The Need for Standardization

AS THE PENETRATION OF DISTRIBUTED ENERGY RESOURCES (DERs) in distribution systems increases, their integration and interconnection to the grid, and their impact on the grid, need to be addressed in a coherent and structured manner. In the case of a large penetration, DERs can be integrated by aggregating the units using a DER energy management system (DERMS) or can form part of the devices constituting a microgrid, in which case they are managed by the microgrid control system. This article stresses the need for standards to facilitate the large-scale deployment of DER in the distribution system within a microgrid.

Integration of Distributed Energy Resources

DERs are being integrated into distribution systems at an increasing rate. They include

- ✔ distributed generators based on renewable energy resources (solar and wind), which have variable and intermittent power output characteristics that are not dispatchable
- ✔ distributed storage, typically using electrochemical batteries and flywheels, that can be used to manage the variability of renewable resources and load
- ✔ smaller dispatchable distributed generators, using unconventional fuels (biogas and biomass) and conventional fuels (diesel and natural gas), and other power producing devices such as fuel cells.

Standards already exist and are being updated to accommodate the growing deployment of DERs in distribution systems, especially inverter-based photovoltaic, wind, and storage systems. In a grid-tied mode, the rules of the original IEEE

By Geza Joos, Jim Reilly, Ward Bower, and Russ Neal

Digital Object Identifier 10.1109/MPE.2017.2690518
Date of publication: 16 June 2017

The Benefits to the Core Functions of the Microgrid Control System

Standard 154-2003, *Interconnecting Distributed Resources with Electric Power Systems*, apply to the interconnection of DERs. IEEE Standard 1547-2014 (amendment to IEEE Standard 1547-2003) addresses new requirements and concerns, such as voltage support, and voltage and frequency ride-through of DERs. The revision currently being developed for IEEE Standard 1547 concerns additional issues arising from the interconnection of a larger number of DERs. As DERs displace conventional generation, they may be required to be more tolerant of voltage and frequency deviation in the distribution grid and to support its operation either individually or in aggregate form.

DER units can be integrated into distribution systems by aggregation using a DERMS, by integration into a virtual power plant, or by forming part of the devices constituting a microgrid. In this case, they are controlled and managed by the microgrid control system.

To facilitate the deployment of microgrids, new standards have been proposed. Project authorization requests include IEEE P2030.7, *Specification of Microgrid Controllers*, and IEEE P2030.8, *Testing of Microgrid Controllers*, with the latter being based on functional specifications defined in IEEE P2030.7. Guidelines for microgrid design and operation are being developed by other organizations, such as the International Electrotechnical Commission (IEC). These include the IEC/TS 62898-1, *Guidelines for General Planning and Design of Microgrids*, and IEC/TS 62898-2, *Technical Requirements for Operation and Control of Microgrids*.

In this article, we focus on the benefits of standardizing the microgrid control system's core functions and the associated testing requirements. We describe the role of the microgrids and identify key functionalities that define the attributes of the microgrid control system. These attributes are used to develop, configure, and validate the performance of the control system's core functions. A concept is proposed of a generic microgrid that allows the specification of basic and required microgrid controller functions that all microgrids must have to fulfill the requirements of integration and interconnection with the distribution grid. An approach to develop testing methods is proposed to validate the operation of the core functions, and tests are based on operating scenarios.

Microgrid Structure and Operation

Definition and General Features of Microgrids

Microgrids are broadly defined as "electricity distribution systems containing loads and distributed energy resources, operated in a controlled, coordinated way either connected to the main distribution network or islanded," according to the U.S Department of Energy Microgrid Exchange Group. Microgrids can be either normally connected to the utility distribution grid or permanently isolated, as in the case of remote microgrids. This article applies to both configurations. In the case of isolated microgrids, the constraints imposed by the distribution grid are absent since the microgrid does not interact with a larger distribution grid.

