Microgrid Overview

Grid Deployment Office
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GDO
GRID DEPLOYMENT OFFICE

Introduction

Authorized by Section 40101(d) of the Bipartisan Infrastructure Law (BIL), the Grid Resilience State and Tribal Formula Grants program is designed to strengthen and modernize America's power grid against wildfires, extreme weather, and other natural disasters that are exacerbated by the climate crisis. Grid resilience formula grants may be used for activities, technologies, equipment, and grid hardening measures to reduce the likelihood of and consequences of disruptive events.

Purpose of this Guide

This guide is intended to provide recipients of 40101(d) grid resilience formula grants with:

- Brief overview of microgrids and their resilience benefits,
- Understanding of the extent to which 40101(d) grid resilience formula grants can be used towards developing components of microgrid systems,
- Preliminary, order-of-magnitude cost estimates for developing a microgrid, and
- Additional resources pertaining to microgrid development, as well as alternate uses of 40101(d) grid resilience formula grants.

Note, much of the content for this guide is adapted with permission from Sandia National Laboratories' "Microgrid Conceptual Design Guidebook (2022)."[1]

Microgrid Overview

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.[2] A microgrid can operate in either grid-connected or in island mode, including entirely off-grid applications.

Figure 1 shows one example of a microgrid. Microgrids come in a wide variety of sizes and levels of complexity, but generally the key components include:

1. Electricity generation resources (e.g., solar arrays, diesel or natural gas generators, wind turbines)
2. Battery energy storage
3. Microgrid control systems: typically, microgrids are managed through a central controller that coordinates distributed energy resources, balances electrical loads, and is responsible for disconnection and reconnection of the microgrid to the main grid.

Definitions

Load: the amount of electricity consumed by customers.

Critical loads: Loads that correspond to the buildings and/or services that are essential or most important to a community during an outage.

Distributed energy resources (DERs): small-scale and localized electricity generators connected to the distribution system (e.g., rooftop solar arrays, wind turbines, battery storage).

[1] Robert Broderick, Brooke Marshall Garcia, Samantha E. Horn, Matthew S. Lave. 2022. "Microgrid Conceptual Design Guidebook." https://energy.sandia.gov/wp-content/uploads/2022/05/ETI_SNL_Microgrid_Guidebook_2022_SAND2022-4842-R_FINAL.pdf

[2] Dan Ton and Merrill Smith. October 2012. The U.S. Department of Energy's Microgrid Initiative. *The Electricity Journal*, 25(8), 84-94. doi:10.1016/j.tej.2012.09.013 (energy.gov)

