"One word. Are you listening? Microgrids. There's a great future in microgrids. Think about it. Will you think about it?"
Course Outline

- Introduction
- Concepts and Issues
- Architecture and Standards
- Case Study
- Evolution of the Microgrid Roadmap
FEEDER Industry Training Session
Microgrids (Concepts and Issues)

Microgrids
Concepts and Issues
University of Central Florida
Orlando, Florida

Jim Reilly, Consultant
July 25, 2014

Topics

- Microgrid and Smart Grid
- Microgrid and Distributed Energy Resources
- Microgrid Projects in the United States
- Challenges for Microgrid Deployment
- Evolution of Microgrids
Microgrid and Smart Grid

Evolution of Smart Grid

- **AMI: Customer Service / Cost Savings**
  initial AMI deployments (2000 to 2008)

- **AMI: Utility Operations/Outage Management**
  expanded AMI deployments (2009 to 2013)

- **Demand Response in Wholesale Markets**
  FERC Orders 719 and 745 (2008 to 2011)

- **Integration of Renewable Energy**
  demonstration and pilot projects (2007 to 2013)

- **Smarter Transmission Grid**
  Wide Area Measurement Systems and Situational Awareness (2009 to 2013)

- **Grid Modernization and Distribution System Resiliency**
  smart grid technologies for distribution systems and microgrids (2013 to present)
Future Power Delivery System Characteristics

- **Interactive** with consumers and markets
- **Self-Healing** and **Adaptive**
- **Optimized** to make best use of resources and equipment
- **Predictive** rather than reactive, to prevent emergencies
- **Accommodates** a variety of generation options
- **Integrated**, merging monitoring, control, protection, maintenance, EMS, DMS, marketing, and IT
- **Cyber Secure**

Microgrid Definition

A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island mode.
Microgrids: Integral Part of a Smart Grid

Microgrid and Distributed Energy Resources
Microgrid vs Related DER Concepts

Evolution of Microgrid Generation

- **CHP Dominance**: Most operational and many planned microgrids are based on natural gas turbines and co-generation;
- **Reliable Diesel**: Diesel remains a popular choice for back-up generation when cost efficiency is the most important optimization parameter;
- **Microgrids go Solar**: Integration of solar PV becomes a key parameter of next-gen microgrid in next 5 years, documented cases (military, campuses) drive adoption.
Islanded DER or µGrid?

- Are we talking about DER in islanded systems
  Or
  µGrid with grid-like functionality?
- The µGrid configuration and functionality define the interfaces of Actors – device, system, person – within the boundaries of the µGrid and between the µGrid and the area EPS across the PCC.
DR Island Systems


The term “DR island systems”, sometimes referred to as microgrids, is used for electric power systems that:

1. have DR and load
2. have the ability to disconnect from and parallel with the area EPS
3. include the local EPS and may include portions of the area EPS, and
4. are intentionally planned.

DR island systems can be either local EPS islands or area EPS islands.

Source: IEEE Std 1547.4™-2011

Recent Events Support a Need for Advanced Microgrids
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 and resiliency to the grid.

Early definitions of microgrids focused on “islanding” characteristics; now definitions have expanded to include the management of generation and load as a part of the electric power system.

Along with broadened definitions, the scale of microgrids is changing from less than a megawatt to two megawatts to 10 megawatts to sixty to one hundred megawatts.

These changed concepts, definitions, and scale characterize an Advanced Microgrid.

Source: The Advanced Microgrid: Integration and Interoperability, Sandia National Laboratories (DOE/OE Microgrid Working Group)

Microgrid – Definition / Features

- Geographically delimited
- Connected to the main grid at one point (PCC)
  - fed from one substation
- May operate islanded
- Includes distributed resources (DR), but generator agnostic according to needs of customer
  - renewables (inverter interfaced)
  - fossil fuel based (synchronous generators)
- Includes an energy management system
  - controls for power exchanges, generation, load, storage and demand response
  - load management controls to balance supply and demand fast

Power and information exchanges take place on both sides and across the PCC in real time.