A grid-connected microgrid is a group of interconnected loads and DERs with clearly defined electrical boundaries that acts as a

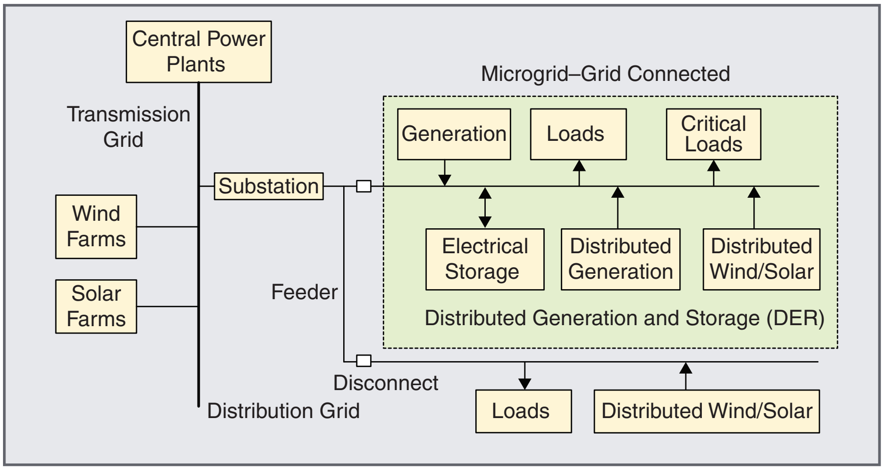

figure 1. The microgrid structure and its connection to the power system.

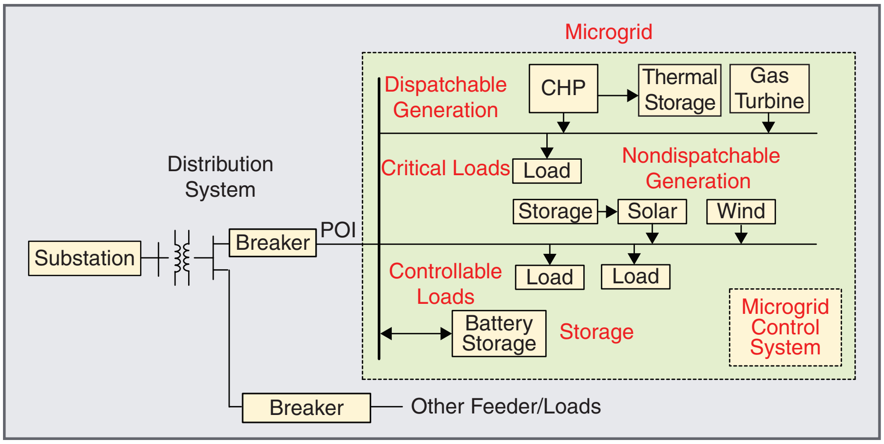

figure 2. The inner structure and components of the microgrid. CHP: combined heat and power; POI: point of interconnection.

single controllable entity with respect to the grid and can connect and disconnect from it to operate in either grid-connected or island modes. The discussion is limited to those microgrids having a single point of interconnection with the larger grid. The general structure of the microgrid and its relation to the broader distribution and transmission grids are shown in Figure 1.

Microgrid Devices and Components

Microgrids are characterized by having a microgrid control system capable of automatically integrating and coordinating the generation, storage, and controllable loads within the microgrid and the grid intertie equipment to interact with the larger grid and act as an aggregated single system.

A key defining element of the microgrid is its control system, which manages all aspects of the microgrid operation at the point of interconnection with the distribution grid, in both steady-state and transient operation. Under steady-state operation, the control system dispatches the microgrid assets, including DER units and switching and control devices. Under transient conditions, the control system is responsible for ensuring the connection and disconnection from the distribution grid.

The microgrid control system is also called a microgrid energy management system. The term “microgrid control system” is preferred for developing microgrid standards to avoid confusion with the accepted uses of the term “energy management system,” as used in transmission system operation and generation dispatch and in large industrial installations. Many of the features usually implemented in generation dispatch and load management in industrial installations can be designed into the microgrid dispatch function, as this function dispatches DERs and controls the loads and other devices within the microgrid.

