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KEY STEPS IN MINI-GRID TECHNICAL DESIGN

Part of the Technical Design module of USAID's Mini-Grids Support Toolkit.

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KEY STEPS IN MINI-GRID TECHNICAL DESIGN

There are five key steps in the mini-grid technical design process:

1. Define the geographic scope of the project
2. Assess the available energy resources
3. Size the system
4. Select system configuration
5. Design distribution system

Successful design is an iterative process, not a linear one. In each technical design step, project developers must consider tradeoffs in cost, operations and maintenance (O&M) requirements, ability to provide power on demand, grid connection potential, load efficiency and load flexibility. Decisions in later steps influence choices made in earlier steps. In particular, project developers will need to revisit availability and cost of energy resources after sizing the system.

1. DEFINE THE GEOGRAPHIC SCOPE OF THE PROJECT

The first step in mini-grid design is to define the project's geographic area, including the total number of customers to be served. A mini-grid may supply power to multiple communities, a single village or a cluster of buildings. The number and type of customers (i.e., residential vs. commercial/industrial) are key factors in selecting the resource and power generation technology. Geographic features such as terrain, and ease of accessing resources, will also influence system design.

Finally, developers need to consider policies and grid extension plans that may affect the mini-grid in the future. Rural electrification plans and other potential grid expansion or power projects impact the viability of a mini-grid in a particular area.

2. ASSESS AVAILABLE ENERGY RESOURCES

After defining the geographic scope of the project, developers need to assess local energy resources, including quantity, availability, cost, sustainability and potential conflicting uses. Mini-grids require reliable, affordable supplies of energy resources that can meet local power needs—and different resources have distinct benefits and drawbacks. For example, a mini-grid in an area with seasonally available biomass resources could provide on-demand power for an anchor commercial customer such as a mill, but not year-round electricity for a community. Similarly, in drought-prone areas, hydropower may not be a reliable year-round resource.

During the assessment process, developers need to work closely with local communities. The women and men who use local natural resources can provide valuable information about availability and potential conflicting uses.

After identifying the most promising resources, developers select the energy generation technology (or technologies). Developers can choose from among different technologies for each energy resource. The following section introduces the most common technologies for biomass, diesel, hydropower, photovoltaic (PV), wind and hybrid energy generation, including where each technology works best.

MOST PREVALENT MINI-GRID GENERATION TECHNOLOGIES

Biomass	Biomass power generators can use solid biomass (including wood chips from timber milling and solid crop waste from agricultural processing), liquid biofuels (such as biodiesel) or gaseous fuel (such as methane from organic liquid waste) to produce electricity. Biomass-based electricity can work well in areas with reliable sources of inexpensive biomass, where electricity is expensive, and where industry must pay to dispose of biomass.
Diesel	Diesel generators have historically powered mini-grids, particularly in remote areas. Diesel can provide power on demand, but fuel is expensive, and burning diesel produces greenhouse gas emissions. Diesel gen-sets require periodic maintenance and overhaul, but because the technology is so prevalent, many rural areas have skilled technicians who can maintain them. Integrating renewable energy into existing diesel mini-grids can improve system performance, decrease costs and reduce environmental impacts.
Hydropower	Hydropower converts the power of flowing water into electricity. Hydropower is a site-dependent energy source: The power produced is directly proportional to the amount of water and the height from which the water falls. In rural communities with adequate water resources, mini-hydro may be the least-cost option. Developers can choose from among a wide variety of turbine types and designs that maximizes performance under different conditions.
PV	PV power systems convert energy from sunlight into electricity. PV is becoming more financially viable for mini-grids. Once very expensive, the cost of PV panels has decreased by more than 80 percent from year to year, and costs are continuing to fall. PV systems, which provide intermittent power supply, often integrate well into hybrid mini-grids that can co-generate with diesel systems.
Wind	Wind power turbines generate electricity from wind energy. Wind is available on a variable basis, but the resource is dependable and easy to monitor and forecast over time. Wind conditions vary significantly by geography, so wind-based mini-grids are only good options in areas with proven wind resources. Good locations for wind-powered systems include mountain ranges and coastal areas with persistent trade winds. Wind is commonly used in hybrid mini-grids.
Hybrid	Hybrid-power generation systems use more than one source of energy. Combining technologies with different energy sources provides operational and reliability advantages compared to using a single technology. Integrating diesel power with PV, for example, combines PV's low- maintenance requirements with power on demand from diesel.

3. SIZE THE SYSTEM

A mini-grid's size dictates its maximum power output. The power generation system should have sufficient installed capacity to meet loads. To size the system, planners must calculate variations in loads in half-hour intervals and estimate future load growth. Estimating and planning for current and future loads are critical steps, especially for financial viability.

Mini-grid developers can estimate current loads by surveying and assessing current and potential customers. Anticipating future loads is more difficult. Demand for electricity grows in conjunction with demographic changes and economic expansion, which are difficult to predict. Developers and planners can use a tool like Hybrid Optimization of Multiple Energy Resources (HOMER) software to model and define a system's expected loads, network design, consumption and cost. Well-developed models give planners insight into how to best use different fuel sources and those decisions' impact on resource usage, consumption and cost.

Ideally, mini-grids should be scalable, allowing operators to add generation capacity as demand for electricity grows. A mini-grid that can meet increased demand over time is more financially sustainable. The best size for a mini-grid also depends on whether it is likely to connect to the national grid in the future.