Source: Dr. Geza Joos
Rapid Changes Distribution

- The grid was designed for bulk generation and one-way power flow
- Renewables and distributed generation have become prevalent enough to cause two-way power flow
- Some distributed generation is from intermittent power producers requiring spinning reserve and/or energy storage to smooth the intermittency
- Utilities are becoming more a distributor of electrical power rather than a generator
- Congestion and limited generation is resulting in a need for dynamic pricing (demand, standby)
Microgrid Components

- **Distributed Resources**: generation (natural gas, bio-fuels), solar, storage, fuel cells, demand response

- **Devices / Systems to perform μGrid functions**:
  - Inverters
  - Switchgear
  - Microcontrollers (devices)
  - Energy Management Systems (μEMS, μDMS, BEMS)
  - Monitoring and measurement (PMUs)
  - Communications
  - Models (state estimator)
Hierarchical Levels of Control

Hierarchical levels of control for microgrids may be categorized as primary, secondary, and tertiary.

- **Primary control** is the level in the control hierarchy that is based exclusively on local measurements, which includes islanding detection, output control, and power sharing (and balance control).
- **Secondary control**, the μEMS, is responsible for microgrid operation in either the grid-connected or islanded mode.
- **Tertiary control** is the highest level of control and sets long-term and “optimal” set points depending on the host grid’s requirements.
Operational Mode: Interconnected

Interconnected Microgrid
  – Dispatched, Scheduled, Interoperable
    • Commanded shutdown
    • Commanded curtailment
    • Ramp-up and ramp-down
    • Scheduled and commanded voltage regulation/VAR support
    • Two-way communications are integrated into the advanced microgrid

Syncrophasors can detect changes in the grid characteristics over long distances

Operational Mode: Islanded

Islanded Microgrid
  – Still communicating but operates autonomously
  – Load management and controls (critical loads, tiered priorities or fully prioritized)
  – Voltage and frequency regulation
  – Capable of energy storage management
  – Black start in an islanded state
  – Can connect and disconnect from distribution lines without disruptions
  – Can predict resources and learn load profiles
Microgrid Operating Modes
Normal day-to-day operations

All loads are grid-tied to a feeder supplied by the utility.

Source: Microgrid Cybersecurity Reference Architecture, ver1, Sandia National Laboratories

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Microgrid Operating Modes
Islanded, with connected DER

Islanded condition with connected renewable energy sources.

Source: Microgrid Cybersecurity Reference Architecture, ver2, Sandia National Laboratories
A New Microgrid Paradigm

Microgrid: A microgrid is a power system designed to achieve power and economic goals. These are determined by the regulatory structure, the power delivery system, utilities, developers and end-users.

Drivers: The need for a power delivery system that offers the benefits that microgrids are uniquely well suited to deliver, namely in the areas of:

- Resiliency
- Reliability and power quality
- Economics
- Power system
- Environmental
Microgrid: Value Proposition
Multiple Value Streams

- **Resiliency**
  - Security and Safety
  - Improved energy situational awareness

- **Reliability and Power Quality**
  - Reduced power interruptions (and avoided costs from interruptions)
  - Critical load reliability
  - Elective load service
  - Congestion relief

- **Economic**
  - Savings in electricity costs (purchases from macro-grid)
  - Revenue from market participation (capacity, frequency regulation)

- **Power System**
  - Voltage support
  - Loss reductions (T&D)
  - Black Start support
  - Generator efficiency

- **Environmental**
  - Reduction in emissions
  - Renewable integration

Microgrid Projects in the United States
Current Microgrid Landscape

When a disturbance to the utility grid occurs, the automatic disconnect switch enables the facility to "island" itself from the main utility grid and independently generate and store its own energy.

Santa Rita Jail

The distributed energy resources management system (DERMS) serves to reduce peak demand during normal grid-connected operation or during a demand response event.
Energy Surety: SPIDERS

PEARL HARBOR / HICKAM AFP CIRCUIT LEVEL DEMONSTRATION
- Renewables
- Storage
- Energy Management

FT CARSON MICRO-GRID
- Large Scale Renewables
- Vehicle-to-Grid
- Large scale storage
- Critical Assets
- Demonstration to tie in with COOP Exercise

CAMP SMITH ENERGY ISLAND
- Entire Installation
- Smart Micro-Grid
- Installed Installation
- High Penetration of Renewables
- Demand-Side Management
- Redundant Backup Power
- Makana Pahii Hurricane Exercise

TRANSITION
- Template for DoD-wide implementation
- CONOPS
- TIPs
- Training Plans
- DoD Adds Specs to GSA Schedule
- Transition to Commercial Sector via DOE
- Transition Cyber-Security to Federal Sector and Utilities

