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Microgrid Controller Standardization – Approach, Benefits and Implementation

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SUMMARY

Microgrids are receiving attention for their advantages for integrating distributed energy resources (DER) – renewable energy resources, conventional and alternative distributed generation, and electric energy storage, as well as load management and demand response. The microgrid is an effective means of balancing the variability of renewable resources and loads. The benefits of setting up microgrids include resiliency to exceptional atmospheric events and contingencies, a reduction of the cost of supplying electric energy from central generation plants though a transmission network, and the diversification of the energy supply. A key element of the microgrid is the microgrid control system that manages the DERs and loads and presents to the distribution grid operator at the point of interconnection a combined system that has a well-defined and controllable real and reactive power consumption and that can be islanded as required.

Standards are a key enabler to the deployment of microgrids, and the associated DER within them. Standards for microgrid control systems that meet minimum interconnection and interoperability requirements are particularly important. This paper presents the latest standards development initiatives for microgrid controllers. It discusses grid codes developed by utilities for DER connected to the distribution grid. It summarizes the guidelines and standards developed by technical organizations such as the IEC and the on-going standardization initiatives within the IEEE Standards Association. It focuses on standards related to the interconnection and interoperability of DER connected to the distribution grid and the standards related to the functional specification of microgrid control system and testing. This paper addresses issues related to the adoption of standards for microgrid controllers and their implementation in projects by developers and utilities.

KEYWORDS

Microgrid, microgrid controller, Distributed Energy Resource, Standard, Interconnection, Integration, Distribution System, Microgrid Control System

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INTRODUCTION

Microgrid technology is being deployed in different applications and contexts across distribution systems. Standards are now under development by the IEEE Standards Association that recognize the nature and configuration of microgrids and their value for optimizing the grid integration of distributed energy resources (DER), including distributed generation and energy storage, and controllable loads (demand response). When implemented these standards will facilitate these deployments and the adoption of microgrid concepts by the utility industry.

Although still in their infancy, microgrid technologies will play an increasingly important role in the evolution of the power grid, particularly in providing a solution that will enable large penetration of intermittent renewable energy sources while also enhancing the stability of the grid. Initial specifications, standards and guidelines for interconnection are being developed in the IEEE 2030 series of standards.

Consistent, uniformly applied interconnection and information model standards, supported by implementation guidelines, are required for microgrids. The standards development process brings together a broad set of stakeholders to address this need.

A major task in the development of standards for microgrid controllers is defining generic functions between the control and power functions of microgrid components and its controller. This simplifies the design, configuration and operation of microgrids. Interoperability is a major consideration.

1. DISTRIBUTED ENERGY RESOURCES INTEGRATION

1.1 DER deployment and aggregation – DERMS, VPP and microgrids

Distributed Energy Resources (DER) are being deployed in increasing numbers in distribution systems. Distributed energy resources are oftentimes generators using renewable energy resources, namely solar and wind, alternative fuels (bio-gas and bio-mass), conventional fuels (natural gas and diesel fuel), and energy efficient approaches such as combined heat and power (CHP). In the case of renewable energy resources that are variable and intermittent, generators using these resources are non-dispatchable, and their output power cannot be controlled, other than being partially or fully curtailed. DERs also include energy storage systems, using batteries, flywheels or other energy resources.

One of the advantages of integrating DER is the ability to feed local loads without making use of the transmission infrastructure. This allows the enhancement of the reliability and resilience of distribution systems and the possibility of feeding loads during faults and outages on the transmission and distribution grids.

When the penetration of DER is low (10 % or less), it is used essentially to provide real power and has limited impact on the grid. DER based on renewable energy resources are typically operated at their maximum output power level, set by the maximum power point tracking mechanism, to maximize the return on the investment.

For higher penetration levels, DER may have an impact on the grid. To limit power output variability, they can be associated with local energy storage systems. For enhance flexibility in the management of the distributed resources, they can be aggregated into systems managed by Distributed Energy Resources Management Systems (DERMS), into Virtual Power Plants (VPP) or into a microgrid structure, Fig. 1.

