Business & Technology Surveillance

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WHAT HAS CHANGED IN THE INDUSTRY?

Electric cooperatives are committed to providing safe, affordable, and reliable power to all members. Over the past few years, there has been an increasing focus on reliability, especially as it refers to "resiliency," which Sandia National Labs describes as the ability to remain "operational in the face of adversity."[1] Adversity includes weather-related events, such as ice storms, tornadoes, flooding, and hurricanes, as well as physical or cyber attacks on utility infrastructure.

Microgrids are becoming an option to enhance resiliency, starting with critical loads (e.g., military bases, medical campuses, government offices, and protective services) and eventually to all customers. Utilities across the U.S. (including some co-ops) have started implementing microgrids. However, full understanding of what constitutes a microgrid, and how to specify them, is still in early phases.

A microgrid typically consists of distributed generation (fossil-based and/or renewable), energy storage, load control, and distribution system management. In the U.S., it is usually connected to the main grid most of the time, and only isolated (or "islanded") under special circumstances. Because most microgrids operate in two fundamentally different modes, there are many special considerations in planning, designing, and controlling a microgrid.

WHAT IS THE IMPACT ON COOPERATIVES?

Co-ops are increasingly evaluating advanced technology, such as distributed renewable generation (both utility and customer managed), large scale and distributed energy storage, advanced load management, and "smart-grid" applications, such as advanced metering infrastructure and smart-feeder switching. These technologies can have more value if planned for integration into a microgrid, even if that is a future phase of grid development.

1 https://energy.sandia.gov/energy/ssrei/gridmod/resilient-electric-infrastructures

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WHAT DO COOPERATIVES NEED TO KNOW OR DO ABOUT IT?

As the need for these systems becomes more common, it is important for co-ops to understand how they are specified, especially with regards to new IEEE standards, such as IEEE 2030 and IEEE 1547-2018. As co-ops are starting to implement microgrids on a wider scale, cost-efficiency will be improved through the use of existing standards rather than treating every new system as a "blank slate" design.

Better understanding of microgrids and their operation will also help co-ops develop the financial structures needed to support the different operational modes of a microgrid.

This article uses the structure suggested in the IEEE 2030.7 standard as a basis for developing the functional specification for a microgrid.

The IEEE 2030.7 standard offers the most comprehensive technical process for describing the functions of a microgrid controller.

What Is a Microgrid?

Microgrids are an increasing part of the national discussion on resiliency, but the concept is still new and evolving.

The U.S. Department of Energy (DOE) defines a microgrid as "*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. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.*"[2]

CIGRÉ C6.22 Working Group's Microgrid Evolution Roadmap, the **International District Energy Association** (IDEA), **ARUP** (an engineering company), **TrustRE**, and IEEE standard 2030.7 all define microgrid in similar terms—loads, distributed energy resources (which include distributed generation, storage and load control), and the concept of operating with or without a grid.[3]

Although there is general agreement on what a microgrid should include, there has been very little standardization on how to describe the functional requirements of a microgrid or on how the microgrid should operate in practice. This is where the IEEE 2030.7 standard comes in.

IEEE 2030.7-2017

The IEEE 2030.7[4] standard offers the most comprehensive technical process for describing the functions of a microgrid controller. Although aimed at the controller, these functional modes serve as a convenient way to actually specify the full microgrid.

The standard reduces microgrid complexity to two steady state (SS) operating modes and four types of transitions (T), as shown in Figure 1:

- SS1 – Steady State Grid Connected
- SS2 – Stable Island
- T1 – Transition from Grid Connected to Steady State Island (Planned)
- T2 – Grid Connected to Steady State Island (Unplanned)
- T3 –Steady State Island reconnect to Grid
- T4 – Black Start into Steady State Island

