Energy
Security
Project

Methodology For Developing Microgrid Projects

IMPROVEMENT OF POWER SUPPLY RESILIENCE WITH DISTRIBUTED GENERATION

1/8/2025

Agenda

- Assessment Of Proposed Microgrid Region
- Data Collection
- Defining Boundaries of the Microgrid
- Microgrid Power Requirements in Isolated and Grid-Connected Modes
- Load Analysis
- Generation Planning and Generation-Load Matching
- Network Modelling And Power System Analyses For Validation Of Microgrid Operational Scenarios
- Defining Telemetry/Telecontrol Systems And Microgrid Management System (MGMS)
- Cost Estimation
- Economic Comparison of Design Options (or Design Decision via Optimization)

Microgrid Objectives & Planning and Design Steps

Objectives

- Enhance energy resilience with grid scale solutions
- Reduce dependency on centralized power grids
- Ensure reliable power during outages, natural disasters, or peak demand periods
- Provide localized, efficient, and flexible energy management
- Incorporate renewables and distribution generation

Main Planning and Design Steps

1. **Assessment Of Proposed Microgrid Region**
2. **Determination of Critical Consumers and Analysis of Their Loads**
3. **Defining Boundaries of the Microgrid**
4. **Microgrid Power Requirements in Isolated and Grid-Connected Modes**
5. **Generation Planning and Generation-Load Matching**
6. **Network Modelling And Power System Analyses For Validation Of Microgrid Operational Scenarios**
7. **Defining Telemetry/Telecontrol Systems And Microgrid Management System**
8. **Cost Estimation**
9. **Economic Comparison of the Design Options**

Assessment Of Proposed Microgrid Region

DATA FOR ASSESSMENTNWW	PURPOSE OF USE
1. Digital Network Model (or network single line diagrams)	Overall design activities for candidate regions and power system analyses (mainly to identify power carrying capabilities of existing conductors and transformers, or upgrades required if a larger capacity is needed)
2. Geographic Locations of Existing System Components	Physical location of system and optimal allocation of critical loads and generation
3. Existing Generation Data	Comprehensive assessment of existing and potential generation sources, including dispatchable and variable options, to ensure sufficient capacity to meet electrical load requirements while considering factors like operational characteristics, fuel availability, and cost considerations.
4. Energy and Demand Data for Critical and Non-Critical Loads	Required for detailed load data analysis, ideally using high-resolution consumption data over extended periods, to ensure accurate sizing and optimal performance in both grid-connected and islanded modes.
5. System Protection and Switching	Identify existing devices that could be isolation or sectionalizing points for the microgrid, or upgrades required to operate the microgrid safely
6. Investment and Future Planning	In order to consider near-term plans on the existing grid and develop a design which matches with those investment plans
7. Future Generation Considerations	This data, including location availability, fuel supply options, economic incentives, and interconnection feasibility, informs critical decisions in microgrid design to optimize generation mix, system layout, and overall performance for both normal and contingency operations.
8. Existing Telemetry and Telecontrol Systems	Any existing systems for Supervisory Control and Data Acquisition (SCADA), grid Automated Meter Reading (AMR), etc. should be considered either to be part of the microgrid management system or be integrated to the newly designed monitoring and control system
9. Existing Reliability and Performance of the Main Grid	Historical data is crucial to ensure that proposed microgrid solutions enhance system reliability and resilience, with site-specific reviews of current systems and maintenance practices providing insights for effective microgrid integration and outage mitigation.

Determination of Critical Consumers and Analysis of their Loads

- ✓ The design must have the capacity to support the peak load demand of critical systems when they are engaged in normal and peak activity (along with any non-critical loads that are incidental or non-segregable).
- ✓ An analysis of the load profile during normal and peak periods must be performed to verify that adequate generation and load following capacity is available.
- ✓ Load analysis must give specific consideration to step loads, highly nonlinear loads, motor and high volt-amperes reactive (VAR) inductive loads, as well as projected and actual or tested requirements in island mode.
- ✓ Load analysis must be conducted for both grid-connected and island modes.
- ✓ Especially under the high Renewable Energy Sources (RES) microgrid scenarios, adaptive border of microgrid would help to extend the boundaries of microgrid in high-RES hours.