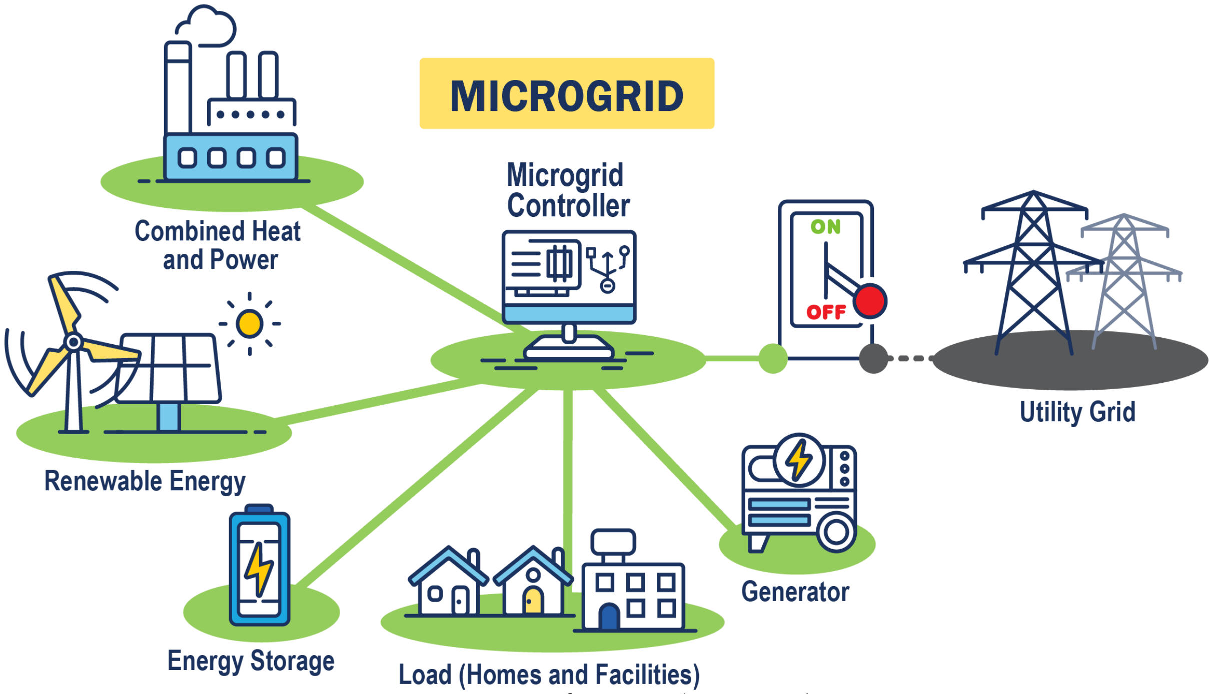


Figure 1: Features of an example microgrid.

Resilience Benefits of Microgrids

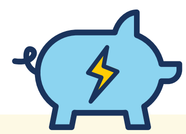
The primary resilience benefit of microgrids is their ability to disconnect from the main grid when there is an outage and operate autonomously. Thus, facilities connected to and powered by the microgrid can continue serving a community during an outage. This ability to continue serving critical loads, such as medical facilities or grocery stores, can mitigate the social and economic costs of disruptive events.

Depending on their components, microgrids may also be able to provide additional benefits above and beyond energy resilience benefits:

- Microgrids that incorporate renewable energy resources can have environmental benefits in terms of reduced greenhouse gas emissions and air pollutants.
- In some cases, microgrids can sell power back to the grid during normal operations.

However, microgrids are just one way to improve the energy resilience of an electric grid and they do have some potential disadvantages:

- **Depending on the complexity, microgrids can have high upfront capital costs.**
- Microgrids are complex systems that require specialized skills to operate and maintain.
- Microgrids include controls and communication systems that contain cybersecurity risks.



Rule of Thumb for Microgrid Costs

A 2018 study conducted by the National Renewable Energy Laboratory found that microgrids in the Continental U.S. cost an average of **$2 million-$5 million per megawatt.**

Since microgrids are not the only way to enhance energy resilience, communities may want to consider alternate resilience investment options, including hardening existing transmission and distribution systems, weatherizing power generation sources, and building additional distribution systems to provide energy supply redundancy. To learn more about other solutions that have lower capital costs and are less technically complex than microgrids, see the Grid Deployment Office's "Low-Cost Grid Resilience Projects" document.

Eligible Uses of 40101(d) Grid Resilience Formula Grants for Microgrid Components

Section 40101(d)'s prohibition on the construction of a new electric generating facility limits the eligible uses of 40101(d) grid resilience formula grants for microgrid development. Nonetheless, costs associated with building a microgrid that do not involve new generation sources may be allowable. For example, 40101(d) grid resilience formula grants could be used to purchase and/or fund installation of:

- Batteries that will be used to supply electricity during disruptive events,[3]
- Equipment or management systems required to integrate existing generation sources and/or a battery into a microgrid, such as an inverter,
- Microgrid controller (includes the equipment required to balance the system and connect/disconnect from the main electric grid),
- Electric cables (to connect multiple buildings within the microgrid),
- Distribution equipment (protective devices, transformers, etc.) required to distribute power throughout the microgrid.

Grant recipients are encouraged to speak with their assigned Federal Project Officer about eligible uses of 40101(d) grid resilience formula grant funding.

Microgrid Design Considerations

If your community is considering designing a microgrid, the questions raised in this section can give an indication of the relative degree of complexity and cost of the project. These preliminary design considerations dictate the number of distributed energy resource (DER) assets that are included, such as generation resources and battery storage systems, as well as the control architecture, load management systems, and level of automation of the microgrid, all of which increase complexity and cost of development.

Is solar paired with battery storage a microgrid?