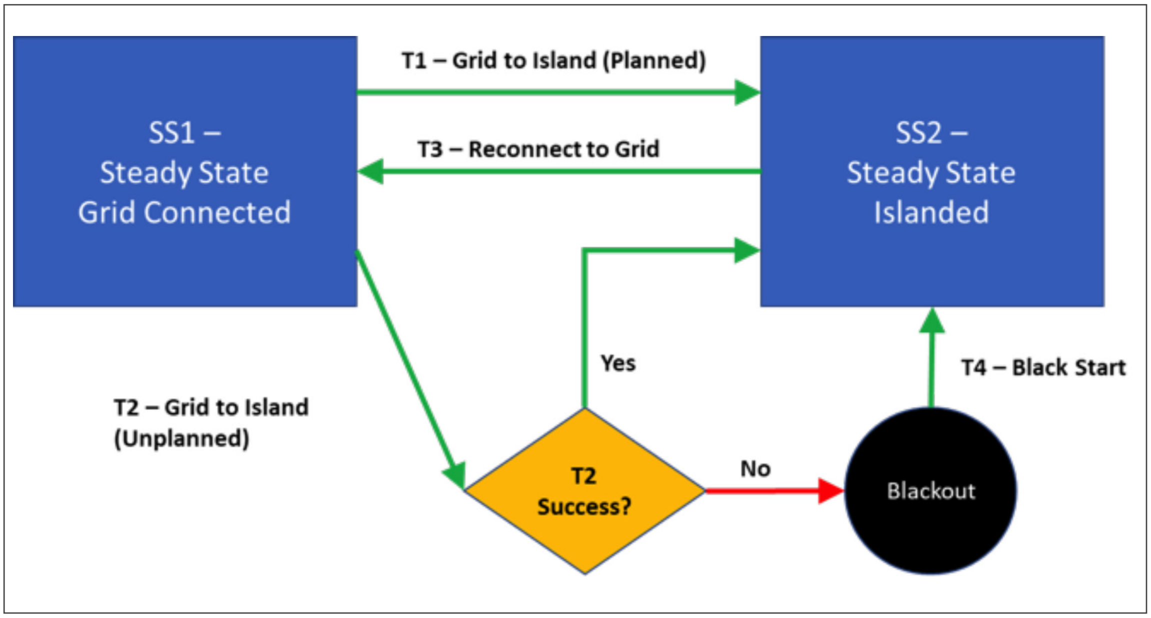

FIGURE 1: Simplified Microgrid Control Flow Diagram

2 **https://www.energy.gov/sites/prod/files/2016/06/f32/The%20US%20Department%20of%20Energy%27s%20Microgrid%20Initiative.pdf**

3 Note: The TrustRE definition assumes off-grid operation (such as the co-ops operating in isolated Alaskan communities), but more detailed analyses discuss what happens "**when the little grid meets the big grid**."

4 **https://standards.ieee.org/standard/2030_7-2017.html**

In a complex microgrid with many generation sources, it is important to define the generation component that is responsible for "forming the grid."

SS1 – STEADY STATE GRID CONNECTED

In this mode, the microgrid is connected to the larger grid. Assets in the microgrid can provide services to the grid, including peak shaving, frequency regulation, renewable smoothing, reactive power support, and ramp management. The microgrid controller provides a single communication point to access all of these services.

SS2 – STEADY STATE ISLAND

In this mode, the microgrid has disconnected from the main grid and is operating independently (typically called "islanding"). This requires an ongoing balance between loads and local generation/storage capabilities. Depending on the generation capabilities in the microgrid, it may be possible for this condition to persist indefinitely. It is important to realize that protective devices (overcurrent devices, regulators, etc.) may require different settings than in grid connected mode, because of the lower fault current and changes in direction of power flow within the microgrid.

Operating a stable island may also require load management, if the total generation is insufficient to power the total load, or if a microgrid operating with energy storage does not have enough reserve to provide full power for the entire day. Load control can come in many forms, from sectionalizing feeders to direct load control (typically for commercial customers) to standard demand response techniques, including HVAC load control switches and direct thermostat control.

Microgrids whose generation sources are entirely based on solar or wind will usually require energy storage to provide a buffer between the variable energy sources and the variable load. This will also require the ability to curtail generation sources, if storage is full and generation exceeds the load. A standard generator (internal combustion or turbine) can provide some of these functions, but curtailment may still be necessary to prevent excess power being delivered to the grid, causing high frequency/high voltage issues.

