of the equipment.

Installing distributed energy resources within an existing electrical power distribution system can increase the available fault current beyond the withstand ratings of existing equipment. Many times, upgrading or replacing distribution system equipment is impractical, time-consuming, and cost-prohibitive. In these instances, it may be necessary to connect distributed energy resources to the system using means to limit the fault current contribution of the source, such as connecting the source to the system through an isolation transformer.

7.3 Overcurrent Protective Devices for Microgrid Generation Sources and Energy Storage Systems

Microgrid distributed energy resources have special requirements for overcurrent protection of sources, conductors, and equipment:

- Equipment and conductors that are connected to more than one electrical source (backfed) must have a sufficient number of overcurrent devices located so as to provide protection from all sources.
- Overcurrent protection of a transformer supplied by a solar photovoltaic power system on one side and another electric power production source on the other side of the transformer must be evaluated by considering each side of the transformer as the primary source of power. *NOTE: In general, transformers installed in microgrid applications will have both primary and secondary overcurrent protection.*
- Overcurrent devices, either fuses or circuit breakers, used in any DC portion of a utility-interactive inverter power system must be listed for use in DC circuits and must have appropriate voltage, current, and interrupt ratings.

7.3.1 Utility-Interactive Power Inverters

Input and output circuit conductors and overcurrent protective devices for utility-interactive power inverters are sized based on the maximum input and maximum continuous output current ratings of the inverter. Because those circuits are considered to be continuous, overcurrent protection must be sized not less than 125% of the maximum current ratings of the inverter. Circuit breakers that are listed for continuous operation can be applied at 100% of their rating.

7.3.2 Solar Photovoltaic Power Systems

Solar photovoltaic power system circuits are considered to be continuous. Overcurrent protective devices must be sized for not less than 125% of the maximum current ratings of the circuits. Series-connected solar modules are permitted to be protected by a single overcurrent protective device. Supplementary overcurrent protective devices are permitted within solar photovoltaic source circuits, such as between solar modules, series-strings of modules, and parallel-connected modules.

Where a single overcurrent device is used to protect a set of two or more parallel-connected module circuits, the ampacity of each of the module interconnection conductors must be sized not less than the sum of the rating of the single fuse plus 125% of the short-circuit current from the other parallel-connected modules.

7.3.3 Wind Turbines

Wind turbines are protected in accordance with requirements for generator overcurrent protection for AC and DC generators (see Section 7.3.6).

7.3.4 Fuel Cells

Additional overcurrent protection is not required when a fuel cell system is provided with overcurrent protection sufficient to protect the circuit conductors that supply the load.

7.3.5 Microturbines

Microturbine output circuits are considered to be continuous. Overcurrent protective devices must be sized for not less than 125% of the maximum continuous output current rating of the microturbine.

7.3.6 Engine-Generators

Synchronous generators must be protected from overloads by inherent design, circuit breakers, fuses, or other acceptable overcurrent protective means suitable for the conditions of use. *NOTE: Unit-mounted molded-case circuit breakers on low-voltage generators are typically 100% rated devices, capable of continuous operation at their rating without applying the 125% multiplier of continuous loads.*

7.3.7 Energy Storage Systems

See NECA 416, Recommended Practice for Installing Energy Storage Systems (ESS) for guidance in sizing overcurrent protection for energy storage systems.

Provide overcurrent protective devices for circuits, conductors, and equipment rated in accordance with NEC Article 240. Protect circuits from overcurrent at the source end of the circuit. Provide overcurrent protective device ratings of not less than 125% of the maximum currents calculated.

Overcurrent devices, either fuses or circuit breakers, used in any DC portion of an ESS must be rated, listed, and labeled for use with direct current (DC), and must have appropriate voltage, current, and interrupt ratings. *NOTE: Third-party tested values, vendor listed values and label values are not always consistent. Manufacturers rate their max current higher than third party testing values. It is important to validate required equipment qualification with the appropriate design authority.*

7.4 Ground-Fault Protection

Ground-fault protection is a system intended to protect equipment from arcing line-to-ground fault currents by operating a disconnecting means to open all ungrounded conductors of the faulted circuit. Arcing line-to-ground faults typically have high impedance, which limits the fault current below the operating threshold of the supply overcurrent protective device. Since the supply overcurrent protective device typically will not operate for a high-impedance ground-fault, the fault can exist for prolonged periods of time under certain conditions. Consequently, the NEC requires ground-fault protection of equipment under those conditions to detect and clear high-impedance ground faults.