The microgrid typically integrates the following components (shown in Figure 2): 1) equipment connecting the microgrid to the distribution system at the point of interconnection, typically a breaker; 2) the microgrid control system (energy management system); 3) local distribution system components, including transformers, switchgear, capacitors for voltage regulation, and reactive power management; 4) devices for the interconnection components within the microgrid (breakers); and 5) physical devices, including distributed generators and storage (DERs) and loads, such as controllable/curtailable and critical/sensitive loads, within the microgrid boundaries.

To be considered a microgrid within the scope of the standards, an electrical system must have the following three distinct features:

- ✔ clearly defined electrical boundaries
- ✔ a control system to manage and dispatch resources within the microgrid, considered as a single controllable entity
- ✔ installed generation capacity that exceeds the critical load, which allows the microgrid to be disconnected from the main grid, operate as an autonomous entity in islanded mode, and supply local loads, as required (the generation source is often combined heat and power).

Types of Microgrids

Microgrids can be implemented in many different environments and can take many forms. An example of a geographically constrained electric grid that has limited

> A key defining element of the microgrid is its control system, which manages all aspects of the microgrid operation at the point of interconnection with the distribution grid.

impact on and interaction with the electric grid is a large industrial plant. Such plants have been operating for many years and use an energy management system that manages internal operations.

There has been a significant interest in and deployment of microgrids in the last few years. These can be categorized based on the type of customers (including university or research campuses and military, residential, commercial, and industrial entities), the type of application (including the supply of premium power for critical loads and facilities requiring high reliability and resilience), and the type of connection, including remote and grid-connected installations. Voltage and power levels may vary significantly, and the grid voltage may be ac or dc or mixed ac and dc. Microgrids may be either utility or nonutility owned.

Microgrid Functions and Benefits

Microgrids have a number of identifiable and quantifiable benefits that define the manner in which they are operated and the functions they need to perform. They are an enabling technology for the following power system planning and operation requirements in the context of the newer active distribution systems, with intelligent features both at the aggregate DER and the distribution system levels:

- ✔ integrating DERs installed close to the load
- ✔ integrating DERs using renewable energy resources (green power)
- ✔ reducing the aggregate power variations on the distribution grid
- ✔ reconfiguring existing distribution systems with enhanced reliability and operating efficiency
- ✔ deploying new distribution systems, either grid connected or isolated
- ✔ enabling market participation of DERs installed within the microgrid
- ✔ empowering customers and end users.

Quantifiable benefits can be used in the development of a business case for deploying microgrids. A business case can be based on one or more of the following benefits:

- ✔ enhancing the reliability of the power supply to end users
- ✔ matching power quality to end user requirements
- ✔ providing ancillary services to the grid, including voltage- and frequency-related services
- ✔ lowering the carbon footprint
- ✔ enhancing grid stability
- ✔ enhancing energy security and resiliency of the distribution grid using local energy resources.

Microgrid Control System Structure and Operation

Microgrid Control System Requirements

A microgrid control system includes the control functions that define the microgrid as a system able to manage itself, operate autonomously or grid connected, disconnect from the main distribution grid, and exchange power with and provide ancillary services to the distribution grid. Typical control system functions include the following:

- ✔ operation coordination in grid-connected and islanded modes
- ✔ automatic transition from grid-connected to islanded mode to provide uninterrupted power to microgrid loads during abnormal power system operation conditions (blackout)
- ✔ resynchronization and reconnection from islanded to grid-connected mode
- ✔ energy management to optimize real and reactive power generation and consumption within the microgrid
- ✔ providing ancillary services, including support to the distribution grid and participation in the energy market and/or utility system operation, as applicable.

Since there are many microgrid configurations, depending upon location and purpose, the requirements and functions of the microgrid and microgrid controller differ. Regarding implementation, a microgrid control system can consist of software, hardware, or a combination of both and can be physically implemented in a variety of ways, including centralized or distributed control approaches. However, all such systems should satisfy minimum functional requirements to allow standards to be proposed and developed. These specify the core-level functions common to any microgrid control system.

