Microgrid Controller Initiatives

By Dan Ton and Jim Reilly

THE MICROGRID IS A CONCEPT FOR WHICH THE CONTROLLER IS THE DEFINING AND enabling technology. Indeed, the microgrid may be defined as the resources—generation, storage, and loads—within a boundary that are managed by the controller.

The microgrid controller manages the resources within the microgrid's boundaries, at the point of interconnection with the utility and in interaction with the utility during normal operations (sometimes called cooperative control). It is at this level that the microgrid controller achieves its full potential for optimizing the value of distributed energy resources (DERs) for grid operations and customers, both those served by the microgrid directly and by the utility overall. The microgrid controller is what defines the microgrid's operational relationship with the distribution utility.

This article focuses on R&D initiatives with respect to the evolution of microgrid controllers that the U.S. Department of Energy (DOE) Office of Electricity Delivery and Energy Reliability (DOE/OE) has undertaken since 2010. We describe demonstration projects that are planned to show the viability and value of controller technology to support the on-going and future deployment of DERs and microgrids. The DOE/OE's initiatives follow a deliberate and planned time line, as shown in Figure 1. Each of these initiatives is discussed in the context of the DOE/OE R&D to advance microgrid controller technology for microgrids that are remote and islanded, as well as interconnected and interactive with the distribution utility.

Microgrid Controllers for the Advanced Microgrid

Advanced Microgrid

The term "microgrid" is broadly used today to refer to solutions for maintaining power supply in the event of outages caused by extreme weather events. This comes from thinking about a microgrid as a self-contained organization of DERs capable of islanding. This describes a microgrid whose purpose is strictly for resiliency with a control mechanism to simply open a switch to island.

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An Overview of R&D by the U.S. Department of Energy

This view of microgrids was first articulated in a DOE/OE-funded study on the advanced microgrid. The findings of this study are described in the report, "The Advanced Microgrid: Integration and Interoperability." This report introduced the term "advanced microgrid" to differentiate types of microgrids that were simply for back-up power from those with complex configurations of generation, storage, and loads with energy management systems (EMSs), i.e., controllers.

Early definitions of microgrids focused on islanding; now definitions have expanded to include the management of generation and load as a part of the electric power system. These changed concepts, definitions, and scale characterize an advanced microgrid. The concept of the microgrid is changing to fully recognize its benefits in terms of market participation, renewable integration, cost savings and reliability to the grid, as well as resiliency.

Advanced microgrids contain all the essential elements of a large-scale grid, such as the ability to 1) balance electrical demand with sources, 2) schedule the dispatch of resources, and 3) preserve grid reliability (both adequacy and security). Advanced microgrids require controllers with the capability to perform these functions.

Microgrid Controller as an Energy Management System

A key element of microgrid operation is the microgrid EMS (MEMS), the control function that defines the microgrid as an autonomous system and properly connects to the main grid for the exchange of power and the supply of ancillary services. The MEMS enables the interplay of different controllers and components needed to operate the EMS through cohesive and platform-independent interfaces. This approach will allow for component flexibility and customization and for control algorithms to be deployed without sacrificing plug-and-play or limiting potential functionality.

Microgrid components and operational solutions exist in different configurations with different implementations. Regardless of whether equipment and software are commercial or custom, components should be interoperable and have interfaces that comply with functional standards defined by the MEMS. State-of-the-art control methods must be developed that pertain to different control levels from the perspective of the advanced microgrid. Figure 2 shows the layered architecture for a utility-interactive microgrid.

At the most basic level, the microgrid controller must be able to disconnect from the grid and island. This delivers resiliency, the most common benefit of the microgrid as perceived by the public. However, disconnection is an infrequent event, and reconnection and synchronization with the grid is important for normal 24/7 operations. This is achieved through the controller in a complex relationship with the resources that it manages and the utility at the point of interconnection.