Ground-fault protection is required for solidly grounded wye-connected electrical systems of more than 150 volts to ground but not exceeding 600 volts phase-to-phase for each individual device used as a building or structure main disconnecting means rated 1000 amperes or more. Where ground-fault protection is used, the output of an interactive system must be connected to the supply side of the ground-fault protection. When there is ground-fault protection for all sources, the connection may be made on the load side of ground-fault protection. The purpose of these provisions is to ensure that distributed generation sources do not supply ground-fault current to the system during a ground-fault.

7.4.1 Solar Photovoltaic Systems

Solar photovoltaic systems have special requirements for ground-fault protection, based on whether the system is grounded DC, grounded AC, or ungrounded.

Grounded DC solar photovoltaic arrays must be provided with DC ground-fault protection. The required ground-fault protection system must be capable of:

- Detecting ground-fault current
- Interrupting the flow of fault current
- Providing an indication of the fault

The faulted circuits can be isolated by either automatically disconnecting the ungrounded conductors of the faulted circuit, or automatically shutting down the inverter or charge controller fed by the faulted circuit. Ground-fault protection is not required for ground- or pole-mounted arrays with not more than two paralleled source circuits and with all DC source and output circuits isolated from buildings. Ground-fault protection is also not required in other than dwelling units where each equipment grounding conductor has an ampacity of at least two times the circuit conductor ampacity, adjusted for ambient temperature, roof-top installations, and the number of current-carrying conductors in the raceway.

Systems that automatically open the grounded conductor of the faulted circuit to interrupt the ground-fault current path are permitted. If a grounded conductor is opened to interrupt the ground-fault current path, all conductors of the faulted circuit must be opened automatically and simultaneously. Manually operating the main solar photovoltaic disconnecting means must not activate the ground-fault protection system or result in grounded conductors becoming ungrounded.

The utility-interactive power inverter must have a warning label near the ground-fault indicator at a visible location, stating: “Warning – electric shock hazard if a ground fault is indicated, normally grounded conductors may be ungrounded and energized.” For solar photovoltaic systems with energy storage batteries, the same warning must be applied in a visible location at the batteries.

AC solar module systems are permitted to use a single ground-fault detection device to detect only AC ground faults and to disable the array by removing AC power to the faulted AC modules.

Ungrounded solar photovoltaic power systems with ungrounded solar photovoltaic source and output circuits must have a ground-fault protection system for all sources and output circuits that:

- Detects a ground-fault
- Indicates that a ground-fault has occurred
- Automatically disconnects all conductors
- Automatically causes the inverter or charge controller connected to the faulted circuit to cease supplying power to output circuits

7.4.2 Other Distributed Generation Systems

Wind turbines, fuel cells, and engine-generators of sufficient ratings must have ground-fault protection. Fuel cells and engine-generators that are installed as emergency systems are not required to have ground-fault protection of equipment due to the life-safety role of the equipment. Emergency systems are required to have equipment and signals to indicate that a ground-fault has occurred on the system.

NOTE: Microturbines are inherently small-scale distributed generation resources and typically fall below the current levels that require ground-fault protection of equipment.

7.4.3 Energy Storage Systems

See NECA 416, Recommended Practice for Installing Energy Storage Systems (ESS) for guidance in installing ground-fault protection of equipment for energy storage systems.

8. Grounding Microgrid Distributed Energy Resources

Microgrid distributed energy resources must be grounded and bonded in accordance with the NEC and manufacturer instructions.

8.1 Solar Photovoltaic Power Systems

For a grounded solar photovoltaic power source, one conductor of a 2-wire system operating over 50 volts, and the reference, center tap, or grounded conductor of a bipolar system must be solidly grounded or must employ other methods that accomplish equivalent system protection, such as limiting the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines, and stabilizing the voltage to earth during normal operation, using equipment listed and identified for the purpose. The premises grounding system is permitted to be used for the grounding system for solar photovoltaic systems with utility-interactive inverters.

All solar photovoltaic systems are required to have a grounding electrode system. Where solar photovoltaic power systems have both AC and DC grounding requirements, the DC grounding electrode system must be bonded to the AC grounding electrode system. The bonding jumper between the AC and DC grounding electrode systems is sized as the larger of the DC requirement for the solar photovoltaic equipment grounding conductor, the AC requirement for the inverter AC output overcurrent protective device, and the system bonding jumper requirement between the two grounding electrode systems.

Supplemental grounding electrodes are required at the location of all ground and pole-mounted solar photovoltaic arrays and as close as practicable to the location of roof-mounted solar photovoltaic arrays, unless the structures, poles, and metal frames of buildings are considered grounding electrodes. These electrodes must be connected directly to the frames and supporting structures of the array.