Microgrid Control System Functions

The microgrid control system can carry out some or all of the tasks listed below, which are determined by the type and application of the microgrid and its desired functionalities, internal to the microgrid, and in its interaction with the distribution system:

- ✔ coordinating, in an optimized manner, the integration and dispatch of local DERs and loads
- ✔ setting the power exchanges (real and reactive) with the grid
- ✔ managing disconnection and reconnection to the grid
- ✔ enabling the provision of ancillary services to the grid
- ✔ enabling market participation of DER units contained within the microgrid.

Not all microgrids will have the ability to carry out all tasks, for example, enabling market participation.

Structure of a Microgrid Control System

The microgrid control system functions operate at different control levels and in different time frames. They act on different components and assets of the microgrid. The functions range from the device-level functions, typically embedded in the DER, to the microgrid supervisory and grid interactive functions, as in Figure 3.

The time frame in which the different microgrid control system functions operate is specified in Figure 4. The lower- or device-level functions run on the short timescale while the core functions typically operate on a longer timescale. The functions associated with transitions from connection to disconnection and the dispatch of DER assets run on different timescales. The transition functions, in the unplanned disconnection case, need to be executed in a short time frame and implemented with the shortest delay. The dispatch function can be executed at regular intervals and a longer timescale, typically in the minute range (15 min or lower).

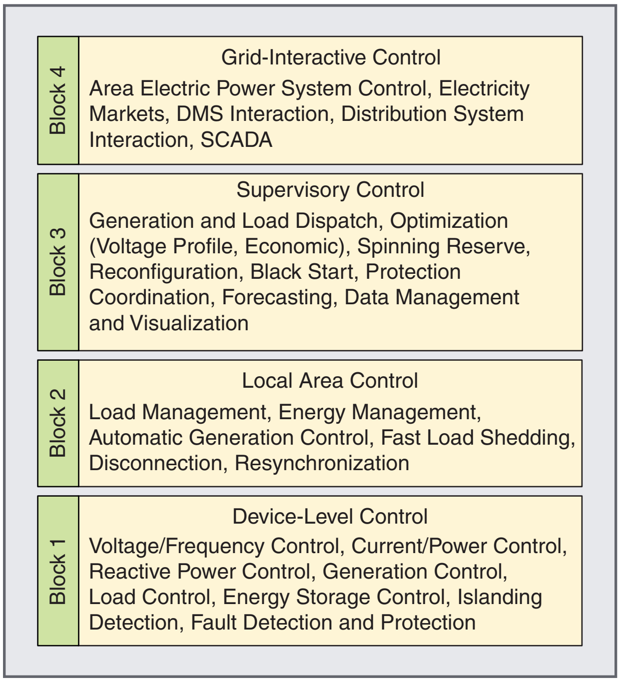

figure 3. The microgrid control system function classification. DMS: distribution management system; SCADA: supervisory control and data acquisition.

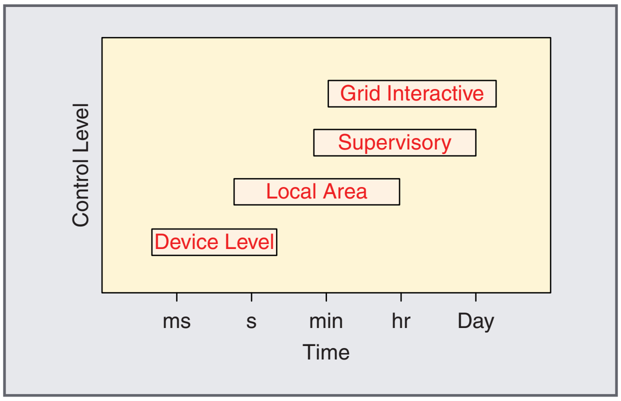

figure 4. Microgrid control function timescales.

Microgrid Control System Function Standardization

Standardization Benefits and Activities

Microgrids are being deployed in increasing numbers and places and for different applications and contexts, and new standards defining minimum requirements would greatly aid this deployment. Defining generic core-control functions would facilitate the basic design of the control system and the configuration and operation of microgrids.