The interconnection of DER is dictated by utility grid codes or by standards. These typically specify grid operating ranges for voltage and frequency under steady state and transient conditions, the operating power factor of the DER (if specified), and the grid voltage and frequency ranges outside of which the DER needs to disconnect. In the early interconnections, DER did not interact with the grid and did not support the grid. Later requirements included reactive power capability, power ramp rate and curtailment requirements.

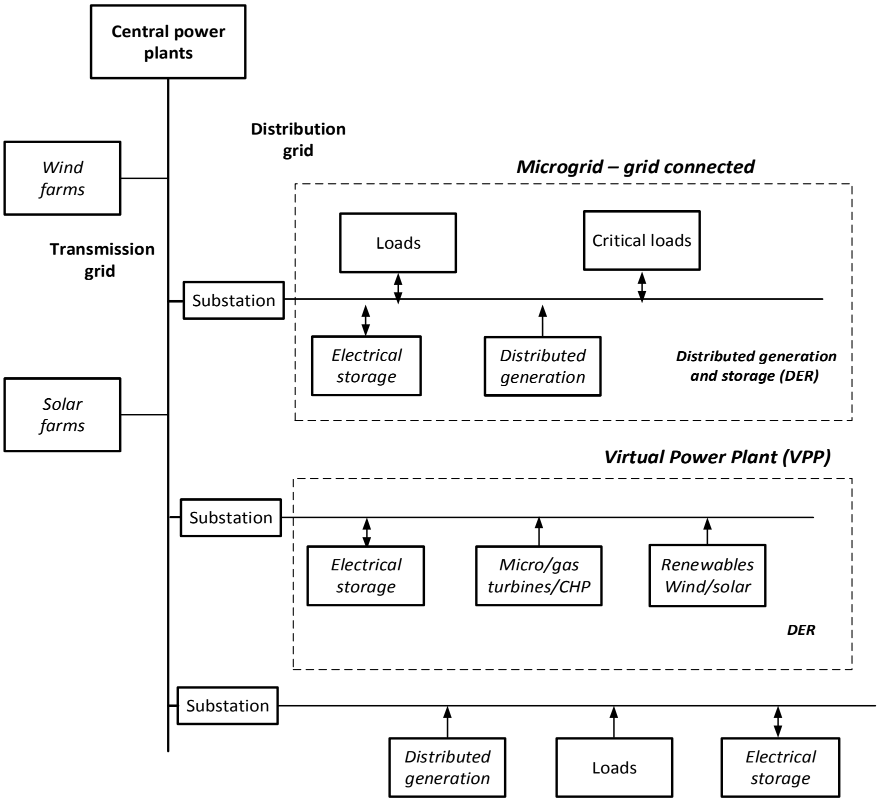


Fig. 1. Integration of distributed energy resources (DER) in distribution systems.

1.2 Microgrids as a tool for aggregation of DER and loads

Microgrids are an efficient solution for aggregating generation, storage and loads in a single entity that can serve many purposes from the optimization of resources to serve loads within a specified boundary to optimizing the power flow across the point of interconnection with the distribution utility to participating in markets, as well as islanding for resiliency.

1.3 Microgrid control system requirements for aggregation

A microgrid is an aggregation of DER and loads. It consists of a group of interconnected loads and DER with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island modes. The discussion in this paper assumes that the microgrid has a single point of interconnection with the distribution grid. The general structure of the microgrid and its relation to the broader distribution and transmission grids is shown in Fig. 2.

The control system requirements for aggregation include:

Energy management function – for local management of distributed energy resources, particularly their variability and intermittency. From a power and energy perspective, this this can be done either by means of storage or by load management (load curtailment and demand response). There needs to be an energy management system that dispatches the assets to supply the load and meet contractual agreements at the point of connection to the grid. Several use cases have been developed.

Standalone or islanded operation – for connect/disconnect, black start capability, system restoration services; supplying local critical loads in the event of the failure of the distribution grid, features that improve the reliability, security and resilience of the electric power supply to the loads within the microgrid. This requires that the microgrid can disconnect and operate in islanded mode.

Grid connected mode – for power exchanges (real and reactive power) and DMS interaction; DSO and TSO benefits and control. One of the important features and benefits of creating a microgrid is to locally manage DER and loads and present to the DSO a fully defined net power consumed or fed back into the grid. The recent interest of the TSO to observe and control DER is directly associated with the impact that aggregated DER can have on the transmission system, particularly the ability to predict loading on transmission lines and changes in transmission capacity. Aggregating DER within a microgrid would greatly facilitate the ability of the TSO to manage the transmission grid.

