Office of Electricity
Delivery & Energy
Reliability

Microgrid Controls and Management Systems

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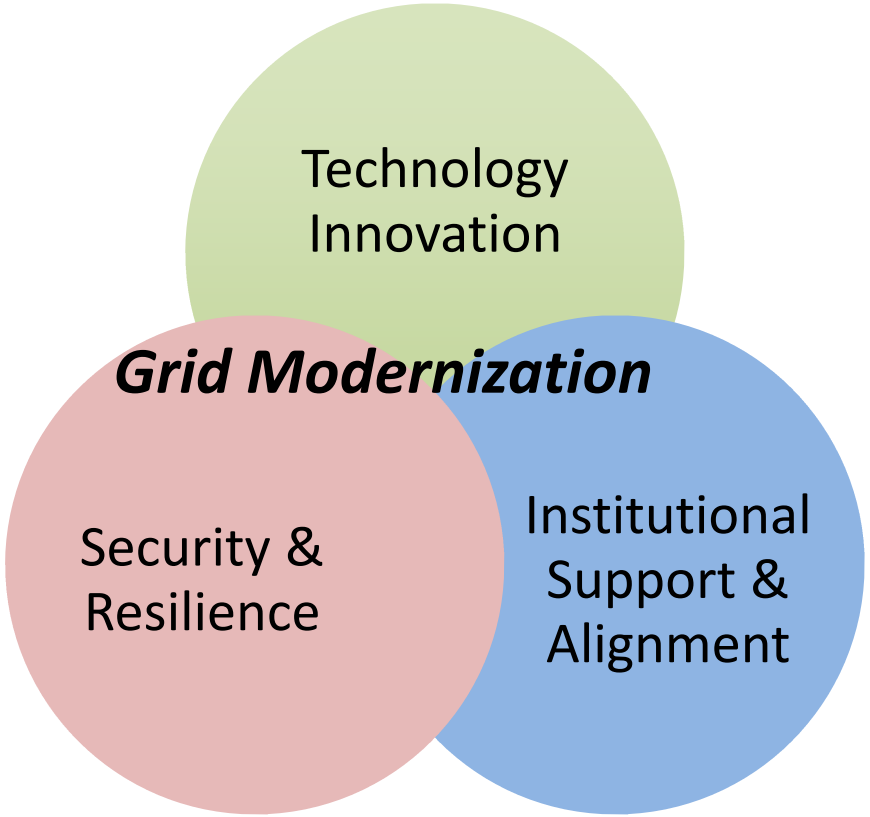
Power Systems Engineering Research and Development

July 9, 2015

OE Mission

The Office of Electricity Delivery and Energy Reliability (OE) drives electric grid modernization and resiliency in the energy infrastructure.

- OE leads the Department of Energy's efforts to ensure a resilient, reliable, and flexible electricity system.
- OE serves as the Energy Sector Specific lead for the Federal emergency response when activated by DHS/FEMA.



Grid Modernization Vision

*The future grid provides a critical platform for U.S. prosperity, competitiveness, and innovation in a global clean energy economy. It must deliver **reliable, affordable,** and **clean electricity** to consumers where they want it, when they want it, how they want it.*

Achieve Public Policy Objectives

- 80% clean electricity by 2035
- State RPS and EEPS mandates
- Access to reliable, affordable electricity
- Climate adaptation and resilience

Sustain Economic Growth and Innovation

- New energy products and services
- Efficient markets
- Reduce barriers for new technologies
- Clean energy jobs

Mitigate Risks and Secure the Nation

- Extreme weather
- Cyber threats
- Physical attacks
- Natural disasters
- Fuel and supply diversity
- Aging infrastructure

Smart Grid R&D Focus Areas

Microgrid R&D

For commercial viability, reliability, and resiliency

Continue R&D pathway to support achieving the DOE program goals (in reliability, efficiency, CO_2 reduction, and cost effectiveness) and implementing the DOE CAP strategy, leading to creating a smarter and more resilient grid and community.

Advanced Distribution Management System (ADMS)

Providing better control and visibility

Develop architectures that integrate new & existing applications across the utility enterprise to accommodate rapid and complex communications/interactions between D&T; develop operational control strategies using advanced analytics.

Resilient Electric Grid R&D

For enhanced grid resilience

Implement high-priority R&D projects identified in the resilient grid roadmap, developed in a broad stakeholder workshop in 2014 and finalized during the QER in 2015.

Market-Based Control Signals

Enabling economical and flexible stability

Develop simulation tools for the impact of transactive control, establish valuation basis for customer-delivered and grid-delivered energy services, and assess how to achieve a more distributed customer-driven grid.

Smart Grid R&D Program

Modernizes distribution grid through advanced control and distribution management and control systems and new operational paradigms (integrated microgrids and DER controls)

Supports increasing demand for renewable energy integration and grid reliability and resiliency at regional, state and local levels

FY 2014 and Prior

- Microgrids
- DER/DR/PEV Integration
- Distribution Automation

FY 2015/ FY2016

- Microgrids
- Advanced Distribution Management Systems
- Restoration Strategies
- Resilient Distribution Grid

DOE Microgrid R&D Program

2011 Workshop

Defined the DOE 2020 targets	Recommended further integration of component- and system-level R&D areas

2012 Workshop

Prioritized R&D topics in planning/design	Prioritized R&D topics in operations/control

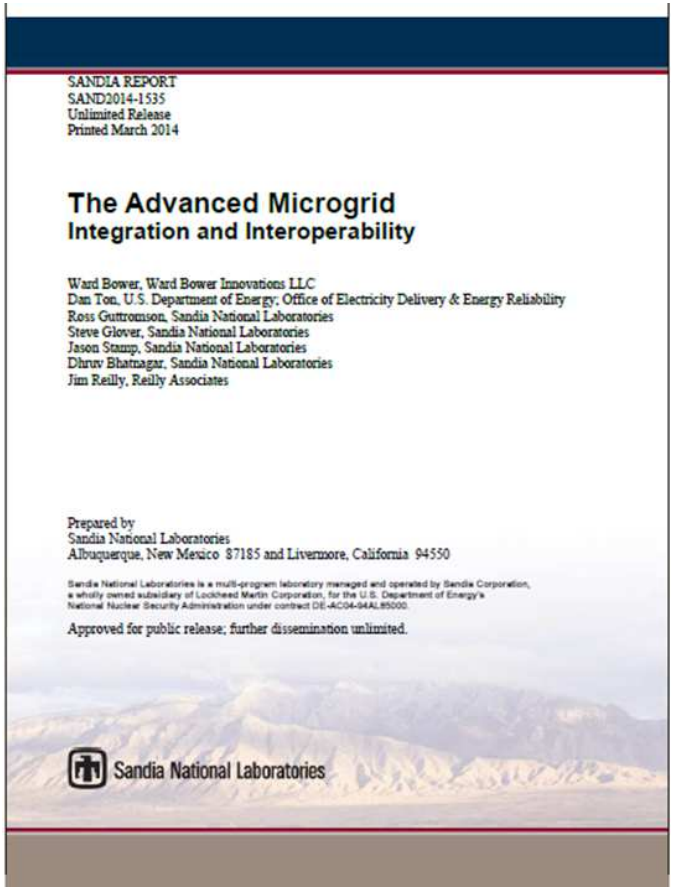
Develop <u>commercial scale</u> (<10 MW) microgrid systems capable of meeting the 2020 targets:

- Reduce outage time of critical loads by >98% at a cost comparable to non-integrated baseline solutions (uninterruptible power supply + diesel generator)
- Reduce emissions by >20%
- Improve system energy efficiencies by >20%

Advanced Microgrid

SAND 2014-1525

- Objectives
- Operational modes
- System architecture
- Technical challenges
- Development impact areas
- Ownership of microgrids
- Microgrid applications
- Standards and codes
- Microcontrollers
- References


SANDIA REPORT
SAND2014-1535
Unlimited Release
Printed March 2014

The Advanced Microgrid
Integration and Interoperability

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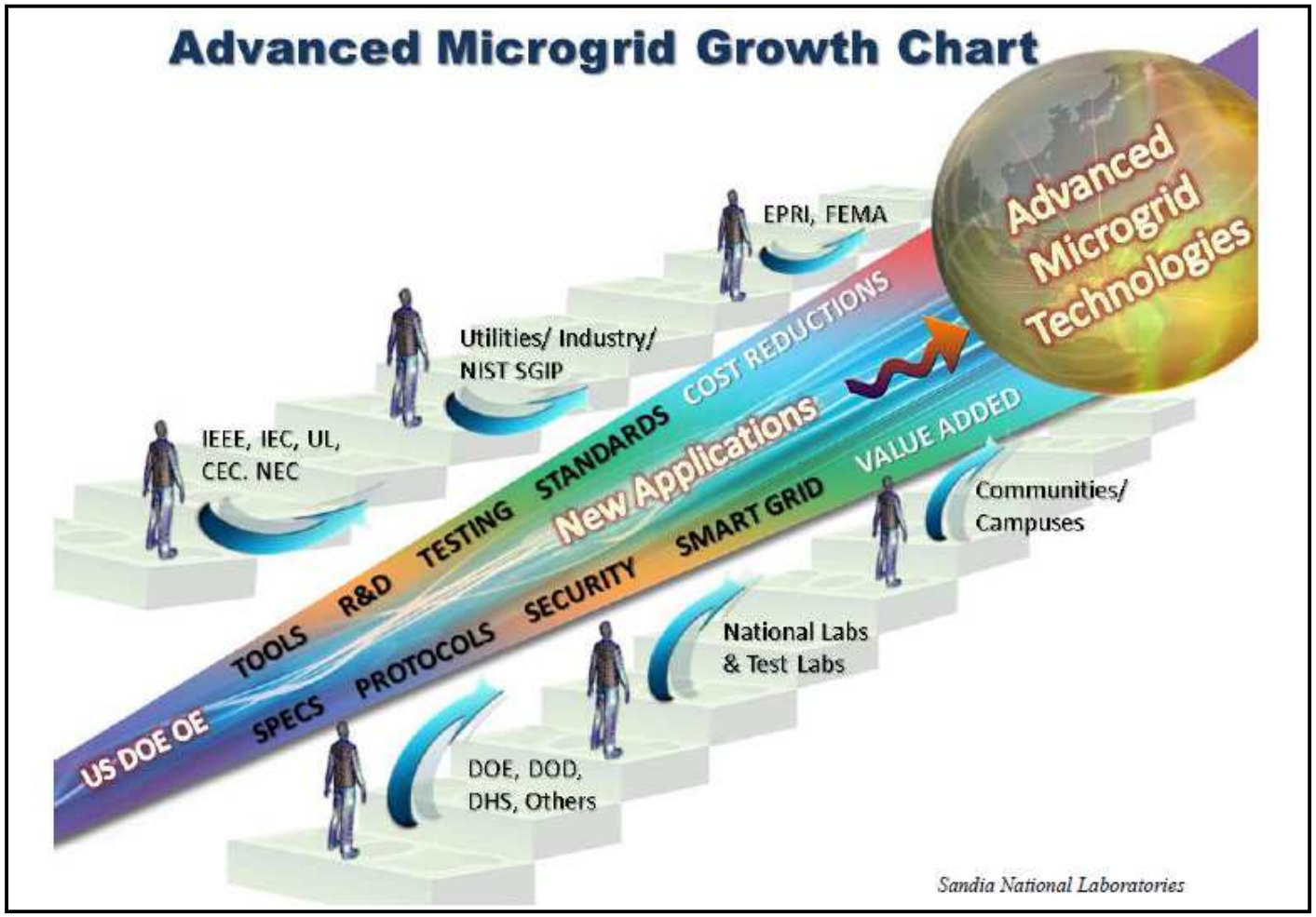
Sandia National Laboratories

"An advanced microgrid is one that provides functions at the PCC beyond basic islanding (disconnect) and synchronization (reconnection) functions. An Advanced Microgrid interacts with the larger grid (macrogrid) cooperatively managing power flows across the PCC optimizing benefits for both the microgrid and macrogrid."

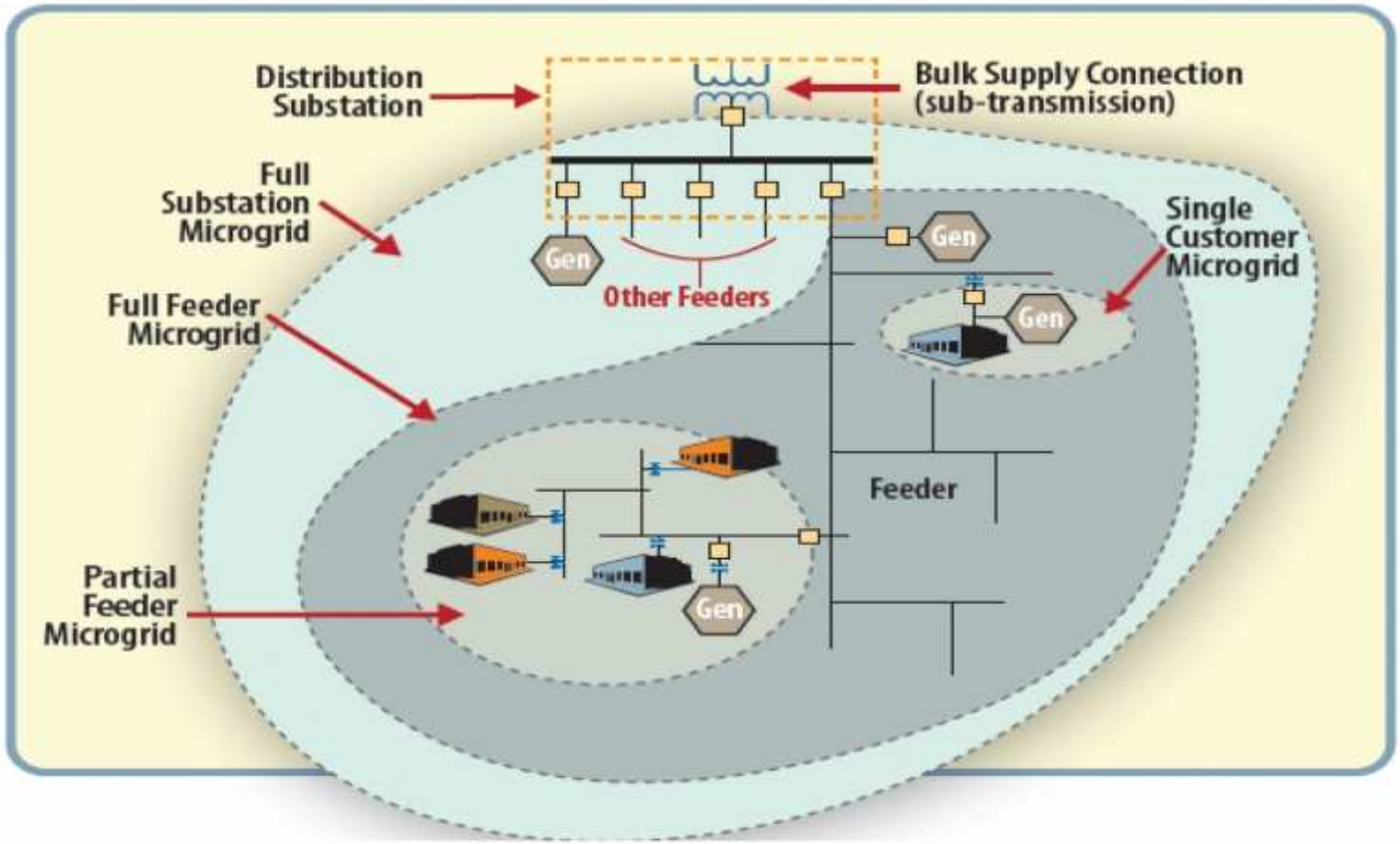
Advanced Microgrid R&D Program Participants



A well-coordinated team of technical experts and stakeholders/customers, applying advanced technologies, cost sharing demonstration projects, developing standards and codes.

Defining Microgrids

A **microgrid** is 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. It can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.



Benefits and Challenges

Benefits

- Enables grid modernization
- Integrates multiple Smart Grid Technologies
- Enhances integration of distributed and renewable energy sources
- Ensures energy supply for critical loads; controls power quality and reliability at the local level
- Promotes customer participation through demand side management
- Supports the macrogrid by handling sensitive loads and supplying ancillary services to the bulk power system

Challenges

Technical/Economic

- Microcontrollers
- Energy Management Systems
- Interoperability
- Costs
- Return on Investment (business case)

Regulatory/Policy

- Market entry requirements
- Tariffs
- Interconnection rules
- Investment incentives

Integrated µGrid R&D Plan
FY 2015-2016

Vision

The Integrated µGrid R&D Program foresees the technical requirements for advancing the microgrid to a fully integrated entity within the distribution system, interacting seamlessly with the Distribution System Operator.

Integrated µGrid R&D Plan FY 2015-2016
Program Areas

Design and Planning Tools

- Microgrid Design Optimization Using DER-CAM
- Technical Resource Exchange to Support Microgrid Development
- Impact Analysis of Interactive Operations of Microgrid and Distribution System

System Control and Power Flow

- Guidelines for DMS for Grid Modernization
- Grid Interactive Microgrid Controllers & Aggregated DER
- Microgrid Integrated Controls (CSEISMIC)
- Virtual Microgrid & Reference Design for Sectionalized/Islanded Feeders

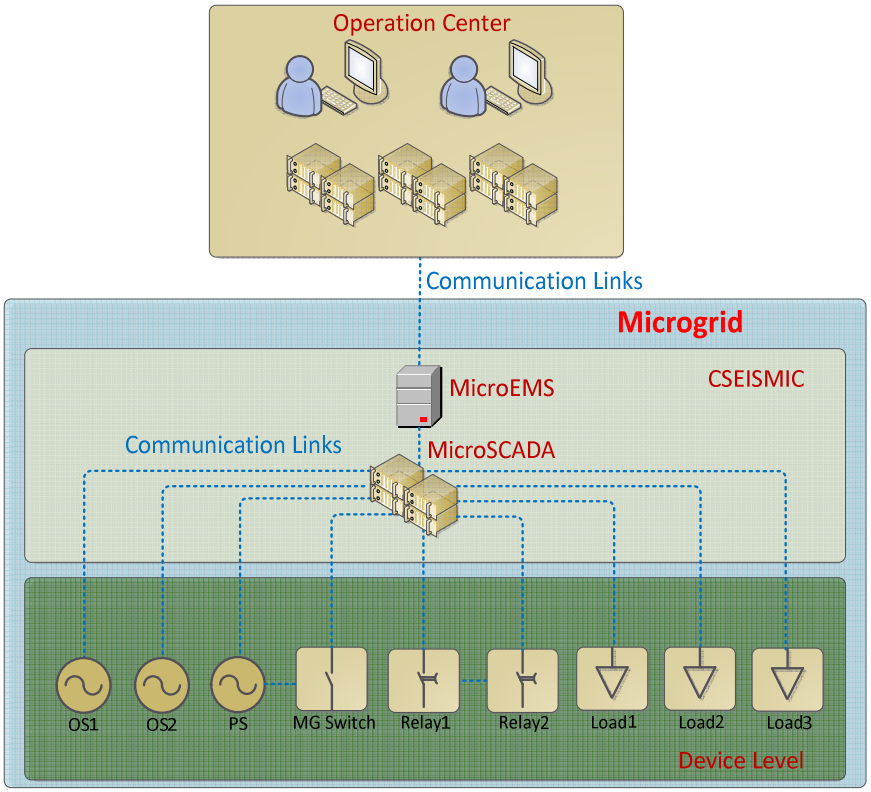
Device and Integrated Testing

- Microgrid Controller HIL Test Bed (simulation- uGrid EMS and DMS)
- Grid Self-Aware Elastic Extensible Resiliency (Grid-SEER) Platform

Standards

- IEEE p2030.7 Standard for Specification of Microgrid Controllers
- IEEE p2030.8 Standard for Testing of Microgrid Controllers

Complete System-Level, Efficient & Interoperable Solution for Microgrid Integrated Controls (CSEISMIC)



Year-end targets: Complete standardized microgrid communication development, load shedding testing, and protection scheme testing

- Microgrid Supervisory Control And Data Acquisition (MicroSCADA) for sources, loads, microgrid switch, protection relays, etc.
- Volt/freq control and transition control are performed at device level with control modes and setting points dispatched by MicroEMS.
- Single-point interface between microgrid and system operator/energy market to participate in utility operation and energy market activities.

Real Time Digital Simulator (RTDS)-Based Hardware-in-Loop (HIL) Microgrid Test Bed

Flexible platform for testing, verification, and assessment of microgrid components and controllers for system operation, energy management, and protection under different operation scenarios

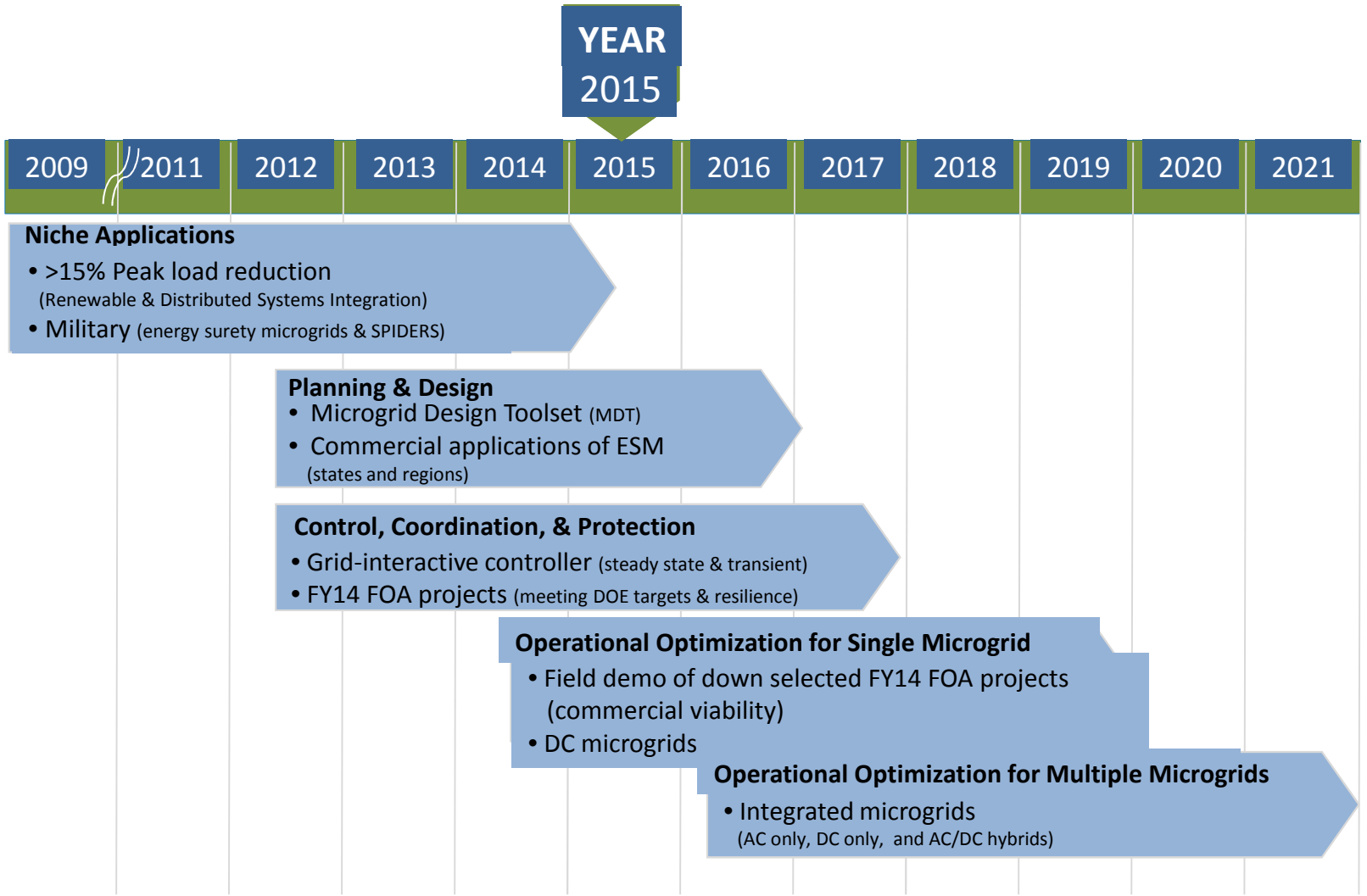
Purposes

- Provide standardized and independent testing
- Reduce deployment cost for new devices and solutions
- Perform research
- Investigate safety issues
- Facilitate standards development

Conduct testing of:

- Both system level and device level
- Microgrid energy management
- Microgrid control and operation (CSEISMIC testing in FY15)
- Communication
- Protection

Microgrid R&D Timeline



Microgrid Research, Development, and System Design (DE-FOA-0000997)

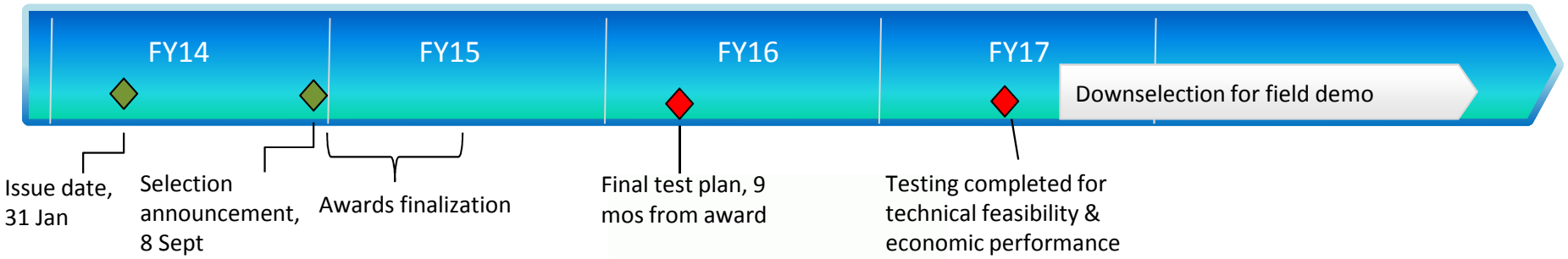
FOA Objective:

Advance microgrid system designs (<10MW) and control functionalities to support achievement of DOE program targets and community-defined resilience objectives

FOA Partnered Projects:

>$12M in total investment (OE: 59%; Indian Energy: 9%; private sector: 33%);

2-year project period of performance, including 18-month R&D and 6-month testing, data collection, and analysis



GE Global Research

ComEd An Exelon Company

EPRI ELECTRIC POWER RESEARCH INSTITUTE

ALSTOM | Grid

TDX power a tanadgusix company

Microgrid Institute

UCI University of California, Irvine

Standards for Microgrid Controllers and Testing

IEEE P2030.7 *Standard for the Specification of Microgrid Controllers*.

- PAR Approved by IEEE SA on June 11, 2014
- Working Group formed – FOA Awardees encouraged to participate
- Projected Completion Date – August 2017

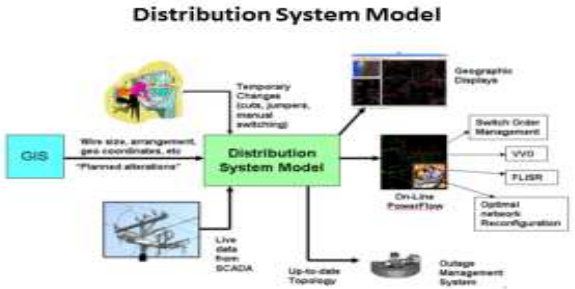
IEEE P2030.8 *Standard for the Testing of Microgrid Controllers.*

- PAR Approved by IEEE SA on June 11, 2015
- Working Group being formed – FOA Awardees encouraged to participate
- Projected Completion Date – May 2018

DMS + Microgrid Controls

- Distribution management system (DMS) plays a critical role in control and management of distribution systems
- Distribution systems have to manage high penetration distributed energy resources (DERs) and microgrids
- The integration of DERMS and microgrid controllers with the ADMS offers a solution

Guidelines for Distribution Management Systems for Grid

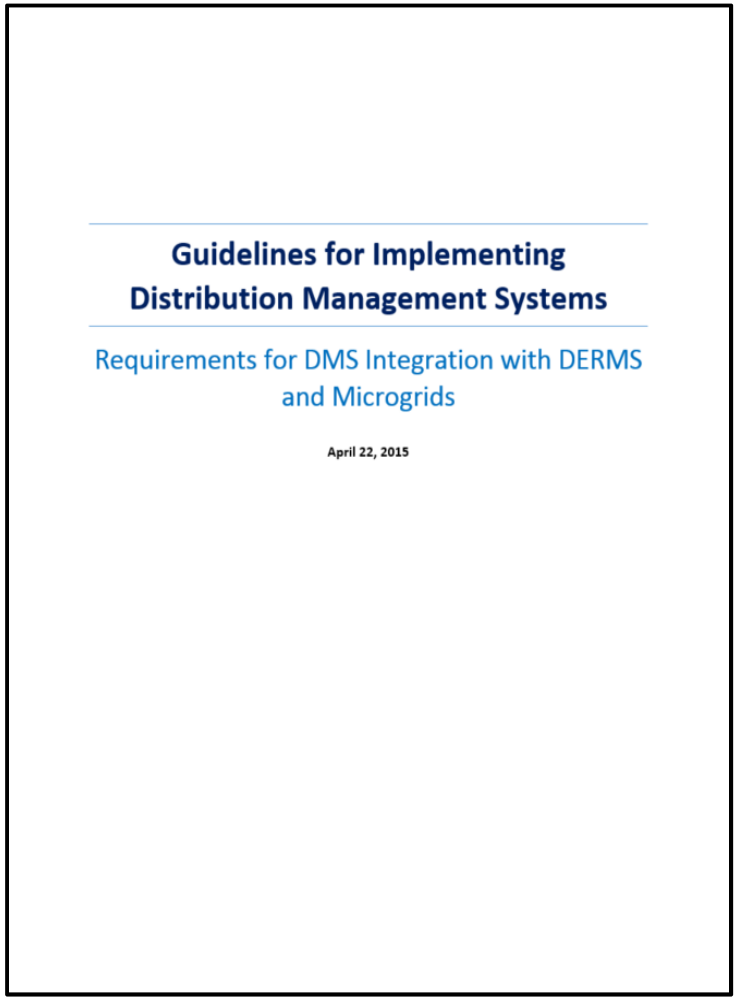


Source: Robert Uluski, EPRI

The objective of this project is to identify the functional gaps of DMS and propose a guideline for DMS development and implementation for grid modernization.

The scope of the project is divided into tasks that address the needs for DMS, requirements for DMS for integration of microgrids and DERs, and standardization of the guidelines.

DMS Integration with DERMS and Microgrid Controller

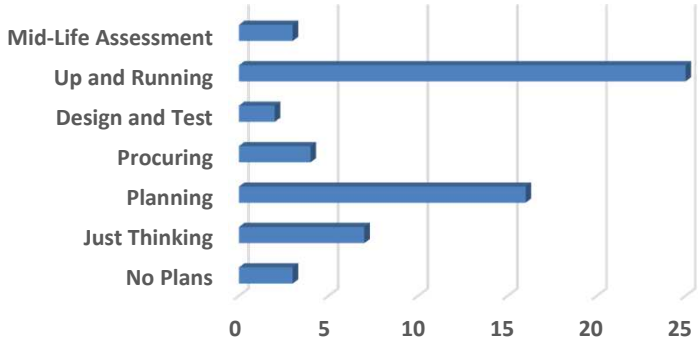


- Chapter 1: Introduction
- Chapter 2: DMS – Current Status and New Challenges
- Chapter 3: Microgrid Operation
- Chapter 4: Distributed Energy Resources
- Chapter 5: Distributed Energy Resources Management Systems
- Chapter 6: DMS Integration with Microgrid
- Chapter 7: DMS Integration with DERMS
- Chapter 8: Design Principles of DMS for Integration with DERMS and Microgrids

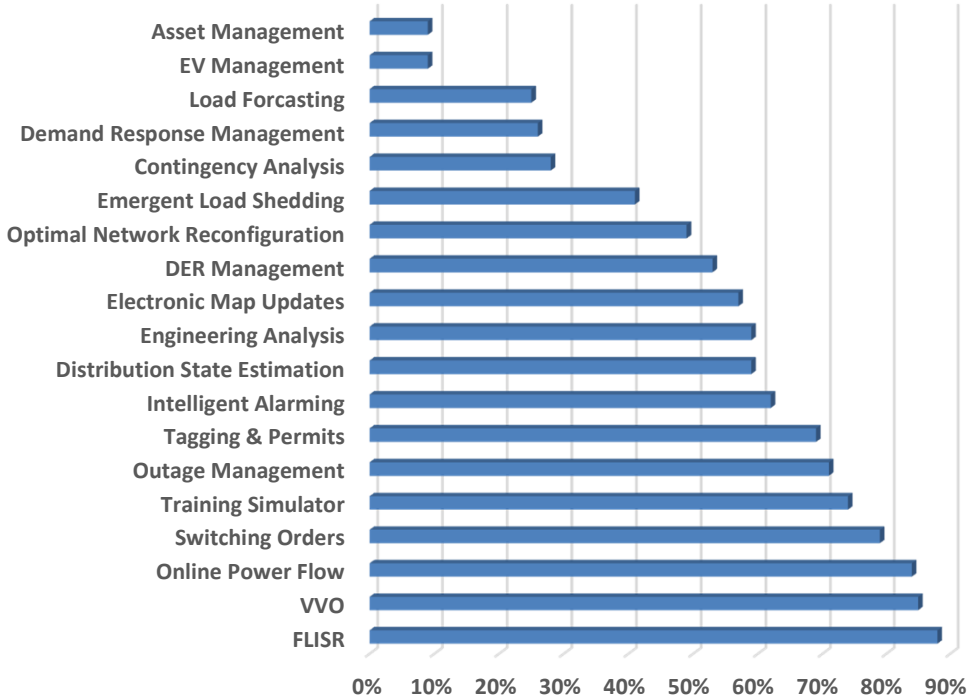
DMS – Current Status and New Challenges

Current status of DMS development

- Based on the information gathered from an industry survey, DMS has been widely implemented in existing distribution systems
- Only some of the DMS functions have been realized by utilities



DMS implementation status*

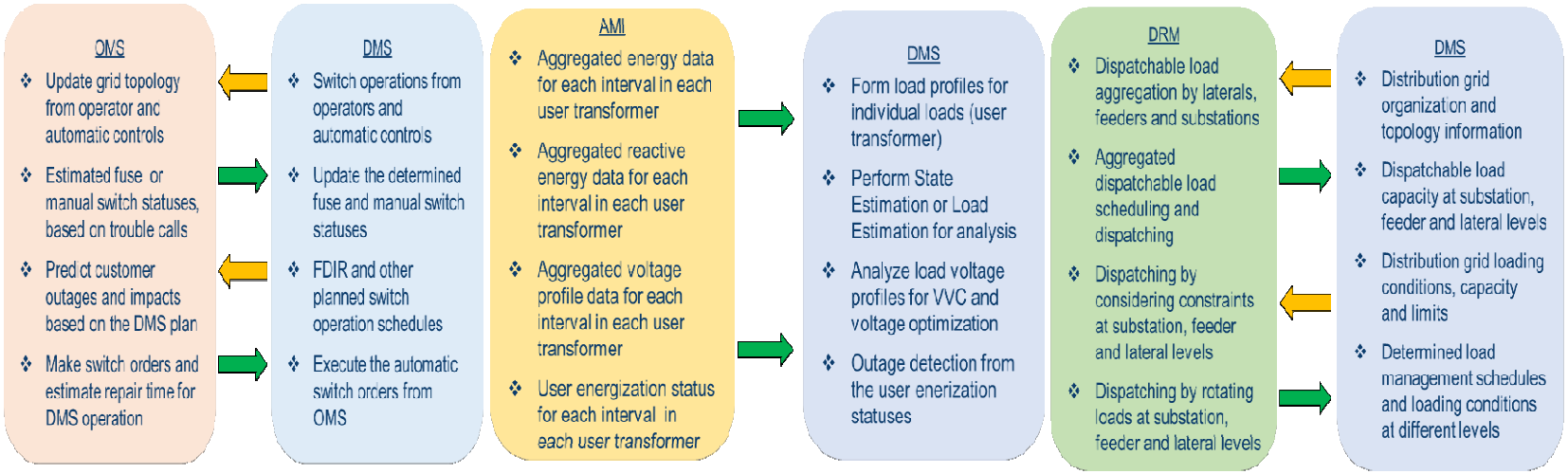


DMS applications being implemented*

* IEEE industry survey, April 2015.

DMS – Current Status and New Challenges

Integration of New Applications with Existing DMS



Interaction and data communication between DMS and other systems
(a) OMS-DMS (b) AMI-DMS (c) DRM-DMS

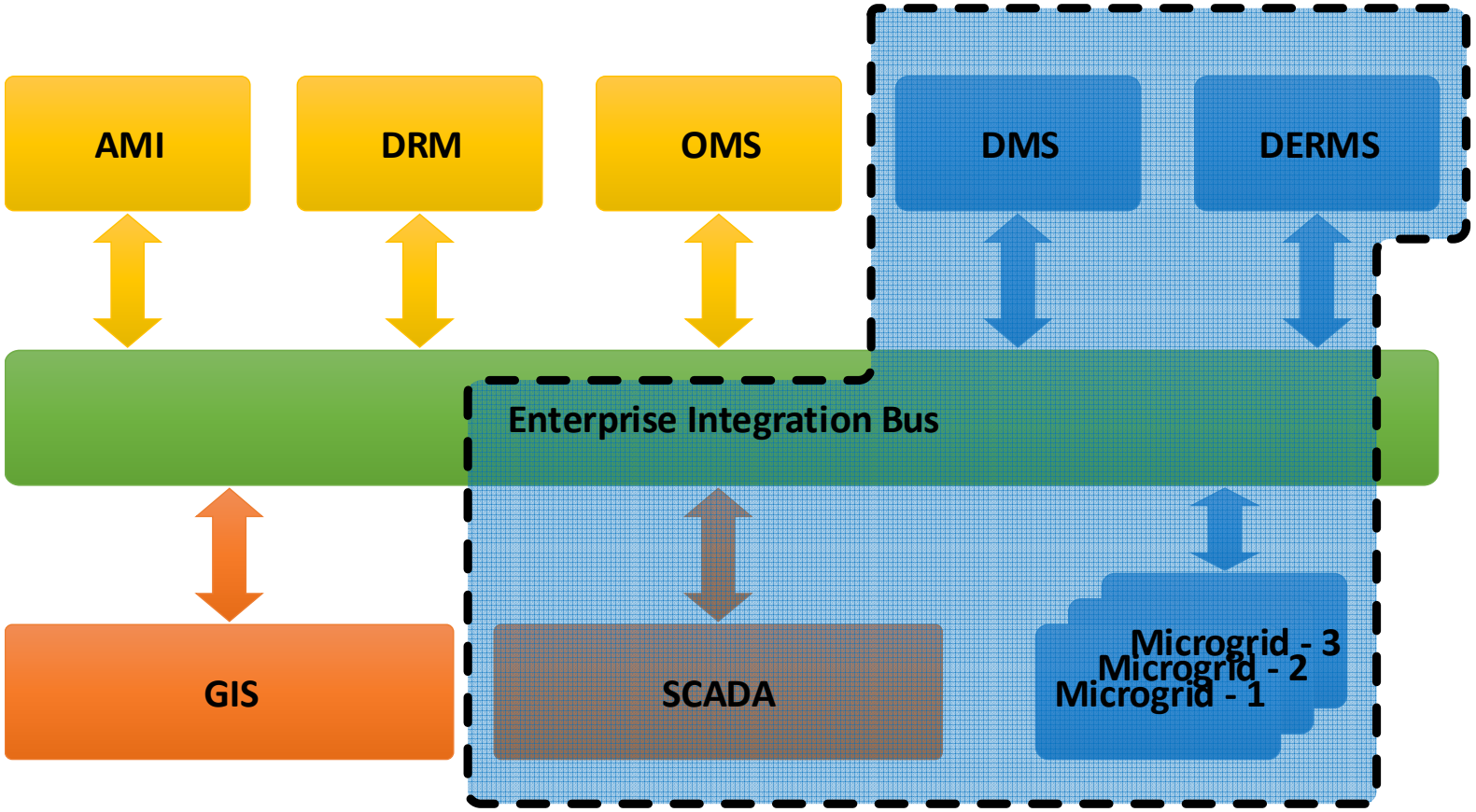
DMS – Current Status and New Challenges

- Impacts of DERs and microgrids on DMS
  - DER penetration
    - Impacts of DERs on distribution grid operation: change of voltage profile and power flow direction, reliability degradation imposed by dynamic connection and disconnection of individual DERs, etc.
    - Impacts on advanced applications in DMS: impact on different applications, including topology processor (TP), distribution power flow (DPF), short circuit analysis (SCA), etc.
  - Microgrid connection
    - Connection modes: islanding or grid-connected
    - Interface at POC to distribution systems: may have multiple POCs, configuration with only one active POC is suggested, may split into multiple islands
    - Power exchange: maintain scheduled power transaction
    - Mutual supporting in emergency: capability of emergent voltage and energy support

IMPACTS of DERMS on DMS

- ❑ Reduce the uncertainties caused by dispersed DERs
- ❑ DMS can obtain real-time generation values of grouped DERs and operation schedules for the future time intervals

Distribution Management System (DMS), Microgrid Controller and DER Management System (DERMS)



Source: IEEE industry survey, April 2015.

Distributed Energy Resources Management System (DERMS)

- Objective and functionalities
  - Effectively manage, optimize and control the DERs
- Group structures and aggregation policies
  - Properly organize and group the DERs that are physically dispersed along distribution systems
- Operation rules and resource optimization
  - Constrained optimization of DERs based on DERs' energy availabilities and demands at different levels, i.e., substation, feeder and feeder sections
  - DMS for real-time operation condition and committed operation plan
- Control and monitoring of individual DERs
  - Remotely monitors the operation of DERs or collect the operation data through the integration to DMS
  - May directly control the DERs by downloading the set-point values under remote control based on committed operation schedules

DMS Integration with DERMS

- Responsibilities of DERMS for DMS
  - DERMS is responsible for simplifying and aggregating the information of virtually grouped DERs into the level that DMS requires
  - DERMS should provide tentative operation schedules of DERs for DMS to validate
  - DERMS is responsible for responding to the emergency requests from DMS
- Responsibilities of DMS for DERMS
  - Provide real-time operation condition of distribution system, committed operation schedule, constraints and available margins for DERMS optimization
  - Validate the tentative operation schedules of DERs and provide feedbacks
  - Initiate emergency requests to DERMS with clearly defined specific demands for support
- Strategies/policies for emergency control and management
  - DMS should initiate the request for emergency support to DERMS
  - DERMS shall actively participate in the emergency control and management to assist DMS

DMS Integration with Microgrid Controller

- Responsibilities of microgrid for DMS
  - Microgrid controllers are responsible for maintaining real power exchange, heathy voltage profiles at the active POCs when connected to the distribution grid
  - Microgrids should provide simplified operation topology to DMS when multiple POCs are activated
  - Microgrids should automatically disconnect from the distribution grid in any grid fault condition beyond the threshold of ride-through
  - Microgrids shall automatically disconnect from the distribution grid for any internal fault condition that triggers the back up protection at POCs

- Responsibilities of DMS for microgrid
  - DMS should provide operation guidance, including the voltage ranges and power exchange fluctuation tolerance around the scheduled targets at active POCs to the microgrids
  - DMS can initiate emergency requests to microgrids for clearly defined specific emergency support, including support through wheeling

DMS Integration with Microgrid Controller

- Data communication between DMS and microgrid
  - In normal operation, DMS needs to know the energy interchange and Voltage/Var support schedules at the POCs of microgrids in addition to the real time data on voltage, current, etc.
  - In emergency condition, timely support between microgrid and distribution system is needed. The emergency support requests shall be confirmed and responded to quickly.
  - For intentional disconnection, both microgrid controller and DMS should be notified for alleviating transient power fluctuation.

- Operation rules for both DMS and microgrids
  - Microgrids should follow the operation rules of distribution system at the POCs
  - DMS should not interfere with the internal operation of a microgrid while it can enforce the microgrid not to induce operational difficulties to distribution systems
  - Microgrid should be capable of disconnecting from distribution system in case of a severe fault and riding through the standard level of low voltage during a short fault time period
  - Microgrids should maintain a healthy voltage profile at the active POCs when connected to the distribution system

DMS Integration with Microgrid Controller

- Synchronization and connection/disconnection
  - Automatically detects voltage and frequency deviations by synchronizing relay
  - Should not induce voltage or power disturbance during synchronization process
  - Power exchange ramping should be provided for intentional disconnections
  - Sufficient resource and proper control strategies should be provided in both distribution grid and microgrids for non-intentional disconnections

- Microgrid control while integrated with DMS
  - Frequency control and load following
  - Voltage/Var control
  - Emergency support

- Resource optimization in microgrids
  - Resource optimization in microgrids done by microgrid controller
  - DMS is responsible for defining the constraints on microgrids at their POCs

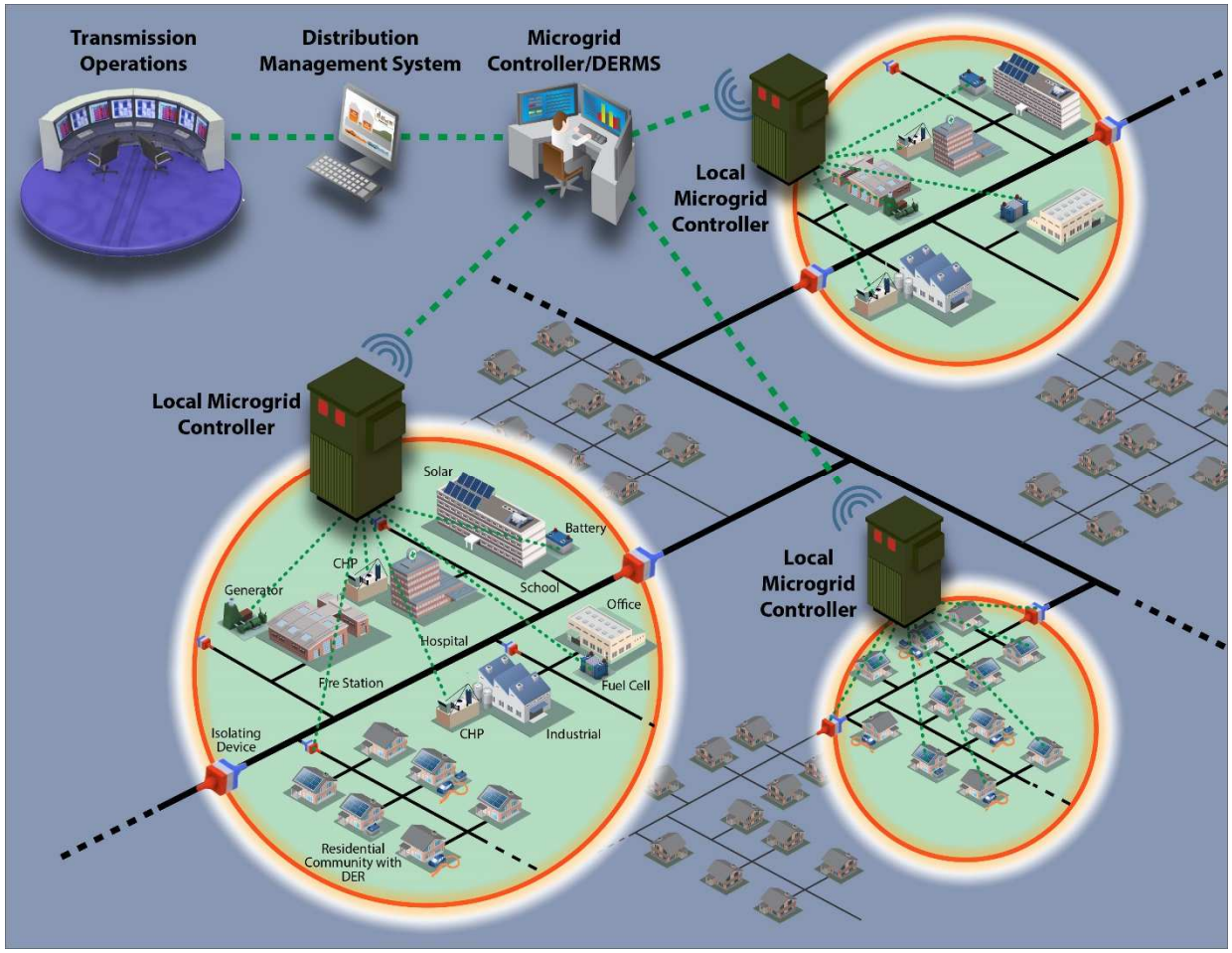
DMS Integration with Microgrid Controller

- Energy transactions and wheeling between the distribution grid and microgrid
  - Energy transactions that are fully monitored and controlled
  - Energy wheeling, i.e., one party delivers certain amount of power to one POC and receives the power from another POC, may need to be avoided in normal operation while executable in emergency support

- DMS function enhancement with microgrid integration
  - Microgrid can be operated as an energy source or a load
  - The connection of microgrids to utility system benefits the operation reliability and power quality of distribution grid
  - Corresponding operation strategies in DMS adjusted to coordinate with the operation rules of microgrids

- Protection schemes
  - Cope with the issues induced by two-way power flow, multi-source contributions of short-circuit currents
  - Protection coordination between microgrid and utility system
  - Dedicated protection mechanism at the POCs to effectively isolate the faults
  - Automatic reconnection shall be done by microgrid controller

Integrating Microgrids and Distributed Controls



Source: EPRI

Microgrid Resources

Office of Electricity Delivery and Energy Reliability
http://www.oe.energy.gov

Microgrids
http://energy.gov/oe/role-microgrids-helping-advance-nation-s-energy-system

Sandia National Laboratory – Energy Surety Microgrid™
http://energy.sandia.gov/?page_id=819

Berkeley Lab (DER-CAM and International Symposium)
https://building-microgrid.lbl.gov/projects/der-cam

Microgrid workshop results
http://www.e2rg.com/reports