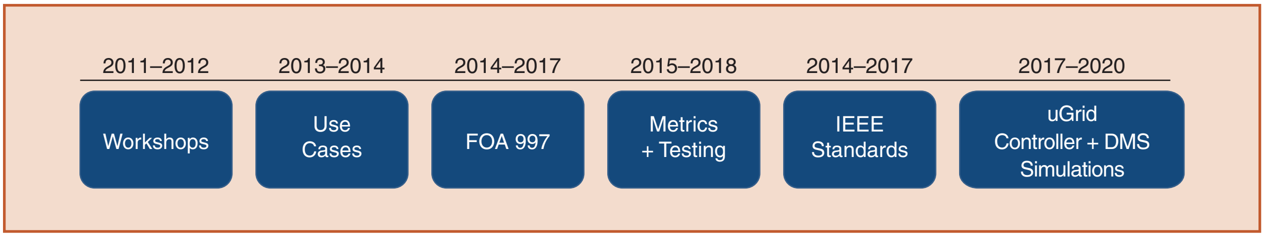

figure 1. A time line of the microgrid controller-DOE program.

When properly integrated, microgrids can contribute to the flexibility and resiliency required to meet the demand for the continuous supply of electric power in the future. Individual microgrids may operate in a grid-tied mode most of the time, with power flowing both ways between the microgrid and the surrounding system. A parallel bidirectional connection can achieve operational goals, such as improved reliability, cost reduction, and diversification of energy sources. The ability to separate from the grid adds resiliency value and provides a backup or emergency operation mode.

Microgrids contain elements of grid-modernization technologies such as distributed generation (dispatchable or nondispatchable), controllable loads, demand response, energy storage, microgrid controller, and EMS. The technology that enables the microgrid to operate in grid-tied and islanded modes and perform local energy optimization is the microgrid controller.

Distributed resources are interconnected with distribution networks in combination with one another within the boundary of the microgrid. For example, solar may be combined with gas generators or storage to mitigate intermittency and can be managed with loads of varying profiles. The optimal management of these resources is achieved through the microgrid controller.

A microgrid controller is an advanced control system, potentially consisting of multiple components and subsystems. It is capable of sensing grid conditions and monitoring and controlling the operation of a microgrid to maintain electricity delivery to critical loads during all microgrid operating modes (grid connected, islanded, and transition between the two). The microgrid and its constitutive components are shown in Figure 3.

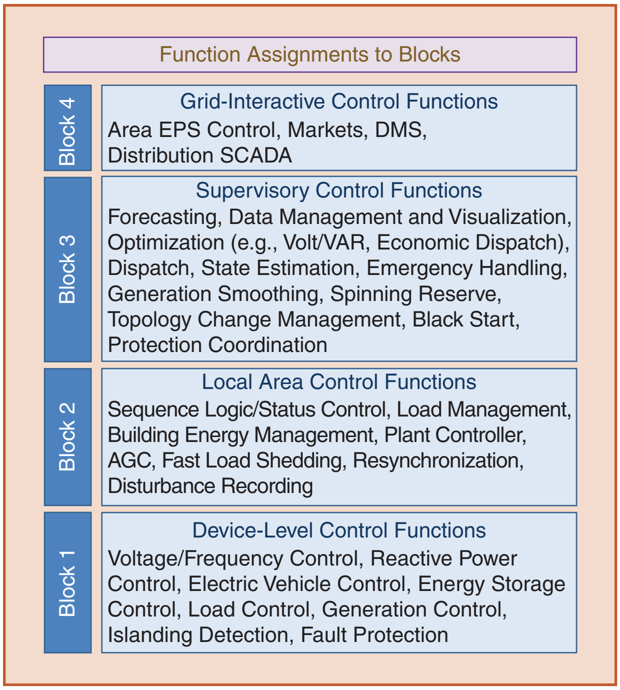

figure 2. The microgrid control system function classifications (IEEE p2010.7 Working Group). SCADA: supervisory control and data acquisition.

The Critical Role of Controllers in Microgrid Program

Workshops

The DOE/OE held a Microgrid Workshop 30–31 August 2011 in San Diego, California. The purpose of the event was to convene experts and practitioners to assist the DOE in identifying and prioritizing R&D areas in the field of microgrids. There were 73 registrants, representing vendors, utilities, national laboratories, universities, research institutes, and end users. One of its major conclusions was the importance of microgrid controllers as a priority for DOE/OE R&D for its microgrid program.