Grid connected mode – for provision of ancillary services to the distribution grid; providing ancillary services to the distribution grid, including the supply or real and reactive power (voltage support) as required. Ancillary services that can be provided by the microgrids are also of interest to the TSO as this would facilitate the management of the transmission grid by providing required reactive power support at the distribution level.

1.4 Application examples

Microgrids are deployed in many different contexts and applications, among them:

Large self-contained complexes – These systems exchange power with the grid (buying and selling under contract, for example), have enough local generation to operate in islanded mode, usually only serving part of the load, and can provide ancillary services to the distribution grid. They can include large commercial and industrial installations (processing plants, ports), large building complexes, larger mixed use (commercial and residential) urban areas, utility distribution microgrids, institutional and government installations (research centers, hospitals, and prisons), university campuses, and critical infrastructures (military).

Community microgrids – These entities typically include renewable distributed generation, distributed or centralized storage, and controllable loads. A community microgrid is a coordinated local grid area usually serving residential customers. It is connected to the distribution network which supplies power to support loads not served by resources within its boundaries.

Remote and isolated communities and installations – These entities typically include conventional generation (diesel generators) and renewable generation. They are not grid connected and do not exchange power with surrounding electric transmission or distribution grids. They need a microgrid control system if they have multiple sources of generation, including diesel (usually the base load generator) and renewable energy resources (wind, solar). They can integrate energy storage as a means of balancing loads and variable generation. Since remote and isolated microgrids are not connected to a distribution grid, the control system does not include the functions required to interact with the grid.

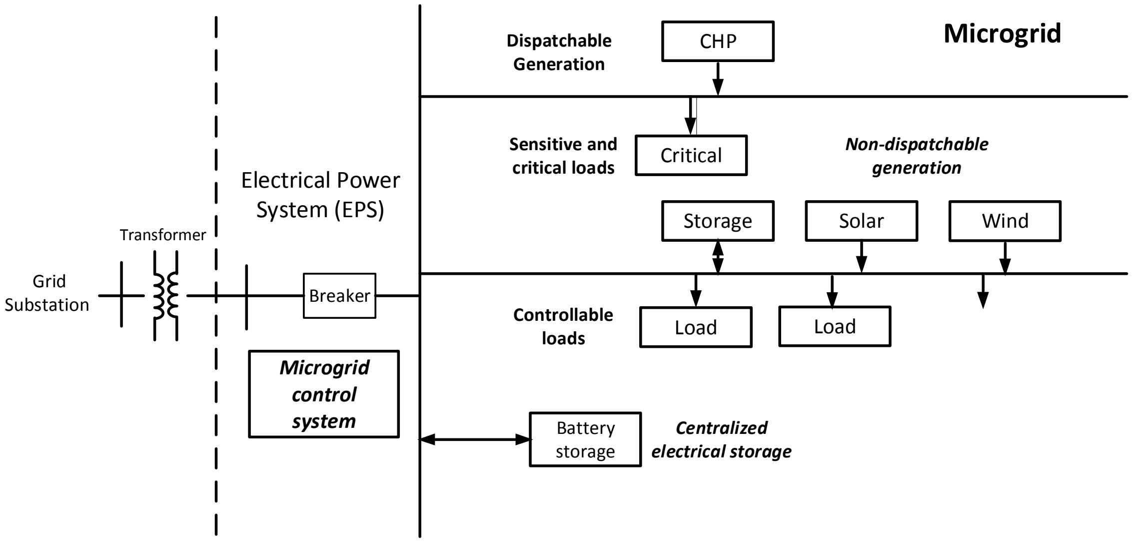


Fig. 2. Microgrid structure and components.

