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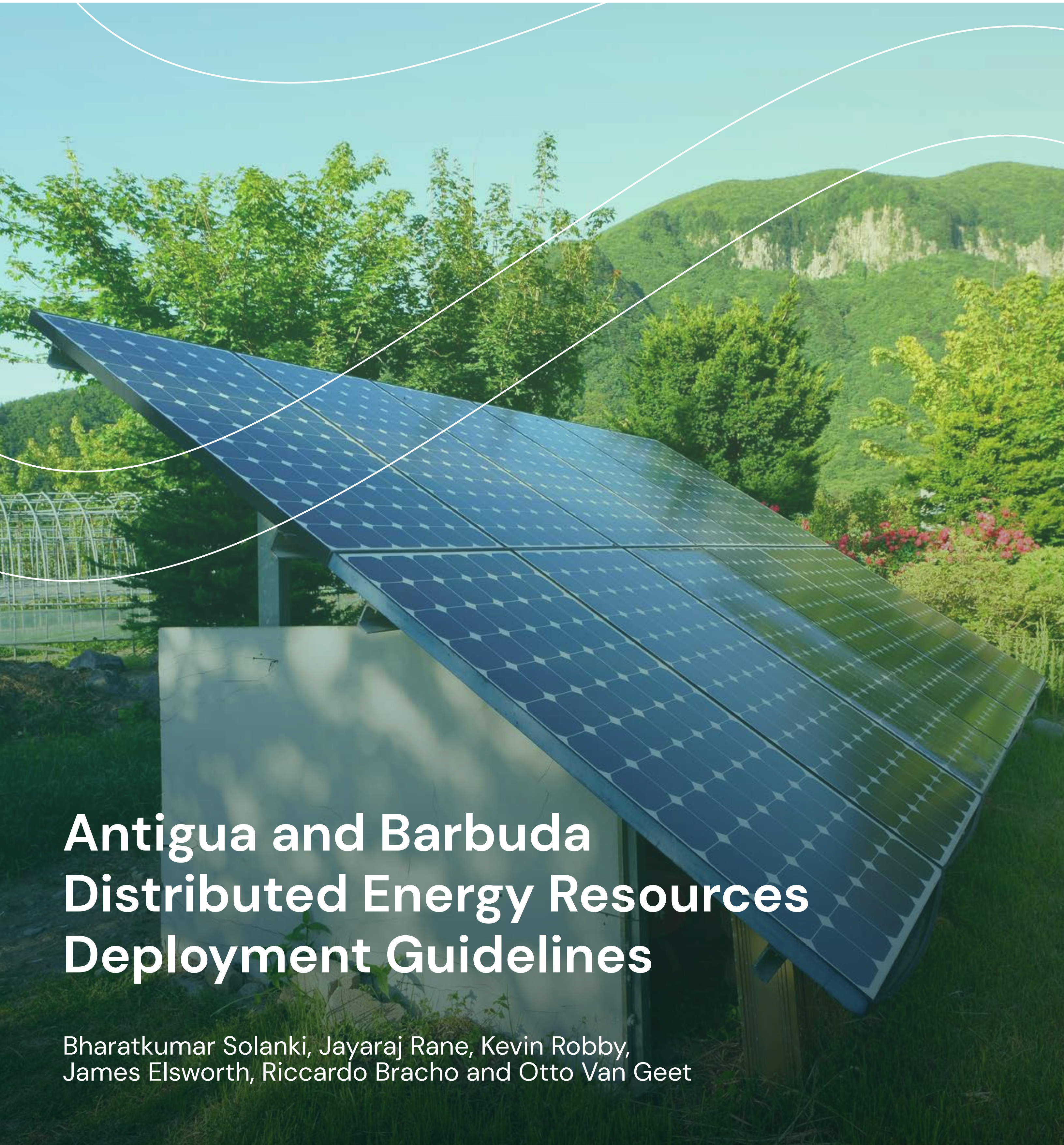

Antigua and Barbuda Distributed Energy Resources Deployment Guidelines

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List of Acronyms

AC	alternating current
ACP	American Clean Power
AFCEC	Air Force Civil Engineer Center
ANSI	American National Standards Institute
APUA	Antigua Public Utilities Authority
ASCE	American Society of Civil Engineers
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
AWEA	American Wind Energy Association
BESS	battery energy storage system
CORE	continuously optimized reliable energy
DC	direct current
DERs	distributed energy resources
DIN	German Institute for Standardization
EMC	electromagnetic combability
EPC	engineering procurement construction
EPS	electrical power systems
ESS	energy storage system
GHG	greenhouse gas
ICC	International Code Council
ICS	industrial control system
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRP	integrated resource plan
ISE	interconnection system equipment
ISO	International Organization for Standardization
NABCEP	North American Board of Certified Energy Practitioners
NAVFAC	Naval Facilities Engineering Systems Command
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NERC	North American Electric Reliability Corporation
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NSC	National Standards of Canada
O&M	operation and maintenance
OECS	Organization of Eastern Caribbean States
OSHA	Occupational Safety and Health Administration
PCE	power conversion equipment
PID	potential-induced degradation
POCC	point of common coupling
PPA	power purchase agreement
PV	photovoltaic
PVC	polyvinyl chloride

RE	renewable energy
SAE	The Society of Automotive Engineers
SCADA	supervisory control and data acquisition
SCC	Standards Council of Canada
SDO	Standards Development Organization
SEAOC	Structural Engineers Association of California
STC	standard test conditions
TIA	Telecommunications Industry Association
UFGS	Unified Facilities Guide Specifications
UL	United Laboratory
UPS	uninterrupted power supply
USACE	U.S. Army Corps of Engineers
VAR	volt ampere reactive

Executive Summary

Antigua and Barbuda (A&B) is an island country, comprised of two namesake islands located in the Caribbean with approximately 94,000 inhabitants and an estimated annual growth rate of 1%. Its economy is primarily derived from the service industry with tourism being the largest contributor at around 80% of gross domestic product (GDP). A&B is exposed economically, environmentally, and socially to projected climate change impacts, such as greater intensity and frequency of hurricanes, more frequent droughts, high temperatures, and sea-level rise (Climate Analytics 2020). Between 2008 and 2017, the combined cost incurred to A&B from tropical storms and hurricanes was at least $232 million (U.S.) (Government of Antigua and Barbuda 2020). On average, hurricanes account for 8.4% of the annual loss in GDP for A&B (Global Facility for Disaster Reduction and Recovery 2017). On September 6, 2017, a Category 5 hurricane (Irma) hit Barbuda and destroyed 95% of the island's structures, including its power generation capabilities. Energy resilience and security is an imperative for A&B (Mejia 2016).

The U.S. Department of Energy's National Renewable Energy Laboratory is providing technical assistance to the Government of A&B (GoAB), under the Global Climate Action Partnership, and their partners. This technical assistance is in support of the objectives of the GoAB, with the sponsorship of the Department of State in partnership with the U.S. Department of Energy, in two general areas:

1. Technical assistance for clean energy and resilience project development and implementation
2. Local capacity building and credentialling to support deployment of clean energy systems.

For the energy transition envisioned in A&B's nationally determined contribution (NDC), grid-interactive renewable energy generation and storage forms an important part of the country's pathway to a climate-resilient, low-emission economy. This report is provided to support the A&B's Department of Environment with international codes, standards, and best practices for the design, construction, operation, and maintenance of distributed energy resources that could be implemented by the Antigua and Barbuda Bureau of Standards, the Antigua Public Utilities Authority (APUA), the Antigua and Barbuda Ministry of Energy, and other agencies.

Applications of renewable-based distributed energy resources (DERs) are growing day by day as they are becoming economical compared to fossil-fuel-based resources. Islands similar to A&B mainly rely on imported greenhouse gas (GHG)-emitting and expensive fossil-fuel-based resources to meet their electrical demands. The application of renewable resources such as solar photovoltaics (PV) for such islands could be a potential solution to reduce the dependency on fossil-fuel-based resources. However, there are technical challenges implementing renewable-based energy systems. There are limited technical resources available providing comprehensive detailed guidelines to aid power system operators and government officials in various aspects and considerations for the application of renewables. This document provides such guidelines aiming to aid the Department of Environment in planning for the integration of DERs into the existing system as well as for developing new projects.

This document lists (non-exhaustive) standards and guidelines that can be referred to for manufacturing of the equipment, integration, and procurement during the implementation of a project. This document also considers not only DERs but also associated critical components and related standards and technical specifications. These listed standards and technical specifications can be adopted to prepare documents such as requests for proposals.

This document also discusses how these DERs can be reliably and safely integrated and implemented as a microgrid to achieve the maximum benefits with coordinated control in the terms of resiliency, decarbonization and economics. Different conceptual design steps are highlighted at a very high level which can be considered for most of the typical microgrid use cases. Important electrical modeling and studies required for microgrid design and implementation are also briefly described in the document. Best practices applied by similar islands for microgrid implementation are also presented.

In order to ensure the overall safe and reliable operation of an island electrical system with integration of renewable- based resources, interconnection requirements need to be introduced and regulated by the utilities. Therefore, the critical factors to be considered to prepare the interconnection requirements are provided in this document.

The microgrid project involves a number of different stakeholders, which makes such projects complex and different from the other typical projects for electrical systems. It is very important to understand the roles and responsibilities of stakeholders for the success of the project. At the same time, the qualifications of the key resources involved in the microgrid project need to be identified. This document provides examples of roles and responsibilities of stakeholders to develop a project along with the qualifications of the project resources.

Finally, this document provides critical information associated with maintenance and warranty for the DERs and microgrid systems. How these can be specified and other related considerations are highlighted in the document.

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1 Summary of Applicable Standards for Each Potential DER

Note that all locations and specifications in this section are based on the preliminary analysis and these need to be verified and modified based on the final site plan and hardware specifications. Key technical specifications are mentioned for each key component considering interoperability and functionality requirements. The following subsections provide a non-exhaustive list of standards/guidelines and can be considered based on the needs of the project and requirements. The following are the key institutes providing the standards and guidelines for various aspects of microgrid/renewable energy systems.

The American National Standards Institute’s (ANSI's) primary objective is to develop American National Standards. ANSI does this by reviewing and approving the procedures that standards organizations use for developing standards, and by affirming that the completed standards conform to its requirements.

In the United States, Underwriters Laboratory (UL) is accredited by the American National Standards Institute as an audited designator. In 2013, UL was accredited by the Standards Council of Canada (SCC) as a nationally recognized Standards Development Organization (SDO) able to develop National Standards of Canada (NSCs).

The American Clean Power (ACP) administers the ANSI standards process through ACP consensus bodies (committees) that develop and maintain voluntary national consensus standards for the renewable energy industry, ensures that the process for revision of standards is timely and in accordance with the ANSI Essential Requirements procedures, and publishes the final product of the consensus process.

The American Society of Civil Engineers (ASCE) standards provide technical guidelines for promoting safety, reliability, productivity, and efficiency in civil engineering. Many of their standards are referenced by model building codes and adopted by state and local jurisdiction.

The American Society for Testing and Materials (ASTM) standards are developed by committees of relevant industry professionals who meet regularly in an open and transparent process to deliver standards, test methods, specifications, guides, and practices. ASTM creates many standard procedures governing environmental and engineering services, such as ASTM E1527-13[1].

The American Wind Energy Association (AWEA) was a Washington, D.C.-based national trade association formed in 1974, representing wind power project developers, equipment suppliers, service providers, parts manufacturers, utilities, researchers, and others involved in the wind industry. The group was succeeded in 2021 by the American Clean Power Association (ACP).

The International Electrotechnical Commission (IEC) authors international standards for all electrical, electronic, and related technologies. This standards collection addresses product

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[1] ASTM E1527-13 provides standard Practice for Environmental Site Assessment process.

development, performance, compatibility, and related topics to ensure product compatibility and environmental safety.

The Institute of Electrical and Electronics Engineers (IEEE) is a professional association for electrical engineering, electronics engineering, and other related disciplines. It also has subsidiaries IEEE standards association providing key standards related to inverters and other energy systems.

The North American Board of Certified Energy Practitioners (NABCEP) Board Certifications ensure you have the knowledge and skills to meet the demands of renewable energy projects and employers across the world. Developed by subject matter experts for industry professionals, their U.S.-based certifications are built on rigorous standards and ongoing research to meet the real-world needs of customers, businesses, utility companies, and governmental organizations.

The National Fire Protection Association (NFPA) develops, publishes, and disseminates more than 300 consensus codes and standards intended to minimize the possibility and effects of fire and other risks. Virtually every building, process, service, design, and installation in society today is affected by NFPA documents.

The National Institute of Standards and Technology (NIST) is based at the U.S. Department of Commerce. The NIST Cybersecurity Framework helps businesses of all sizes better understand, manage, and reduce their cybersecurity risk and protect their networks and data.

The Structural Engineers Association of California (SEAOC)'s 3,500 members are leaders in the practice of structural and earthquake engineering and key participants in the development, interpretation, and implementation of building standards and codes.

The Telecommunications Industry Association (TIA) standards apply to a wide variety of telecommunications products. These include cellular systems, fiber optics, modems, towers, satellite communication, and Voice Over Internet Protocol (VOIP).

The Unified Facilities Guide Specifications (UFGS) are a joint effort of the U.S. Army Corps of Engineers (USACE), the Naval Facilities Engineering Systems Command (NAVFAC), and the Air Force Civil Engineer Center (HQ AFCEC). UFGS are for use in specifying construction for the military services.