CYBER-SECURITY

Princeton Microgrid

http://youtu.be/Wtijl91imSQ
White Oak Microgrid

Core Elements
- Local power generation – 55 MW
- Co-exists with the utility (net exporter of electricity)
- Can operate totally independent of utility grid (islanding capability)
- Manages and controls local loads

Reliability & Resiliency
- Operated in island mode more than 70 times between 2010-2013.
- In the last two years the critical infrastructure has remained online 100%.
- While buildings near the campus went dark, White Oak avoided interruption during the 2011 earthquake, the 2012 Derecho, and Hurricanes Irene & Sandy

Primary Drivers:
Cost Savings and Reliability

Princeton Microgrid
- Economic Benefit
  - Cost savings on power purchases from utility
  - Participation in real time markets for energy and grid services
- Reliability Metrics
  - Automatic load shedding when islanded
  - Black start capability
  - Islanding, automatic or manual
  - Islanded during Hurricane Sandy

White Oak Microgrid
- Economic Benefit
  - Net exporter of power to local utility
- Reliability Metrics
  - Uptime over the last 12 months is > 99.999%.
  - Islanded, either automatically or manually, more than 70 times over the past 2 ½ years.
  - Operations have not been interrupted for any weather related events.
Cost Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Energy Resources</th>
<th>Switchgear Protection &amp; Transformers</th>
<th>Communications &amp; Controls</th>
<th>Site Engineering &amp; Construction</th>
<th>Operations &amp; Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Ratio</td>
<td>30-40%</td>
<td>20%</td>
<td>10-20%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Description</td>
<td>Energy storage; controllable loads, DG; renewable generation; CHP</td>
<td>Switchgear utility interconnection (incl. low-cost switches, interconnection study, protection schemes, and protection studies)</td>
<td>Standards &amp; Protocols; Control &amp; protection technologies; Real-time signals; Local SCADA access; power electronics (smart inverters, DC bus)</td>
<td>A&amp;E (System design and analysis); System integration; testing &amp; communications; O&amp;M</td>
<td></td>
</tr>
</tbody>
</table>

Industries Most Likely to Deploy Microgrids over the next 5 years

Source: Zpryme
Challenges for Microgrid Deployment

Challenges

Technical / Economic
- Microcontrollers
- Energy Management Systems
- Interoperability
- Costs
- Business case

Regulatory / Policy
- Markets
- Tariffs
- Interconnection standards
- CHP portfolio standards
- Investment incentives

Integration Operations Standards
- microgrid integrated into power delivery system
- relationship of microgrid to distribution utility
- interconnection and communications protocols
Technology and Standards

- Microgrid Components – technological readiness
- Controls
- Measurement
- Analytical Tools
- Operations – relationship of microgrid to distribution utility
- Standards:
  - Interconnection
  - Communications Protocols
- System Level – Microgrid integrated into power delivery system
Deployment
Utility and Microgrid Owners

- μGrid components must be ready to be integrated
  - Interoperability
  - Standards
- μGrids are site-specific and require “mitigation” for interconnection with area EPS
  - Not necessarily “plug and play”
  - “Mix and match”?
- Cost reduction
  - Amortized cost for engineering development
  - Reasonable commissioning times

Regulatory Issues

“The reliability of our power systems needs to improve. Microgrid Resources (MRs) represent the single most promising avenue to improve grid performance and realize the promise of the smart grid. While movement toward MRs is currently being driven by large customers’ needs for power stability and reliability, the promise of MRs will only be fully realized if the services they can provide are fully compensated.”

Microgrid Resources Coalition
Regulatory Rules & Regulations

- Implement dynamic pricing
- Refine interconnection policies
- Adjust retail rate designs and refine rates for partial-requirements service
- Establish utility DER investment policies
- Develop retail-market participation rules
- Provide utilities with appropriate regulatory incentives
- Coordinate microgrid policies with other policies
- Encourage consistent regulatory policies across utility-service areas

Power System: Collection of Microgrids

“During severe system disturbances, large transmission systems will break up into preplanned islands where load and generation are balanced. As DER becomes more integrated into the distribution system, it will be possible to break up the distribution system into islands that are also self-regulating, providing extremely high levels of power quality to critical loads.

“These islands may be as small as 10 MW of load or as large as several hundred MW. The islands could be pre-planned and instituted as a result of potential contingencies, or they could be developed in real time using a set of algorithms that decide the best system configuration for any post-contingency set of available circuits and generation.”

Intentional Islanding

Intelligent System Separation

Microgrids
Integrated Energy Management Systems

Source: EPRI
Do you see a microgrid in your future?

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Microgrid Architecture and Standards

Jim Reilly, Consultant

Topics

- Microgrid Functional Model
- What are standards?
- Standards related to microgrids
- Use cases
- Example of Standard – IEEE Std 1547a™ – 2014 (excerpt)
Microgrid Functional Model

Smart Grid Architectural Model
EU Extension of NIST Model

Component Layer of Microgrid
Functional layer for the UC 'Switching to-from Islanding Mode'

Information layer for UC 'Switching to-from Islanding Mode'
What are standards?

Standards are published documents that establish specifications and procedures designed to maximize the reliability of the materials, products, methods, and/or services people use every day. Standards address a range of issues, including but not limited to various protocols to help maximize product functionality and compatibility, facilitate interoperability and support consumer safety and public health.

Standards form the fundamental building blocks for product development by establishing consistent protocols that can be universally understood and adopted. This helps fuel compatibility and interoperability and simplifies product development, and speeds time-to-market. Standards also make it easier to understand and compare competing products. As standards are globally adopted and applied in many markets, they also fuel international trade.

It is only through the use of standards that the requirements of interconnectivity and interoperability can be assured. It is only through the application of standards that the credibility of new products and new markets can be verified. In summary standards fuel the development and implementation of technologies that influence and transform the way we live, work and communicate.

IEEE Standards Association
July 25, 2014

IEEE Std 2030
Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads

- IEEE Std 2030
  This document provides guidelines for smart grid interoperability. It also provides a knowledge base addressing terminology, characteristics, functional performance and evaluation criteria, and the application of engineering principles for smart grid interoperability of the electric power system (EPS) with end-use applications and loads. The guide discusses alternate approaches to good practices for the Smart Grid.

  This document provides guidelines for discrete and hybrid energy storage systems that are integrated with the electric power infrastructure, including end-use applications and loads. This guide builds upon IEEE Std 2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation With the Electric Power System (EPS), and End-Use Applications and Loads.
  Clause 9.7 ESS for MicroGrid + Annex C (Use Case)
  Status: first ballot underway.

July 25, 2014
IEEE Std 2030™ – Architecture

IEEE 1547 Series
IEEE Std 1547™
IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems


Under Section 1254 of the act:
"Interconnection services shall be offered based upon the standards developed by the Institute of Electrical and Electronics Engineers: IEEE Standard 1547 for Interconnecting Distributed Resources with Electric Power Systems, as they may be amended from time to time."

Status: approved by the IEEE Standards Board in June 2003. It was approved as an American National Standard in October 2003.

IEEE 1547.4
DR Island System Configurations

Point of Common Coupling

IEEE 1547:

Point of common coupling (PCC): The point where a Local Electric Power System (EPS) is connected to an Area EPS.

PCC location may vary based on the point where the microgrid is planned to be disconnected from the area EPS.
DR Island System
Connected to EPS through “tie” breaker

Note: “tie” breaker (B1) will open for the fault shown before generator breaker (B2)

IEEE 1547a

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
Amendment 1
IEEE 1547a

- Volt/VAR control is allowed.
- Under/Over voltage ride through is allowed.
- Under/Over frequency is allowed.

Volt/VAR Control

The DR shall not actively regulate the voltage at the PCC. Coordination with and approval of, the area EPS and DR operators, shall be required for the DR to actively participate to regulate the voltage by changes of real and reactive power. The DR shall not cause the Area EPS service voltage at other Local EPSs to go outside the requirements of ANSI C84.1-2011 1995, Range A.
IEEE 1547a
Under/Over frequency ride through

<table>
<thead>
<tr>
<th>DR size</th>
<th>Frequency range (Hz)</th>
<th>Clearing time(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤10 kW</td>
<td>≥60.5</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>≤59.3</td>
<td>0.16</td>
</tr>
<tr>
<td>≥30 kW</td>
<td>≥60.5</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>≤(59.8 ... 57.0) (adjustable set point)</td>
<td>Adjustable 0.16 to 300</td>
</tr>
<tr>
<td></td>
<td>≤57.0</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Table 2—Interconnection system default response to abnormal frequencies

<table>
<thead>
<tr>
<th>Function</th>
<th>Frequency (Hz)</th>
<th>Clearing time (s)</th>
<th>Frequency (Hz)</th>
<th>Clearing time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UF1</td>
<td>&lt; 57</td>
<td>0.16</td>
<td>56 – 60</td>
<td>10</td>
</tr>
<tr>
<td>UF2</td>
<td>&lt; 59.5</td>
<td>2</td>
<td>56 – 60</td>
<td>300</td>
</tr>
<tr>
<td>OF1</td>
<td>≥60.5</td>
<td>2</td>
<td>60 – 64</td>
<td>300</td>
</tr>
<tr>
<td>OF2</td>
<td>≥65</td>
<td>0.16</td>
<td>60 – 64</td>
<td>10</td>
</tr>
</tbody>
</table>

IEEE 1547a
Under/Over voltage ride through

<table>
<thead>
<tr>
<th>Voltage range (% of base voltage)</th>
<th>Clearing time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V &lt; 45</td>
<td>0.16</td>
</tr>
<tr>
<td>45 ≤ V &lt; 85</td>
<td>2.00</td>
</tr>
<tr>
<td>85 ≤ V &lt; 120</td>
<td>1.00</td>
</tr>
<tr>
<td>V ≥ 120</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Table 1—Interconnection system default response to abnormal voltages

<table>
<thead>
<tr>
<th>Voltage range (% of base voltage)</th>
<th>Clearing time (s)</th>
<th>Clearing time: adjustable up to and including (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V &lt; 45</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>45 ≤ V &lt; 60</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>60 ≤ V &lt; 85</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>85 ≤ V &lt; 120</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>V ≥ 120</td>
<td>0.16</td>
<td></td>
</tr>
</tbody>
</table>

1 Under normal operation between the EPS and DER operators, other static or dynamic voltage and clearing time trip settings shall be permitted
2 Base voltages are the nominal system voltages stated in ANSI C84.1-2011, Table 1.
Ride-through required for DER connected to a planned microgrid

The ride through settings for DER connected to a planned microgrid may be different than those required due to Transmission System stability issues.

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IEEE p1547.8

Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Standard 1547
IEEE p1547.8:
Functionality of the DR island system

Area EPS-connected mode
1. Area EPS operator should approve the sustainability of the island.

2. The automatic sectionalizing devices should be capable of communicating with the area EPS operator via real time telemetry.

3. Remote Terminal Unit (RTU) or any relay that meets the Area EPS Operator communication protocol requirements, i.e. DNP3, MODBUS, and etc. is recommended to be installed at the DR site.

4. Metering (Amperes, Voltage, real/reactive Power, frequency, and time stamp) with two way communications is recommended to be installed at the automatic sectionalizing devices.

IEEE p1547.8:
Functionality of the DR Island System

Transition-to-island mode
1) For the distribution level islands, Pulse Based Power Line Carrier (PLC) is recommended to be installed at the distribution bus [1]. The DRs, that are planned to be included in the island, will sense the island formation once the PLC signal is lost. Proper communication is needed to disconnect the unplanned load from the island.

2) SCADA based communications between the automatic sectionalizing devices and the DR may be considered as well.

3) The relays at the DRs, that are planned to be included at the island, are recommended to be set to ride through the system transients, which varies based on the system stiffness factor. The Under Frequency Load Shedding and VAR match technology is recommended to be set to operate prior to the DR relays.
**IEEE p1547.8:**

**Functionality of the DR island system**

**Island mode**

1) For ground faults on four wire distribution circuit, where a ground fault current source is provided by the interconnecting entity, since the fault current contribution from the DR to the system ground faults is much smaller than that of the Area EPS, it is recommended to install voltage controlled over current relay on each DR to detect the grid ground faults. The pickup of the voltage controlled over current relay can be set below the nominal rating of the DR. All parallel DR relays should coordinate with the mainline relays/reclosers. The voltage controlled over current relay might not be able to detect the low fault current contribution from the DR. An alternative to the voltage controlled over current relay is zero sequence current detection from a detectable fault current source.