T1 – TRANSITION FROM GRID CONNECTED TO STEADY STATE ISLAND (PLANNED)

In some cases, an operator may want to operate in the microgrid in islanded mode even when the full grid is available. This might be for testing purposes, in advanced of a scheduled outage, or because it is simply more economic to operate as an island rather than grid connected. T1 describes the process that is needed to provide a seamless transition between grid-connected and islanded modes. This would typically involve starting auxiliary generation, if used, and balancing the load to match the available generation. Once this is achieved, the microgrid can be seamlessly disconnected through the "point of interconnection." Local generation must also be capable of switching from "grid-following mode" to "grid-forming mode."

In a complex microgrid with many generation sources, it is important to define the generation component that is responsible for "forming the grid." This is typically the largest, most stable generator, although it might be a battery inverter for microgrids that rely primarily on renewable generation. Other generators continue in "grid following mode." Protection setpoints on devices, such as solar and battery inverters, are typically set for anti-islanding protection of a large, stable grid and may need to be adjusted to prevent them from disconnecting if the microgrid voltage and frequency fluctuate more than in grid-connected mode. Some relays and other devices which normally operate in one direction may become bi-directional during microgrid operation, and it is critical that setpoints on these devices be adjusted correspondingly.

T2 – GRID CONNECTED TO STEADY STATE ISLAND (UNPLANNED)

This is the IEEE 2030.7 version of an uninterruptible power supply. When the main grid experiences a failure, the microgrid seamlessly disconnects and forms an independent power system (an island), while continuing to supply loads. One of the key factors in this transition is ensuring that the loads can be supplied by the local generation. This is easy in the case of a small, dedicated microgrid (e.g., a hospital), but may be more difficult with a larger, more diverse microgrid, such as a distribution feeder. In some cases, everything except critical loads may need to be disconnected during the transition until additional generation resources can be brought online. Similar to the planned island, one generator will need to act as the "grid-forming" entity, and protection settings may need to be adjusted on inverters, regulators, and other equipment.

In the transition of a microgrid to an independent power system during a main grid failure, it is key that the local generation can supply the loads.

T3 – STEADY STATE ISLAND RECONNECT TO GRID

This transition occurs when the islanded microgrid is ready to reconnect to the main grid. The "grid-forming" generator on the grid must have a "view" of the main grid, because it must adjust the frequency and phase angle of the microgrid to exactly match before reclosing (resynchronization), since reclosing out-of-phase can cause serious damage to local generators and protection equipment.

In addition, the "grid-forming" generator must immediately switch to a "grid following" mode after the reconnection is finished. If any loads have been curtailed, they can be reconnected at this time.

T4 – BLACK START INTO STEADY STATE ISLAND

The fourth transition assumes that the grid has gone completely down and must be brought up in islanded mode. Note that this assumes that the microgrid has been isolated from the main grid at the point-of-interconnection. This situation could occur because of an unexpected outage that the microgrid controller cannot handle using a T2 stable transition, or it might be necessary if the island does not have sufficient generation or energy storage reserve to continue to supply the basic loads and must, therefore, shut down.

In this transition, the microgrid controller must curtail all but the most critical loads and must then bring all available generation online. This is especially important in a system with energy storage, since it is important to bring the storage up to at least partially full before reconnecting loads.

Once there is a stable generation source, loads can be brought online in a prioritized sequence.

Microgrid Equipment and Communications

The second part of specifying a microgrid is to define the equipment and control systems which make up the microgrid. This can be done first ("Here is what we have, what can we do with it?") or second ("This is what we want to do, what do we need to do it?") or, most likely, in an iterative balance of the two. Regardless of the approach, it is important to identify the generators, energy storage resources, load management, and automated distribution system equipment that is available within the microgrid, and then to define how the microgrid controller will communicate with the equipment.

GENERATORS

Generators might include utility-managed photovoltaic (PV) systems and fossil fuel generators (reciprocating gas/diesel engines, gas turbines microturbines, fuel cells), as well as behind-the-meter generators, such as commercial or residential PV systems or even backup generators that are capable of synching with the grid. (Note: In rare cases, local wind generators may be available, but these are typically connected to the bulk electric grid and, therefore, not available as a local generation resource.)