1.1 Applicable Standards, Codes, and Regulations

The following are considered the applicable standards and codes for Antigua and Barbuda:

- IEEE1547-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- Local requirement for grid interconnection of renewable generation
- Antigua and Barbuda Building Code, Caribbean Building Code, and/or International Building Code
- Standards/codes applicable from the Safety Authority in Antigua and Barbuda and the local distribution company
- Ministry of Labor and Occupational Health and Safety Act

- ASCE 7-22 describes the means for determining design loads including dead, live, soil, flood, tsunami, snow, rain, ice, seismic, and wind loads and their combinations for general structural design.
- UFGS 01 35 26 outlines governmental safety regulations. It covers the requirements for safety and occupational health requirements for the protection of Contractor and Government personnel, property, and resources.
- IEEE C2-2017 covers basic provisions for safeguarding of persons from hazards arising from the installation or maintenance of conductors and equipment in electric supply stations, and overhead and underground electric supply and communication lines. Work rules for the construction, maintenance, and operation of electric supply and communication lines and equipment are also included in this standard.
- NFPA 70 includes all standards related to fire, electrical, and related hazards.

1.2 Photovoltaic (PV) Panels/Modules/System

Systems should be capable of monitoring and control as an aggregated PV system to participate in grid services programs, such as utility-sponsored virtual power plant programs. The system should have controls capable of responding to commands sent remotely and be capable of recording and transmitting those responses. Note that some of these considerations are mainly for large-scale PV systems (e.g. 1 MW or larger).

1.2.1 Codes and Standards

- ASTM (Int.) E1036-15 describes the test methods used to assess the electrical performance of PV modules and arrays.
- ASTM International
    - E1036-15 describes the test methods used to assess the electrical performance of PV modules and arrays.
    - E1038-10 describes the test methods used to assess the ability of a PV module to withstand impact from hail.
    - E1171-15 describes the test methods used to stress test PV modules.
    - E1462-12 describes test methods used for testing the current leakage between electrical circuit of PV modules.
    - E1799-12 describes procedures and criteria for visual inspections of PV modules.
    - E1830-15 describes the test methods used to determine ability of PV modules to withstand mechanical loads, stresses, and deflections due to high wind conditions, heavy snow, and ice accumulation.
    - E2848-13 describes the measurement and analysis procedures for determining the capacity of a specific PV system.
    - E2939-13 provides procedures for determining expected capacity of a specified PV system.
- IEC
    - IEC 62738-TS describes general guidelines and recommendations for the design and installation of ground-mounted PV power plants.

  - IEC 62804-TS describes test methods for the detection of potential-induced degradation (PID) on PV modules.
  - IEC 61683 describes guidelines for measuring the efficiency of power conditioners used in standalone and utility-interactive PV systems.
  - IEC 61701 describes test sequences used to determine resistance of different PV modules to corrosion from salt mist.
  - IEC 61829 specifies procedures for on-site measurement of flat-plate PV array characteristics.
  - IEC 60891 defines procedures to be followed for temperature and irradiance corrections to the measured I-V (current-voltage) characteristics of PV devices.
  - IEC 60904 describes procedures for the measurement of current-voltage characteristics of PV devices in natural or simulated sunlight.
  - IEC 61853 describes requirements for evaluating PV module performance in terms of power rating over a range of irradiances and temperatures.
  - IEC 61000-6-3 describes the electromagnetic compatibility (EMC) emission requirements of electrical and electronic apparatuses intended for use in residential, commercial, and light-industrial environments.
  - IEC 61724-1 outlines the equipment, methods, and terminology used for performance monitoring of PV systems.
  - IEC 61724-2 describes the procedure for measuring and analyzing power production to evaluate the quality of the PV system.
  - IEC 61724-3 describes the procedure for measuring and analyzing energy production with respect to expected electrical energy production based on actual weather conditions.
  - IEC 62548 describes design requirements for PV arrays. It includes DC array wiring, electrical protection devices, switching and earthing provisions.
  - IEC 62446-1 defines required information and documentation to be handed over to a customer following the installation of a grid-connected PV system.
  - IEC 62446-2 describes basic preventative, corrective, and performance-related maintenance requirements for grid-connected PV systems.
  - IEC 62093 describes the requirements for the design qualification of balance of systems components for terrestrial PV systems.
  - IEC 61215–1 and IEC 61215–2 outline the test requirements and test procedures, respectively, used to determine the electrical and thermal characteristics of the module and show that the module can withstand prolonged exposure in various climates.
  - IEC 61730-1 and IEC 61730-2 outline the requirements for construction and testing, respectively, to provide safe electrical and mechanical operation.
- SEAOC

  - SEAOC PV 1-2012 provides structural seismic requirements for rooftop solar arrays.
  - SEAOC PV 2-2017 Wind Design for Solar Arrays provides structural specifications for design of PV solar arrays. ASCE 7-22 can also be considered.
- UL Standards
  - UL 1703 describes the standards for fire safety rating of PV systems.
  - UL 2703 addresses requirements of PV mounting rack construction for safety and resilience.
  - UL 1741SB covers inverters, converters, charge controllers, and interconnection system equipment (ISE) intended for use in stand-alone (not grid-connected) or interactive (grid-connected) power systems. Interactive inverters, converters, and ISE are intended to be operated in parallel with an electric power system (EPS) to supply power to common loads.
  - UL 1699 describes requirements of arc-fault circuit-interrupters of the branch/feeder, outlet circuit, portable, and cord type intended for use in dwelling units.
  - UL 1699-B describes the requirements of DC PV arc-fault circuit protection devices used in solar PV systems.
  - UL 4703 is a standard for PV wire which covers single conductor, insulated, and other wiring necessary for interconnection of grounded and ungrounded PV systems.
  - UL 9703 describes the requirements of wiring harnesses intended to interconnect distributed generation system devices.
  - UL 854 describes the requirements for Type USE and USE-2 and Type SE power cables for services entrances and other uses.
  - UL 3730 describes the requirements for PV junction boxes intended to be attached to PV modules and panels as well as for factory and field wiring. May include conduit openings, wiring leads, and/or PV connectors intended for interconnection of PV modules.

1.2.2 PV Modules

Solar modules should be Tier 1 modules[2] with a product/equipment warranty of at least 10 years and a performance warranty of at least 80% rated production at 25 years, following a linear degradation method.

Minimum Performance Requirements:

- IEC 61215 – Silicon Crystal Modules

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[2] "Tier 1 module manufacturers are those which have provided own-brand, own-manufacture products to at least six different projects, which have been financed non-recourse by six different commercial (i.e., not development, not export-import) banks, in the past two years" (BloombergNEF 2024).

- 25-Year Minimum Warranty – Linear
- Minimum Safety Requirements:
    - UL 1703
    - UL 1741 SB or the latest version
    - IEC 61730 (Parts 1 and 2)
- No module will be warrantied to or generate less than 97% of its Standard Test Conditions (STC) rated output in year one. No module should depreciate more than 0.9% for each year of the required minimum 25-year module warranty period.

PV modules should be tested per ASTM E1830-15 prescribed test parameters for loading (snow and wind) of solar modules (front and back).

PV modules should have a front and rear load rating of at least 2,400 Pascals for the specific mounting arrangement used (see module installation manuals for ratings with various mounting arrangements).

1.2.3 Structural Engineering Considerations

1.2.3.1 General Requirements

These requirements are applicable to all the solar installations irrespective of mounting mechanisms.

- Severe Weather
    - The PV system equipment should be designed to withstand severe weather events, including sustained high winds, hurricanes, tornadoes, and thunderstorms, including summer monsoons, and flooding.
- Wind Design Guidance
    - Racking systems should be designed in accordance with ASCE 7-22 and SEAOC PV 2-2017 for wind loading. The systems should be considered Risk Category II or higher, use a Gust Effect factor of 1, and a Directionality factor of 1 for all directions. For buildings within 600 feet of the coast, use Exposure Category D; all other buildings should use Exposure Category C or D. Designers should account for dynamic loading and resonant effects as described in SEAOC PV 2-17.
- Seismic Design
    - Structures should be designed for seismic events in accordance with local/international building codes, such as Caribbean Uniform Building Code (Part 2, Section 3), and the Organization of Eastern Caribbean States (OECS) Building Code (paragraph 1203) and SEAOC PV 1-2012.
- Mounting Solar Modules
    - Modules should be through-bolted to the underlying racking only; top-down clamps should not be used unless modules are flush to a roof. If top-down clamps are used, they should be at least 2 ° (in.) long and be connected to rail systems with robust fasteners that slide into rail systems or are inserted into the rail and

    require at least 1/4 turn of the slotted nut in the rail. The slotted nut should have a contact length in the rail of at least 5/8 in. If modules are through-bolted, washers should be at least 0.125 in. thick with an outer diameter of 0.75 in. or larger to increase surface grip area and prevent bolt tear-out of the pre-drilled module holes.

  - Threaded fasteners should include locking mechanisms to address both preload relaxation and joint slip.
  - Spring washers, such as Belleville washers, should be used to compensate for preload relaxation, as specified by the structural engineer.
  - Wedge-lock washers, UV-rated nylon insert nuts, and pre-applied thread lock can help mitigate slips in the bolted joint; fasteners should be designed and installed by the structural engineer in accordance with standard DIN 65151.
  - Under no circumstances should split washers, double-nutting, star washers, and/or serrated flange nuts be used to provide fastener locking capability.
- Clamping
  - Under no circumstances should clamping systems be used to hold underlying structural frame members together.
- Tapping Sheet Metal Screws
  - Under no circumstances should self-tapping sheet metal screws of any grade be used to hold array structural elements together or to mount conduit, electrical enclosures, metering, and weather station components. Further, these screws should not be used for field-assembled fencing, lighting, security camera systems, or communications equipment.
- Torque Rating of Fasteners
  - Each sub-assembly should be torqued to the manufacturer’s specification using torque wrenches or drivers designed to provide calibrated and metered forces and be rated by ISO 6780-2. For field-assembled components of disparate manufacturers or from custom fabrications, a structural engineer should specify torque ratings and field assembly procedures to be included in submittals and construction drawings. These torque ratings and procedures should be included in operations and maintenance manuals for later use. Fasteners should be torque marked or striped.
  - For fasteners holding friction or clamping forces, Section 3.3 of International Code Council AC 428, 2012 should apply. For permanently locking fasteners such as lock bolts or those with pre-applied thread locking compounds, complete only steps 1-2.
- At a minimum, field assembly and audit procedures should follow these guidelines:
  - Threaded fasteners should be pre- or field-treated with anti-galling compounds. The installation contractor should consider a high-strength removable thread locker compound.

  - Fastener should be torqued with a calibrated torque wrench to specification to achieve full loading.
  - Contractor should mark each fastener torqued with a metal marker to indicate complete installation of the fasteners.
  - Contractor should allow metal surfaces of bolted joints to mate after the initial torque rating is achieved.
  - Each fastener should be torqued to spec a second time. Mark the bolts with a different color or marking. This marking can be referenced in the future to visually inspect whether a fastener has loosened.
  - The installation contractor or their hiring entity must provide a torque log certification after the commissioning of the project.
- Corrosion Resistance
  - All PV hardware and rack components should be of corrosion-resistant material, such as aluminum, hot-dipped galvanized steel, and stainless-steel with the Society of Automotive Engineers (SAE) grade 316. All bolts should be stainless steel.

1.2.3.2 Rooftop Systems

- Roof Structure
  - The roof needs to be deemed solar-ready via a structural and roof inspection. That inspection will at least look at weight and wind loading. The roof inspection will ensure the remaining life of the roof matches the system's lifetime.
- PV Racking
  - PV support racking should be fully anchored to the roof structure. All anchors and roof penetrations should be sealed with a 30+ year rated sealant to prevent water intrusion. PV racking should be sloped to provide a minimum module slope of 2 degrees and a maximum slope of 5 degrees. On roofs with a slope of at least 2 degrees, PV should be mounted flush with the roof, with the lower side of the modules no higher than 8 in. above the roof surface. On roofs flatter than 2 degrees, the high side of the module should not extend more than 12 in. above the roof surface to minimize wind loading.

1.2.3.3 Ground-Mounted Systems

- Systems should use a front and rear support post.
- Systems should be installed with the panels as low to the ground as is feasible to still allow mowing and other vegetation management.
- Ensure tracker systems are able to withstand heavy winds before installation, considering that the region is prone to heavy winds.
- Systems should have a drainage plan.
- Systems should have a maximum tilt angle of 10 degrees to maximize summer generation and reduce wind loading.

- Geotechnical engineering should be used to determine the soil type(s), groundwater level, topography, and corrosion factors. Geotechnical engineering should be performed by awardee or subcontracted to firm with experience in solar geotechnical engineering. Site-specific foundations should be designed based on site research, soils investigation, and analytical foundation load testing, rather than using generic foundation design.
    - Incorporate loads induced from the racking (i.e. wind, dead load, seismic load).
    - Perform subsurface investigation using test pit or borehole testing at multiple locations across the area under consideration for PV to develop a subsurface profile for initial pile design. Soil conditions may vary across the site.
    - For corrosion analysis, sample from the top 1 to 2 feet of soil and perform an electrical soil resistance test on site.
    - Perform a pile pull test on site.
    - Perform pre-production testing of piles to verify design assumptions, optimize design, and reduce risk.
    - Perform production testing during construction to verify design and determine deflection tolerances.
    - Include evaluation of installation in quality assurance/quality control process.