Establishing a standard for microgrid control systems would also allow interoperability of control system functions with microgrid components to enable the operation of a microgrid through cohesive and platform-independent interfaces. This approach allows for component flexibility and customization and control algorithms to be deployed without limiting extended and potential functionality. Microgrid components and operational solutions exist with different configurations and in different implementations. Interoperability requirements are an integral requirement and a principle in standards development. Standards should allow microgrid controllers to be interchangeable from the functional perspective.

To be useful, standards need to be universally applicable and present as few restrictions as possible. Interoperability of control systems from different vendors would apply and be limited to the core functions defined in the standards.

Standardization efforts are carried out by a number of standards organizations, such as the IEEE and IEC. The IEEE Standards Association has initiated two projects on microgrid standards: IEEE P2030.7 and IEEE P2030.8. This second standard uses the functional specification defined in the first standard.

Participants in the standards development include 1) manufacturers offering microgrid controller configuration platforms and configured controllers, 2) consultants specifying and configuring microgrids and microgrid control systems, 3) service providers, 4) utilities and distribution system operators (DSOs), and 5) government and research laboratories.

Requirements for a Successful Standard

The ultimate aim of a standard is enabling interoperability of diverse systems carrying out the same functions, with an industry consensus on what is required to conform to the standard. There also needs to be a balance between being

> Microgrids are being deployed in increasing numbers and places and for different applications and contexts.

prescriptive and providing sufficient latitude for users to choose from a range of implementations and options to better meet the requirements of a given application. Regarding microgrid standards, a clear and simple set of required core functions needs to be defined and used for conformance testing to ensure interoperability of the offerings from different vendors, even though differing implementations are possible. Defining core functions is the purpose of the IEEE P2030.7 standard initiative.

In addition to defining a set of core functions, there needs to be a protocol for conformance testing. This step forms the basis for a certification program to ensure conformance. Testing is covered in the IEEE P2030.8 standard project. An appropriate procedure needs to be determined for compliance testing for the standard. There needs to be a clear and comprehensive set of test scenarios, performance requirements and specifications, and test metrics. There are a number of ways to deal with certification. Self-certification can be an effective solution for more established standards. However, independent validation of performance is desirable. This can be carried out by third-party accredited test laboratories, which ensures true interoperability of the equipment built to meet a specific standard. Conformance to the standard may not necessarily guarantee interoperability. Generally, a broad market adoption is the best indicator of the success of a standard.

Standardization Process

The guiding principle and approach for developing a standard for microgrid control systems include the following:

- ✔ defining a generic microgrid with basic devices and elements common to microgrids (Figure 2), as per definition of the microgrid
- ✔ identifying the main functions and features common to microgrids meeting the definition and having, among others, grid connection and islanding capabilities, as per functions required for a microgrid
- ✔ identifying generic classes of functions 1) internal to the microgrid, to manage of microgrid assets, and 2) external to the microgrid, to define the interactions with the distribution management system
- ✔ defining the minimum required core functions for the microgrid control system (functions associated with steady-state operation and transitions between grid-connected and islanded modes, which are the basic modes of operation of microgrids)
- ✔ defining features of core functions that have measurable, verifiable, and quantifiable performance metrics.

The main element of the standardization process is the definition of core functions of the microgrid control system. These are the functions that need to be standardized. The others can be tailored to the specific application and remain proprietary. The standard is a functionality-driven specification and does not deal with detailed engineering and design implementation issues.

Scope of a Standardized Functional Specification

To be as generic as possible and achieve the widest possible adoption, the functional requirements specified in a standard should be generally applicable to all microgrid control systems, regardless of their specific requirements, configuration, and application and whether they are connected to a distribution network or islanded. To meet the requirements listed previously, the following are excluded from the scope of a standard:

- ✔ the specification of the individual or aggregate capacity of loads or generation installed in the microgrid and the voltage levels at the point of interconnection to the distribution grid or within the microgrid
- ✔ the prescription of protection schemes deployed within the microgrid, consisting of protection functions for individual components and assets and of protection coordination that may be required with the distribution grid protection schemes
- ✔ planning, design, and operating procedures of the microgrid
- ✔ considerations related to the contractual power exchanges between the microgrid and the distribution network at the point of interconnection.