The equipment grounding conductor is permitted to serve the multiple functions of DC grounding, AC grounding, and bonding between AC and DC systems, provided that the conductor is sized for the maximum applied current from the functions served.

A common ground bus is permitted to be used for both the AC and DC systems, as is a common grounding electrode. In this instance, the grounding electrode conductor must be connected to the AC ground system bonding point. The grounding electrode must be sized to meet the requirements of both AC systems and DC systems.

The DC system bonding jumper is permitted at any single point on the solar photovoltaic output circuit. The grounding connection point should be as close as is practical to the solar photovoltaic source for better protection from voltage surges due to lightning. Systems with a ground-fault protection system are permitted to have the required DC circuit grounding connection made by the ground-fault protection device. This bond, where internal to the ground-fault equipment, must not be duplicated with an external connection.

Equipment grounding conductors for solar photovoltaic source and output circuits are sized in accordance with the NEC, but not less than a 14 AWG copper conductor. Where no overcurrent protective device is used in the circuit, the solar photovoltaic rated short-circuit current should be used in the place of an overcurrent protective device in sizing the equipment grounding conductor. Increasing the size of the equipment grounding conductor for voltage drop is not required.

For other than dwelling units where ground-fault protection is not provided, each equipment grounding conductor must have an ampacity of at least two times the conductor ampacity corrected for temperature and conduit fill.

Equipment grounding conductors for solar photovoltaic modules and arrays that are smaller than 6 AWG copper must be protected from physical damage by a raceway or cable armor except where not subject to physical damage or where protected from physical damage by location.

Exposed non–current-carrying metal parts of solar photovoltaic module frames, equipment, and conductor enclosures must be grounded (bonded) regardless of operating voltage. An equipment grounding conductor is required to be installed between a solar array and other equipment.

Devices listed and identified for grounding the metallic frames of solar modules are permitted to bond those frames to the exposed metallic frames of modules and to grounded mounting structures. Equipment grounding conductors for solar arrays and structures must be installed within the same raceway or cable, or otherwise run with the solar array circuit conductors when those circuit conductors leave the vicinity of the array.

8.1.1 Ungrounded Solar Photovoltaic Power Systems

Ungrounded solar photovoltaic power systems are permitted to have ungrounded sources and output circuit conductors, provided the system has:

- Disconnecting means for all solar photovoltaic sources and output circuit conductors
- Overcurrent protection for solar photovoltaic sources and output circuit conductors
- Ground-fault protection for solar photovoltaic sources and output circuits that detects a ground fault, indicates that a ground fault has occurred, and automatically disconnects all conductors or causes the inverter or charge controller connected to the faulted circuit to automatically cease supplying power to output circuits

Ungrounded solar photovoltaic source conductors must be non-metallic-jacketed multiconductor cables, conductors installed in raceways, or conductors listed and identified as solar photovoltaic (PV) wire when installed as exposed, single conductors. Ungrounded DC solar photovoltaic power systems are permitted to be operated with ungrounded battery systems.

An ungrounded solar photovoltaic power source must be labeled with the following or an equivalent warning at each junction box, combiner box, disconnect, and device where energized, ungrounded circuits may be exposed during service: “Warning – electric shock hazard. The DC conductors of this solar photovoltaic system are ungrounded and may be energized.” The inverters or charge controllers used in ungrounded solar photovoltaic source and output circuits must be listed for the purpose.

8.2 Wind Turbines

Exposed non-current-carrying metal parts of towers, turbine nacelles, other equipment, and conductor enclosures must be grounded and bonded to the premises grounding and bonding system. Attached metal parts, such as turbine blades and tails that are not likely to become energized, are not be required to be grounded or bonded.

The wind turbine tower must be connected to a grounding electrode system. Where installed in close proximity to galvanized foundation or tower anchor components, galvanized grounding electrodes must not be used. *NOTE: Copper and copper-clad grounding electrodes, where used in highly conductive soils, can cause electrolytic corrosion of galvanized foundation and tower anchor components*.

Because of installation heights and the requirements for clear space, wind turbines are directly exposed to lightning and require lightning protection systems. Supplemental towers of sufficient height can be constructed in close proximity to wind turbines for the purpose of shunting lightning strikes to ground to protect wind turbines and related equipment from lightning damage.