- ❑ Load shedding via transformer or feeder switching is a key instrument to maximize endurance of higher priority loads.
- ❑ The analysis should include options for active load management and load shedding to maximize off-grid endurance of critical loads.
- ❑ Load shedding plan must consider criticality level criteria and installation load restoration plan to support the level of energy resilience required for the region’s essential facilities.
- ❑ Load shedding can be implemented by sequential restoration at substation breakers or via under frequency load shedding.
- ❑ For cases with nominal non-critical loads (or loads that are not easily segregable), designers must assess the tradeoff between incorporating additional load-shedding switchgear against the marginal cost of additional generation and system capacity required to support those loads.

Defining Microgrid Boundaries as back-up to main grid

Identify Critical and Non-Critical Loads

Start by identifying and categorizing critical and non-critical electrical loads within the distribution network portion which has been selected as candidate region.

This includes an assessment of the electrical demand for each transformer and feeder to understand their power requirements and criticality in terms of access to uninterrupted supply.

Assess Existing Grid & Generation Capabilities

Review the existing power system, including generation assets and distribution systems.

Evaluate the location of existing generators, storage systems, and spare circuit breaker bays.

This assessment helps in utilizing existing components effectively, minimizing the need for new construction and reducing costs.

Determine Optimal Microgrid Isolation Points

Select electrical switching points based on the location of critical loads and existing grid and generation.

The choice of switching points should aim to include all critical loads within the microgrid while considering the cost-effectiveness of integrating or excluding certain non-critical loads based on their geographic dispersal and connection feasibility.

Incorporate New Generation Sources

Define boundaries to include new generation or storage sources planned for the microgrid.

The physical and electrical connection points of these new assets should align with the overall design to optimize the microgrid's operational efficiency and resilience.

Power Requirements of the Microgrid in Isolated and Grid-Connected Modes

Microgrid design involves critical decisions across multiple dimensions, including load coverage (from critical-only to full load), operational duration (2 hours to indefinite), Distributed Energy Resources (DER) (various combinations of photovoltaic (PV), Battery Energy Storage System (BESS), diesel and gas), generation topology (centralized to portable), border management (static or dynamic), control strategies (centralized to peer-to-peer), and takeover methods (manual to autonomous). These key aspects allow for tailored designs that balance cost, resilience, efficiency, and flexibility to meet specific operational needs and constraints.

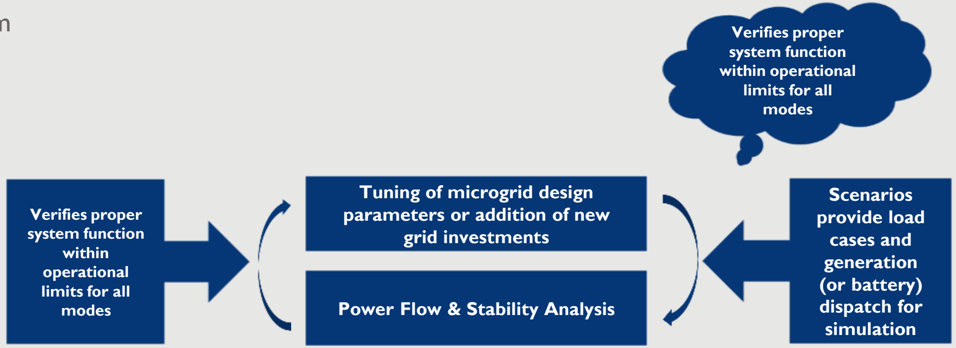
KEY ASPECTS	OPTIONS				
Sizing/Demand to Be Met by the Microgrid	Critical Loads Only	Critical + Non-Critical Loads	Daytime Loads Only	Full Load (Day & Night)	
Expected Off-grid Endurance of Microgrid Operations	2 Hours	8 Hours	24 Hours	1 Month	Indefinite
DER Type/Source	Solar PV + BESS	Diesel + BESS	Gas Generator Set + BESS	Solar + Diesel + Gas	Solar PV + Gas Generator Set
Topology of Generation	Centralized	Decentralized	Hybrid	Modular	Portable
Management of Microgrid Borders	Static/Defined	Dynamic/Adaptive			
Control Strategies	Centralized	Decentralized	Peer-to-peer		
Takeover of Microgrid	Manual Takeover at Site	Manual Takeover via Telecontrol	Autonomous /Hot Standby	Time Programmed	