The core features of the microgrid control system should be functional and not refer to or specify any particular type of equipment type and hardware or software implementation.

The grid operator to which a microgrid interconnects, typically the DSO, has requirements that need to be met at the point of interconnection. These include technical requirements such as anti-islanding, fault isolation, low or high voltage and/or frequency ride-through, and power quality, as well as operational requirements related to real and reactive power import and export. The microgrid as an entity, including the microgrid control system, needs to satisfy these interconnection requirements. These should not limit the applicability of the standard to DSOs.

To be useful, standards need to be universally applicable and present as few restrictions as possible.

Functional Specification of the Microgrid Control System

Identification of Control System Core Functions

The first element of the standardization process is to define the common core functions meeting the definition proposed in this article, regardless of application, topology, configuration, or jurisdiction. These functions define the microgrid as a system that manages itself, can operate autonomously or grid connected, and connects to and disconnects from the main distribution grid for the exchange of power and the supply of ancillary services.

The standard defines core functions, taking into account the requirements of the distribution system and microgrid operators. The functional specification needs to be adequately tested. The two core functions that are defined in the standards (Figure 5) are

- ✔ the dispatch function, which computes and distributes the set points of DER units and controllable loads in grid-connected and islanded modes
- ✔ the transition function, which dictates the control system operation during transitions from grid-connected and islanded modes and in reconnection.

In the function classification of Figure 3, the core functions are made up mostly of blocks 3 and 2 functions. The relation between the core functions and the other functions of the microgrid control system is further illustrated in Figure 5. The interaction between the two core functions is shown in Figure 6. The dispatch function needs to redispatch the microgrid assets during the transition processes. This is done asynchronously, on an interrupt basis.

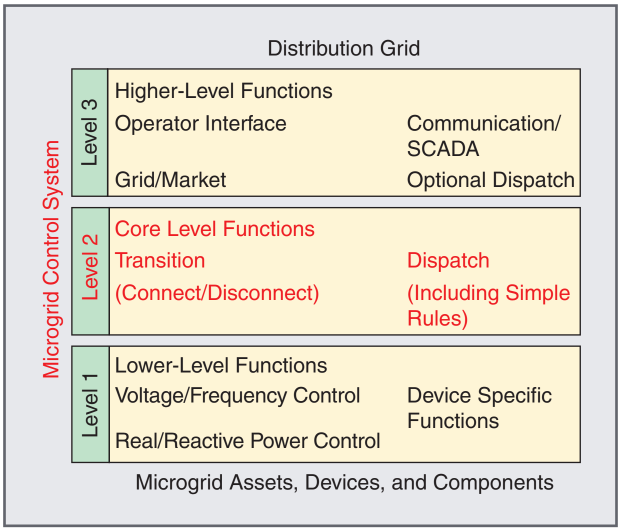

figure 5. The microgrid control system functional framework core functions.

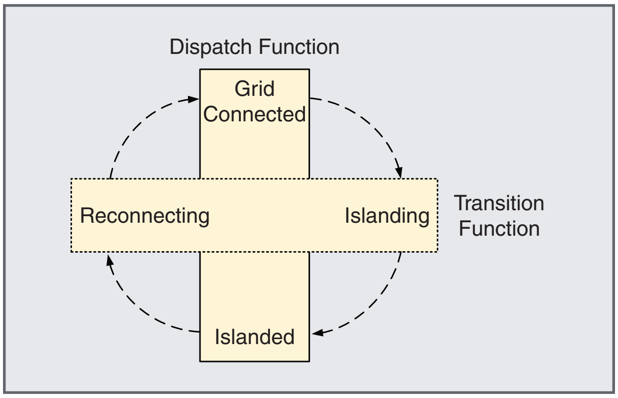

figure 6. The interaction between dispatch and transition and functions.