4. SELECT SYSTEM CONFIGURATION

Mini-grids can have three basic configurations: alternating current (AC) coupled, direct current (DC) coupled or hybrid (both AC and DC). Energy generation technologies, system sizing and battery use are the primary factors in deciding which configuration to use.

Different energy generation technologies favor different configurations. Hydropower, geothermal energy, diesel power and biomass-based power generate AC, so they generally use AC configurations. Solar PV systems produce DC, and wind turbines can be configured to produce either AC or DC. System designers therefore have to decide which configuration to use. Cost, expected usage, and plans to eventually integrate into a larger (typically AC) network are factors that influence decision making.

Each configuration has tradeoffs in costs, maintenance requirements, efficiency, safety and end-use versatility. For example, it is easier to transport electricity long distances using AC systems, but AC systems are more complex and expensive. While DC systems require less equipment to condition and transform power, there are very few consumer appliances that function using DC technology. And converting from AC to the DC generates losses in energy (and therefore in money).

SYSTEM CONFIGURATION TRADEOFFS

DC-coupled Systems	• Generally, more compact with fewer pieces of equipment and controls (no inverter, for example) • More efficient power generation due to lack of inverter losses but less efficient power distribution • Limited to smaller system sizes • Fewer appliance and equipment options for end users (most available appliances are AC) • Greatly impacted by the distance between power generation and use due to voltage losses and construction costs
AC-coupled Systems	• Higher cost • Require inverters, which need more space and system controls • More complicated to control and operate • More appliance and equipment options for end users
Hybrid AC/DC-coupled Configurations	• Increased system complexity • Advantages of both AC and DC systems

DC configurations are typically used for shorter distances, lower voltages and systems generating less power (W rather than kW). AC configurations, which transmit power more efficiently, are more commonly used for longer distances, higher distribution voltages and systems generating more power (MW). Small grids of only a few kilowatts, however, can also use AC.

In addition to choosing a current type, developers must choose between a single-phase or three-phase system. Single-phase systems cannot serve as many load types as three-phase systems. Single-phase systems normally serve lighting and resistive loads. Three-phase systems can handle more diverse loads, including large motors. To connect to the national grid, mini-grid systems generally need three-phase systems.

In terms of cost, single-phase systems require less expensive inverters and have simpler wiring, but they require more expensive transmission cables. Three-phase systems, on the other hand, require more expensive inverters and switches.

5. DESIGN DISTRIBUTION SYSTEM

To design the distribution system, developers first need to design the system layout and select system attributes. The next step is to model system performance based on the preliminary layout and system attributes. Once developers have defined the model for the distribution system, they can evaluate different conductor sizes based on the load allocated across the distribution system. Once project developers have completed the base case model, they can model variations in line routing, single- versus three-phase service and loads.

When planners have finalized system layout and attributes, design crews determine the structural (as opposed to electrical) design features of the distribution system. The design crews produce a list of materials based on benchmarks for the type and number of pole-top structures required for the line length and then determine the total length of the distribution line. Crews perform a final survey of the distribution system alignments to determine pole locations, structures and other requirements.

Mini-grid distribution systems are often more complex than those of standard grids. Unlike standard grids, mini-grids may have bidirectional power flows and multiple energy sources. This operational complexity requires extra controls and software. In hybrid systems, each power source requires separate controllers, and the mini-grid must have an overall management control to integrate the different power sources.

Developers should consider the end-user system, including meters, while designing the distribution system. Tariff collection and the business aspects of the mini-grid project are the primary factors in selecting metering technologies. Developers can select the payment system during one of several parts of the design process. Depending on the required controls, some developers may design metering and payment systems prior to the technical systems. The end-user system should accommodate loads and tariffs while respecting the local cultural context and user preferences.

DISTRIBUTION SYSTEM DESIGN IMPACTS ON EFFICIENCY AND COST

Voltage	The higher the voltage, the greater the distance energy can be transmitted. Accordingly, power is run through transformers to increase voltage in preparation for long-distance transmission. At the destination, it must pass through another transformer to drop the voltage back down. The higher the voltage, the more dangerous it is.
AC vs. DC	AC can run at higher voltages more easily, reducing distribution losses for longer runs, but converting between DC and AC also results in losses. In general, shorter distribution lines favor DC, and longer runs favor AC on the scale of mini-grids.
Single-phase vs. Three-phase Distribution	Three-phase AC power distribution is more efficient and requires smaller conductors compared to single-phase distribution. Because three-phase AC power provides constant power transfer, longer distribution lines tend to use three-phase. Single-phase AC power is commonly used at the household level, where loads are typically lighting. Three-phase distribution is better for industrial enterprises using larger motors. Single-phase distribution uses less wire and costs less but cannot run large electric motors.

RESOURCES

Energy Sector Management Assistance Program (2000). Mini-Grid Design Manual.
This resource provides detailed guidance on mini-grid technical components, the design process, tariffs, operations and maintenance and more. Written in 2000, this document remains a key resource for mini-grid developers.

Sandia National Laboratories, U.S. Department of Energy (DOE) (2019). Fundamentals of Advanced Microgrid Design.
As part of the DOE's Energy Transitions Initiative, this guide served as a module-based coursebook on microgrid design for the May 2019 'Advancing Caribbean Energy Resilience Workshop.'

Tenenbaum, B. et al., World Bank (2014). From the Bottom Up: How Small Power Producers and Mini-Grids Can Deliver Electrification and Renewable Energy in Africa.
This guide focuses on the decentralized approach, providing practical guidance on how small power producers and mini-grid operators can deliver both electrification and renewable energy in rural areas.