Separate grounding electrodes are required for lightning protection systems, but must be bonded to the wind turbine grounding electrode system, along with all available grounding electrodes for power, controls, and communication systems, at individual wind turbines. The grounding electrode system for a wind turbine typically includes a ground ring around the tower foundation that is bonded to the re-enforcing bar structure within the foundation.

Additional bonding measures are recommended within the wind turbine. Metallic conduits or a minimum of three-sided wireways are recommended for wiring within wind turbines. Fiber optics or shielded, bonded conductor cables with multiple levels of surge protection are recommended for communication and control systems and circuits. Wind turbines are recommended to be connected to underground distribution systems to minimize the exposure to lightning and other transient faults that is inherent in overhead distribution systems.

8.3 Fuel Cells

Both AC and DC fuel cell systems must be grounded. When fuel cell power systems have both AC and DC grounding requirements, the DC grounding system must be bonded to the AC grounding system by a bonding jumper sized in accordance with the NEC. A single common grounding electrode and grounding bar may be used for both systems sized for the greater of the AC and DC requirements.

A separate equipment grounding conductor sized in accordance with the NEC is required. Where the manufacturer requires supplementary grounding electrodes, those electrodes must be connected to the equipment grounding conductor.

8.4 Microturbines

Microturbines are designed for connection to wye-connected, solidly-grounded distribution systems. Do not connect microturbines directly to ungrounded or corner-grounded (high-leg) delta-connected or resistance-grounded distribution systems. Make connections to delta-connected or resistance-grounded distribution systems through a suitable transformer with a winding configured to provide a solidly-grounded wye connection for the microturbine generator output.

When connecting microturbines directly to the electric utility grid, connect microturbines as a non-separately derived source, where the microturbine neutral-to-ground bond is the same neutral-to-ground connection (main bonding jumper) as the utility. *NOTE: The grounded conductor of each microturbine must be connected to the grounded conductor of the utility or distribution system, and the neutral-to-ground connection at the output terminal block of each microturbine must be removed.*

When connecting microturbines to the electric utility grid through a transformer, the grounded conductor of each microturbine must be connected to the grounded conductor of the transformer, and a neutral-to-ground connection (system bonding jumper) must be established for the microturbine-transformer circuit at the location of the first overcurrent protective device from the microturbine.

Connecting a microturbine to distribution systems with improper grounding, with no neutral-to-ground bond, or with multiple neutral-to-ground bonding locations can result in mis-operation and/or damage to the microturbine.

8.5 Energy Storage Systems (ESS)

See NECA 416, Recommended Practice for Installing Energy Storage Systems (ESS) for guidance in grounding energy storage systems.

Ground ESS in accordance with contract documents, manufacturer recommendations, standard grounding practices, and the NEC. *NOTE: An improper or inadequate grounding configuration may cause problems at start-up. Failure to properly ground ESS may deteriorate electrical insulation and may cause electric shock due to leakage currents.*

Ensure that the grounded conductor, or neutral, where installed, is properly bonded, keeping in mind that an ESS may be a separately derived source. Provide a separate, insulated equipment grounding conductor in all feeder and branch raceways. Ground non-current-carrying ESS equipment, such as battery racks and battery circuit breaker cabinets, to the feeder equipment grounding conductor with a separate bonding jumper.

When an ESS system has an ungrounded storage battery system with voltage exceeding 100 volts DC, a ground-fault detection system and indication within the storage system is required. Provide ground-fault detection and indication for ESS battery systems where the storage battery operating voltage is greater than 100 volts DC.

9. Commissioning and Maintenance

9.1 General

Each microgrid is unique, from one or more interconnection points to the electric utility grid, to the type and configuration of the loads, from the type and number of distributed energy resources, both generation and energy storage, to the control and communication system used to operate and maintain the microgrid, and from grid-connected to island operation. Consequently, the operation and maintenance of a microgrid must be developed specifically for each microgrid.

Distributed energy resources that fail while in grid-connected operation may be damaged beyond repair due to higher fault currents available during parallel operation with the electrical utility grid than when independently supplying the load operating as an island. As such, microgrid distributed energy resources must be properly designed, installed, operated, and maintained, and should not be operated until failure.

When it comes to maintenance, scheduled shutdowns may be easier to accomplish in a microgrid because of distributed energy resources that permit shutdowns of those resources and associated equipment and systems while maintaining continuity of power to the loads using multiple (and likely redundant) energy sources.

Staff must be trained in the proper operation and maintenance of the different types of generation, whether solar photovoltaic, wind turbines, microturbines, fuel cells, engine-generators, or others, along with the different types of energy storage, such as battery systems, flywheels, ultra-capacitors, vehicle-to-grid systems, or others.