Specification of the Core Functions

The dispatch function sends microgrid assets and provides them with appropriate set points. It maximizes the use of the DERs available within the microgrid and ensures that the microgrid operation meets all requirements, both internally and as seen by the distribution grid at the point of interconnection. A dispatch order is a set of commands generated by the dispatch function and communicated to the microgrid assets and their individual controllers. Examples of these commands include open or close, start or stop generators, and reduce load to critical loads only.

The control system dispatches microgrid assets according to operational requirements to serve installed or selected loads within the microgrid and meet power and power quality requirements. In grid-connected mode, it meets the interconnection agreement stipulations (in terms of energy consumed/produced) and the interconnection requirements (power quality, e.g., harmonics and voltage sags) set by the DSO and the microgrid internal requirements set by the microgrid owner/operator. The relevant requirements apply in the event of a planned or unplanned disconnection or islanding. In an unplanned disconnection, the microgrid, as an entity, shall meet specific requirements such the low-voltage ride-through requirement, as imposed by the DSO.

> The first element of the standardization process is to define the common core functions meeting the definition proposed in this article.

The dispatch core function provides the following functionalities: 1) balancing generation and load under normal islanded operating conditions, 2) redispatching controllable resources in response to internal events related to the load and generation profiles, and 3) responding to external orders, for example, interconnection agreement requirements and external events, by redispatching resources.

The transition function that manages transitions from grid connection to islanding operates in four different situations: 1) unplanned islanding, 2) planned islanding, 3) reconnection, and, as required and applicable, with 4) black start. The transition function provides the logic to switch the dispatch function between the different dispatch modes, which include the different transition modes and the connected and disconnected steady-state modes.

The dispatch function is responsible for the reconfiguration of the control system during transitions. The relationship between the transition and dispatch functions is illustrated in Figure 6.

Testing of Core Functions

General Requirements for Conformance Testing

The scope of the follow-up standard, IEEE P2030.8, to the functional specification IEEE P2030.7 is to develop a set of testing procedures allowing the verification and quantification of the core functions' performance against the defined metrics. Metrics should demonstrate that the requirements of the microgrid operator and the DSO are met. The standard focuses on testing functional requirements, while recognizing that there are many possible hardware and software implementations of the same microgrid control system core functions.

A standard for testing microgrid controllers establishes the interoperability of different control system offerings and facilitates the development of cohesive and platform-independent interfaces. The standardized set of testing procedures facilitates the wide adoption of standard microgrid control system functional and performance requirements by vendors and utilities, including DSOs. Testing standards facilitate the interfacing of the microgrid control system with the distribution management system.

Testing Approach and Protocols

The elements under test are the core functions defined as the basic and key functions required for the operation of the microgrid. These functions may be implemented in any form and combination of hardware and software algorithms, using either a centralized or a decentralized structure.

The proposed testing approach is as follows:

- ✔ Define a generic microgrid that forms an environment suitable for testing the microgrid control system core functions; this microgrid can contain a combination of devices and components shown in Figure 2.
- ✔ Develop test scenarios that allow testing the core functions, either one core function at a time, for example the dispatch function, or the combination of the two core functions, as in the case of transitions, where the transition function calls upon the dispatch function to implement the required changes in asset dispatch.

The test scenarios that allow core function testing include the following:

- ✔ For the transition function, including testing dispatch function algorithms associated with transitions (which involve control decisions and actions determined by the dispatch function), scenarios include 1) planned islanding, resulting from a command from the DSO; 2) unplanned islanding resulting from different fault conditions and equipment failure on the distribution grid; and 3) reconnection. The different tests require the transition process to be verified during the disconnection and reconnection operations and as well as the variations in the critical parameters (voltage, current, power, and frequency, as appropriate). Scenarios define initial (preexiting) conditions.
- ✔ For the dispatch function under steady-state operation, scenarios include grid-connected mode (supplying loads and meeting P and Q interconnection requirements) and islanded mode (balancing generation and load).