Generation Planning and Generation-Load Matching

RES Level in Microgrid	Operational Characteristics	RES Contribution to Peak Load	RES Contribution to Annual Energy	Maturity Level
Low	- Dispatchable generation runs at all times - Renewables reduce net load on dispatchable generation - All renewable energy goes directly to load - No control system typically present	Less than 30%	Less than 20%	High, many examples at large and small scale
Medium	- Dispatchable generation runs almost constantly - Renewables reduce net load on dispatchable generation - Additional load added or renewable energy curtailed at high contributions - Basic control system typically required	30%–75%	20%–50%	High, many examples at large and small scale
High (with energy storage)	- Renewable energy and storage can power load without engine generators - Engine generators used mainly to charge storage during low renewable periods - Minimal basic control system required - Renewable generation can exceed peak loads, with excess energy stored	50%–100%	50%–100%	High, mostly at small scale
High (without energy storage)	- Engine generation can be shut down or reserved when RES meets load requirements - Additional components required for power quality when generator is offline - Requires sophisticated control system	50%–100%	50%–100%	Low to medium, few examples, mostly at small scale

Network Modelling And Power System Analyses For Validation Of Microgrid Operational Scenarios

Power System modeling is crucial for ensuring power quality and system stability when microgrids operate in islanded mode. These models go beyond the capabilities of tools like "Reopt" or "HOMER" and support detailed analysis required for effective microgrid design and operation. A digital model of the microgrid should be developed using the gathered data. This model allows for the simulation and visualization of the microgrid's performance under various scenarios, aiding significantly in planning and design.



Verifies proper system function within operational limits for all modes

Verifies proper system function within operational limits for all modes

Tuning of microgrid design parameters or addition of new grid investments

Power Flow & Stability Analysis

Scenarios provide load cases and generation (or battery) dispatch for simulation

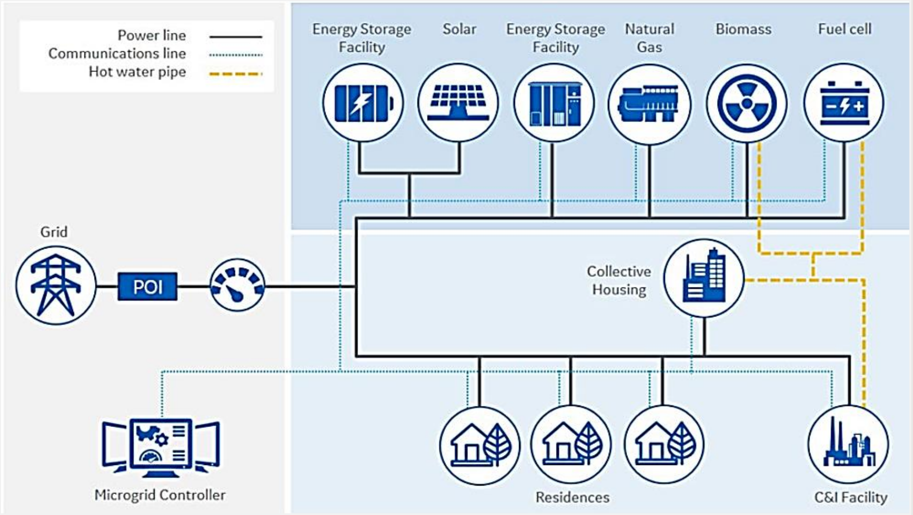
Analytical Studies:

- Steady-State and Load-Flow Analyses: Assess the microgrid's behavior under normal operating conditions to ensure it can meet energy demands efficiently and maintain stability.
- Quasi-Dynamic Analysis: Builds upon steady-state and load-flow insights by incorporating temporal fluctuations, crucial for integrating variable renewable energy sources.
- Short-Circuit Analysis: Focuses on assessing the microgrid's resilience by identifying the impacts of fault conditions such as short circuits. Determines the maximum fault currents possible, which is vital for selecting appropriate protective equipment and designing fault management strategies.
- Voltage Stability Analysis: Examines the microgrid's ability to maintain stable voltage levels under various conditions. Identifies potential issues that could lead to voltage instability or collapse, ensuring the microgrid operates reliably even during abrupt changes in load or generation.
- Protective Relaying and Coordination:
    - Utility-Connected Mode: The utility grid contributes significantly to fault current magnitude.
    - Islanded Mode: Fault current availability is reduced, necessitating adjusted settings for protective devices to ensure coordination and sensitivity.
    - Coordination Study: Essential to determine appropriate protective device settings for both grid-connected and islanded operations, informed by fault current analysis.

Defining Telemetry/Telecontrol Systems And Microgrid Management System

Defining an effective Microgrid Management System (MGMS) integrated with SCADA involves advanced communication, control, and optimization techniques to ensure efficient and reliable operation. Here is a summarized approach:

- **Integration with SCADA**: MGMS relies on SCADA for real-time data collection, monitoring, and processing from all microgrid components, enabling dynamic management and operational decisions.
- **Communication Architecture**: Utilizes fiber optics, Radio Frequency (RF), and cellular technologies for fast, reliable data exchanges, supporting centralized and distributed control strategies.
- **Control and Optimization**: Incorporates predictive algorithms and optimization techniques to efficiently dispatch energy resources, reduce costs, and maintain system stability.



- **Energy Management**: Balances supply and demand, integrating real-time energy flow monitoring, storage management, and demand-side management to optimize renewable energy use.
- **Human-Machine Interface (HMI)**: Provides intuitive access to system monitoring, control functions, and analytical data for quick, informed decision-making.
- **Operational Strategies**: Includes detailed strategies for black start capabilities, load management, and optimizing integration of renewable energy sources and storage systems.
- **PV and BESS Management**: Manages photovoltaic generation and battery storage for maximum efficiency, including protocols for generation curtailment and optimized charging/discharging.
- **Load Management**: Implements load shedding and reconnection protocols to balance the system during peak demands or disruptions.
- **Generation Set Management**: Ensures optimal operation of generation sets within the microgrid, contributing to system stability and efficiency.
- **Coordination and Control**: Specifies coordination and control approaches based on microgrid architecture, considering synchronized or isolated operations and hierarchical control schemes.
- **Protection Scheme**: Adapts protection schemes for islanded microgrid systems, recalculating fault currents, and tuning protection relays for new operational modes.

Microgrid Cost Estimation

CAPEX Estimation for Microgrid Components:

- **Energy Storage and Generation Systems**:
  - **BESS:** Includes costs for batteries, battery management systems, and installation. Plays a critical role in energy shifting and peak load management.
  - **Gas and Diesel Generators**: Accounts for the cost of generators, installation, and any necessary ancillary equipment like exhaust systems and fuel storage.
  - **Photovoltaic (PV) Systems**: Estimates costs for solar panels, mounting structures, inverters, and integration into the existing grid.
- **Distribution System Components**:
  - **Switchgears and Reclosers**: Essential for circuit protection and fault isolation within the microgrid, including costs for units and installation.
  - **Distribution Transformers and Switching Substations**: Key for adjusting voltage levels to match load requirements, includes costs for purchase and installation.
- **Control Systems**:
  - **SCADA Systems**: Price out necessary hardware and software for real-time system monitoring and control.
  - **MGMS**: Include the cost for advanced management software and necessary computing infrastructure.