1.2.4 PV Inverters

- Indicate that set point/curtailment capability should be non-grid-forming but grid-supporting (voltage and frequency ride-through, volt-volt ampere reactive (VAR) support, droop control).
- Check for the capability of remote monitoring and control to be done via software or communications protocol, including ON/OFF and power limit.
- Be certified with UL1741SB and IEEE 1547 (consider their latest edition).
    - IEEE 1547 requires DERs to provide grid supportive functionality, including voltage and frequency ride-through and regulation as well as communications and control functionality.
- IEEE 1547.1 outlines the design, production, and commissioning tests that must be performed to demonstrate conformance to IEEE 1547.
- Support a wide range of DC voltage.
- Maintain ambient temperature range (0° to 75°C)
- Follow a communication protocol: MODBUS TCP/IP; interoperability with microgrid controller.
- IEEE 519 focuses on harmonic measurements and establishes guidance for setting harmonic limits for voltage and current distortion. Note that IEEE 1547 updates consideration for harmonics sourced by DER inverter.
- IEC 62109 defines minimum requirements for the design and manufacture of power conversion equipment (PCE) for protection against electric shock, energy, fire, mechanical, and other hazards.
- UL1741 establishes standards with respect to grid voltage and frequency to certify inverters for interconnection.

- IEC 62116 describes a guideline for testing the performance of automatic islanding prevention measures installed in or with single- or multi-phase utility interactive PV inverters connected to the utility grid.

1.2.5 PV System Electrical Requirements

- Ensure PV connectors (i.e., MC4 connectors) are from the same manufacturer and are compatible according to interminability requirements in Article 690.33(C) of the 2020 National Electrical Code (NEC), including on home-run connections.

- Array Grounding Systems
    - To prevent electric shock and fire, a protective ground must be secured on the frames of solar modules and arrays. The grounding system should be independent of the module mounting system. Components in the array grounding system should comply with module manufacturer requirements and consist only of copper, brass, and stainless-steel componentry. Under no circumstances should grounding lugs be mounted using standard carbon steel fasteners. Grounding lug set screws must be of the same metal as lug or stainless steel to prevent galvanic corrosion.
- Wire Management
    - Under no circumstances should plastic (non-metallic) cable ties be used to secure and organize array wiring exterior to electrical enclosures. Exterior, long-life plastic ties should not be used. Stainless steel ties or other stainless or galvanized hardware should be used in wire management. Ties should be UL-listed and have a minimum breaking strength of 40 lbs.
    - No mast heads entering the top or side of electrical enclosures should be used to route string wiring into cabinets. String electrical conductors are to be routed through the bottom of the electrical enclosures to prevent wind-driven water infiltration.
    - Wire cannot lie exposed directly on the roof surface or ground. Long horizontal conduit runs should have expansion unions every 30 feet to reduce wire abrasion caused by fixed couplings. Couplings and expansion unions should use anti-abrasion bushings. All power wiring should be attached to the system components using strain reliefs or cable clamps unless enclosed in conduit.
- Conduit Routing and Preventing Water Intrusion
    - Conduit routing and fittings must be selected to prevent water intrusion into inverter enclosures, combiner boxes, switchgear, and transformers. Conduits are to connect through the bottom of enclosures and provide fittings to allow water to drain prior to entering the electrical enclosure.
    - Any exterior PVC conduit must be Schedule 80. All exterior wiring downstream of combiner boxes or string inverters must be in conduit.
    - Enclosures must be rated by National Electrical Manufacturers Association (NEMA).

    - All exterior housings must be continuously welded, NEMA 4X (or better), fully gasketed, continuously hinged (piano hinge) with three-point door closure clamps and designed to prevent water intrusion from hose-directed water, splashing water, and wind-driven rain. Gaskets must be molded and of one continuous shape with no seams. All equipment mounted to the interior of the enclosure should use back plates to minimize exterior cabinet penetration. Conduit entry into electrical equipment should be designed to prevent water intrusion. The minimum mounting height of enclosures should be based on the 500-year flood plain and surge levels.

1.3 Small Wind Turbines

Small wind turbines are up to 150 kW wind turbines (FEMP, 2022). These can be deployed in smaller spaces and can also be deployed at residential and commercial levels to increase clean energy production at a local level. Such wind turbines can be also installed at lower wind speed (at least 9 miles/hour) locations (EIA). Some of the technical specifications are as follows:

- Remote monitoring and control via certain software or communication protocol.
- Internal protection for any failure mode operation.
- Foundation requirements and installation options.
- ACP 101-1 or AWEA Small Wind Turbine Performance and Safety Standard 9.1-2009 for small wind turbines.
- ANSI/ TIA-222 for small wind tower structures.
- For a small wind turbine, certification can be demonstrated by being certified to either IEC 61400-1 or IEC 61400-2, depending on size.[3]
- IEC 61400-12 and IEC 61400-11 for performance and sound, respectively.
- UL6142 is a standard for small wind turbine systems. This standard covers small wind turbine systems and electrical subassemblies where a user or service person cannot or is not intended to enter the turbine to operate it or perform maintenance.

1.4 Grid-Interactive Efficient Buildings

Grid-interactive efficient buildings are energy efficient buildings that can smartly respond to time-dependent grid signals in a flexible manner (U.S. Department of Energy 2019). It is important to identify energy efficiency opportunities by replacing equipment or appliances with energy efficient ones. Thus, the first step is to determine the highest consuming loads, generally heating and cooling loads which can be controlled or used optimally based on utility rates and peak/off-peak hours. There are certain smart appliances which can be controlled/monitored such as dishwashers, clothes washers/dryers, and heating and cooling systems. These technologies can schedule/shift such loads based on the renewable generation and thus, allow for smoother and reliable integration of renewable generation and could reduce the need for additional energy storage systems. There are many commercially available home energy management systems

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[3] Note that for large wind turbines (i.e., generally turbines with peak power ratings of greater than 150 kW), certification can be demonstrated through type certification to IEC 61400-22.

(City Of Toronto, 2018) or building automation systems (Oregon State University, 2018). Some of the technical specifications are as follows:

- Remote monitoring and control.
- Communication interface available to control and monitor smart appliances and/or systems.
- Fully programmable with ability to manage various appliances including HVAC and lighting appliances.
- Include complete energy management software, including scheduling building control strategies with optimum start and logging routines.
- Possibilities of interfacing with an external controller such as microgrid controller.

1.4.1 Applicable standards:

- ANSI/The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 135, BACnet.
- Electromagnetic Compatibility (EMC) Directive 89/336/EEC (European CE Mark).
- FCC Part 15, Subpart J, Class A.
- International Building Code (IBC), including state and local amendments.
- NEC.
- ASHRAE Guideline 36-High Performance Sequences of Operation of HVAC Systems.
- UL 916 Underwriters Laboratories Standard for Energy Management Equipment in Canada and the U.S.
- UL-864 UUKL[4] listing for Smoke Controls for any equipment used in smoke control sequences.

1.5 Battery Energy Storage System (BESS)

These are minimum requirements:

- Battery Roundtrip Efficiency: 93% and higher.
- Battery Technology: Lithium ion.
- Ambient Temp: 0° to 40°C.
- Humidity: < 50% relative humidity.
- Operational and control specifications: Setpoint capability, four-quadrant operation and control, grid forming/following, voltage/frequency ride-through.
- Seamless transition: grid tied to island mode.
- Communication protocol: MODBUS TCP/IP (need to make sure that all the technical requirements are met with regard to monitoring and control by the microgrid controller and other interfaces).
- Additional functions: peak shaving, time shifting.

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[4] UUKL is an identifier by UL for smoke control equipment product under UL 864.

1.5.1 *Applicable standards:*

- UL1741 covers inverters, converters, charge controllers, and interconnection system equipment intended for use in stand-alone (not grid-connected) or interactive (grid-connected) power systems.
- UL9540 specifies requirements for installation of Energy Storage Systems (ESS) to include size and separation requirements designed to prevent fires from propagating to adjacent ESS units.
- UL 9540A "Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems." This standard was developed to address safety concerns identified by the building codes and the fire service in the United States.
- IEEE 1547 includes the technical specifications for, and testing of, the interconnection and interoperability between utility electric power systems and DERs.
- UL 1642 includes requirements that cover primary (non-rechargeable) and secondary (rechargeable) lithium batteries for use as power sources in products.
- UL1973 "Batteries for Use in Light Electric Rail Applications and Stationary Applications." These requirements cover battery systems as defined by this standard for use in light electric rail applications and stationary rail applications such as rail substations.
- UN 38.3 "Certification for Lithium Batteries" (Transportation). This standard specifies requirements for the safe transport (by air, sea, rail, or roadways) of lithium batteries.
- ANSI C12.1 (electricity metering) specifies acceptable performance criteria for new types of AC watt-hour meters, demand meters, demand registers, pulse devices, and auxiliary devices.
- ASCE-7-22 Minimum Design Loads for Buildings and Other Structures describes the means for determining design loads including dead, live, soil, flood, tsunami, snow, rain, ice, seismic, and wind loads and their combinations for general structural design.
- IEEE 2030.2: Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure. This process can be applied to ESS applications located on customer premises, at the distribution level, and on the transmission level.
- IEEE 2030.3: Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications.

1.6 General Requirements

The general requirements are for the balance of plant equipment/assets which are also important to be considered in the specifications.

- Switchgear with controllable breaker/contactor, meters (with remote monitoring communication protocol), current transformers/potential transformers, spare connections for future DERs.
- Require uninterrupted power supply (UPS) and AC/DC auxiliary supply for auxiliary systems to ensure operability during an outage or shutdown.
- Protection relay: modular protection relay is preferred which can take care of multiple protection points (breakers), various communication protocol, various protection fault/functions, capable of remote monitoring – Alarms/indication, fault/event logs.
- IEEE PC2030.12: Draft Guide for the Design of Microgrid Protection Systems. This is a Guide whose scope includes "…the design and selection of protective devices and the coordination between them for various modes of operation of the microgrid."

- Cybersecurity requirements: NIST 800-82 provides guidance on how to secure Industrial Control Systems (ICS) while addressing their unique performance, reliability, and safety requirements.
- Coordination of Subcontractor's Responsibilities
    - The contractor should ultimately be responsible for the completeness, accuracy, and coordination of all submittals but may delegate the preparation of submittals in whole or in part to subrecipients or subcontractors.
- Locating Equipment and Appearance
    - Major electrical components, including the inverter, isolation transformer, and metering, should be installed in code-compliant enclosures. Components should be located indoors whenever feasible, in ventilated (or air-conditioned) utility rooms, and where space and codes allow. When inverters and major electrical components are located outdoors, they should be protected from direct exposure to weather. A simple open-sided shed roof structure may be sufficient, making sure that operational temperature and humidity range are within range specified by the inverter manufacturer. Under no circumstances should inverters be located on roofs in direct sun. NFPA 70 National electrical code to be followed for safe electrical design, installation and inspection to protect from potential electrical hazards.
    - Batteries should be installed outside of the house in a weatherproof enclosure provided by the battery manufacturer. NFPA 855 provides guidelines for BESS capacity limits for inside and outside of the house and the spacing requirements.
- Expected Service Life
    - Unless noted otherwise, all materials furnished for the project should have an expected service life of 30 years or more, given the unique service conditions of each array site. Equipment warranties (modules, inverters, switchgear) are shorter than the expected service life. With a 30-year system life, it is common and well-understood by industry that battery cells, inverters and a small percentage of failed modules would need to be replaced, though the system as a whole would provide at least 30 years of service.
- Site Service Conditions
    - Materials should be designed to withstand the year-round temperatures and conditions to which they are exposed (sunlight, heat, humidity, rain, wind, seismic activity, salt air, fog, marine corrosiveness, etc.).
- Markings (Labeling)
    - Strict conformance to system marking requirements of systems and their components is crucial for the safety of operators, service personnel, emergency responders, and others. Contractor should follow general PV + BESS system labeling requirements, as per NEC 690 Ch. VI and specific requirements from Articles 690 and 705. Include all required and desired labeling language in the design drawings for agency review.

    - Electrical equipment and components used in systems should have markings that identify the manufacturer, size, type, ratings, hazard warnings, and other specifications. Equipment markings should never be removed and should be able to withstand the environmental conditions in which the equipment is installed (e.g., “UV rated” for outdoor labels or on an embossed steel placard designed for outdoor use and fastened with adhesive and rivets). Markings must be visible or easily accessible during and after installation. The Contractor should be responsible for all field-applied markings as required by local, state, and federal codes.

1.7 Microgrid Control System and Human Machine Interface with Supervisory Control and Data Acquisition (SCADA)

The following are the key requirements:

- Auto and manual operation. In auto mode, the microgrid controller manages the systems and dispatches the DERs without intervention required from the operator. While in the manual mode, the microgrid can be controlled and operated by the operator using the human machine interface.
- Key use cases such as minimizing use of diesel generator if the microgrid is mainly relying on diesel generators to meet the energy demand.
- Fault and maintenance mode of operation. This is to highlight what could be expected microgrid controller actions if any faults happen or if microgrid or any DERs are enabled in maintenance mode.
- Interface with weather station. Weather stations can be interfaced for forecasting PV generation and load for efficient and economic dispatch optimization.
- Interface with utility SCADA. Some utilities require monitoring and/or control of microgrid as technical interconnection requirement.
- Failure mode fault troubleshooting and clearing. This is to ensure that the proponent is accountable for providing operating manuals describing steps for troubleshooting and clearing the various faults.
- Data archiving. SCADA system has generally capability for data archiving, it is important to specify in the RFP for that requirement, if not specified, during the project execution proponent may ask for change order for such functionality.
- Plug and play architecture is preferred; minimum changes required to interface with future new DERs.

1.7.1 Applicable standards:

- IEEE 2030.4 Draft Guide for Control and Automation Installations Applied to the Electric Power Infrastructure
- IEEE 2030.5 Standard for Smart Energy Profile Application (communication) Protocol
- IEEE 2030.7 Standard for the Specification of Microgrid Controllers
- IEEE 2030.8 Standard for the Testing of Microgrid Controllers.

2 Design Guidelines for a Microgrid System

This section discusses the generic microgrid design guidelines applicable to a wide range of potential microgrid systems. This can be edited or modified specifically for Antigua and Barbuda based on local requirements.

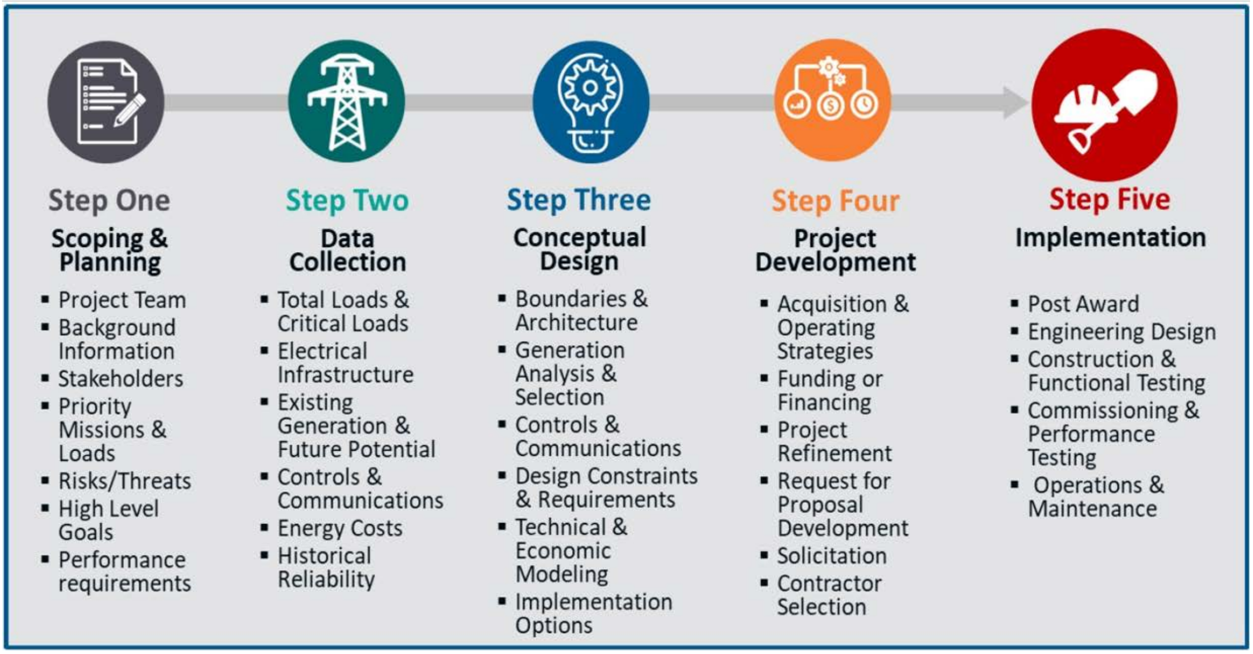


Figure 1. NREL's microgrid design process

Source: Booth, Reilly, Butt, Wasco, and Monohan 2020

Figure 1 shows the NREL updated Continuously Optimized Reliable Energy (CORE) microgrid design process. This process can be applied to microgrid systems, from the planning state to implementation to achieve resiliency, cost savings, and clean energy targets. In this section, the focus is on step three which is Conceptual Design.

To develop a conceptual design, the following information needs to be gathered during the scoping and planning process (step one), and this information will be used as inputs for analysis:

- Microgrid objectives
- Historical/projected load data
- Location and renewable energy potential
- Microgrid geographic and electrical boundaries based on where it will interconnect with the grid and which geographic area it will supply the power in the case of power outage.
- Power requirements
- Utility cost structure

The analysis for the conceptual design will focus on techno-economics, load served, and possible solutions.

The outcome of the analysis will be a high-level design that identifies the existing components that will be used as well as any new components, and the size or capacity of those components. The outcomes also identify operational modes, including potential economic operation in grid-connected mode.

2.1 Defining Microgrid Boundaries

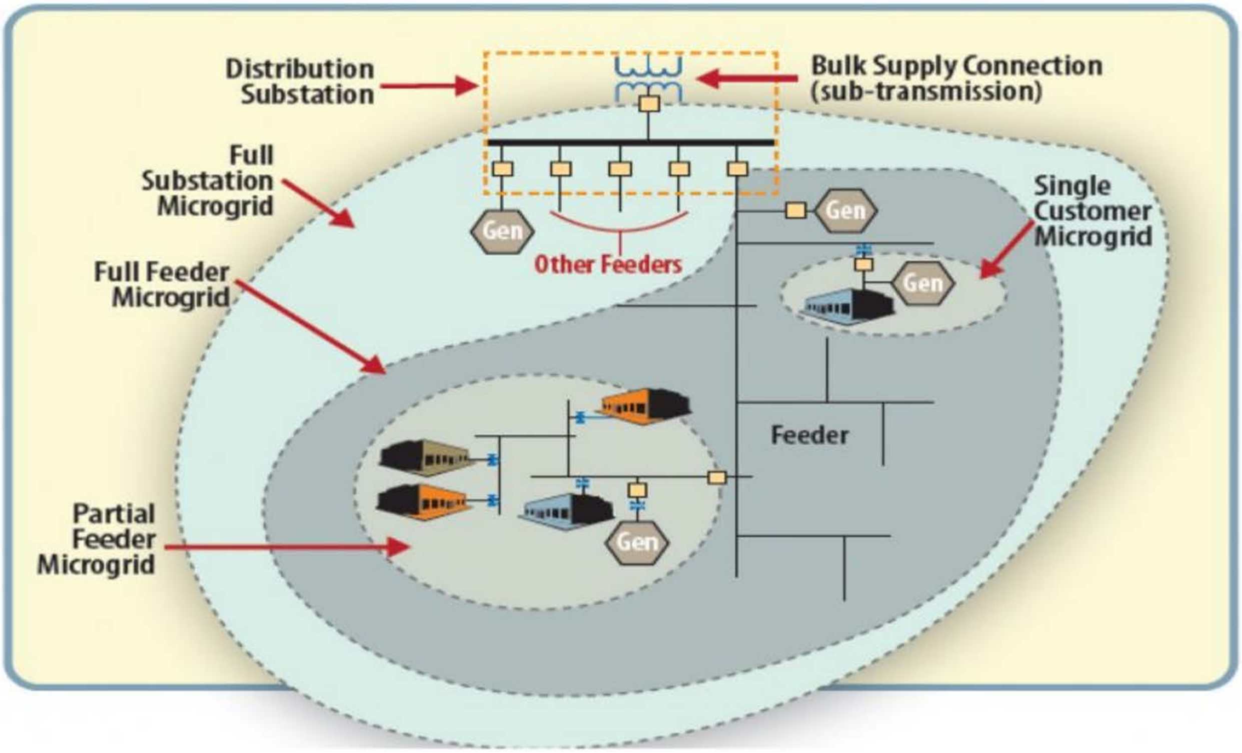


Figure 2. Microgrid boundaries

Source: U.S. Department of Energy n.d.

The graphic illustrates the scale and boundaries of a microgrid on a site. A solution could have a single customer microgrid which could be a single building, a partial feeder microgrid, a full feeder microgrid, a full substation microgrid, or a combination. It depends on the requirements determined during the project planning stage.

- **Location of critical loads**: The primary goal of a microgrid is to provide resilient power to critical loads; this is a key driver of isolation points. Some critical loads are far from others and may need to remain on backup generators. Critical loads may all be on part of a feeder, you may need to power the full feeder, or you may need to power all loads connected to the substation.
- **Available infrastructure**: It is important to understand if the microgrid's existing location is where its potential can be utilized to the fullest (in case of generators), and the requirement to upgrade or add additional transmission or distribution components is minimum. The existing panels of the distribution systems should be inspected for availability of spares, and if the new equipment can be tied into the existing system without adding new equipment. The operational condition and the maintenance record of these systems need to be checked. This

gives the project team a better idea to make an informed decision if it is feasible to tie into the existing infrastructure or modify the existing infrastructure or upgrade the infrastructure. A well-maintained system can be modified with less difficulty, whereas in an ill-maintained system—or if it is too old and cannot be compatible with newer systems—it is cheaper to add new equipment.

- **Existing generation**: Using existing generation or rehabilitating existing generation can reduce costs, by selecting a different isolation point. Selection of the isolation point depends on modifications needed to the equipment itself, and existing agreements and policy constraints e.g., an existing PV deployment can be under a power purchase agreement. In order to make changes to the power purchase agreement (PPA), there might be a fee that will be incurred or the PPA might need to be updated.
- **New generation**: Boundaries may be dictated by the location of new generation.
- **Types of microgrids**: Regardless of scale, the microgrid could have multiple isolation points and be a combination of the types below:
    - Grid connected/islanded
    - AC/DC/hybrid
    - Industrial/commercial/residential/community.

2.2 Power Requirements and Considerations

The following list of examples of considerations are important in planning and integrating new energy resources in terms of power quality requirements for demand and supply.

- **Redundancy and reserve**: Determine the amount of generation needed and ensure reliable operation of the system by planning and adding additional generation or back up.
- **Inrush currents**: During black start, transformers will be loaded, causing high initial currents to magnetize transformers. This can be addressed by bringing load and generation online in stepped fashion.
- **Reactive power**: Reactive power is required for inductive and capacitive loads in the system and for maintaining the Power factor of the system. Not all generators and DERs are capable of supplying reactive power.
- **Harmonics, nonlinear loads, and balancing**: Current pulses, fluctuations in final output, transients in case of connecting and disconnecting a new load or generation, and imbalance in demand or supply are needed to be considered for appropriate sizing of DERs and selection of power electronics devices.
- **Contingency and load growth**: Future addition of load or energy efficiency program needs to be considered to ensure enough DERs and their operational characteristics.
- **Energy Audit**: To identify the energy efficiency opportunities, it is important to perform an energy audit determining where, when, and how the energy is used. There are three levels of energy audits based on the ASHRAE which are as follows:
    - **Level 1:** Site assessment or preliminary audits by inspecting the site and looking into the energy bill to determine no or little cost energy saving opportunities.
    - **Level 2**: Energy survey and engineering analysis audits by performing in-depth analysis of how energy is used, total energy use and costs, and building type and

its characteristics to identify energy saving opportunities and potential capital investment required.

    - **Level 3:** Detailed analysis of capital-intensive modification audits by collecting data, monitoring and performing engineering analysis to identify more concrete recommendations, which may require major capital investments to achieve energy savings.

  For additional details, technical reports can be followed including "A Guide to Energy Audits" (Baechler, Strecker, and Shafer 2011) for the U.S. Department of Energy.

- **Transition:** *Grid-island-grid*: There should be enough generators available to meet the load demand when disconnecting from the grid and islanding, and there should be grid-forming DERs to energize the grid and regulate frequency and voltage of the islanded system. In case of connecting to the grid, the DERs and control elements should be able to ramp down the onsite DERs and regulate the voltage and frequency to be in phase (synchronize) with the grid.

2.3 Dispatchable and Variable Generation

Advanced microgrids are generally a hybridized system that combines dispatchable and variable generation and energy storage systems to minimize curtailment from the variable generation.

The final choice of generation sources is often determined by several factors:

- Power requirements
- Black-start capability
- Prime vs. backup generators
- Available renewable energy resources
- Existing generation assets
- Locally available fuel sources
- Air emissions
- Economic return.

One of the dispatchable assets will need to be grid-forming. All other assets will follow this asset. Variable resources are generally grid-following.

Note for paralleling existing generators, these generators will usually need modification which includes new controls, and the replacement of an automatic transfer switch with paralleling switchgear. If the asset is a backup generator dedicated to a critical building, take a "Do no harm" approach. This means that if there is a problem with the microgrid, such as losing communication, the generator will revert to powering the building that it is dedicated to. This will be implemented in controls locally.

2.4 Operating Characteristics of Renewable Energy (RE)

Table 1. The Operating Characteristics of RE in a Hybrid System

Amount of Renewable Energy	Variable Renewable Energy Contribution		Operating Characteristics of Renewable Energy: Hybrid Systems
	Peak	Average	
Low	<30%	<20%	• In island mode, dispatchable generation runs full time. • Renewables reduce net load of the system. • All renewable energy goes directly to load. • No control system is required in many cases.
Medium	30%–75%	20%–50%	• In island mode, dispatchable generation runs full time. • Renewables reduce net load, also at excess renewable energy generation, load is added, or renewable energy is curtailed, charged to energy storage system, or exported to grid. • Basic control system is typically required to manage the load and generation.
High (with energy storage)	50%–100%	50%–100%	• Renewable energy and storage can meet the load by themselves most of the time. • If dispatchable generators are in the system, they can be shut off, unless needed—for example, to charge the battery during periods of low renewable energy resource. Excess renewable energy is curtailed, charged to energy storage system, or exported to grid. • Basic or advanced control system is required for load and demand management.

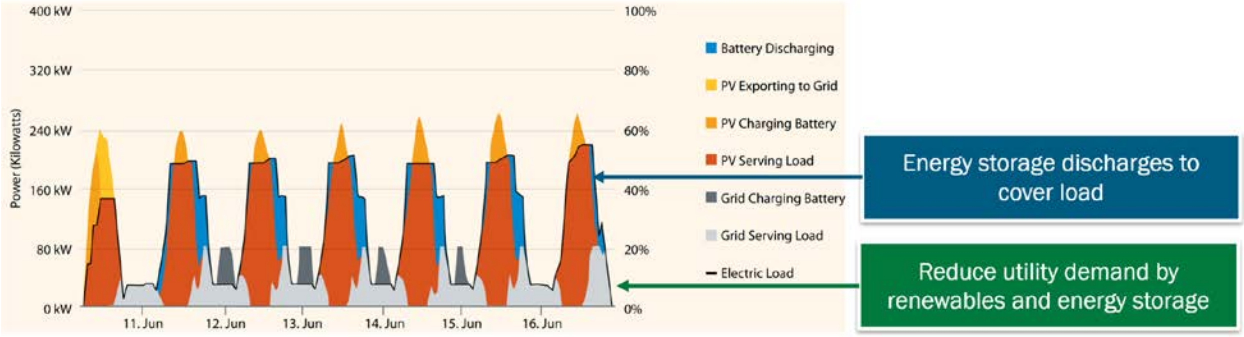
Table 1 shows the operating characteristics of renewable energy (RE) in a hybrid system. For a low amount of RE (Variable Renewable Energy Contribution column), there are many examples at large and small scales. For a medium amount of RE, there are many examples at large and small scales. Dispatchable generation and RE operate in the same way, but basic controls are likely needed to add load or curtail RE. For a high amount of RE with storage, there are many examples mostly at small scale. Generators may be shut down because of high renewable generation causing a generator to operate below its minimum operating power. Therefore, a microgrid controller will be needed to curtail renewable generation, making sure generators have enough margin to balance supply and demand without operating beyond their limits. An energy storage system would be a good solution with high penetration of renewables, since it can store the energy during excess renewable generation without curtailing.

2.5 Techno-Economic Analysis

During conceptual design, a techno-economic analysis should be performed. This analysis considers capital costs, operations and maintenance costs, utility bills, and other life cycle costs. There are available tools to perform this analysis such as the REopt® web tool. Such tools optimize the life cycle costs of the project considering capital costs, operations and maintenance costs, utility bills, other life cycle costs, operational characteristics of DERs, and dispatch strategies for DERs. The potential outcomes of the analysis include DERs and their respective sizes and dispatch strategy, potential financial outcomes, and potential savings in GHG emissions.

To complete the techno-economic analysis, the items below must be identified:

- DER capacity (generation and storage)
- Microgrid dispatch/control strategy
- Economic savings such as reducing consumption using demand response.



Energy storage discharges to cover load

Reduce utility demand by renewables and energy storage

Figure 3. Example microgrid dispatch staked area plot for a week

A microgrid dispatch and control strategy could have both costs and savings associated with it. The same strategies that save money may be implemented by a microgrid operations staff that will be on payroll as a cost.

In addition to financial costs, savings associated with the microgrid should be included. These include self-generation, demand response, peak shaving, and ancillary services such as frequency response or regulating power factor.

As presented in the graph, in the blue box, energy storage discharges to cover load as PV production drops at the end of the day. This will help reduce peak demand. In the green box and looking at the gray area under the curve, we see that overall utility demand is reduced by PV generation.

2.6 Electrical Modeling and Studies

The following are the key analysis and studies performed during the different stages of a microgrid project:

- Power flow analysis: Calculates steady-state bus voltages, phase angle, real and reactive power, and currents carried on conductors and supplied to loads in an electrical power system.
- Dynamic stability analysis: Primarily performed to investigate generator stability under changes in generation or load in a power system.
- Transient analysis: Investigates system stability in the post-fault system subsequent to a specific fault scenario.
- Interconnection application and studies: Performed by the utility based on microgrid size (factor into project costs).
- Protective relaying and coordination: Fault currents are much lower in an islanded microgrid compared to when the circuit is grid-connected. Separate group settings will be required in protective relays for each scenario.

Any or all of these models may not occur until after the project is awarded. Because microgrids are complex, it is important to do this modeling.

2.7 Best Practices

Classify the islands based on the size, grid interconnection, issues such as power quality and resilience, and utility tariff. On the smaller islands without grid interconnection, resilience would be an important consideration, thus the microgrid solution can be different with appropriate DERs and specific microgrid protection and control requirements. Also, note that similar islands can adopt identical solutions which can be replicated and benefited from the operation and maintenance of the microgrid system.

Determine the policy requirement for each island group based on their unique features and needs, for example island to reduce the reliance on fossil-fuel-based generation and have significant potential for renewable generation and island can identify appropriate policies to promote greener resources and the same way other islands can identify the policies focusing on improving resiliency. A legal framework could be the first step toward transitioning to clean energy technologies where a goal is set for renewable energy penetration or GHG emission reduction by the power sector. Then, it is important to develop an integrated resource plan (IRP) identifying the long-term plan for meeting the electricity demand efficiently, reliably, and economically by selected supply and demand side resources. Various stakeholders—including but not limited to energy experts, community leaders, utilities, government, and policy planners—should be engaged for preparation and review of the IRP.

Islanded systems need to make sure their grids are prepared for anticipated renewable generation penetration. For successful and reliable integration of clean generation technologies, island systems need to identify technical requirements and a screening process for grid interconnection considering different sizes of microgrids.

Develop financial incentives and mechanisms to encourage microgrid penetration depending on the needs of the island systems. One of the key barriers surrounding microgrid procurement is how to ensure owners are properly incentivized by financial/contractual mechanisms to adopt clean energy technologies. These mechanisms can include but are not limited to single PPA for qualified users, aggregated procurement, and distributed generation at or near demand centers.

3 Interconnection Related Guidelines

Note that the following discussion provides an example of interconnection guidelines which can be edited and modified to meet specific requirements for Antigua and Barbuda. Antigua Public Utilities Authority (APUA) has a published "Interconnection Procedures Guideline" (2019) for non-fossil-fueled distributed generating facilities with capacities up to 50 kW. The guidelines published by APUA provide details on the application and review process and include their own technical requirements which can be supplemented by the more general microgrid interconnection requirements. Special attention should be given to those general requirements applicable to facilities with generating capacity greater than 50 kW. Section 9 of the APUA guidelines discusses requirements for a feasibility study, impact study, and facilities study, along with equipment and recommended modifications to the system. Section 10 describes power quality requirements for the interconnection.

3.1 Technical Interconnection Requirements

Technical interconnection requirements can be developed by the utility to help ensure that microgrid systems can be installed without affecting grid operations. It is important to highlight the key standards by which all inverters must comply, for example UL1741 SB.

This section provides the best practices for the technical requirements to qualify for seamless interconnection to the grid and lists typical conditions and responses to abnormal conditions that the system is required to meet. Note that these requirements can be set for different sizes of microgrid systems as larger systems can affect the grid more. For example, Puerto Rico has categorized microgrid systems in the following sizes:

- Microgrid with generation capacity of up to 10 kW feeding up to 3 customers.
- Microgrid with generation capacity of up to 30 kW feeding from 4 to 10 customers.
- Microgrid with generation capacity of up to 100 kW feeding more than 10 customers.

Microgrids can consist of various DERs, including but not limited to solar PV, wind turbines, battery energy storage systems, and generators. For individual resources, key certification requirements can be identified from Section 1. Consider manufacturer's data sheets, manuals, and other details along with the interconnection application.

The interconnection application is important to demonstrate that the microgrid will not affect the grid adversely and can isolate itself in the case of fault or adverse events. Voltage, current, and power limits are key operating parameters to be reviewed. The following subsections highlight the potential requirements for interconnection application which can be considered from operational requirements during normal and adverse events.

3.1.1 Protection

The system should identify any protection events occurring in the boundary of the microgrid system and isolate itself from the grid. At the point of common coupling, over current, under/over voltage, under/over frequency, or overpower, inrush protections should be considered. Note that voltage and frequency protection need to be coordinated properly, taking into account the voltage/frequency ride-through setting required.

3.1.2 Point of Common Coupling (POCC)

The point of common coupling (POCC) should be identified with the breaker and have a visible and lockable AC disconnect; the status of these switches is very important to the utility system depending on the size of the microgrid system. Note that for unintentionally islanded mode of microgrid operation, due to outage, the POCC breaker is tripped and the microgrid is regulating the voltage and frequency and feeding the microgrid loads. The POCC breaker should stay in open condition and interlocked until the grid comes back and microgrid is in de-energized state.

3.1.3 Current Harmonic Distortion

The microgrid systems need to comply with IEEE Standard 1547-2018 current distortion limits regarding harmonic current injection into the grid, as shown in Table 2.

Table 2. Current Harmonic Distortion Limits Based on IEEE 1547-2018

Total Rated Current Distortion Limit	**5.0%**
	Maximum Distortion
Harmonic Numbers	
h = 2	1.0%
h = 4	2.0%
h = 6	3.0%
other h < 11	4.0%
11 ≤ h < 17	2.0%
17 ≤ h < 23	1.5%
23 ≤ h < 35	0.6%
h > 35	0.3%

3.1.4 Inverter Response to Abnormal Voltages (Ride-Through)

The inverter must be able to meet the UL 1741 SB voltage response and ride-through criteria, as stated in standard IEEE 1547-2018.

The figure and table below show the required operation ranges and clearing times (times until trip), where p.u. is per unit; UV is undervoltage; and OV is overvoltage. Voltage and time values are fixed for operating ranges. Clearing times and voltages for trip are adjustable.

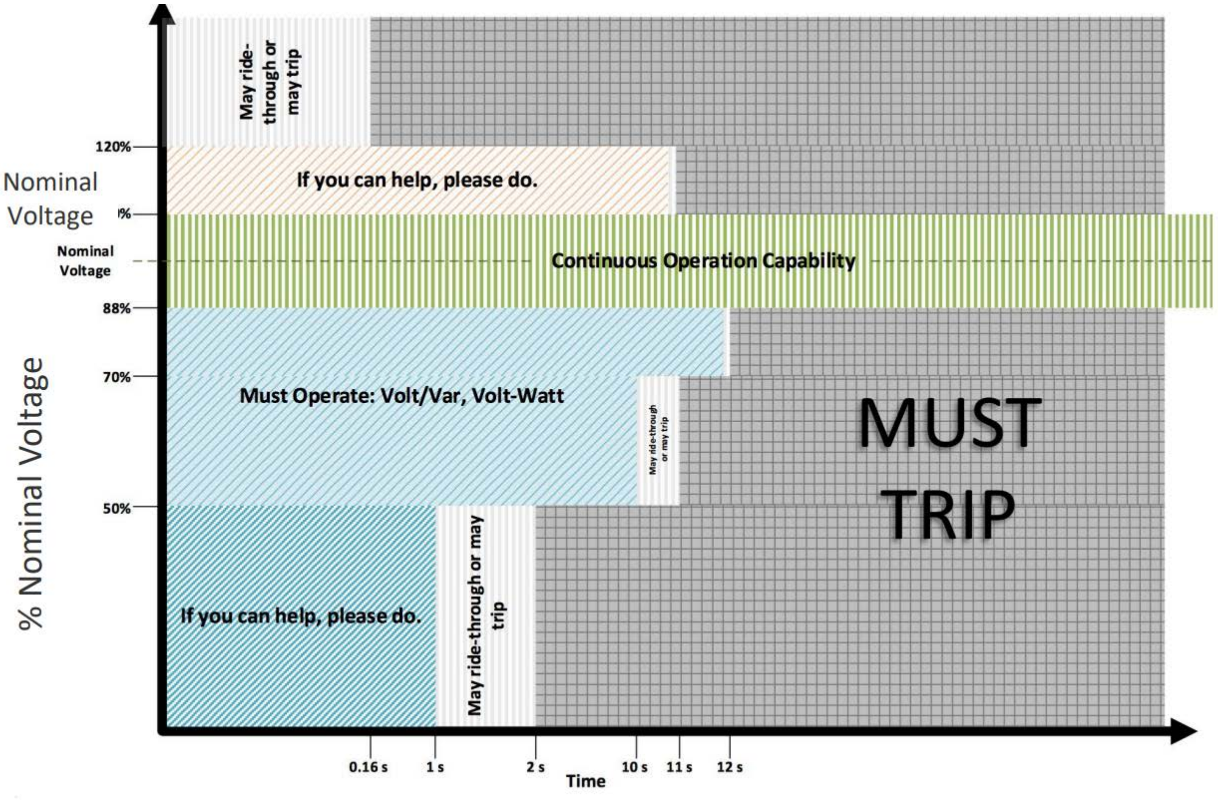


Figure 4. Voltage ride-through setting

Based on: IEEE 1547-2018 Figure H.9. Please see the original for details.