It is important that one of the active generators be operated as "grid-forming," which means that generator supplies the voltage and frequency signal with which all other "grid-following" generators synchronize. This is typically either a traditional rotating engine-generator or a battery-based inverter. Since solar (and wind) are highly variable, they cannot help "form the grid."

Generation resources must be actively controlled. For example, PV arrays must have curtailment capabilities in case the generation exceeds the load and any energy storage resources are fully charged. This control can either be active or based on some sort of droop control. Inverter setpoints may also need to be adjusted to a more tolerant range for islanded operation than setpoints which are suitable for grid-connected operation. This can be an issue with behind-the-meter (BTM) consumer-owned solar inverters, since utilities may not have control over these devices. As a result, some solar and energy storage inverters may not be able to stay connected to the grid, limiting their ability to help support the microgrid.

ENERGY STORAGE

Load management is one of the most important components of a microgrid.

Energy storage is a technology that sits somewhere between generation and load management. Battery systems, such as grid-scale lithium-ion or flow batteries, can act as generation resources, but must also be recharged with other resources. BTM consumer-owned storage can also contribute resources, but care must be taken to balance the needs of the consumer versus the requirement of the microgrid.

Thermal energy storage, such as controllable water heaters or ice storage (for commercial cooling), can also help stabilize the grid, although these cannot actively contribute electric power to the microgrid. One example of this is to use excess solar energy during the day to "charge" water heaters, which can then be used even if the house is cut off as "non-critical" during periods of low generation.

Electric vehicles (EVs) can also serve as energy storage, if they are charged when excess generation (from wind or solar, for example) is available. In the future "vehicle-to-grid" applications may enable EVs to act as bi-directional energy storage.

One of the largest challenges for a microgrid controller is communicating with a large number of diverse devices.

LOAD MANAGEMENT

Load management is one of the most important components of a microgrid, since it is vital to balance the (typically) constrained generation with the desire to supply as much load as possible. Load management can take many forms, including typical utility demand response techniques (water heater and air conditioner curtailment or thermostat control), remote-disconnect meters at residences and small commercial entities, active load disconnects at large commercial and manufacturing facilities, and feeder sectionalizing (disconnecting entire groups of users based on location).

The microgrid controller must have "situational awareness" of which loads are being served at different points in the microgrid, and of a priority schedule of which loads are the most critical if generation resources are limited. Since there are many different devices, this complicates the communications and cybersecurity requirements of the system.

AUTOMATED DISTRIBUTION SYSTEM EQUIPMENT

There are two major concerns for automated distribution system equipment in a microgrid. The first is the sectionalizers mentioned above, which are used to perform low-resolution load management, such as rotating blackouts if necessary due to limited generation.

The second is the sensing and protective equipment. An islanded microgrid will have significantly different electrical characteristics than when it is connected to the larger grid. For example, current flow in a grid-connected system will generally be from the substation towards the load. However, in an islanded microgrid, power flows may be bidirectional based on available resources, time of day, and other factors. This means that devices, such as reclosers, voltage regulators, and circuit protection devices, must be able to sense bidirectional flow and deal with it appropriately. Another critical issue with islanded microgrids is that the available fault currents are very different than when the system is connected to the main grid. This means that protective devices, such as circuit breakers and reclosers, may not operate as expected. Modern devices contain relays which have programmable trip characteristics, so a microgrid may need to have access to these devices to modify setpoints for the different modes of operation.

COMMUNICATIONS, CYBER SECURITY AND INTEROPERABILITY

In order to have the appropriate "situational awareness" required in a microgrid, the microgrid controller must communicate with a large number of diverse devices ranging from inverters in utility-scale PV systems to residential thermostats. This is one of the largest challenges of designing and operating a modern microgrid. Not only are there a great variety of communications technologies (RF, cable, fiber, PLC, cellular), but there are many different standards and protocols, and those used by

Cybersecurity should be built into the software process as early as possible.

Microgrids will add a new level of complexity to utility billing.

utilities (Modbus, DNP3, IEC 61850, OpenADR) can be very different than those used by consumer-oriented behind-the-meter (BTM) protocols (Zigbee/ZWave, WiFi, Ethernet).