2. MICROGRID CONTROL SYSTEM STANDARDIZATION

2.1 Standardization activities – IEEE P2030.7 and IEEE P2030.8

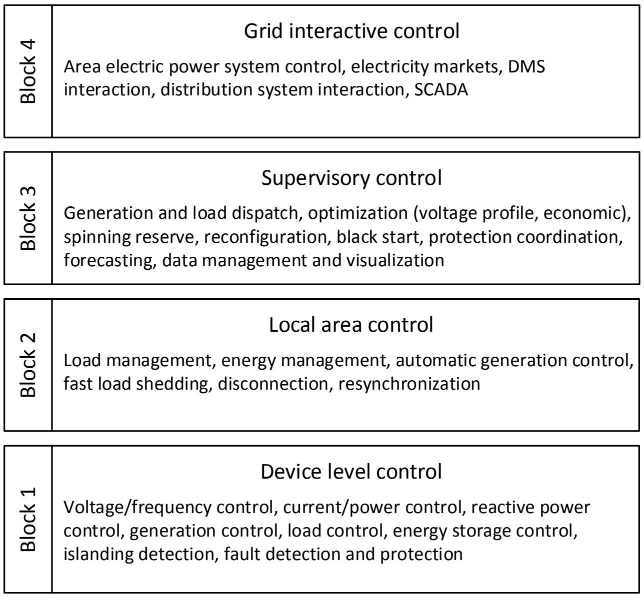
The IEEE Standards Association has issued Project Authorization Requests for the following:

P2030.7 Standard for the Specification of Microgrid Controllers – "The reason for establishing a standard for the Microgrid Energy Management System (MEMS) is to enable interoperability of the different controllers and components needed to operate the MEMS through cohesive and platform-independent interfaces. This approach will allow for flexibility and customization of components and control algorithms to be deployed without sacrificing or limiting potential functionality. Microgrid components and operational solutions exist in different configurations with different implementations."

P2030.8 Standard for the Testing of Microgrid Controllers – "The reason for establishing a standard for testing microgrid controllers, in the context of enabling interoperability of the different controllers and components needed to operate the controller through cohesive and platform-independent interfaces, is to establish standardized testing procedures. The standardization focuses on testing functional requirements, while recognizing that there are many possible hardware and software implementations of the same microgrid controller generic functions."

2.2 Microgrid control system functions

The control system manages all aspects of the microgrid operation at the point of connection to the distribution grid, in steady state and under transient operation. Under steady state operation, the control system dispatches the microgrid assets, including DER units and interface and switching devices. Under transient conditions, the control system is responsible for ensuring the connection and disconnection from the distribution grid. Many of the functions used to control a microgrid are described in Fig. 3. They cover the different levels of operation, from the faster functions (typically in the ms range), the device level functions, associated with the control of the assets, including the DER, to the slower functions (in the min range), the grid interactive control, associated with the interaction with the grid. The intermediate levels deal with the local area control and the supervisory control. The representation is a generic one and the boundaries between blocks can vary from one microgrid control system implementation to another. In addition, since these functions are conceptual functions, and there are many possible hardware and software implementations.



Block 4
Grid interactive control
Area electric power system control, electricity markets, DMS interaction, distribution system interaction, SCADA

Block 3
Supervisory control
Generation and load dispatch, optimization (voltage profile, economic), spinning reserve, reconfiguration, black start, protection coordination, forecasting, data management and visualization

Block 2
Local area control
Load management, energy management, automatic generation control, fast load shedding, disconnection, resynchronization

Block 1
Device level control
Voltage/frequency control, current/power control, reactive power control, generation control, load control, energy storage control, islanding detection, fault detection and protection

Fig. 3. Microgrid control system functions.

2.3 Control system core functions

The standardization effort should take into account the fact that the planning and operation of the microgrid will depend upon many variables and constraints, including: (a) the motivations for deploying the microgrid; (b) the specific context, application, and nature of the microgrid; (c) the nature and requirements of the loads to be served (critical, controllable); (d) the choice and mix of generation, dispatchable (diesel, CHP) or based on renewable energy resources (solar, wind); (e) the desired operating features, including variables to be optimized (cost of electricity, reliability, resilience).

The following approach was adopted to identify a minimum set of core functions by the P2030.7 working group:

- Defining a generic microgrid, based on the definition adopted in Section 1.3;
- Identifying the main features and corresponding functionalities of a microgrid, based on the requirements listed in Section 1.3; these include the ability to operate in grid-connected and islanded modes, as required by the distribution system operator or the state of the grid;
- Identifying, from the list of functions of Fig. 3, the minimum required functions to qualify as a microgrid, based on minimum requirements; and

- Defining the features of the core functions that are implementable, verifiable and can be tested against quantifiable performance metrics.