Steps for CAPEX Estimation:

- **Detailed BoQ Listing**: Create a detailed list of all required components based on the microgrid's architectural and functional specifications.
- **Market Pricing**:
  - Obtain current market prices for each component. This may involve contacting multiple suppliers to get competitive bids or quotes.
  - Include costs for any custom components or specialized technology that may be necessary for the microgrid's unique requirements.
- **Installation and Integration Costs**:
  - Estimate labor costs associated with installation of each component, including manpower for physical installation, electrical integration, and system testing.
  - Consider costs for integrating new components with existing infrastructure, which may require additional hardware or modifications.
- **Permitting and Compliance**:
  - Includes costs associated with securing permits and ensuring compliance with local and national regulations. This can include environmental assessment.

Economic Comparison of Design Options

Compare microgrid configurations by calculating their Levelized Cost of Energy (LCOE) and selecting most cost-effective option.

Steps:

- **Define scenarios:** Identify different design scenarios for the microgrid, such as:
  - Scenario 1: Renewable Energy Sources (RES) + Battery Energy Storage Systems (BESS)
  - Scenario 2: Gas Motor Only
  - Scenario 3: Gas + RES
  - Scenario 4: Gas + RES + BESS
- **Identify Cost Components:** Separate costs into CAPEX and OPEX.
- **Calculate Present Value (PVal) of Costs:**
  - Use the discount rate to calculate the present value of both CAPEX and OPEX over the project's lifetime.
  - Present Value of CAPEX (PVal_CAPEX) is the sum of all initial capital costs.
  - Present Value of OPEX (PVal_OPEX) is the sum of annual OPEX accrued over the project's lifetime.
- **Calculate Present Value of Energy Production:**
  - Determine the present value of the total energy produced over the project's lifetime.
  - Present Value of Energy Production (PVal_Energy) is the sum of annual energy production accrued over the project's lifetime.
- **Compute LCOE for Each Scenario:**
  - Calculate LCOE by dividing total present value of costs by total present value of energy production: LCOE = (PVal_CAPEX + PVal_OPEX) / PVal_Energy
- **Compare Scenarios:**
  - Compare LCOE values of different scenarios.
  - Scenario with the lowest LCOE is typically the most cost-effective option over the project's lifecycle.

Approach via Comparison of LCOE for Alternative Design Options

Typical Comparison Table (note that figures are only illustrative to show the result table structure)

Cost Item	RES + BESS	Gas Motor Only	Gas + RES	Gas + RES + BESS
CAPEX				
Grid ($)	200	200	200	200
New DER ($)	1,000,000	0	500	500
Dispatchable Gen ($)	0	600	600	600
Grid Components ($)	500	100	100	500
Control Systems ($)	300	100	100	300
OPEX (per year)				
Grid ($)	20	20	20	20
New DER ($)	30	0	20	20
Dispatchable Gen ($)	0	50	50	50
Grid Components ($)	50	10	10	50
Control Systems ($)	40	10	20	40
Fuel ($)	0	200	150	150
BESS ($)	200	0	0	200
VOLL ($)	20	50	30	20
Energy Production				
Annual (kWh/year)	1,500,000	1,000,000	1,200,000	1,500,000
Lifetime (years)	20	20	20	20
LCOE ($/kWh)	**0.410**	**0.580**	**0.520**	**0.540**

THANK YOU!

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USAID UKRAINE CONTACT

For the published report and to get more information, please contact Kathleen Kirsch at kkirsch@usaid.gov

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