While pairing a solar photovoltaic system with energy storage to support a single building (behind the utility meter) may be considered a small microgrid by some, for the purposes of this document we use "microgrid" to refer to more complex systems that connect multiple buildings or facilities. For more information about the costs and resilience benefits of deploying a small solar and storage project to support a single critical load, please refer to GDO's "Low-Cost Grid Resilience Projects" document.

1) Will the microgrid be connected to the main power grid?

If the microgrid is grid-connected (i.e., connected to the main electric grid), then the community can draw power from the main electric grid to supplement its own generation as needed or sell power back to the main electric grid when it is generating excess power. When the main electric grid loses power, the microgrid goes into island mode (i.e., operates independently of the main electric grid) and serves its own customers with the generation and other DERs (i.e., batteries or vehicle-to-grid electric vehicles) operating within the microgrid. In terms of microgrid design, this means that the microgrid does **not** have to be built to serve power 24/7, but instead can be built to provide power during times the main electric grid experiences an outage or is expected to be stressed.

A grid-connected microgrid with the sole purpose of providing backup power to a limited number of critical facilities during an outage will require less power generation capacity than an off-grid microgrid designed to provide power to an entire community all year round (e.g., for a community in remote regions without access to the main electric grid), as discussed below. However, relying on a microgrid for backup power requires ensuring the generation source is highly reliable and will be available when you need it, even in extreme conditions. The higher the desired level of availability, the more expensive the microgrid will be in both capital and maintenance costs.

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3 Note that BIL Section 40101(e)(2) specifies that a grant "may not be used for…large-scale battery-storage facility that is not used for enhancing system adaptive capacity during disruptive events."

2) How many different connections are there to the microgrid?

The size of the microgrid will also depend on how many buildings and other end uses (i.e., load) are connected within the microgrid (impacting distribution equipment and cables needed) and how much power these buildings/end uses will need to consume (impacting the type and size of generation and storage needed). The more connections and the larger the individual loads of those connections, the more expensive and complex the microgrid will be.

3) How much of the load needs to be met?

Finally, a community's risk preferences need to be considered when designing a microgrid. The size and therefore cost of the generation and storage is typically based on the peak load of the community that the microgrid is serving, which is the highest level of power required at any point in the year. However, if a community wants to ensure generation is available in the most extreme cases, they may want to oversize their energy sources to ensure an adequate supply of power. Conversely, if a community is budget-constrained and/or wants to only provide critical, life-saving power in an emergency, they could start by designing a smaller microgrid or installing lower capacity generation/storage and scale up with subsequent development as more funds become available. If a community chooses to adopt a phased approach, it is important to procure equipment and design the first phase with this in mind since not all microgrid architectures or controller sets are modular or scalable.

Considering the typical microgrid design scenario of sizing generation to match peak load, Table 1 provides a rough sense of the power generation capacity required for a microgrid depending on the number and type of loads connected to the microgrid.

Table 1. Rule-of-thumb generation capacity for possible loads served by a microgrid.[4]

Microgrid Generation Capacity	Possible Connections
5 kW	1 home[5]
25 kW	10 homes
250 kW	100 homes or 3 retail buildings
500 kW	200 homes or 5-6 retail buildings or 1 supermarket or 1 health clinic or 1 small school
1.5 MW	600 homes or 15-20 retail buildings or 4 supermarkets or 4-5 health clinics or 2-3 schools or 1 hospital

[4] These values serve only as a rough estimate and are based on estimated peak load values by building type in New England produced by U.S. DOE's Energy Efficiency and Renewable Energy Office (https://www.energy.gov/eere/buildings/commercial-reference-buildings). Additionally, these values also assume the microgrid has some sort of energy storage or thermal generation capacity in order to reliably serve these loads.

[5] A single home will often require larger generation capacity relative to peak load to accommodate the starting wattage required for household appliances. This extra starting wattage can often be ignored when considering multiple connections, because each connection will use power at different times.

Microgrid Cost

One of the key cost drivers for a microgrid is its size, as measured by its generation capacity. A 2018 study conducted by the National Renewable Energy Laboratory found that microgrids in the Continental United States cost an **average of $2 million-$5 million per megawatt (MW) to develop**.[6] Table 1 can help determine the approximate range of generation capacity (in MW) required for a desired load size and facility mix; the generation capacity estimate can then be used to get a ballpark estimate of the microgrid development total cost.