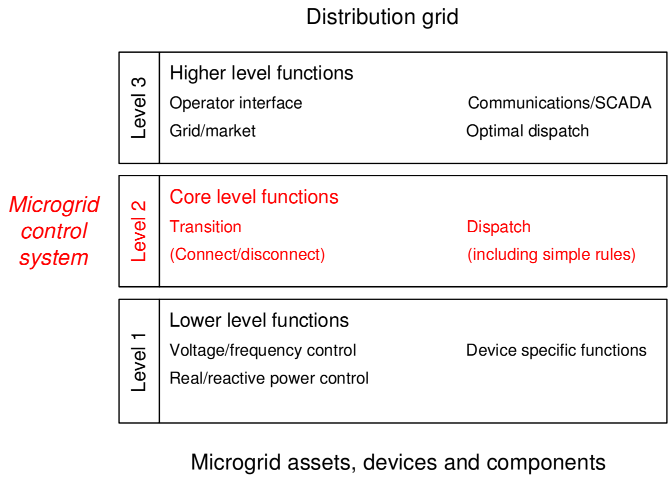


Fig. 4. Microgrid control system core functions.

2.4 Defining the control system core functions

The two core functions identified as being essential for all microgrids are the following:

- The dispatch function – computes and distributes the set-points of generation and storage, including DER units and loads (controllable and curtailable) in grid-connected and islanded modes, under steady state and transient conditions, including disconnection from and reconnection to the grid; and
- The transition function – defines the operations required to implement the transition from grid-connected to islanded modes, including disconnection from the distribution grid and resynchronization to the grid.

The core functions are made up of the appropriate functions selected from the blocks of Fig. 3. Because of the nature of the core functions, their role and position in the microgrid control system structure are between the lower and higher-level functions as illustrated in Fig. 4.

3. CONTROL SYSTEM STANDARDIZATION IMPLEMENTATION

3.1 Functional specification of the core functions – P2030.7

The functional description and specification of the core functions is summarized below:

- The dispatch function – maximizes the use of the assets, including the DER, and ensures that the operation of the microgrid meets the requirements, both for the internal operation and as seen from the point of interconnection to the distribution system; a dispatch order is a set of commands sent to the microgrid assets, devices and components; the commands may be simply rules, or be based on the optimization of predetermined operating characteristics of the microgrid, including the minimization of the cost of electricity, while serving the required loads; the operating rules or considerations may be different in grid-connected and islanded modes; under steady state conditions, the dispatch function executes its commands at regular intervals (typically 15 min or less); during transitions, see below, it executes emergency dispatch orders, in a interrupt mode, to ensure that transitions take place in an orderly manner, dispatching assets as required, including curtailing load;

- The transition function – manages transitions and operates in the following four situations: (a) unplanned islanding, resulting from a loss of distribution grid power; (b) planned islanding, resulting from a request from the distribution grid operator to disconnect; (c) reconnection/resynchronization; (d) black start as required in the islanding process; disconnection from the grid can be carried out without interruption or require a shut-down and restart; this can be in the form of a black start using one of the microgrid assets, either a dispatchable generator or a storage device; the transition function provides the signal to switch the dispatch function from one mode to another, the dispatch function then being responsible for reconfiguring the control system functions during the transitions and as a function of the new mode of operation.

3.2 Approach to the testing of core functions – P2030.8

The purpose of the standard for testing is to establish the minimum requirements for the interoperability between the offerings of different vendors and facilitate the development and deployment of cohesive and platform independent interfaces. A standardized set of testing procedures can facilitate the wide adoption of a standard microgrid functional specification.