A second workshop was held 30–31 July 2012 in Chicago, Illinois, to identify system integration issues to meet DOE program 2020 targets for microgrids and to define specific R&D activities for the needed functional requirements. This served as the basis for the DOE Microgrid R&D road map. In the discussion on operations and control, the session on steady-state control and coordination reported recommendations in two major areas: 1) internal services within a microgrid and 2) interaction of the microgrid with utilities and other microgrids. Taken together, these recommendations pointed toward microgrid controllers and their relationship with distribution management systems (DMSs) as areas where R&D should concentrate.

Microgrid Specification and Testing (FOA 997)

Recognizing the importance of the advanced functionalities of microgrid controllers for coordinated control, protection, and operations of microgrid assets, the DOE microgrid program issued Funding Opportunity Announcement

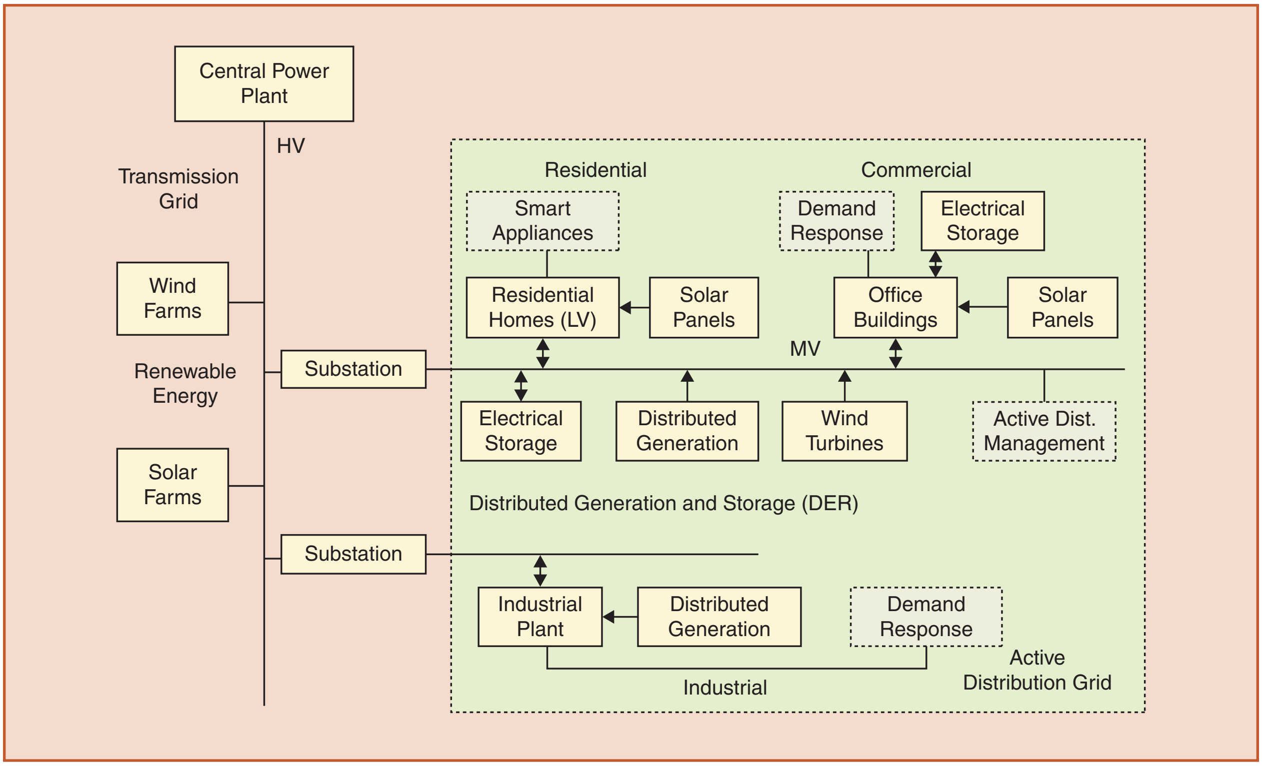

figure 3. The microgrid and its constitutive components (used with permission from G. Joos).

997—Microgrid Research, Development, and System Design (FOA 997) on 31 January 2014. The objective was to advance microgrid system designs and control functionalities to realize DOE program goals for reliability, emissions, system efficiency, and resiliency.