A microgrid project's cost structure will vary as a function of location, size, and complexity. Nevertheless, rules of thumb developed from historical data can help estimate the up-front financial investment for various components necessary to build a microgrid.[7] Table 2 shows the approximate cost breakdown for key components of a microgrid project.

Table 2. Approximate Up-Front Cost Breakdown for Hypothetical Microgrid Project

Component	Description	% of Total Estimated Cost
Equipment and installation costs	Procurement and labor costs	75%
Construction management	Construction oversight and project management costs	15%
Design and engineering	Surveying the electrical system; running supporting analysis; creating plans, environmental compliance documents, and permit applications	10%
TOTAL		100%

Historical microgrid project cost data suggests that of the equipment expenses, conventional generation resources make up the bulk of the cost, followed by energy storage, renewable generation, and control systems. See the Appendix for additional details.

[6] Note these are nominal amounts from a 2018 study that have not been adjusted for inflation. The 2018 study can be found here: Julieta Giraldez, Francisco Flores-Espino, Sara MacAlpine, and Peter Asmus. October 2018. "Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States." Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-67821. https://www.nrel.gov/docs/fy19osti/67821.pdf

[7] Note that in addition to the initial financial investment necessary to build a microgrid, there will also be operations & maintenance costs spread over the life of the asset.

Next Steps for Microgrid Design

After considering the resilience benefits and high-level cost considerations for a microgrid project, if a microgrid appears to be an effective and feasible resilience investment option, the next step is to craft a full conceptual design. Sandia National Laboratories' "Microgrid Conceptual Design Guidebook" provides a step-by-step approach to creating an initial design of a microgrid that considers the specific threats, needs, limitations, and investment options for a given location.[8] The framework guides a community through data collection and a high-level assessment of its needs, constraints, and priorities, prior to engaging engineers, vendors, and contractors.

The resulting conceptual design provides enough detail to create a cost estimate, begin procurement processes (e.g., solicit requests for proposals) and identify regulatory challenges and opportunities – all of which are some of the requisite steps between the conceptual and final design. If a community is planning a microgrid that will connect to the main electric grid or that uses wires belonging to a distribution provider, one of those key steps will involve collaboration with the local utility. It is important to discuss plans with the local utility as early as possible to identify potential system studies, infrastructure upgrades, fees, or other steps that may be required.

Figure 2 below illustrates the building blocks and phases of the Microgrid Conceptual Design Methodology.