The proposed testing approach for the microgrid control system includes the following elements and steps:

- Defining test scenarios – scenarios allow testing the core functions under well-defined and representative conditions; they allow testing of individual core functions or the combination of the two core functions, as in the case of transitions, where the transition function initiates an emergency dispatch order, particularly in the case of an unplanned islanding event. These scenarios assume a given/generic microgrid configuration.
- Defining performance metrics – these need to consider existing applicable standards related to electric distribution systems, applicable distribution grid requirements and grid codes, and relevant and applicable instrumentation and measurement techniques.
- Defining the testing environment – this can range from a fully numerical/software environment to a fully hardware (full scale) set-ups; one of the accepted and readily implementable environments is the real-time simulation with a Hardware in the Loop approach for testing all or elements of the microgrid control system.

3.3 Metrics – P2030.8

In the testing procedures, based on the scenarios used to test the core functions, the only variables being measured are voltage and current. The derived quantities are frequency, real and reactive power, and power quality related indices (voltage and current harmonics, voltage sags and swells, flicker).

This standard only deals with the steady state and transient response of voltage, frequency, and power exchanges (real and reactive) at the point of interconnection (POI).

The typical shape of the allowable operating ranges of the microgrid at the POI in terms of voltage and frequency requirements are given depicted in Figures 5 and 6. These are the same type of plots that apply to any generator or DER connected to a distribution grid.

The actual voltage and frequency levels and the interval over which they apply are set either by the interconnection requirements with the DSO, or the applicable grid codes in the jurisdiction in which the microgrid is operating, or set by any applicable or accepted standard in this jurisdiction.

Islanded microgrids can operate under relaxed voltage and frequency constraints, as shown in Figure 7, if the equipment is designed accordingly. The islanded constraints are unique to each microgrid.

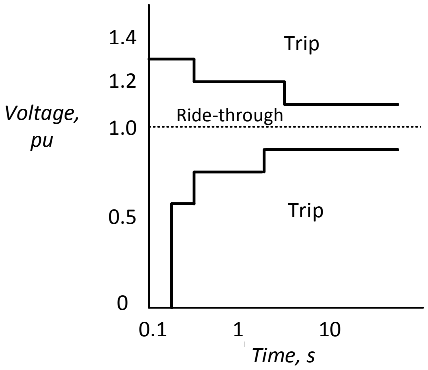


Fig. 5. Generic operational voltage ranges – grid-connected mode

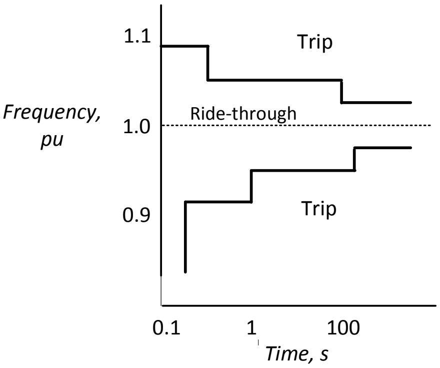


Fig. 6. Generic operational frequency ranges – grid-connected mode

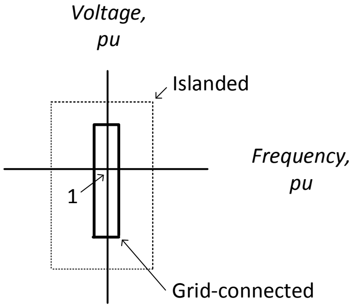


Fig. 7. Voltage and frequency ranges in grid-connected and islanded modes

3.4 Conformance testing of the core functions – P2030.8

It is proposed that the compliance of the microgrid control system with the standard be tested in accordance to the test scenarios and metrics section. The test shall be carried out by the vendor and as required by the utility or entity to which the microgrid is connected, and that has issued the interconnection requirements and agreements or the system specification.

4. IMPLEMENTATION

The implementation of the standard for microgrid controllers parallels the technology adoption cycle for microgrids. As microgrids become accepted and widely deployed in the electric power industry, the rationale for standards becomes compelling, along with a recognition of the contribution they make to the advancement of the technology and benefits in terms of interoperability and economics. This is illustrated in Figure 8 below.