The DOE made competitive awards to seven industry-led project teams in September 2014, with US$1.2 million per award. The period of performance was two years, including 18 months of R&D and six months of testing, data collection, and analysis. The FOA required the submission of a preliminary test plan to be approved by the DOE as a deliverable under the contracts. An evaluation rubric was developed for evaluating test plans for feasibility testing of controllers/system designs in meeting the defined functional requirements; see "Test Plan Functional Requirements."

The evaluation rubric required replies to basic questions to assess the understanding of the awardees on performance metrics and industry standards related to the interconnection of microgrids to the grid, e.g., IEEE Standard 1547. A test plan checklist was also included in categories such as tools, test setup diagram, step-by-step test procedure, and uncertainties of the test plan.

Test Plan Functional Requirements

- C.1 Disconnection
- C.2 Resynchronization and reconnection
- C.3 Steady-state frequency range, voltage range, and power quality
- C.4 Protection
- C.5.1 Dispatch: Optimization of energy consumption and generation
    - C.5.2.a Dispatch: Grid services: Energy
    - C.5.2.b Dispatch: Grid services: Volt/var support
    - C.5.2.c Dispatch: Grid services: Frequency regulation
    - C.5.2.d Dispatch: Grid services: Spinning reserve
    - C.5.2.e Dispatch: Grid services: Black-start support
    - C.5.2.f Dispatch: Grid services: Demand response
- C.6 Enhanced resilience

Microgrid Controllers—Functional Use Cases

Relationship of Use Cases to Microgrids

The microgrid, whatever the configuration of generation and loads, may be characterized in terms of the functionality of its controller. These functions are defined by use cases that are the basis for both standards and testing. For example, both IEEE P2030.7, *Standard for Specifications of Microgrid Controllers,* and IEEE P2030.8, *Standard for Testing Microgrid Controllers*, are based upon use cases to derive requirements. Use cases capture the functional requirements of the system and describe the actors, interfaces, information exchanges, and sequence of events.

A use case is a means of describing a microgrid to facilitate analysis and decision making. It defines the conditions for microgird operations and control in both isolated and interconnected modes with the power delivery system. The use case also helps developers plan the microgrid and determine its cost/benefit ratio. While use cases normally define the functions of power systems, here they are developed for the unique functions of microgrids; see "The Functional Use Cases of Microgrid Controllers."

In 2014, the DOE/OE determined that use cases for ten functions should be developed and made available to vendors, utilities, microgrid developers, and most importantly, standards development organizations. These use cases may be found in the Electric Power Research Institute (EPRI) use case repository (microgrids).

Standards

Establishing standards for the specification and testing of microgrid controllers is a major goal of the DOE/OE microgrid program. Standards are necessary to provide 1) a common basis for defining controller functionality from a technical point of view and 2) policy makers and regulators with a benchmark and definition for the operational capabilities of the microgrid itself. Requests for proposals and regulatory rulings are major beneficiaries of standards, giving a solid technical basis for achieving their objectives. Standards help to advance the

The Functional Use Cases of Microgrid Controllers

Frequency Control

This function balances the generation and loads in a microgrid, therefore maintaining its stability by controlling its frequency. It is a fast real-time control in the time scale of subseconds. The function is realized by one or more primary sources are responsible for frequency control. The microgrid's supervisory control and data acquisition (SCADA) system determines whether a microgrid source is operated as a primary source or other source and sends the frequency set point to the primary sources.

Voltage Control

This function regulates voltage at the point of common coupling within a specified range. It is a fast real-time control in a time scale of subseconds. This function is realized by one or more primary sources responsible for controlling voltage. The SCADA system determines whether a microgrid source is operated as a primary source or other source and sends the voltage set point to the primary sources.

Grid Connected to Islanding Transition: Intentional Islanding Transition

This use case describes the function in which a microgrid disconnects from the area electric power system (AEPS) in a planned manner when the system is grid connected and in a normal operating mode. This is the process by which the microgrid intentionally transitions from grid-connected operation to islanded operation.

Islanding to Grid Connected Transition: Unintentional Islanding Transition

This use case describes the function in which a microgrid disconnects from the AEPS when there is a large disturbance internally or externally so that the microgrid can be isolated from the disturbance and continue power supply to its loads in an islanded mode. The large disturbance can be internal or external faults, loss of the AEPS, or some other disturbances so that the AEPS is no longer able to provide power supply to the microgrid with specified power quality.

Islanding to Grid-Connected Transition: Resynchronization and Reconnection

In this function, a microgrid resynchronizes and reconnects to the AEPS and transitions from islanded operation mode to grid-connected operation mode.

Energy Management: Grid Connected and Islanding

This use case describes the EMS functions of a microgrid working in both grid-connected and islanding mode. The microgrid is connected to the distribution grid at a single point and controlled by the EMS. The EMS participates in utility operation and energy market activities by making optimal bids into corresponding markets. Also, the EMS coordinates energy generation and consumption among multiple DERs, energy storage, and responsive loads and develops optimal operating strategies in multiple time scales.

Microgrid Protection

This is the function in which a microgrid configures protection devices for different operating conditions, and the protection devices detect faults and isolate the microgrid from them.

Ancillary Services: Grid Connected

This use case describes the function of a microgrid providing ancillary services to the AEPS when the microgrid is grid connected.

Microgrid Black Start

This is the function in which a microgrid restores islanded operation after a complete shutdown.

Microgrid User Interface and Data Management

This function defines the databases of a microgrid to organize and archive both real-time and non-real-time data. It also defines the user interfaces and accessibility of different actors.

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deployment of microgrids by establishing a common technical basis for interconnection and interaction with the distribution utility at the point of interconnection.

The DOE/OE supported preparation and submission of the project authorization request (PAR) for a microgrid controller standard to the IEEE Standards Association (IEEE SA) in the fall of 2013. Under sponsorship of the transmission and distribution committee of the IEEE Power & Energy Society, the PAR was submitted to the IEEE SA in April 2014 and a working group was formed. IEEE P2030.7 was approved by the IEEE SA on 11 June 2014. The draft standard was submitted to the IEEE SA in February 2017 as the first step in the balloting process.

The PAR for IEEE P2030.8 was approved by IEEE SA on 11 June 2015. The working group, already formed, promptly scheduled its meetings to coincide with those of the IEEE P2010.7 working group to better align the development of requirements. As of this writing, a balloting group has been formed, and the draft standard is being balloted with results expected by June 2017.

Both working groups received the support of individuals engaged with other DOE/OE projects, and FOA 997 awardees were encouraged to participate actively and contribute to writing groups. The working groups called upon the functional use cases in their initial discussions, forming the basis for the discussion on functionalities and requirements.

Microgrid Controller for Interactive Operations with Utilities

Grid Interactive Microgrid Controller

The DOE/OE requested that EPRI study issues related to grid interactive microgrid controllers in early 2014. This project was intended to advance the state of the art of microgrid controllers by developing and defining standardized functions for them. A key focus was on the overall utility system architecture of microgrid controllers with respect to the DMS. As result, the roles of the microgrid operator (via the functionality of the microgrid controller) and the distribution system operator (DSO) (via the DMS) were defined, as well as the interfaces between them.

The report examined the relationship between DERs and the microgrid controller and the distributed energy management system (DERMS), as well as the relationship between the microgrid controller/DERMS and the DMS. Architectural variations among DMS, microgrid controllers, DERMS, and DERs were explained. Looking at the architecture from DERs to microgrid controllers/DERMS, the report identified the interface, messages, information exchanged, communications protocols, and functional requirements for each of the functions that relate DERs to microgrid controllers/DERMS. An in-depth discussion of the integration of the microgrid controller/DERMS with the DMS was included. The remaining technical gaps in the integration of DMS, DERMS, and microgrid controllers were also identified.

This project advanced the state of the art in microgrids and aggregated DERs by developing and defining standardized functions for the microgrid controller. Further, it established the roles of microgrid management and DERMS functionalities within the microgrid controller and identified the interface between the microgrid controller and the DSO through interaction with the DMS. The result contributes to a modernized distribution grid that uses optimal methods to meet both local (microgrid) and overall grid operations. The relationship between the microgrid controller and the DMS is shown in Figure 4.

Microgrid Controllers and Distribution Management Systems

Coincident with the research project with EPRI on grid interactive microgrid controllers, the DOE/OE requested that Argonne National Laboratory (ANL) conduct a research study on advanced DMSs. The purpose was to examine issues related to the integration of microgrids and DERs with distribution networks; effectively, this means the microgrid controller and the DMS. The resulting report includes much useful information on the interaction of microgrids and distribution utilities.

The relationship between the distribution utility and the microgrid is important for optimizing DERs within the microgrid and the power delivery system overall. This takes place through the interaction between the utility's DMS and the microgrid controller within the context of an operating agreement for the interconnection of the microgrid with the utility.

The EPRI and ANL projects were developed in parallel to give complementary perspectives on the functionality and interaction of the microgrid controller, both within the microgrid and across the point of interconnection with the utility. Simply put, grid to point of interconnection (POI) and microgrid to POI. These projects were intended to provide the industry with a point of reference and guidance to research and standards development organizations.

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Structuring DMS Project

The research in microgrid controller technology led to interest in verifying and validating controller functionalities when operating microgrids interactively with distribution utilities. This interest provided the rationale for the structuring DMS project, which is directed toward R&D efforts to integrate microgrid controllers with DMSs and distributed energy resource management systems (DERMSs), eventually leading to distribution system platforms and distribution system operations in the grid of the future.

The objective of the structuring DMS project is to develop integrated control and management systems for distribution systems with high penetrations of interconnected generation from renewable energy sources (RESs) as part of grid modernization. This project is built on the findings of reports by ANL and EPRI, described previously. These reports revealed technical gaps and proposed solutions to integrate DMS, MEMS, and DERMS. The project calls on the capabilities of the National Renewable Energy Laboratory (NREL) for modeling and simulation of proposed solutions.

This project is designed to 1) fill the gaps for the integration of DMS, MEMS, and DERMS to accommodate high penetrations of RES in the distribution system; 2) identify interactive functions in DMS, MEMS, and DERMS; 3) conduct integrated system characterization through simulation and testing; and 4) recommend a testing site or sites to verify the integration of the three control and management systems in field operations at a distribution utility.

The key objectives with respect to structuring a demonstration project are 1) extract findings on current gaps and enabling technologies for integrating DMSs, MEMSs, and DERMSs from the ANL and EPRI reports; 2) identify and define the interactive functions of controllers to fill those gaps; 3) conduct a proof-of-concept simulation to evaluate the effectiveness of integrating the three control and management systems; 4) establish the criteria for the selection of the site(s) suitable for field

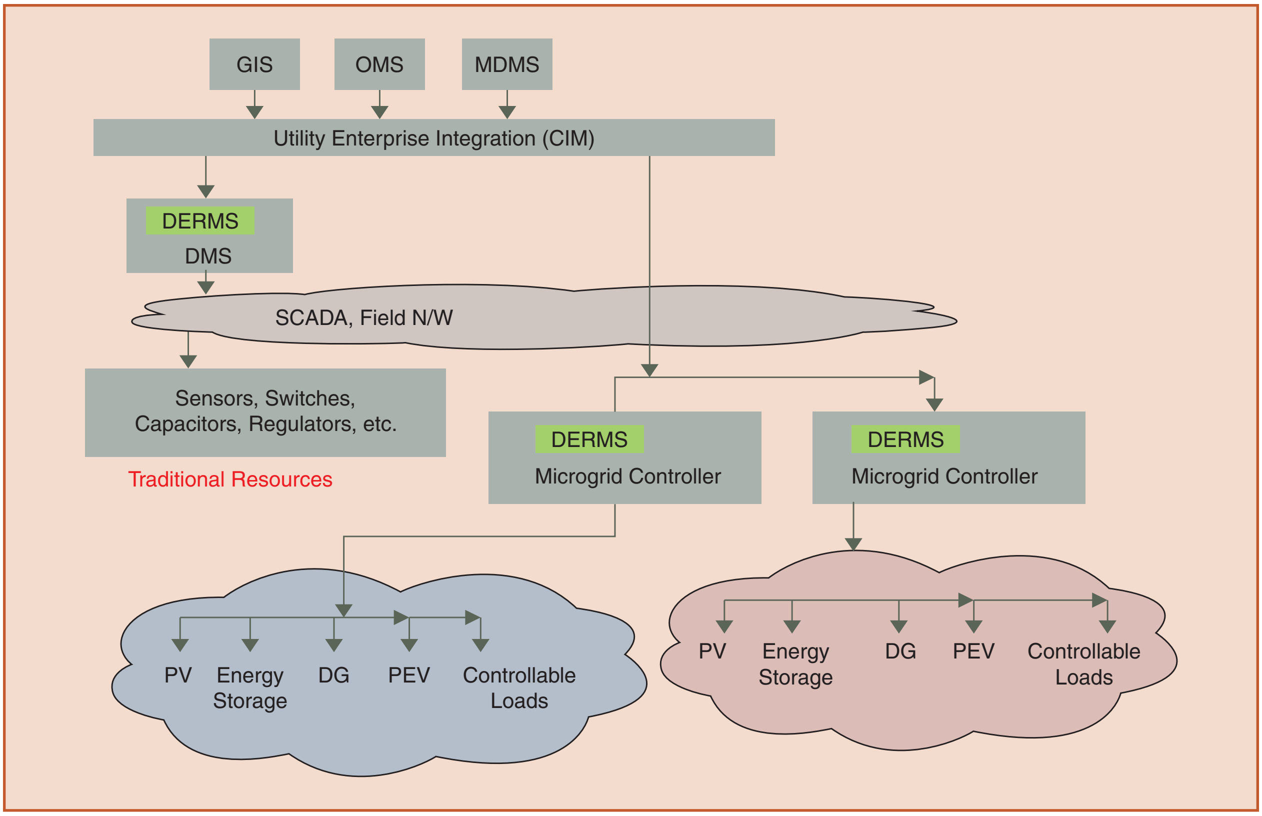

figure 4. The microgrid controller and DMS relationship.

Structuring the DMS Project

Scope

- ✔ Identify gaps and enabling technologies for integrating DMS, MEMS, and DERMS.
- ✔ Identify and define the interactive functions of controllers to fill those gaps.
- ✔ Conduct a proof-of-concept simulation to evaluate the effectiveness of integrating the three control and management systems.
- ✔ Establish the criteria for selecting a testing site(s) to verify the integration of the three control and management systems in field operations at a distribution utility.

Deliverable

Field site/demonstration project recommendations for validating the operational viability and effectiveness of integrated control and management systems.

Project Team Members

- ✔ ANL
- ✔ EPRI
- ✔ NREL.

testing integrated microgrid and utility operations. Later, the scope of the project may be extended to the participation of DERs and microgrids in wholesale markets, especially those for capacity and ancillary services, such as frequency regulation and black start for system restoration.

Project team members include ANL, EPRI, and NREL. ANL leads the project and is responsible for synthesizing the findings and possible solutions for integration from the reports of ANL and EPRI, identifying the interactive functions to be tested, evaluating the simulation results, and clarifying the criteria for the site selection. EPRI supports these activities with ANL, identifying the interactive functions and evaluating the simulation results, and is responsible for structuring the comprehensive demonstration approach and plan. NREL is conducting the proof-of-concept simulation and participating in the evaluation of the simulation results.

A stakeholder advisory group comprises technology providers (four vendors), microgrid owner/operators (three locations), and distribution utilities (five) at sites that are potential candidates for field testing demonstrations; see "Structuring the DMS Project."

The primary benefits expected from the deliverables from this project are: 1) a deep and comprehensive understanding of integrating DMSs, MEMS, and DERMSs, 2) the simulation test bed to demonstrate the interactive functions among the above three systems, and 3) establishing criteria for field site and demonstration project selection in the distribution system to validate the operational viability and effectiveness of the integrated control and management systems.

Microgrid Controller—Interconnection and Interaction with Utilities

The central function of the microgrid controller is management of the resources within the microgrid's boundaries, at the point of interconnection with the utility, and in interaction with the utility during normal operations (sometimes called cooperative control). The interaction between the microgrid and the utility is accomplished through the microgrid controller and DMS/SCADA of the utility, as shown in Figure 4.

The structuring DMS project is where the DOE/OE's research on microgrid controllers is being directed today. This research activity will bring the microgrid controller to its full potential as a component of the EMS—managing DERs at the local level as an integral component of the power delivery system of the grid of the future.

For Further Reading

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