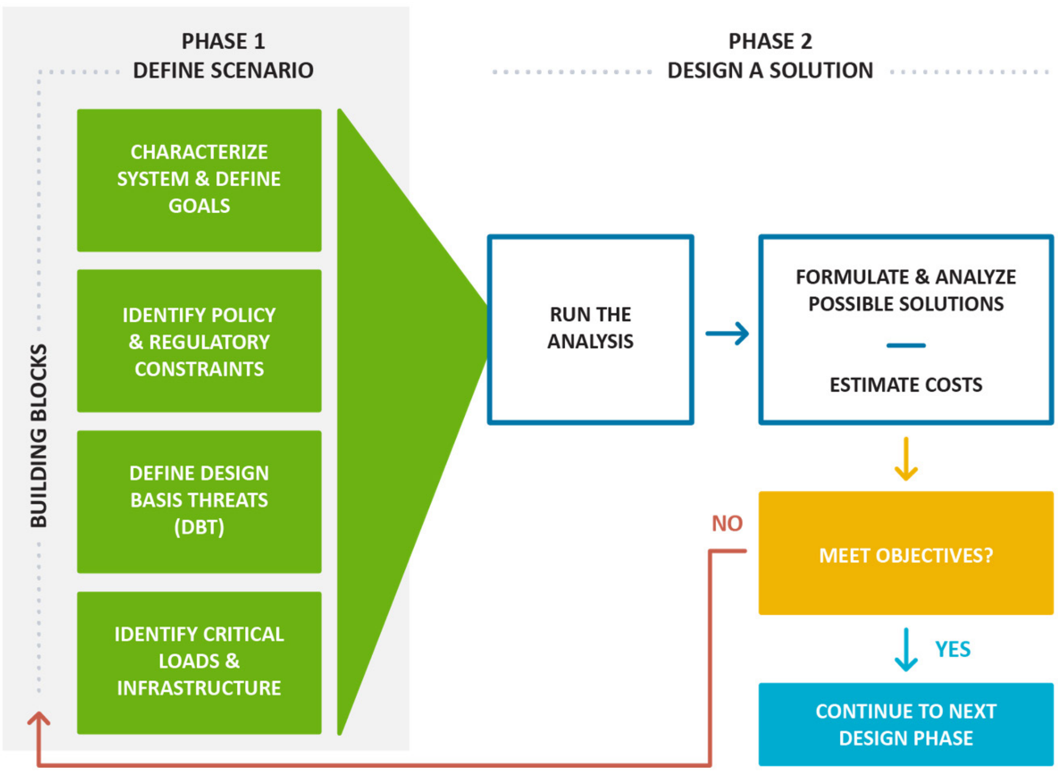

Figure 2. Sandia National Laboratories' Microgrid Conceptual Design Framework.

The Resources section of this document provides additional information and assistance opportunities that may be helpful for determining whether a microgrid is the right option and, if so, moving forward with microgrid design and implementation.

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[8] Robert Broderick, Brooke Marhsall Garcia, Samantha Horn, and Matthew Lave. 2022. "Microgrid Conceptual Design Guidebook." Albuquerque, NM: Sandia National Laboratories. No. SAND2022-4842R. https://energy.sandia.gov/wp-content/uploads/2022/05/ETI_SNL_Microgrid_Guidebook_2022_SAND2022-4842-R_FINAL.pdf

Additional Resources

Microgrid Development Guides and Case Studies

- Sandia National Laboratories Microgrid Conceptual Design Guidebook
  https://energy.sandia.gov/wp-content/uploads/2022/05/ETI_SNL_Microgrid_Guidebook_2022_SAND2022-4842-R_FINAL.pdf
- Community Microgrid at the Blue Lake Rancheria
  - Brief case study: https://schatzcenter.org/blrmicrogrid/
  - Full Project Report: Carter, David, Jim Zoellick and Marc Marshall. Schatz Energy Research Center, Humboldt State University. 2019. Demonstrating a Secure, Reliable, Low-Carbon Community Microgrid at the Blue Lake Rancheria. California Energy Commission. Publication Number: CEC-500- 2019–011. https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2019-011.pdf
- Renewable Energy Development in Indian Country: A Handbook for Tribes
  https://www.energy.gov/sites/prod/files/2016/04/f30/indian_energy_legal_handbook.pdf

Assistance Programs and Opportunities for Technical Consultations

- Request Grid Resilience Assistance from the DOE Grid Deployment Office
  https://www.energy.gov/gdo/request-grid-resilience-assistance
- Clean Energy to Communities (C2C) Program
  https://www.nrel.gov/state-local-tribal/clean-energy-to-communities.html
- C2C connects local governments, tribes, electric utilities, and community-based organizations with national laboratory experts and customized, cutting-edge analysis to achieve clean energy systems that are reflective of local and regional priorities.
- Communities Local Energy Action Program (LEAP) Pilot
  https://www.energy.gov/communitiesLEAP/communities-leap
  - Through Communities LEAP, the U.S. Department of Energy provides customized, high-quality technical assistance to competitively selected communities to develop clean energy-related economic development pathways.
  - The Iowa Tribe of Kansas and Nebraska and the Columbia River Inter-Tribal Fish Commission are participants in this program.

Appendix

The table below summarizes results from a 2018 National Renewable Energy Laboratory study that estimated the percent breakdown of microgrid equipment cost by equipment component.[9]

Table A1. Breakdown of the major equipment costs in microgrid development and the approximate percent of cost that each component comprises.

Cost component	Approximate percent of equipment costs attributed to each component
Conventional generation (natural gas, oil, diesel)	54%-76%
Renewable generation	10%
Energy storage	9%-15%
Control systems	3%
Soft costs (engineering, construction, commissioning, regulatory costs)	2%-9%
Additional electrical infrastructure (e.g., switchgear, supervisory control and data acquisition systems)	<1%-9%

[9] Giraldez, Julieta, Francisco Flores-Espino, Sara MacAlpine, and Peter Asmus. 2018. Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-67821. https://www.nrel.gov/docs/fy19osti/67821.pdf. p24-32.