Similarly, staff must be trained in the proper techniques of de-energizing and isolating specific distributed energy resources for the purpose of performing maintenance, testing, and repairs. Typically, each piece of equipment will require a dedicated operating and maintenance procedure that describes the steps necessary to de-energize and isolate the equipment, including de-energizing control power and discharging stored energy, if possible, and the specific inspection, maintenance, and testing tasks to be performed, along with a maintenance schedule for the equipment.

All inspections, maintenance, testing, and repairs must be properly documented. Test results are used to gauge the degradation of equipment over time to determine whether increased maintenance is required and to schedule equipment replacement before its end-of-life.

Microgrid owners and operators should refer to NFPA 70B for general guidelines for equipment inspections, maintenance, and testing, along with specific manufacturer instructions, in developing processes and procedures for equipment operation and maintenance. For additional guidance, see NECA/EGSA 404 for maintenance of engine-generator sets, NECA 412 for maintenance of solar photovoltaic power systems, and NECA 416 for maintenance of energy storage systems.

Recommission microgrid equipment in accordance with Section 9.2 after any repairs, any changes in programming, equipment settings, operational parameters, or any significant inspection, maintenance, or testing, prior to placing equipment back into operation.

9.2 Commissioning

Commission microgrid electrical components, equipment, and systems in accordance with contract documents, drawings and specifications, manufacturer instructions, industry-accepted practices, and

NECA 90.

The intention of commissioning is to ensure that all electrical equipment, components, sub-systems, and systems are installed properly, that they are complete, and that they receive adequate operational checkout and detailed testing, calibration, and adjustment by the installing contractor (general contractor or sub-contractor). Commissioning verifies that electrical equipment and system performance meets or exceeds the Owner's requirements, and the design intent as documented in the contract documents, drawings and specifications.

Commissioning ensures proper initial operation, establishes the baseline of operation, performance, efficiency, and optimization, and provides the foundation for the maintenance program of microgrid components, equipment, and systems.

9.3 Monitoring and Controls

Operating generation and/or energy storage capacity must meet (or preferably exceed) the connected load at all times to prevent the loss of system stability, voltage and frequency collapse, and, ultimately, an electrical outage and loss of the ability to supply power to all or some of the loads being served.

Microgrids necessarily have sophisticated, high speed monitoring and control systems that permit operation and control of distributed energy resources, generation and energy storage, in real-time while either synchronized and paralleled to the electric utility grid in grid-connected mode, or while independently supplying the dynamic load in island mode.

Microgrid monitoring and control systems used by microgrid operators should be used to verify proper operation, and to track electrical and operating characteristics over time to identify operational anomalies and other opportunities for predictive maintenance or needed repairs. Additionally, specific equipment monitoring systems, such as modern battery monitoring systems, should be installed and used to continuously diagnose the overall health of electrical components, equipment, and systems.

To ensure longevity of microgrid equipment and systems, it is imperative that the data from monitoring and control systems be actively tracked and used to develop schedules for maintenance, repairs, and replacement of system components and equipment, and that maintenance, repairs, and replacements are timely in response to the data.

Similarly, microgrid control systems should be programmed with system contingencies in response to abnormal operating conditions of the microgrid, such as a utility outage, the loss of one or more microgrid distributed energy resources, generation or energy storage, a significant change in the load, a fault, or equipment failure. After the automatic operation of the microgrid control system, the system response should be evaluated to determine whether the response was appropriate, and whether improvements to overall system operation and reliability can be made.

(This annex is not part of the standard)

Annex A: Reference Standards

ANSI/NFPA 70-2017, *National Electrical Code* (ANSI)

IEEE C2, National Electrical Safety Code (NESC)®

IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems

IEEE 1547a Standard for Interconnecting Distributed Resources with Electric Power Systems -- Amendment 1

IEEE P1547.1 Draft Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces (full revision of IEEE Std 1547.1)

IEEE 1547.2 Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems

IEEE 1547.3 - 2007 Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems

IEEE 1547.4 Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

IEEE 1547.5 Draft Technical Guidelines for Interconnection of Electric Power Sources Greater than 10MVA to the Power Transmission Grid - Withdrawn 12/2011

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

IEEE P1547.7 Draft Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection

IEEE P1547.8 Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Standard 1547

IEEE 2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads

IEEE P2030.1 Draft Guide for Electric-Sourced Transportation Infrastructure

IEEE 2030.2 Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure

IEEE P2030.3 Draft Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications