Microgrid System Project Development Checklist

This checklist provides federal agencies with a standard set of tasks, questions, and reference points to assist in microgrid project development. The included items are intended for use in the development of a commercial-scale microgrid and help identify the key actions to be taken during the project planning, design, procurement, and implementation phases.

Agencies are encouraged to use Federal Energy Management Program (FEMP) technical specification resources ([Solar Photovoltaic (PV) Technical Specification](https://www.energy.gov/femp/technical-specifications-site-solar-photovoltaic-systems)s, [Battery Energy Storage System (BESS) Technical Specifications](https://www.energy.gov/eere/femp/articles/lithium-ion-battery-storage-technical-specifications), [On-Site Wind Turbine Technical Specifications](https://www.energy.gov/femp/articles/technical-specifications-site-wind-turbine-installations), and [Geothermal Heat Pump Technical Specifications](https://www.energy.gov/femp/articles/geothermal-heat-pump-system-technical-specifications)) and relevant checklists ([BESS Procurement Checklist](https://www.energy.gov/femp/articles/battery-energy-storage-system-procurement-checklist) and [Distributed Energy Interconnection Checklist](https://www.energy.gov/eere/femp/articles/distributed-energy-interconnection-checklist)) in developing their microgrid projects.

Abbreviations and Acronyms

AC alternating current

AHJ Authority Having Jurisdiction

ATO Authority to Operate

BESS battery energy storage system

DC direct current

DER distributed energy resource

EPC engineering, procurement, and construction

FEMP Federal Energy Management Program

IP internet protocol

O&M operations and maintenance

PV photovoltaic

PCC point of common coupling

RACI responsible, accountable, consulted, informed

RFP request for proposal

SCADA supervisory control and data acquisition

SAT system acceptance test

UESC utility energy service contract

UPS uninterruptible power supply

USC utility service contract

## Microgrid Project Scoping and Planning

### Define high-level goals and requirements.

Discuss the team’s objectives and motivations for developing a microgrid. Common objectives and motivations may include improving resilience for critical site loads, reducing utility costs and/or fuel costs and greenhouse gas emissions, or any combination thereof.

**Resilience:** This is an important objective for critical facilities, off-grid systems, and/or those facing very frequent power quality/outage issues. Local threats and vulnerabilities will determine the resilience requirements. Vulnerabilities are weaknesses within infrastructure or a system, such as having a single utility point of connection to the site or having operators that are not knowledgeable in operating the microgrid. Threats could be natural, such as a hurricane, or man-made, such as a cyber or physical attack. For microgrid projects, identify and define which threats and vulnerabilities they should be designed to mitigate. Furthermore, identify the microgrid’s requirements (e.g., size of the microgrid system, outage survival duration, and critical loads) based on historical data of utility outages, severe weather threats, and critical loads.

**Cost savings:** Microgrids can bring potential economic benefits by reducing utility peak demand and/or energy consumption at peak or expensive time-of-use rates. Sites should conduct an analysis of the cost-savings potential, considering the on-site load profile and utility tariff. Sites with large and short-duration peak demands, higher potential for renewable generation, and/or favorable time-of-use tariffs are more likely to be cost-effective.

**Emissions impacts:** If the facility is in a remote location and meets its own electricity generation needs using fossil-fuel-based resources, renewable generation solutions can help reduce emissions and extend operations if fuel supply is disrupted. This objective is in line with operating limitations related to generator use (40 CFR Part 63, Subpart ZZZZ).

### Identify project team.

Developing a robust project team is critical to project success; microgrid development requires extensive distribution system information, electrical load data, and buy-in from facilities staff who will be maintaining the system. The table below summarizes the project team’s roles:

|  |  |
| --- | --- |
| Project Team | Participants and Roles​ |
| Project manager | Manages all stakeholders, from scoping, planning, designing, implementation, to testing and training. Follows best practices for project management. |
| Site and mission leadership and staff ​ | Provide project leadership and make critical project decisions. Includes installation leadership, mission owners, installation security, and legal. |
| Public works management staff and agency departments ​ | Provide critical data and operational requirements for the microgrid. Includes: 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 teams. |
| Safety officer | Ensures following of safety practices, highlights safety risks, and provides risk-mitigation plan. |
| Information systems ​ | Include information technology, communications, and cybersecurity. Responsible for reviews, internet/network repair, monitoring, and updates. |
| Owner’s engineer | As a microgrid expert, supports the facility/agency throughout the microgrid project with guidance, reviews, comments, and questions. |
| Utilities ​ | Execute system study and interconnection agreement. Include electric (utility representative, interconnection team), water, gas, communications, and utility privatization contractors. |
| State and local authorities ​ | Execute permits with authorities having jurisdiction (AHJs), environmental and natural resource divisions, emergency management and first responder procedures. |
| Developer/contractor​ | Responsible for developing/performing specifications, drawings, modeling, and analysis, following applicable codes and standards. Responsible for successful component and system integration. Typically performed by the engineering, procurement, and construction (EPC) team. |
| Integrator​ | Responsible for successful component and system integration. Often the prime contractor on the project. |
| Technology vendor​ | Supplies microgrid components (may include installation and commissioning). |
| Operator​ and technician | Responsible for maintaining and operating equipment after installation and commissioning. Include facilities staff or microgrid operations and maintenance subcontractor. |

### Ensure site staff and agency leadership buy-in.

Early-and-often coordination with all relevant decision makers is necessary to ensure there are no unknown barriers that may prevent the project from being successful. All parties should be made aware of the project in the scoping and planning stage, the proposed financing method(s), and any impacts the project may have on the site (e.g., reduced or increased utility costs, added site resilience, or required land-use commitments).

### Perform data collection.

Data collection informs microgrid design by providing a more complete understanding of the loads, existing systems, generation resources, energy costs, and historical reliability at a site. Ideally, the following types of data are gathered:

* **Load data:** Load data provides insight into the site’s load profile, including peak demand times and seasonality. Hourly kilowatt load data is typically used, but subhourly time step data is preferred. Collecting 3 years of data is also beneficial to control for annual changes and identify unusual trends. Building-level interval data can be helpful for critical facilities, where available.
* **Electrical infrastructure:** Drawings for electrical infrastructure provide information about how the existing distributed energy resources (DERs) are connected in the system, where loads/critical loads are connected, and whether there are any spare connections available for future DERs. DERs may be fossil fuel generators; renewable generators, such as solar photovoltaic (PV) or wind turbines; or energy storage technologies. Existing system drawings will also provide information about any constraints or needed upgrades to the system protection and metering. One-line diagrams may be required at the distribution system, substation, and building levels. Maps indicating building numbers, manholes, switches, poles, and transformer locations are helpful as well. Isolation points are key considerations when planning/designing a microgrid to perform islanding operations.
* **Existing generation:** Information about existing DERs, such as on-site PV, energy storage, cogeneration, and backup generators, is beneficial. The following information should be collected about DER capabilities:
  + Generation/storage nameplate capacity
  + Generation type: dispatchable (e.g., generator or battery) or variable (e.g., solar PV)
  + Grid-forming/grid-following capability
  + Controllability: supported communication protocols
  + Asset age and condition (e.g., date placed in service)
  + Location and associated electrical and communication connections
  + Operations and maintenance (O&M): O&M requirements, records, and fuel storage
  + Emission permitting: U.S. Environmental Protection Agency tier, permitted run hours.
* **Communication infrastructure:** Communication architecture showing how buildings and existing DERs are connected through communication systems, protocols, etc., is beneficial.
* **Energy costs:** Collecting 2–3 years of monthly utility bills, showing monthly energy and power consumption, the name and details of the utility tariffs, and utility meter details, is recommended to control for annual variation in load.
* **Existing resilience and reliability:** It is important to analyze outage history, such as the site utility’s System Average Interruption Duration Index and System Average Interruption Frequency Index, and identify existing deficiencies, such as aged utility poles or untrimmed trees. Consulting outage logs, if available, and categorizing outages by their cause (e.g., utility failure or site distribution system failure) can also provide valuable insight.

### Analyze load data.

Analyzing how the load varies throughout the day, week, and season will inform what types and sizes of DERs are most suitable to meeting a site’s microgrid requirements.

* **Load data:** Typically graphed as a time series showing the load profile, which indicates the minimum, average, and peak loads by time of day and season, load data includes electricity consumption over time (kilowatt-hours) and electricity consumption at a given time (instantaneous demand in kilowatts). Advanced meters typically track a site’s electricity consumption on an hourly or 15-minute basis; this is referred to as interval data.
* **Critical loads:** A key resilience use case for a microgrid is to supply electricity to critical loads. As DERs are costly to install and maintain, it is beneficial to minimize the loads that must be served by the microgrid during a utility outage. Noncritical loads can be incorporated as part of a microgrid based on priority or connection/interfacing feasibility. Note that designing a system to serve exclusively critical loads can be more expensive and complex than adding generation to serve all (or most loads). If critical loads are spread across multiple feeders, the design may require adding or upgrading controllable breakers, communication infrastructure, and complex control operating sequences. Thus, it is important to investigate the interfacing feasibility if prioritizing the critical loads. There may be different critical loads for different outage duration scales (e.g., supplied for several hours vs. sustaining operations for several weeks) or potential mission changes.

Critical loads can often be identified through critical facility lists, emergency readiness and response plans, and/or information on standby generators. Critical loads may include:

* + Life safety loads
  + Communication/information technology infrastructure
  + Emergency lights
  + Critical mission-related equipment or functionality.

Critical loads also can be identified with the following questions:

* + What is your site’s critical mission?
  + What functions are needed to carry out that mission?
  + Which facilities house critical functions?
  + What interdependencies exist (e.g., electric, thermal, water, personnel, transport and communications)?

### Understand interconnection requirements.

Early-and-often coordination with the utility regarding interconnection cost and study timelines is necessary to ensure there are no unknown barriers that may prevent the project from being successful. Whether the project will be required to perform system impact studies will depend on grid-interconnection requirements and the utility’s study process, which depend, in turn, on distribution feeder size and microgrid DER generation capacity.

The cost of these studies is typically incorporated into the project cost and is not covered by the utility. In addition to requiring interconnection agreements for any generation assets that will operate in parallel with the utility grid, utilities may also require an operating agreement for the microgrid to ensure utility system stability, to define operating sequences when islanding and connecting back to the grid, and to verify environmental compliance. Refer to FEMP’s [Distributed Energy Interconnection Checklist](https://www.energy.gov/femp/articles/distributed-energy-interconnection-checklist) for additional information.

### Perform resilience assessment.

For critical facilities where the power outages may cause significant economic loss, it is important to perform resilience assessments identifying key resilience issues, opportunities for improvement, and the cost of an outage. The FEMP [Customer Damage Function Calculator](https://www.energy.gov/femp/articles/customer-damage-function-calculator) helps users understand the costs of an electric grid outage at their site.

### Identify risks.

Severe weather threats vary regionally in their frequency and impacts and should be considered in the context of the microgrid project. For example, if a region is prone to hurricane-force winds, the microgrid distribution system may need to be hardened against wind (e.g., key circuits may need to be underground).

It is also important to investigate the cybersecurity risks and how they can be mitigated during the microgrid design phase. Reference the [Cybersecurity for Microgrids Workshop Workbook for Cyber-Informed Engineering](https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_90569.pdf) from Idaho National Laboratory for more information.

### Develop high-level scope and work plan.

Choose one of the two primary approaches to scoping the microgrid project:

1. Perform a prefeasibility study for the microgrid, develop a conceptual design, and then determine technical and functional specifications for the microgrid in a request for proposals (RFP, similar to a design-bid-build process).
2. Develop high-level specifications that highlight the key requirements for the microgrid and develop an RFP for the project’s design and construction (similar to a design-build process).

Due to the high complexity of microgrid projects, it is recommended to conduct as much prefeasibility study and data gathering as feasible prior to solicitation, as uncertainty on the system details is likely to result in higher overall bid pricing.

### Observe microgrid project management best practices.

Microgrid project management is a complex endeavor involving a large project team with many disciplines; delays or design issues with one component can affect the entire project schedule. Schedule frequent (weekly or biweekly) update meetings to ensure team members are kept informed and that their responsibilities are clearly defined.

Design meetings can be arranged to have the full project team present to discuss and review the design documents at various milestones and to resolve any issues regarding interdependencies, milestones, and resources. Consider a RACI (responsible, accountable, consulted, informed) matrix for the team to help define responsibilities for deliverables.

## Microgrid Conceptual Design (Prefeasibility, Initial Design–10%)

### Define microgrid boundaries (physical location and interconnection point).

The graphic below illustrates the scale and boundaries of various microgrid solutions. A solution could be a building-level backup system, a partial feeder microgrid, a full feeder microgrid, a full substation microgrid, or some combination thereof. The best solution for a site entirely depends on the requirements identified during project scoping and planning.

Diagram

Description automatically generated

Illustration from the U.S. Department of Energy Office of Electricity

The most common goal of a microgrid is to provide resilient power to critical loads. Some critical loads are farther from others and may be cheaper to support with backup generators instead of connecting them to a microgrid. Critical loads are rarely the only loads on an electrical feeder line, so the microgrid may need to power the full feeder line (i.e., full feeder microgrid).

If there are numerous or sizeable noncritical loads on a feeder, consider installing equipment to disconnect those loads (i.e., partial feeder microgrid), but be aware that this may add complexity and be potentially more costly than building larger DERs to serve the entire feeder. Similarly, where critical loads are distributed across many feeder lines, it may be more cost-effective and practical to develop a microgrid that serves an entire substation’s load rather than attempting to isolate critical loads.

### Evaluate available infrastructure.

The location, operational condition, and maintenance record of existing infrastructure should be evaluated carefully to assess whether it is feasible to tie into the existing infrastructure with minimal modifications or upgrades. The existing distribution system panels should be inspected to determine the availability of spares and whether new infrastructure can be tied into the existing system without adding new equipment.

A well-maintained system can be modified with less difficulty, whereas a poorly maintained system or one that is too old and/or incompatible with newer systems may be more expensive to integrate than to simply replace. If upgrades are needed in the near future (5–10 years), consider plans for future expansion, electrification, electric vehicle charging infrastructure, and the addition of new DERs in the design.

### Consider existing DERs.

Using or rehabilitating existing DERs can offset the need to purchase new ones, but only if the DERs are sufficiently large and modern to be cost-effectively incorporated into the microgrid. The existing interfacing or isolation points may need to be upgraded, and communications between the DERs and microgrid controller will need to be established.

Many factors must be considered when retrofitting an existing DER to support a microgrid, including its size, age, make, model, location, and condition, and the associated cost. If existing DERs are owned and operated by a third party, such as under a power purchase agreement, do not assume they can be automatically incorporated into the microgrid. Review the existing contract and discuss any potential contract modification and cost implications with the owner.

### Determine power requirements.

Note that the microgrid system size will depend on the maximum, average, and minimum loads, among other constraints. Consider the following list of power demand and quality factors when planning and integrating new DERs:

* **Uninterruptible power requirements:** Sites with frequent outages and/or poor power quality may need uninterruptible power supplies (UPS) and/or DERs with grid-forming capability. These sites may also wish to consider a microgrid capable of closed (seamless) transition from grid service to islanding operation, although this can result in higher cost and complexity.
* **Future load:** Planned additions of load should be considered when planning for adequate generation capacity. Consider how the location, scale, and timing of these loads might impact the microgrid project.
* **Energy efficiency:** Energy efficiency opportunities should be explored in the early stages of a microgrid project, as they can save energy, reduce utility costs, and reduce the scale and capital cost of the planned microgrid. Perform an energy audit to determine where, when, and how energy is used at your site. Energy efficiency savings may be bundled into a comprehensive performance contract to help finance the broader microgrid scope (see the [“Identify microgrid procurement options”](#Identify) checklist item below for additional detail).
* **Redundancy and reserves:** Determine the DER generation capacity needed to sustain microgrid operations during a power outage and as well as redundant DER generation in the event of generating asset-failure scenarios. Some agencies may have generation redundancy requirements for certain critical loads and require additional DERs, exceeding the capacity requirements.
* **In-rush currents:** During black start (when a microgrid initially starts up after a site loses utility grid service), transformers will be loaded, causing high initial currents to magnetize transformers. One method to mitigate this large power demand is 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 DERs have the same capability to supply reactive power.
* **Harmonics, nonlinear loads, and balancing:** Current pulses, transients in case of connecting and disconnecting a new load or generation, and imbalance in demand or supply must be considered for appropriate sizing of DERs and selection of power electronics devices.
* **Transition between grid and island:** There should be enough DER capacity available to meet site demand when disconnecting from the grid and islanding, and there should be grid-forming DERs to energize the microgrid and regulate frequency and voltage of the islanded system. When connected to the grid, the microgrid control system should be able to manage the DERs and regulate the voltage and frequency to be in phase (synchronized) with the utility grid.

### Identify new DERs.

Which DERs should be incorporated into a microgrid depends on several factors, including:

* Microgrid objectives: resilience, economic, and/or emissions impacts
* Available funding
* Site-specific power requirements and black-start capability
* Existing electrical infrastructure and DERs
* Available fossil fuel supply
* Renewable energy resource potential
* State and local environmental permitting requirements
* Maximum and average demand
* Grid-forming and grid-following capabilities
* Physical, economic, social, and environmental constraints:
  + - Physical constraints include land availability, limited access, lack of proper transportation infrastructure, and limited available resources.
    - Economic constraints include life cycle costs, budgeting for replacements in future years, large up-front capital investment required (e.g., unit cost, logistical costs, engineering/installation/commissioning costs, and balance of plant costs), and O&M costs.
    - Social constraints include limitations due to public opinion, local labor resource availability, and visual impact to neighbors.
    - Environmental constraints include air permitting, sensitive or endangered species, wetlands, and cultural and historic resources.

### Determine DER size(s).

To determine the optimal size and mix of DERs for a microgrid, performing a techno-economic analysis is recommended. Techno-economic analysis can identify the economically optimal size of DERs, considering capital and operational costs, utility tariffs, project life, and other technical and economic parameters.

One resource for this analysis is the National Renewable Energy Laboratory’s [Renewable Energy Optimization Tool (REopt®)](https://reopt.nrel.gov/tool), which allows users to evaluate the techno-economic viability of distributed PV, emergency generators, wind, battery storage, combined heat and power, geothermal heat pumps, and thermal energy storage. REopt can also evaluate the resilience of the resulting systems (e.g., how long a system can sustain critical loads during a grid outage) and help identify microgrid dispatch strategies to achieve the desired microgrid objectives.

The following chart includes the minimum inputs, analysis steps, and expected outcomes for the techno-economic analysis.

### Develop microgrid operation strategy.

The microgrid operational strategy is based on the prior techno-economic analysis and provides key information about how the microgrid controller will achieve the desired objectives. It defines key microgrid operating modes (e.g., when to charge/discharge BESS when grid-connected, what load DERs can support when islanded). This strategy may also highlight the microgrid controller’s functional requirements (e.g., peak shaving, demand response, load-shedding, load restoration).

## Microgrid Procurement and Proposal Review

### Identify microgrid procurement options.

Microgrid systems can be acquired through appropriated funding or third-party financing mechanisms. Some common federal procurement approaches include turnkey EPC solicitation, energy savings performance contract, utility energy service contract, and utility privatization contract modification. Typically, third-party-financed projects will still require additional appropriated funding due to the large capital requirements for a microgrid system.

Depending on the funding available, your site may consider implementing the microgrid in phases; however, a phased approach can introduce system integration challenges and make it difficult to assign responsibility to a single contractor for system deficiencies. For additional information, refer to the [Federal On-Site Distributed Energy Procurement Options and](https://www.energy.gov/femp/federal-site-distributed-energy-procurement-options) [Financing Microgrids in the Federal Sector](https://www.nrel.gov/docs/fy20osti/77559.pdf) resources.

### Investigate federal and local rebate and incentive programs and third-party-owned tax incentives.

State or utility rebates and incentives may be available for a microgrid project and its DER subcomponents. Consult with your local utility, potential installing contractors, and the [Database of State Incentives for Renewables & Efficiency](https://www.dsireusa.org/) to see if your project will qualify. The contractor should be made responsible for completing and submitting all documentation required to qualify for any available rebate or incentive program.

Depending on the procurement method, if the equipment is owned by the installing contractor or another third party, as in a power purchase agreement or energy savings performance contract energy sales agreement, additional tax incentives, may be available. The savings generated by these tax incentives can be passed on to the customer, making the project more economically viable.

### Define technical specifications.

This section lists the key DERs and respective microgrid technical requirements. Agencies are encouraged to use FEMP’s [Solar PV Technical Specification](https://www.energy.gov/femp/technical-specifications-site-solar-photovoltaic-systems)s, [BESS Technical Specifications](https://www.energy.gov/eere/femp/articles/lithium-ion-battery-storage-technical-specifications), [On-Site Wind Turbine Technical Specifications](https://www.energy.gov/femp/articles/technical-specifications-site-wind-turbine-installations), [Geothermal Heat Pump Specifications](https://www.energy.gov/femp/articles/geothermal-heat-pump-system-technical-specifications), and [Distributed Energy Interconnection Checklist](https://www.energy.gov/eere/femp/articles/distributed-energy-interconnection-checklist). The following are additional microgrid requirements for consideration:

* Specify general requirements:
  + Ensure switchgear has controllable breaker/contactor and meters (with remote monitoring, using communication protocol).
  + Ensure current transformers/potential transformers have spare connections for future DERs.
  + Ensure consideration of UPS and AC/DC auxiliary supply for the auxiliary systems including but not limited to communication ethernet switches, protection relays, binary inputs/outputs, and controllers.
  + Specify the protection relay requirements, such as modularity, support of multiple protection points, communication protocols, protection fault/functions, and remote monitoring (alarms/indication, fault/event logs).
  + Establish cybersecurity requirements, including hardening of the equipment, disabling the unused communication ports, and asking for details on any external communication interfaces and how these external communication interfaces will be cybersecure. This will ensure proponents will be compliant with the processes to be used or followed by the agency.
* Specify interoperability requirements for PV inverters:
  + Indicate that set point/curtailment capability should be non-grid-forming but grid-supporting (voltage and frequency ride-through, volt-ampere-reactive (VAR) support, droop control).
  + Qualify communication protocols: MODBUS Transmission Control Protocol /internet protocol (IP).
  + Ensure all technical requirements are met, considering the monitoring and control by the microgrid controller and other interfaces.
  + Check for the capability of remote monitoring and control to be done via software or communications protocol, including ON/OFF and power limit.
  + Ensure internal protection for any failure mode operation.
* Specify interoperability requirements for BESS:
  + Define operational and control specifications: Setpoint capability, four-quadrant operation and control, grid-forming/-following, voltage/frequency ride-through.
  + Ensure seamless transition capability: grid-tied to island mode.
  + Define communications protocol: MODBUS Transmission Control Protocol/IP.
  + Ensure all technical requirements are met, considering the monitoring and control by the microgrid controller and other interfaces.
* Specify key requirements for microgrid control system and Human Machine Interface with Supervisory Control And Data Acquisition (SCADA):
  + Indicate that plug-and-play architecture is preferred, which allows minimum changes in the microgrid controller to interface with future new DERs and systems.
  + Ensure both automated and manual operation are possible. In automated 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.
  + Minimize use of diesel generator if the microgrid is mainly relying on diesel generators to meet the energy demand.
  + Define fault and maintenance mode of operation. This is to highlight what microgrid controller actions could be expected if any faults happen or if any DERs are enabled in maintenance mode.
  + Ensure the ability to interface with weather stations, utility SCADA, and/or any external microgrid controller. Some utilities require monitoring and/or control of microgrid as technical interconnection requirement. Weather stations can be interfaced for forecasting PV generation and load for efficient and economic dispatch optimization. If any agencies have multiple microgrids, they may be interested in cloud-based DER management systems to monitor and control multiple microgrids with just one user interface.
  + Clarify failure-mode fault troubleshooting and clearing. This is to ensure that the contractor is accountable for providing operating manuals describing steps for troubleshooting and clearing the various faults.
  + Ensure data will be archived. A SCADA system generally has data archiving capability; it is important to specify that requirement in the RFP (otherwise, the contractor may request a change order for such functionality during the project execution).
  + Ensure use of extended warranties. Most of the intelligent electronic devices (e.g., microgrid controllers) have a short-term warranty (mostly 5 years); an extended warranty can be requested in the RFP to ensure support throughout the project life.
* Derive functional specifications or requirements mainly for the microgrid control system and SCADA system. This can be drawn from microgrid operational philosophy developed from techno-economic analysis. The following list is an example of the functional requirements:
  + Specify and prioritize the following functional requirements for grid-connected mode:
    - **Peak-shaving:** The controller can minimize the site’s peak demand billing by dispatching the DERs.
    - **Active/reactive power control at point of common coupling (PCC):** The controller can optimize and follow the identified active reactive power set point at PCC.
    - **Define control modes:** The controller can operate the microgrid system in different control modes (minimizing cost, maximizing resilience, maximizing DER usage and respective dispatch strategies) and have different dispatch strategies for these control modes.
    - **Demand response:** The controller can also dispatch and control the smart and controllable loads to minimize the demand from the grid when utility tariff is high.
    - **Volt-ampere-reactive (VAR) optimization:** The controller can control the voltage/reactive power at PCC, which can also reduce the consumption from the grid.
  + Specify the following requirements for islanded mode:
    - **Clarify when to use isochronous/droop control:** The controller can operate the microgrid in isochronous and droop control mode. In droop control mode, the microgrid can send the voltage and frequency set points and identify the droop settings for the participating DERs.
    - **Use PV and BESS under/over power frequency characteristics:** The controller can manage inverter-based DERs using their active power and frequency settings and curves.
    - **Clarify ability to switch an asset from grid-following to grid-forming, or vice versa.** This is to ensure the controller would be able to switch the DER from different modes, ensuring reliable operation of the microgrid in islanded mode.
  + Specify the following transition requirements: The microgrid can transition from grid-connected mode to islanding and vice versa, but it can also be planned or unplanned. Unplanned transitions can happen due to a power outage and return of the grid, whereas planned transitions can be scheduled based on weather conditions, scheduled grid maintenance, and/or microgrid testing.
    - Clarify requirements for automated grid connection after unplanned islanding: This may include specifying the time for checking the healthy level of grid voltage before starting the reconnection process.
    - Establish requirements for planned or manually triggered islanding and grid reconnection: This may include identifying the triggered input and associated interlocks for safer operation.
    - Define the transition to automated islanding after outage: This is to specify in what conditions it could perform automated islanding, and what potential wait time would be needed to avoid automated islanding in case of momentary outages.
  + Specify network standards: Use American National Standards Institute C84.1: Electric Power Systems Voltage Ratings (60 Hz).
  + Specify interoperability standards: Use Institute of Electrical and Electronics Engineers 2030.2: *Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure*.
  + Specify microgrid control standards: Use Institute of Electrical and Electronics Engineers 2030.7: *The Specification of Microgrid Controllers*.

### Define permitting and licensing requirements.

The installing contractor should be responsible for preparing and funding all permits and licenses for the project and acting as the primary liaison with local permitting and licensing agencies. Agencies should communicate to the contractor which permits and licenses are needed to complete required work on-site, such as local electrical permits, building permits, and trade licenses.

### Identify project phases and milestones

Project phases and milestones should be defined within the project contract, with example milestones depicted below:

### Confirm completeness of microgrid submittals (RFPs).

* Equipment manufacturer, product names, cut sheets/brochures (including the battery, PV modules, other DERs, inverters, transformers, control equipment, protection devices, enclosures, etc.)
* Site plan
* Electrical schematic diagrams (interconnection, system one-line diagrams)
* Technical specifications of DERs, protection, communication, switchgear, and control systems:
  + Useable energy storage capacity (kilowatt-hours) for BESS
  + BESS capacity maintenance strategy
  + Rated power (kilowatts alternating current [AC]) for all generation assets
  + AC: AC efficiency (including auxiliary loads)
  + Asset life and any planned replacements
  + Annual degradation factor, efficiency, life cycle for BESS
  + Communication protocol
  + Ambient temperature control system
  + Fire protection/suppression system description, as required by code.
* Microgrid operational philosophy or high-level functional specifications (sequences of operation should be included for all modes of operation and use cases)
* Microgrid SCADA system screens
* Microgrid interconnection requirements
* Detailed cost breakdowns
* Project implementation plan and milestones
* Documentations/deliverables
* Maintenance requirements
* Project team, any subcontractors
* RACI chart
* Warranty.

### Verify compliance with standards for microgrid submittals.

All submittals should include a statement from the engineer of record confirming the contents of the submittal adhere to the project requirements in the contract and project specifications. Additionally, all final design drawings, calculations, and specifications should be signed, dated, and bear the seal (stamp) of the engineer or architect responsible for their preparation (designer of record). The site should not accept any engineering or architectural services from personnel not professionally licensed in the location of the project.

## Microgrid Base Design (~30%)

### Review base design documents.

Once the project reaches the 30% base design stage, the design submittal should include the following items (discussed in more detail in the subsequent checklist items in this section):

* Design drawings: high-level drawings (one-line diagram, communication architecture, site layout, general arrangement drawings for panels)
* Protection and control philosophy documents
* Electrical modeling and studies
* Key component considerations: list of generation assets, interconnection switches, and communications systems, and their respective catalogs/manuals.

### Develop microgrid protection and control philosophy.

It is important to develop a microgrid protection and control philosophy document that highlights high-level operational scenarios for the microgrid, detailing the expected behavior of the key DERs during the operational and protection fault scenarios. Note that the microgrid operational strategy document can be used as a reference and can be made more specific with finalized DERs, one-line diagram, communication architecture, and protection points.

This is a building block for development of microgrid control system algorithms and will help to develop commissioning testing scenarios. The protection philosophy details the behavior of the different levels of the protection system for various fault and failure scenarios. This ensures that relevant fault scenarios are considered, and that the protection system can address them in a safe and efficient manner. This document will be one of the inputs for performing the protection coordination study.

### Conduct electrical modeling and studies.

There are several types of studies that may be required to ensure safe and reliable operation of the microgrid, including:

* **Protective relaying and coordination study** (mandatory for most microgrids): Fault currents are much lower in an islanded microgrid compared to when the site is grid-connected. The microgrid protection and control philosophy document will be one of the inputs for this study, along with design documents (e.g., one-line diagram). Separate group settings will be required in protective relays for each scenario. The outcome of the study will determine the protection functions and respective settings.
* **Interconnection application and studies** (mandatory for most grid-connected microgrids): Studies are typically paid for by the contractor but are performed by the utility. Megawatt-scale projects, as well as projects that export large amounts of power to the utility, are more likely to trigger additional interconnection studies, such as power flow analysis, dynamic stability analysis, and transient analysis.
* **Power flow analysis** (optional depending on the size of microgrid, commonly required at megawatt scale): Power flow analysis involves calculating the steady-state bus voltages, phase angle, real and reactive power, and currents carried on conductors and supplied to loads in an electrical power system. This study will be required based on utility technical interconnection requirements as well as the size of the microgrid, where the microgrid is located, and utility/grid infrastructure. It can be at the feeder level, the substation level, or at a higher level.
* **Dynamic stability analysis** (optional depending on the size of microgrid, commonly required at megawatt scale): Dynamic stability analysis is primarily performed to investigate generator stability under changes in generation or load in a power system. This study will be required based on utility technical interconnection requirements, the size of the microgrid, and types of DERs.
* **Transient analysis** (optional depending on the size of microgrid, commonly required at megawatt scale): Transient analysis investigates system stability in the post-fault system for a specific fault scenario. This study will be required based on utility technical interconnection requirements, the size of the microgrid, and type of DERs.

### Identify key components’ interoperability considerations.

* **Existing or new DERs:** All existing DERs should be inventoried along with the new. This inventory should ideally include system nameplate capacity, fuel capacity (for generators), remaining life, communication protocol, controllability, location, make and model, signal list, and operating sequences. All DERs shall be checked for interoperability with the microgrid controller. For new DERs, timelines for factory acceptance testing shall be planned. If the generation has auxiliary systems such as thermal conditioning for a BESS, ensure that those systems are not solely reliant on grid power.
* **Interconnection switches:** Develop an inventory of relevant interconnection switches. Identify which switches require upgrading to be controllable and monitored. These switches need to be interfaced with a microgrid controller and/or protection relays and powered by UPS.
* **Communication systems:** Outline the communication architecture to enable the microgrid control. Inventory all relevant communicating devices and their respective AC/DC power requirements. Consider IP address and other communication protocol considerations. Understand how your agency’s cybersecurity requirements apply to the microgrid, and start obtaining Authority to Operate (ATO), if necessary.

## Microgrid Detailed Design (~90%)

### Develop construction/deployment drawings and documents.

At the 90% design stage, all drawings should be fully detailed and include:

* DER installation drawings
* Detailed electrical drawings: schematics, site layout, protection functions, and wiring diagrams
* Detailed communication drawings highlighting all the ports of communication devices, power supply, and IP addresses
* Construction/mechanical system drawings
* Auxiliary system drawings, how they are powered, monitored, and protected.

### Develop factory acceptance testing and specifications.

DERs, switchgears, transformers, electric panels (protection and control), and similar electrical equipment should be tested at the factory before arriving on-site. The contractor/agency should review these test specifications and ideally witness the factory testing. The agency should review the final testing reports for accuracy and completeness.

### Develop microgrid protection and control function specifications.

The microgrid protection and control functional design specifications determine the microgrid control system hierarchy, identifying the different microgrid control layers such as primary controller (DER controller), secondary controller (microgrid controller), and tertiary controller (SCADA and/or utility SCADA).

The document may specify the microgrid controller functional blocks. Each functional block can represent the operating mode (e.g., peak-shaving mode) and the respective key inputs (current power consumption, renewable generation) and outputs (BESS charge/discharge decision). The document defines a priority listing or the dispatching order of the DERs (i.e., the DER with lowest operating costs is generally used first). This document may also include the comprehensive operating sequences with DERs and protection relay for transitioning from grid-connected mode to islanding mode and vice-versa. Finally, this document typically discusses how SCADA systems can be used for microgrid operation, control, monitoring, and maintenance, and highlights how key alarms can be managed and troubleshot.

### Develop system acceptance testing requirements.

DERs, protection and control panels, communication devices, protection devices, and switchgears will be tested using system acceptance tests (SATs) after installation and commissioning. The SAT requirements shall be provided by stakeholders (EPC, DER, and microgrid protection and control vendors), highlighting their timelines, requirements, and any interdependencies in advance. The SAT requirements need to be reviewed and planned accordingly, so each critical component and integrated system can be tested to ensure the whole system operates as expected for all considered operating scenarios. Some SATs may require external generation or programmable loads.

## Commissioning and System Acceptance

### Schedule microgrid commissioning.

The following is an example sequence of microgrid commissioning:

* Installation and commissioning of:
  + Switchgear, transformers, laying cable conduits, etc.
  + Communication infrastructure
  + Individual DERs
  + Microgrid control and protection panel or equipment.
* Electrical inspection
* Testing of:
  + Switchgear
  + Protection system
  + Communication network
  + Individual DERs.
* Testing and commissioning of microgrid controls as a complete system.

### Develop microgrid operation manual and schedule training.

Most microgrids will be operated using a SCADA system; the operator manual should include step-by-step explanations for operating the system in different microgrid operational scenarios. This manual should also include key steps for troubleshooting and maintaining the system. The agency should specify that the microgrid operation manual be used while training the operators. Trainings should be recorded and retained for future use.

### Develop as-built documents and plan for project handover.

All key documentation shall be stored carefully with and marked “as built” for the project handover. These documents will be needed for troubleshooting, maintenance, and future explanation. In the project handover, the responsibility for operation and maintenance of the microgrid will be transferred to the facility manager.

## Operation and Maintenance Planning

### Specify microgrid O&M requirements.

After the design, construction, testing, and demonstration of a microgrid project, the O&M period will begin. However, O&M needs to be considered during different microgrid design phases to resolve related issues at the early stage and to identify and procure O&M resources during the operating period. The project team should allocate funding for O&M and develop an O&M strategy during the procurement stage. Determine whether site staff or contractor support will be needed for system operation and maintenance. Roles and responsibilities for microgrid O&M should be clearly identified, and respective personnel should be trained and qualified for the roles.

If a contractor will be performing O&M services, clearly specify the minimum response times for maintenance, repair, and replacement. The system should be tested regularly and ideally involve “pull-the-plug” (shutting off or disconnecting the power/communication cable to the equipment) exercises that ensure microgrid system operational capability during various failure scenarios (communication failure, asset failure, and operational failure). Testing or actual outages should result in documentation of any failures and their resolution. Budget should be allocated for regular cybersecurity reviews and updates for continued compliance and to maintain ATO.

### Develop maintenance plan.

Develop a preventive maintenance checklist in coordination with the O&M provider. Corrective maintenance includes monitoring indicators for key DERs or infrastructure that requires frequent maintenance. Schedule maintenance without affecting the microgrid operation and minimize the impact on critical loads. Also consider functionality for remote updates such as software/firmware updates and security patches.

### Document warranty requirements.

Document the lifetimes, terms, and conditions of all warranties on microgrid system equipment. Monitor the key performance indicators for all critical assets, and document deficiencies with respective vendors about any warranty violations.