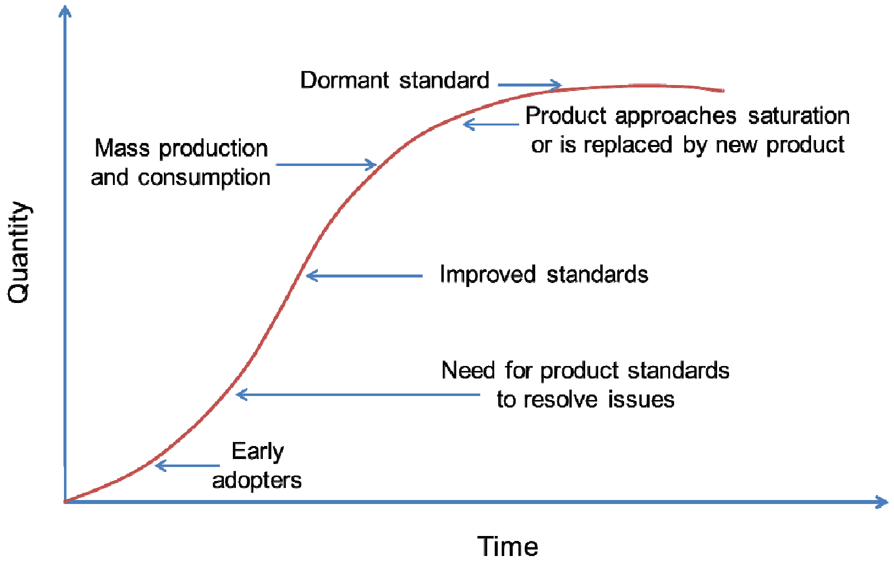


Fig. 8. Technology adoption and standards development cycle

The goal is to create standards that encourage – and not stifle – innovation, while balancing with the need to deploy new technology and solutions for infrastructure project development.

Benefits from Implementation of Standard for Microgrid Controllers

- ✓ Facilitates acceptance of microgrid technology in an evolving industry structure
- ✓ Facilitates development of related standards-based products, increasing vendor population
- ✓ Reduces system integration costs
- ✓ Reduces time to deployment (helps resolve in-the-field interoperability issues)
- ✓ Lowers technical barriers to advanced applications for microgrids

The need for a microgrid controller standard did not arise until the complexity of microgrids and their importance as entities interconnected to the grid was recognized. A standard for functionality was essential for their integration into the power delivery system. These are commonly described as “advanced microgrids.” Before the adoption of microgrids as entities connected to distribution networks, the control technology was limited to switching to backup power. For microgrids interconnected to distribution networks the requirements for controllers with well-defined functionality became necessary for acceptance by utilities. Therefore, it became necessary to develop a standard for the microgrid controller and testing of its functionality.

The importance of the standard for a specification for microgrid controllers, combined with a standard for testing at the point of interconnection with the distribution network, is a major requirement that can be imposed by regulators for grid modernization and integrated resource planning proceedings, rate cases and other state and federal dockets focused on tariffs.

For cases involving microgrids and other aggregated resources with controller capabilities, it is important that regulators have assurance that minimal performance standards will be met. This is especially the case for microgrids with respect to their capability to disconnect and reconnect according to the needs of the distribution utility and customers. For example, the ability of a microgrid to disconnect and island in the event of a catastrophic event is paramount to achieving the resiliency benefits that may merit tariff relief. The ability of the microgrid to perform the disconnect function and island is directly related to the microgrid controller.

Furthermore, regulators have an interest in having a level of assurance that resources within the microgrid can be managed to minimal performance standards to offer support services to the distribution network. Again, this is directly related to the microgrid controller meeting a minimal testable performance standard.

Conforming to a standard is definitive and verification through testing provides a high level of confidence to end users.

Implementation of the standard for microgrid controllers depends greatly on its adoption by regulators as a requirement for the interconnection of aggregated DER and microgrids.

5. SUMMARY

This paper argues that the integration of DER with the distribution system is readily achieved within a microgrid structure which is enabled by the adoption of standards for the microgrid controller. It further argues that the standard for the specification for microgrid controllers should be defined by core functions that are applicable to all microgrids that are normally grid-connected with islanding capabilities in the event of faults on the distribution system or requests from the distribution system operators. The standard for a microgrid controller should be applicable to a variety of microgrid configurations and applications with complex control system implementations. The implementation of the standard – its actual application and relevance to microgrid projects – depends on its adoption by industry which in turn is a function of its simplicity, flexibility, and openness to advances in technology and solutions to challenges over time.

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