Figure credit: Adarsh Nagarajan (NREL)

Table 3. Under and Over Voltage Setting Range

Based on: IEEE 1547-2018 Table 11. Please see the original for details.

Shall trip – Category III				
Shall trip function	Default Settings		Ranges of allowable settings	
	Voltage (p.u. of nominal voltage)	Clearing time (s)	Voltage (p.u. of nominal voltage)	Clearing time (s)
Over voltage 2	1.2	0.16	1.2	0.16
Over voltage 1	1.1	13	1.1-1.20	1.0-13.0
Under voltage 1	0.88	21	0-0.88	21-50
Under voltage 2	0.5	2	0-0.5	2-21

While voltage is in the continuous operation range, the inverter must be capable of providing reactive power support to offset voltage deviations. The reactive power support must follow the curve in the figure below. Points on the figure must be adjustable to any value in the ranges given in the table below for Category B settings for DERs as identified in IEEE 1547. Inverters must be capable of meeting a 1-second open loop response time.

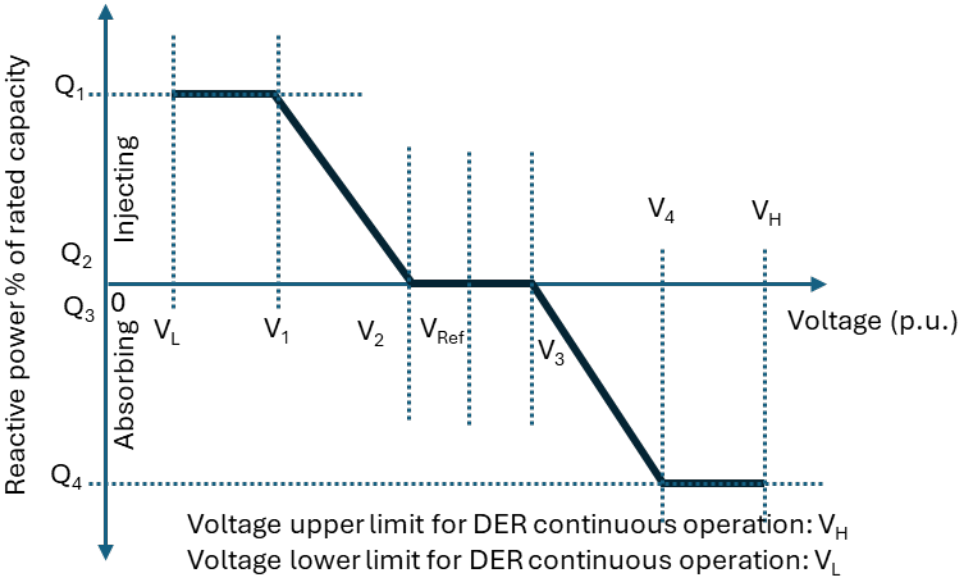


Figure 5. Reactive power/voltage support setting for inverters

Based on: IEEE 1547-2018 Figure H.4. Please see the original for details.

Table 4. Reactive Power/Voltage Support Setting for Inverters

Based on: IEEE 1547-2018 Table 8. Please see the original for details.

Voltage/Reactive power parameters	Default settings	Ranges of allowable settings	
		Minimum	Maximum
V_{Ref}	Nominal voltage (V_N)	0.95 V_N	1.05 V_N
V_2	$V_{Ref} – 0.02\ V_N$	$V_{Ref} – 0.03\ V_N$	V_{Ref}
Q_2	0	100% of rated reactive power capacity for absorption	100% of rated reactive power capacity for injection
V_3	$V_{Ref} + 0.02\ V_N$	V_{Ref}	Category B: $V_{Ref} + 0.03\ V_N$

Voltage/Reactive power parameters	Default settings	Ranges of allowable settings	
		Minimum	Maximum
Q_3	0	100% of rated reactive power capacity for absorption	100% of rated reactive power capacity for injection
V_1	$V_{Ref} - 0.08\ V_N$	$V_{Ref} - 0.18\ V_N$	$V_{Ref} - 0.02\ V_N$ *
Q_1[#]	44% of rated reactive power capacity for injection	0	100% of rated reactive power capacity for injection[$]
V_4	$V_{Ref} + 0.08\ V_N$	$V_{Ref} + 0.02\ V_N$	$V_{Ref} + 0.18\ V_N$
Q_4	44% of rated reactive power capacity for absorption	100% of rated reactive power capacity for absorption	0
Open loop response time	5s	1s	90s

The reactive power capability of DERs may be reduced at lower voltage.
$ DER may reduce active power output in order to meet this reactive power requirement.
* Improper value section can cause instability in the system.

3.1.5 Inverter Response to Abnormal Frequencies (Ride-Through)

The inverter must be able to meet the UL 1741 SB frequency response and ride-through criteria, as stated in standard IEEE 1547-2018. The figure and table below show the required operation ranges and clearing times (times until trip).

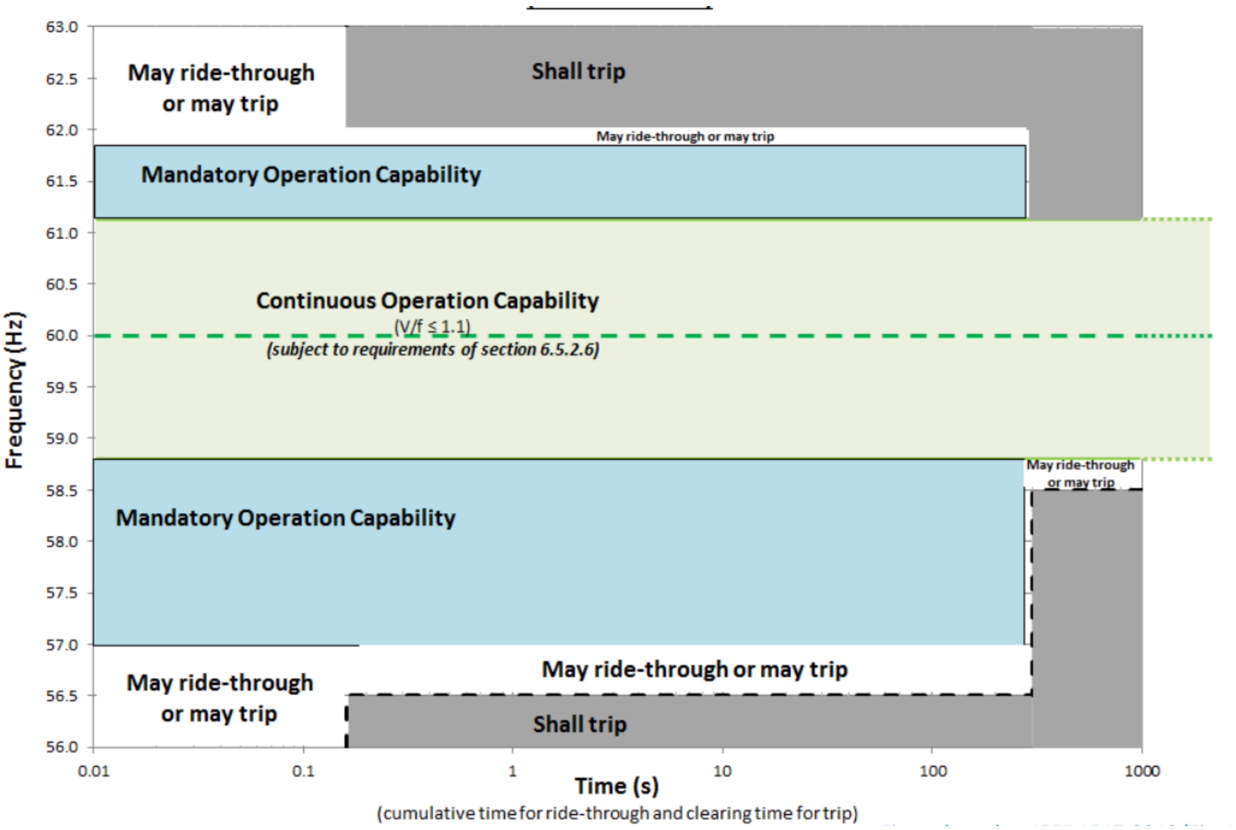


Figure 6. Frequency ride-through setting range

Based on: IEEE 1547-2018 Figure H.10. Please see the original for details. [Figure credit: David Narang (NREL)]

Table 5. Under and Over Frequency Protection Setting Range

Based on: IEEE 1547-2018 Table 18.

Shall trip function	Default Settings		Ranges of allowable settings	
	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s)
Over frequency 2	61	0.16	61.8-66	0.16-1000
Over frequency 1	61.2	300	61-66	180-1000
Under frequency 1	58.5	300	50-59	180-1000
Under frequency 2	55.8	0.16	50-57	0.16-1000

While frequency is in the continuous operation range, the inverter must be capable of providing active power support to offset voltage deviations. The active power support must follow the formula in the table below and droop parameters in the following table. Inverters must be capable of meeting a 0.5-second open loop response time. Finally, the inverter must be capable of riding through a 3 Hz/s frequency ramp.

Table 6. Active power support formula for low and high frequency conditions for inverters

Active power for low-frequency conditions	Active power for high-frequency conditions
$p = \min\limits_{f<60-db_{UF}} \left\{ p_{pre} + \dfrac{(60-db_{UF})-f}{60\ k_{UF}}\ ;\ p_{avl} \right\}$	$p = \min\limits_{f>60+db_{OF}} \left\{ p_{pre} + \dfrac{f-(60+db_{OF})}{60\ k_{OF}}\ ;\ p_{min} \right\}$

Based on: IEEE 1547-2018 Table 23. Please see the original for details.

Formula definitions based on IEEE 1547-2018. Please see the original for details:

p is the active power output, in per-unit of the DER nameplate active power rating

f is the disturbed system frequency in Hz

p_{avl} is the available active power, in per-unit of the DER rating

p_{pre} is the pre-disturbance active power output, defined by the active power output at the point of time the frequency exceeds the deadband, in per-unit of the DER rating

p_{min} is the minimum active power output due to DER prime mover constraints, in per-unit of the DER nameplate active power rating

db_{OF} is a single-sided deadband value for high-frequency and low-frequency, respectively, in Hz; default is 0.036 and setting range is 0.017-1.

db_{UF} is a single-sided deadband value for high-frequency and low-frequency, respectively, in Hz; default is 0.036 and setting range is 0.017-1.

k_{OF} is the per-unit frequency change corresponding to 1 per-unit power output change (frequency droop), unitless; default is 0.05 and setting range is 0.02-0.05.

k_{UF} is the per-unit frequency change corresponding to 1 per-unit power output change (frequency droop), unitless; default is 0.05 and setting range is 0.02-0.05.

Response time default is 0.5 seconds and setting range is 0.2-10.

3.1.6 Synchronization

The microgrid systems should be connected in parallel with the grid if the system DERs can follow the grid voltage and frequency with its synchronizing capabilities. Synchronization may occur once the grid has stabilized following an outage or another disturbance event. Note that the synchronization happens at the terminal of the DER. For the point of common coupling, the synchronization check condition of live bus deadline should be incorporated to avoid closing the breaker when voltage is available on both of its sides (bus and line).

3.1.7 Soft Start/Stop Ramp Rates and Random Delays

Active power should increase linearly or in a stepwise linear ramp, with an average rate-of-change not exceeding the DER nameplate active power rating divided by the enter service period. The duration of the enter service period should be adjustable over a range of 1 to 1,000 seconds and will be specified in the interconnection agreement. The maximum active power increase of any single step during the enter service period should be less than or equal to 5% of the DER nameplate active power rating. Where a stepwise ramp is used, the rate of change over the period between any two consecutive steps should not exceed the average rate-of-change over the full enter service period. This requirement is a maximum ramp rate requirement, and the DER may increase output slower than specified. A random delay between 0 and 600 seconds must be implemented during reconnection after a grid event.

3.1.8 Remote Monitoring

The remote monitoring requirement can be highlighted and implemented for microgrid systems larger than a certain threshold (Austin Utilities n.d.),[5] depending on the policy and agreement. Consider providing the utility with read-only and control access that will allow:

- Real-time monitoring of the system
- The ability to view configuration parameters
- The ability to download historical performance and log data from the system up to a certain period as per the policy and agreement.
- Send command for transfer trip or disconnect the microgrid system during inadvertent conditions.

Allowed protocols include DNP3, SunSpec Modbus, and 2030.5. Inverters should have monitoring systems with one common internet-accessible interface for ease of monitoring.

Note that there could be non-technical interconnection requirements such as ownership model and insurance.

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[5] These thresholds are defined by the utility based on the overall system size and how the microgrid system can affect the existing operation and protection of the system. For example, in this reference, the threshold is 1 MW for remote monitoring. (Austin Utilities n.d. https://www.austinutilities.com/assetmanager/downloads/documents/pdf/DER/Interconnection-Technical-Requirements.pdf)

3.2 Developing Technical Filters for Interconnection Process

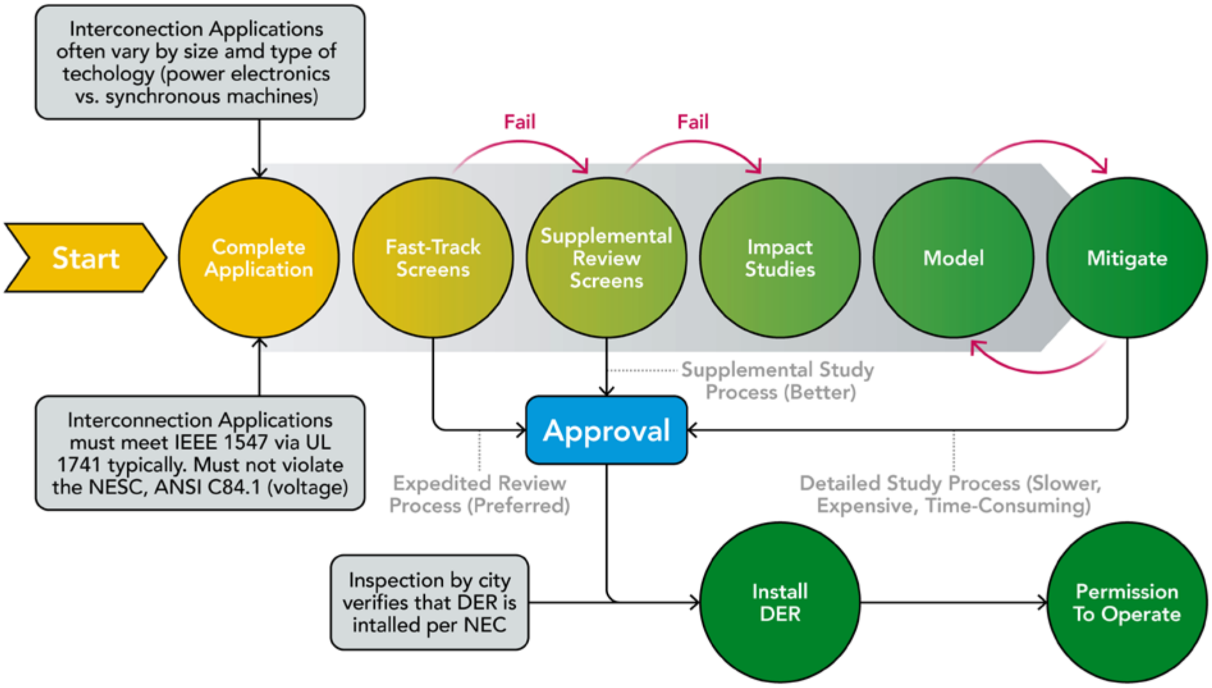

Figure 7. Interconnection process used in the United States

Source: Shepherd, Gagne, and Shah 2021

Figure 7 shows the development interconnect process with technical filters allowing the implementation of a fast-track approval process. This process with technical filters can be considered along with the technical interconnection requirements. With this process, only the systems which fail in the fast-track filters and also in the supplementary filters need to proceed through expensive and time-consuming detailed interconnection studies. The interconnection studies can include power flow analysis, short circuit analysis, and dynamic or transient analysis.

The technical filters can be developed based on following key parameters:

- Grid hosting capacity limits, as percentage of transmission/distribution infrastructure capacity or minimum load of respective area
- Interconnection voltage level
- Impact on voltage regulators
- Impact on protection system
- Existing spinning reserve capacity
- Requirement of having energy storage system as percentage of renewable generation capacity
- Requirement of monitoring and control of microgrid system by utility.

3.3 Commissioning, Inspection, Testing, Authorization

Any new grid-connected system that is to be deployed is required to pass commissioning, inspection, testing, and authorization as per the regulation and standards the system is planned to operate in parallel to the grid. Some examples of parameters that can be considered can include inspection of the system by utility before its commissioning for larger system designs[6] that have risk of back-feeding into the grid. The customer should coordinate with the utility before installing larger systems that can feed the energy back into the grid. The utility should have guidance for net-metering. The customer should inspect the equipment before installation and check the tests and compliance to standards as recommended by the regulations in the region and the utility.

These parameters vary depending on the type of the system. Thus, it is important to establish regulation and local standards or any adopted standards that can be applied to the existing system. Any improvements or new deployment must comply with these established regulations.

3.4 Microgrid Technical Requirement Context for Different Islanded System Types

Microgrid technical requirements will likely be important regardless of the islanded system characteristics, but it is worth noting that for non-interconnected systems, these requirements may not be as relevant. Every island system differs based on its location, robustness and types of loads connected to the system, etc. These differences require the stakeholders to implement proper filters in order to select appropriate equipment and the right design. The local interconnection regulations and guidelines must be followed to avoid imbalance of voltage or frequency in the system. Integrating large amounts of DERs and direct generation into the system can lead to these issues. Inverters connecting the DERs and the grid must be IEEE 1547 compliant to avoid failure in these scenarios as discussed in Section 3.3. Selecting appropriate filters for this is discussed in Section 3.2. Before integrating new generations into the system, the operators or the integrators should conduct detailed interconnection studies by performing power flow analysis, short circuit analysis, and dynamic or transient analysis of the system. This analysis helps in determining any required upgrades for the system and how new generators will impact the system.

Filters should be developed around the existing system and the regulations that the systems follow. These technical filters should also consider the policies around which systems are being designed or implemented. These can help in the planning and approval of the new systems before implementation. As mentioned above, grid-connected systems should conduct the required analysis to understand the impact on the system; if the impact is within the limits set by the filter, it should move forward in the approval process. However, for an isolated system there is no grid impact, so filters for such systems should not have the barrier of grid impact analysis and should be designed appropriately to analyze the independent system.

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[6] Sometimes for resilience purposes or favorable net metering arrangements, the systems can be oversized compared to peak load. Such systems can potentially back-feed to the utility in significant amounts when the site load is low.

In terms of isolated systems and smaller grid-connected systems with the ability of electrical isolation, microgrids following technical requirements and capabilities are essential.

4 Stakeholder Roles and Qualification of Installer

During the steps (Figure 1) of Scoping and Planning, Project Development, and Implementation of the project, it is important to identify the roles of stakeholders and all parties involved in the project for the ease of implementation and project management. Table 8 below gives an example of some of the roles and responsibilities of stakeholders and parties involved in a project or who will be impacted by the project.

Table 7. Stakeholder Groups and Their Roles

Stakeholder Groups	Roles
Site and mission leadership and staff	Installation leadership, mission owners, emergency management personnel, installation security, legal
Public works management staff and departments	Energy manager, electrical engineering and operations staff, water program manager, wastewater management, generator testing and maintenance staff, geographic information systems, environmental, real property, contracting and acquisition
Information systems	Information technology, communications, cybersecurity
Utilities	Electric, water, gas, communications
Other authorities	Environmental quality, energy commission, utility privatization contractors (if any)
Community	Local emergency management, other critical facilities near the installation, community engagement and education
Developer/contractor	Engineering, procurement, construction (EPC)
Integrator	Responsible for successful component and system integration
Technology vendor	Supply microgrid components which may include installation and commissioning
Operator	Responsible for microgrid operation
Technician	Maintains equipment after installation

Once the roles are identified, it is important to define preferred minimum qualifications for each role. These can vary depending on the responsibility and the task at hand and can be made more stringent depending on the criticality of the task. In "Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition" (National Renewable Energy Laboratory et al. 2018), Section 8 provides an example of these qualifications for a solar PV operator. In the United States, it is expected for the solar PV operator to be familiar with the plant design and have at least 3 to 5 years of experience in the field. For grid-connected systems, the operator should be North American Electric Reliability Corporation (NERC) certified. An installer should be North American Board of Certified Energy Practitioner (NABCEP) certified or UL PV system installation certified. The operators should be familiar with fire safety codes (NFPA 70E), Occupational Safety and Health Administration (OSHA) codes, and other health and safety codes mentioned earlier in this document. Appendix D of the "Best Practices" report also specifies requirements for other auxiliary tasks associated with the maintenance of the system. An example is as follows:

Table 8. Qualification Requirement and Responsibilities for Different Roles

Source: National Renewable Energy Laboratory et al. 2018

Role	Responsibility	Qualification
Designer, Developer, Contractor (Engineering, procurement and construction), also can be an Integrator	Specifications, drawings, modeling and analysis, codes and standards	Bachelor of Science in electrical engineering (civil engineering for construction-related work) (4-year degree); registered PE licensed to practice engineering in the jurisdiction; NABCEP PV Installer certification; CAD (AutoCAD) and graphics skills; knowledge of IEEE, NEC, NESC, and other codes and standards for PV systems; required level of errors and omissions insurance
Inspector, installation, and commissioning of PV system	Diagnostic analysis, visual inspection, specific testing	Diagnostic analysis; NABCEP PV Installer Certification; 2 to 5 years of experience, licensed Electrical Engineer (Professional Engineering license in case of U.S.)
Journeyman electrician	Module replacement, inverter replacement, fuse/breaker replacement, conduit routing, wiring, ground-fault repair	(estimated) 50-hour OSHA card; training in arc-flash, lock-out/tag-out, and other special protective equipment and procedures; NABCEP PV Installer certification; experience in the design of medium-voltage electrical systems; 5+ years of experience with PV systems; color vision
Lead Electrician / Technician	Module replacement, inverter replacement, fuse/breaker replacement, conduit routing, wiring, ground-fault repair	Electrical contractor's license for the jurisdictions; 50-hour OSHA card; NABCEP PV Installer certification; experience in the design of medium-voltage electrical systems; 5+ years of experience with PV systems; color vision; certification by NERC is necessary for positions that affect the power grid
Network/IT	Internet/network repair, monitoring equipment repair	Knowledge of specific monitoring devices (training by system supplier) and how monitoring system is connected through network connections or wireless or cellular modem; knowledge of Modbus, DNP3, and other protocols and HMI operator interfaces; 2 to 5 years of experience; Locus, Enphase, Itron, etc., monitoring device knowledge
Microgrid Operator	Responsible for operating the microgrid after commissioning completed	Minimum college degree with fundamental knowledge of power system, communication system, distributed energy resources, and control system. On-job training required

Role	Responsibility	Qualification
		by the microgrid controller and other technology vendors following the technical instruction.
Technology Vendor	Responsible for installation and commissioning of respective equipment/asset	Manufacturer certified for commissioning and installation of the respective equipment/asset

It is also important to note that every system has its unique features and specifications. This list of qualifications is representative and non-exhaustive. The operator may require additional training and certifications depending on the local requirements and regulations and/or as recommended by the vendor or supplier of the equipment to get additional training before operating the system.

5 Warranty Requirements

High-level details are provided here for the warranty requirements, referred from "Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition" (National Renewable Energy Laboratory et al. 2018).There are mainly two kinds of warranties: product warranties and performance warranties. Product warranties include materials and craftmanship and provide protection for any failure caused by manufacturing defects. Different assets or equipment have different years of warranty which can be extended based on requirements. Most of the manufacturers for solar panels provide up to 12 years of product warranties, while inverter manufacturers cover product warranties for 10 years which can be extended for total of 20 years.

The performance warranty covers operational output and/or efficiency which may differ as the aging of the equipment or asset. For example, PV output power capacity reduces over time due to natural degradation, reducing approximately to 80% of rating after 25 years.

Note that PV modules may have very long-term performance warranties of 20 or 25 years considering guaranteed performance in linear decline or stair-step fashion. The EPC can provide a year or two warranty.

The following are the considerations for warranty:

- Warranty requires the handling and operation of the asset/equipment within the specified conditions by the manufacturer. For example, operating or storing equipment beyond the specified ambient temperature range would void the warranty.
- There can be the possibility of the manufacturer going out of business.
- The identified performance parameters are to be monitored or tested to check if they are beyond the operating limits determining any defect or malfunction in the equipment. Note that such test equipment or testing could be expensive.

- Ensuring what is covered in the warranty, i.e., replacement of the asset only or other costs as well as logistics and labor costs. This needs to be checked in the proposal or the purchase contract.
- Identifying how the warranties would be handled in the case of change of system ownership.
- Warranty insurance is very important for large projects considering the various risks including manufacturer running out of business.
- It is important to carefully review who will be providing the warranties and the period of warranty by the stakeholders (EPC, manufacturers). This may need to be negotiated based on the project requirements. The warranty start may depend on the contract either commissioning of the project or the operation and maintenance (O&M) period.
- In the case of remote locations, where logistic and supply chain management may be challenging, it could be beneficial to have replacement stock available for any repair.
- Following the preventive maintenance as instructed/specified by the manufacturer is necessary to preserve the warranties.
- Record-keeping could be very helpful in discussion with the manufacturer or vender in the case of warranty issues, which includes all the details about the physical conditions, performance parameters, preventive maintenances, work orders, issues and diagnosed solutions, and also trouble tickets.

6 Maintenance of Systems

In the Request for Proposal procurement document, the maintenance requirement can be added for the microgrid, considering the limited expertise and experience of the onsite staff. At least 5 years of O&M experience should be specified, which must include but is not limited to software updates, maintenance required by the equipment, and operational inquiries. Consider options for remote and onsite maintenance and the requirements. There would be an additional cost for onsite maintenance, depending on the days, hours, hourly rate of the staff, and other travel-related expenses. If any equipment is recommended for spare inventory, this needs to be highlighted and procured accordingly. Note that if the local staff is trained and certified for operations and maintenance of the system, the need for third party maintenance can be minimized.

A well-maintained system can improve the performance of the system, increase longevity, and increase the system's earnings. Some things can be considered during the design, procurement, and engineering portion of the project. Considering low- or no-maintenance alternatives wherever possible in the design process can help bring down the O&M expenditure. Similarly, during the design process, measures should be taken to protect the system from rodents like rats, squirrels, and rabbits; and natural hazards such as flooding, earthquakes, and storms. Adding redundancy is another option to support uninterrupted service during outages and O&M. Another important consideration is to design effective access to the system that will serve ease of access for maintenance of the system.

The "Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition" (National Renewable Energy Laboratory et al. 2018) provides further guidance for scope and prerequisites for O&M, and best practices for O&M of a system, in Section 3 of the document. Similarly, in Section 5 it discusses dependencies as per site and maintenance of electrical systems, inverters, different configurations of roof- mount and ground-mounted PV systems, environmental conditions that affect performance, different use cases of batteries, and how the plans should be modified as per requirements. Section 6 of the document provides guidance for planning the system's performance, and its indicators that can be monitored for improving an existing plan. The document also provides a checklist and guidance for developing an O&M plan.

Glossary

Term	**Definition**
Active power	The real power or real load in the system, measured in kilowatts (kW).
Black start	Reenergizing the microgrid system after a blackout caused by an outage or loss of power.
Grid-following	The asset that does not form or energizes the grid at black- start but is connected to an already energized grid and operates at the grid's defined set points.
Grid-forming	The ability of an asset to set the operational voltage and frequency to energize the grid.
Harmonics	A small sinusoidal ripple in current or voltage that causes distortion in final target output.
Inrush current	A high surge of current when an asset or load is energized.
Peak shaving	The ability to control and protectively manage demand by eliminating short-term demand spikes to smooth the overall peak loads and reduce demand charge.
Point of common coupling (POCC)	The point in the electrical system where the metered output represents the total average load/generation of the system. This can be the point where the utility meter is connected.
Reactive power	Non-real power introduced in the system due to inductive (motors, coils) or capacitive (capacitor banks) loads. This power affects the power factor of the system and is measured in kilo-volt-amps-reactive (KVAR).
Thermal runaway	An exothermic chain reaction inside the battery due to damage or fault, causing discharge of excess heat and can lead to fire or explosion.
Transients	A momentary induced surge in voltage or current caused by a sudden electrical change in the system.
Voltage/frequency ride-through	The ability of an asset to ride through momentary faults without tripping.

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Appendix A. Applicable Design Standards

A.1 PV Panels/Modules/Systems

The following are links to all standards applicable to the design and installation of PV panels, modules, and systems.

ASTM (Int.) E1036-15: "Standard Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells." https://webstore.ansi.org/standards/astm/astme103615

ASTM E1038-10: "Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls." https://webstore.ansi.org/standards/astm/astme103810

ASTM E1171-15: "Standard Test Methods for Photovoltaic Modules in Cyclic Temperature and Humidity Environments." https://webstore.ansi.org/standards/astm/astme117115

ASTM E1462-12: "Standard Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules." https://webstore.ansi.org/standards/astm/astme146212

ASTM E1799-12: "Standard Practice for Visual Inspections of Photovoltaic Modules." https://webstore.ansi.org/standards/astm/astme179912

ASTM E1830-15: "Standard Test Methods for Determining Mechanical Integrity of Photovoltaic Modules." https://webstore.ansi.org/standards/astm/astme183015

ASTM E2848-13(2018): "Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance." https://webstore.ansi.org/standards/astm/astme2848132018

ASTM E2939-13(2018): "Standard Practice for Determining Reporting Conditions and Expected Capacity for Photovoltaic Non-Concentrator Systems." https://webstore.ansi.org/standards/astm/astme2939132018

UL 1703: "Standard for Flat-Plate Photovoltaic Modules and Panels." https://www.intertek.com/building/standards/ul-1703/

UL 2703: "PV Mounting Systems Certification." https://www.ul.com/services/pv-mounting-systems-certification

UL 1699: "UL Standard for safety Arc-Fault Circuit-Interrupters." https://global.ihs.com/doc_detail.cfm?document_name=UL%201699&item_s_key=00308197

UL 1699-B: "UL Standard for safety Photovoltaic (PV) DC Arc-Fault Circuit Protection." https://global.ihs.com/doc_detail.cfm?document_name=UL%201699B&item_s_key=00767814

UL 4703: "UL Standard for safety Photovoltaic Wire." https://global.ihs.com/doc_detail.cfm?document_name=UL%204703&item_s_key=00632589

UL 9703: "Solar Materials and Components Certification." https://www.ul.com/services/solar-materials-and-components-certification

UL 854: "UL Standard for Safety Service-Entrance Cables." https://global.ihs.com/doc_detail.cfm?document_name=UL%20854&item_s_key=00097261

UL 3730: "UL Standard for Safety Photovoltaic Junction Boxes." https://global.ihs.com/doc_detail.cfm?document_name=UL%203730&item_s_key=00635130

IEC 62093:2022: "Photovoltaic system power conversion equipment - Design qualification and type approval.". https://webstore.iec.ch/publication/34094

IEC 60891:2021: "Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics.". https://webstore.iec.ch/publication/61766

IEC 60904-1:2020: "Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics.". https://webstore.iec.ch/publication/32004

IEC 61000-6-3:2020: "Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for equipment in residential environments.". https://webstore.iec.ch/publication/27413

IEC 61215-2:2021: "Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures.". https://webstore.iec.ch/publication/61350

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IEC 61730-2:2016: "Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing.". https://webstore.iec.ch/publication/25680

IEC 61724-1:2021: "Photovoltaic system performance - Part 1: Monitoring.". https://webstore.iec.ch/publication/65561

IEC 61730-1:2016: "Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction.". https://webstore.iec.ch/publication/25674

IEC 61829:2015: “Photovoltaic (PV) array - On-site measurement of current-voltage characteristics.”. https://webstore.iec.ch/publication/23561

IEC 61853-1:2011: “Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating.”. https://webstore.iec.ch/publication/6035

IEC 62446-1:2016: “Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection.”. https://webstore.iec.ch/publication/24057

IEC 62446-2:2020: “Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 2: Grid connected systems - Maintenance of PV systems,”. https://webstore.iec.ch/publication/27382

IEC 62548:2016: “Photovoltaic (PV) arrays - Design requirements.”. https://webstore.iec.ch/publication/25949

IEC TS 62738:2018: “Ground-mounted photovoltaic power plants - Design guidelines and recommendations.”. https://webstore.iec.ch/publication/26942

IEC TS 62804-1-1:2020: “Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1-1: Crystalline silicon – Delamination.”". https://webstore.iec.ch/publication/28390

SEAOC PV 2-2017: “Wind Design for Solar Arrays PV2-2017.” https://www.seaoc.org/store/viewproduct.aspx?ID=10228815

A.2 PV Inverters

The following are links to all standards applicable to the design and installation of PV inverters.

AWEA 9.1 Standard Testing and Certification: “Intertek provides testing and certification services for small wind turbines according to the American Wind Energy Association (AWEA) 9.1 Standard”..” https://www.intertek.com/wind/awea-standard/

IEC 62116:2014: “Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures”..” https://webstore.iec.ch/publication/6479

IEEE 519-2022: “IEEE Standard for Harmonic Control in Electric Power Systems”..” https://standards.ieee.org/ieee/519/10677/

IEEE 1547.1-2020: “IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces”..” https://standards.ieee.org/ieee/1547.1/6039/

IEEE 1547-2018: “IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces”..” https://standards.ieee.org/ieee/1547/5915/

IEC 61400-11:2012: “Wind turbines - Part 11: Acoustic noise measurement techniques”..” https://webstore.iec.ch/publication/5428

IEC 61400-2:2013: “Wind turbines - Part 2: Small wind turbines”..” https://webstore.iec.ch/publication/5433

IEC 61400-1:2019: “Wind energy generation systems - Part 1: Design requirements”..” https://webstore.iec.ch/publication/26423

IEC 61400-12-1:2022: “Wind energy generation systems - Part 12-1: Power performance measurements of electricity producing wind turbines”..” https://webstore.iec.ch/publication/68499

IEC 62109-1:2010: “Safety of power converters for use in photovoltaic power systems - Part 1: General requirements”..” https://webstore.iec.ch/publication/6470

TIA-222: “Structural Standard for Antenna supporting structures and antennas and small wind turbine support structures”..” https://global.ihs.com/doc_detail.cfm?document_name=TIA-222&item_s_key=00122271

UL 1741: “UL Standard for Safety Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources.” https://global.ihs.com/doc_detail.cfm?document_name=UL%201741&item_s_key=00315178

UL6142: “UL Standard for Safety Small Wind Turbine Systems”..” https://global.ihs.com/doc_detail.cfm?document_name=UL%206142&item_s_key=00599555

A.3 Battery Energy Storage Systems (BESS)

The following are links to all standards applicable to the design and installation of battery energy storage systems.

ANSI C12.1-2022: “Code for Electricity Metering”..” https://blog.ansi.org/ansi-c12-1-2022-code-electricity-metering/#gref

ASCE/SEI 7-22: “Minimum Design Loads and Associated Criteria for Buildings and Other Structures”..” https://www.asce.org/publications-and-news/asce-7

IEEE 1547-2018: “IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces”..” https://standards.ieee.org/ieee/1547/5915/

IEEE 2030.2-2015: “IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure”..” https://standards.ieee.org/ieee/2030.2/4968/

IEEE 2030.3-2016: “IEEE Standard Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications”..” https://standards.ieee.org/ieee/2030.3/5076/

UL 1642: "UL Standard for Safety Lithium Batteries".." https://global.ihs.com/doc_detail.cfm?document_name=UL%201642&item_s_key=00096965

UL 1973: "UL Standard for Safety Batteries for Use in Stationary and Motive Auxiliary Power Applications".." https://global.ihs.com/doc_detail.cfm?document_name=UL%201973&item_s_key=00602087

UL 9540: "Energy Storage System (ESS) Requirements - Evolving to Meet Industry and Regulatory Needs".." https://www.ul.com/news/ul-9540-energy-storage-system-ess-requirements-evolving-meet-industry-and-regulatory-needs

UL 9540A: "Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems".." https://www.ul.com/services/ul-9540a-test-method

UL1741: "UL Standard for Safety Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources".." https://global.ihs.com/doc_detail.cfm?document_name=UL%201741&item_s_key=00315178

UN 38.3: "Certification for Lithium Batteries".." https://www.intertek.com/batteries/un-38-3-certification/

A.4 Wind Turbine

ACP 101-1 or AWEA: "The Small Wind Turbine Standard". Small Wind Turbine Performance and Safety Standard 9.1-2009 for small wind turbines. https://webstore.ansi.org/standards/ansi/ansiacp1012021

ANSI/ TIA-222: "This Standard provides the requirements for the structural design and fabrication of new and the modification of existing structural antennas, antenna-supporting structures, mounts, structural components, guy assemblies, insulators and foundations." https://natehome.com/regulations-standards/standards/tia-222-g/

IEC 61400-1/IEC 61400-2: "Wind turbines - Part 1: Design requirements; Part 2: Design requirements for small wind turbines." https://webstore.iec.ch/preview/info_iec61400-1%7Bed3.0%7Den.pdf. https://webstore.iec.ch/preview/info_iec61400-2%7Bed2.0%7Den_d.pdf

IEC 61400-11: "Wind turbines – Part 11: Acoustic noise measurement techniques." https://webstore.iec.ch/preview/info_iec61400-11%7Bed3.0%7Den.pdf

IEC 61400-12: "Wind energy generation systems - Part 12-1: Power performance measurements of electricity producing wind turbines." https://webstore.iec.ch/publication/68499

IEC 61400-22: "Wind turbines – Part 22: Conformity testing and certification." https://webstore.iec.ch/p-preview/info_iec61400-22%7Bed1.0%7Db.pdf

UL6142: "Small Wind Turbine Systems." https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=25241

A.5 General Standards and Requirements

The following are links to all other standards and requirements applicable to the infrastructure of DERs.

ASTM: “American National Standards Institute” https://webstore.ansi.org/sdo/astm

IEEE 1547-2018: “IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces”..” https://standards.ieee.org/ieee/1547/5915/

IEEE 2030.4-2023: “IEEE Approved Draft Guide for Control and Automation Installations Applied to the Electric Power Infrastructure”..” https://standards.ieee.org/ieee/2030.4/7060/

IEEE 2030.5-2018: “IEEE Standard for Smart Energy Profile Application Protocol”..” https://standards.ieee.org/ieee/2030.5/5897/

IEEE 2030.7-2017: “IEEE Standard for the Specification of Microgrid Controllers”..” https://standards.ieee.org/ieee/2030.7/5941/

IEEE 2030.8-2018: “IEEE Standard for the Testing of Microgrid Controllers”..” https://standards.ieee.org/ieee/2030.8/6169/

IEEE C2-2017: “2017 National Electrical Safety Code(R) (NESC(R))”..” https://standards.ieee.org/ieee/C2/6681/

IEEE P2030.12: “IEEE Draft Guide for the Design of Microgrid Protection Systems”..” https://standards.ieee.org/ieee/2030.12/7398/

NFPA: “National Fire Protection Association”..” https://www.nfpa.org/Codes-and-Standards

NIST SP 800-82: “Mapping Guide”..” https://www.industrialdefender.com/resources/nist-800-82-mapping-guide-industrial-defender

UFGS 01 35 26: “Governmental Safety Requirements”..” https://www.wbdg.org/FFC/DOD/UFGS/UFGS%2001%2035%2026.pdf

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