The performance criteria are established based on the following abilities:

- ✔ to maintain 1) stable operation, voltage, and frequency within the required range and the required power quality within the microgrid under all circumstances in islanded mode and during transitions and 2) the required power exchanges and power quality at the point of interconnection and within the microgrid in grid-connected mode
- ✔ to meet the interconnection requirements, typically in terms of voltage and frequency ride-through, and the agreed-upon power exchanges at the point of interconnection for grid connection and reconnection.

The test metrics that need to be met include

- ✔ voltage and frequency within defined ranges under steady-state and transient conditions, defined in the

> It is important for a standard to focus on the requirements and functions applicable to a large range of microgrids and microgrid control systems.

utility interconnection requirements or accepted utility and industry standards
- ✔ power, real and reactive, within agreed-upon ranges, under steady-state and transient conditions, with accuracies and ramp rates, among others, defined in the utility interconnection agreements and requirements or accepted utility and industry practices.

Instrumentation, including sensors, measurement and recording devices, data collection and analysis, and data formatting, are specified and depend upon the test environment chosen. Options for the testing environment include

- ✔ in a real-time simulation environment, with hardware-in-the-loop testing of some or all of the hardware and/or software constituting the microgrid control system
- ✔ in a real environment, reproducing all or part of the components of the microgrid installation, with the connection of the microgrid control system to the appropriate devices; this allows for full-scale testing of the hardware, software, and information and communications systems making up the microgrid control system.

Summary

This article demonstrates the need and benefits of standards to facilitate the deployment of a large number of DERs in the distribution system within microgrids. Existing standards for individual DERs are being updated to accommodate their growing deployment, particularly inverter-based photovoltaic and storage systems. An alternative to connecting DERs individually to the grid is to embed them in microgrids. A key defining component of a microgrid is its control system, which manages all aspects of the microgrid's operation, seen from the point of interconnection to the distribution grid, in both steady-state and transient operation.

Since there are many microgrid configurations, depending upon location and purpose, the requirements and functions of the microgrid and microgrid controller differ. For this reason, it is important for a standard to focus on the requirements and functions applicable to a large range of microgrids and microgrid control systems, which are generic and commonly implemented.

The ultimate aim of a standard is to strive to obtain industry consensus on what is required to conform to the standard. There needs to be a balance between being prescriptive and providing a wide latitude to users to choose from a range of options to better meet the requirements of a given application. There needs to be a clear set of core functions required and tested to ensure interoperability of the offerings from different vendors, even though differing implementations are possible. This platform-independent approach allows for flexibility and customization of controllers and control algorithms to be deployed, without limiting other potential functionalities, while ensuring minimum requirements are met and comparative performance indices are set.

Defining core functions is the purpose of the IEEE P2030.7 standard initiative. This initiative established core functions and takes into account the needs and requirements of the DSO and the microgrid operator. It also links the functional specification to a testing approach, developed in IEEE P2030.8.

The two core functions defined in the standards for a microgrid control system are 1) the dispatch function, which computes the set point of the DER units and the status of the controllable loads in grid-connected and islanded modes and 2) the transition function, which defines the controller operation in the transition between grid-connected and islanded modes and in the reconnection process.

For Further Reading

"Powering microgrids for the 21st-century electrical system," NEMA MGRD 1-2016, Aug. 2016.

"Microgrids for critical facility resiliency in New York State," Final Rep., NYSERDA Rep. 14-36, Dec. 2014.

W. Bower, D. Ton, R. Guttromson, S. Glover, J. Stamp, D.Bhatnagar, and J. Reilly, "The advanced microgrid integration and interoperability," Sandia National Labs, Tech. Rep. SAND2014-1535, Feb. 2014.

N. Hatziargyriou, Ed. *Microgrids: Architectures and Control*. Hoboken, NJ: Wiley, Mar. 2014.

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Standard 1547, 2003.

IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure, IEEE Standard 2030.2, 2015.

Biographies

Geza Joos is with McGill University, Montreal, Canada

Jim Reilly is with Reilly Associates, Red Bank, New Jersey.

Ward Bower is with Ward Bower Innovations LLC, New Mexico.

Russ Neal is with the University of California, Irvine.