Microgrid controllers can also be self-contained (i.e., the microgrid controller talks directly to all end-use devices) or hierarchical (i.e., the microgrid controller talks with other controls, such as SCADA, AMI/MDMs, OMS, PV cluster controllers, BESS system controllers). Both cases require significant efforts into interoperability, which is simply a description of the desire for different devices to work together without custom coding enhancements. (The International Standards Organization is a bit more formal in describing interoperability as "the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units."[5])

Closely related to communications and interoperability is cybersecurity. Maintaining secure communications is a daunting task considering the vast diversity of devices, communications technologies, and protocols in use today. Devices in the field must have the ability to determine whether a request for status or control is valid, and must make sure that their responses are secure and can only be decrypted by the appropriate controller. The various microgrid control systems must ensure that the data they are receiving is valid, and that the commands they send out are received and executed appropriately, without being hacked/hijacked by a malicious actor. In general, cybersecurity should be built into the software process as early as possible. Additional challenges can occur when the microgrid controller wants to access BTM equipment at residences or commercial entities, since these are often behind some kind of firewall, and may or may not be as secure as the utility-controlled part of the network.

Financial Considerations

Utility billing used to be simple. A residential bill typically had two parts—a fixed charge and an energy charge (kWh)—while a commercial bill might add one or more demand (kW) charges. More complex rates might involve time-of-use (TOU) charges for energy consumption. The advent of cost-effective distributed generation introduced concepts such as "net-energy-metering" and "feed-in-tariffs," since the "prosumers" were both consuming and producing energy. BTM battery storage has the potential to change the basic profile of a customer load, affecting both energy and demand, especially for TOU rates.

Microgrids will add a new level of complexity to this subject. There are many questions that will need to be answered, including:

- Who pays for the upgrades needed to create a resilient microgrid? Is this shared evenly among all customers, even if they will not necessarily receive the same benefits during microgrid operation?
- Does a customer pay a different rate to have access to microgrid energy during an event? Does this apply all the time, or only during microgrid operation?
- If the energy and other services to power the microgrid are coming from a variety of utility-owned and third-party generators (such as rooftop PV systems), how are these generators metered and compensated for their services? Some examples: Is energy from a battery which can be supplied at any time more valuable than energy from solar? Is energy to recharge the battery cheaper than energy used to charge the battery, to account for round trip efficiency?

5 https://www.iso.org/obp/ui/#iso:std:iso-iec:2382:ed-1:v1:en

Summary

The IEEE 2030.7 Standard for Specification of Microgrid Controllers provides an excellent basis for planning and specifying a microgrid, whether it is a small, dedicated microgrid for a single building, or a complex microgrid covering significant segments of a distribution utility.

The microgrid developer should be able to describe all elements of the two primary operation modes—grid-connected and steady-state islanded—and the four transitions modes associated with these two states. The developer should also be able to describe all generation and load management used in the microgrid, as well as the communications needed to interface with all the various devices and control programs.

Finally, the developer must address new financial issues associated with microgrid operation. ■

ABOUT THE AUTHOR

Douglas Danley designed and installed his first PV system in 1982 while serving as a Peace Corps Volunteer in Botswana, Africa. He has designed a wide range of distributed generation and energy storage projects both in the U.S. and in many countries around the world, ranging from off-grid solar-diesel village electrification systems in the Peruvian Amazon to utility-scale PV systems in the U.S. He recently served as Principal Investigator for SUNDA, a four-year NRECA/DOE project to reduce barriers for electric co-ops who choose to implement utility-scale PV systems, and served as a consultant on a co-op microgrid project. Mr. Danley is currently developing a cost-effective solar electric cooking system for developing countries. Mr. Danley has a degree in Mechanical Engineering from the Massachusetts Institute of Technology.

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The Distributed Energy Resources (DER) Work Group, part of NRECA's Business and Technology Strategies department, is focused on identifying the opportunities and challenges presented by the continued evolution of distributed generation, energy storage, energy efficiency and demand response resources. For more information, please visit **www.cooperative.com**, and for the current work by the Business and Technology Strategies department of NRECA, please see our **Portfolio**.