2) For three wire distribution circuits, or where the DR does not provide an effectively grounded source, it is recommended to detect the L-G faults by a voltage controlled negative sequence or a zero sequence over voltage relay [2].

3) The DR relays are recommended to be set to ride through the temporary faults within the island.

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**Reconnection mode**

1) During the open transition reconnection mode, the island load is recommended to be switched online in small steps to avoid high in-rush current due to induction motor load. The induction motor absorbs a large amount of reactive power during the start-up, which results in transient behavior of the EPS system (Inrush current).

2) All DRs should be able to detect the grid connected mode (receive the PLC signal, or SCADA, etc.) and the relay settings are recommended to be changed to the pre-islanded mode values.
Functionality of the DR island system

Load requirements and planning

1) It is recommended to allow DR to maintain the island frequency and voltage by adjusting the active and reactive power generation. The response time to the load disturbances is recommended to be quicker than the voltage and frequency relays in the island [3].

2) The voltage, frequency, and over current relays are recommended to be set ride through the island switching transients.

3) If the island imbalance is not within the acceptable range, it is recommended to allow more single phase generation on the heavily loaded phases to maintain the phase load balance.

4) In order to avoid ground relay nuisance tripping in an unbalanced island, it is recommended to make the ground relays voltage controlled. The ground relay will only operate during the island fault.

Reactive power considerations

1) It is recommended to install reserve reactive power sources for the island, i.e. STATCOM, capacitor banks, etc.

2) If the reactive power source is lacking, it is recommended to disconnect the non-critical load from the island to balance the reactive power. The DR must be able to stabilize the voltage by disconnecting portion of the non-critical load.
IEEE p1547.8: Functionality of the DR island system

Transformers

1) In order to avoid nuisance tripping during transformer inrush, the timer setting of all over current relays in the island are recommended to be set such that the system rides through the transformer inrush current.

2) Start up series reactance or impedance is recommended to be installed to limit the inrush current. In order to avoid additional system losses, the installed reactance or impedance must be bypassed during normal system operation when the inrush current is diminished.

NIST / SGIP
Microgrid Priority Action Plan (PAP)

- NEED
  - Coordinated and consistent electrical interconnection standards, communication standards, and implementation guidelines are required for microgrids and their interaction with the macrogrid.
  - There are no standards that define the grid interactive functions and operations of microgrids with the macrogrid.

- The PAP will develop
  - interoperability requirements for microgrid interconnection standards;
  - microgrid controller standards;
  - information model standards for grid facing functionalities; and
  - communications to/from the microgrid to macrogrid.
**Microgrid PAP – Task Interactions**

Task 0: Scoping Document
Define Microgrid standards needs

Task 1: Use Cases: Functional + Interactive EPRI-DERMS
Define requirements for different scenarios

Task 2: Microgrid grid-interactive Interconnection standard
1547a, 1547-REV

Task 3: Microgrid Controller/EMS standard
Functionality + Interoperability

Task 4: Regulatory Framework
a) State
b) Federal
c) NARUC

Task 5: Microgrid Controller Information Models
IEC 61850-7-x: CIM, MultSpeak

Task 6: Microgrid Controller and Interconnection Equipment Tests
Interconnection: IEEE 1547.1a; Info exchange; Safety: UL, NEC

**Relationship of Use Cases to Microgrids**

Use cases capture the functional requirements of the system, describing the actors, interfaces, information exchanges and sequence of events.

A use case is a means of describing a microgrid in terms that are helpful for analysis and decision-making to define the conditions for its operations and control in the context of the power delivery system and planning and cost/benefit in the context of the electric power industry.

Use cases define the functions of power systems – here they are developed for the unique functions of microgrids.

The use cases for microgrids are grouped as FUNCTIONAL and INTERACTIVE USE CASES. These are described in the sections below, followed by a diagram which illustrates the interrelationships with various components of the power system.
Functional Use Cases for Control and Operations of Advanced Microgrids

There are ten (10) use cases related to control and operations between the area Electric Power System (AEPS) and Advanced Microgrids in connected, transition and islanded modes. Microgrid operations and control is described in terms of functions.

The Use Cases for Control and Operations of Advanced Microgrids are
1. Frequency control
2. Voltage control (grid-connected & islanding)
3. Grid-connected to islanding transition – intentional
4. Grid-connected to islanding transition – unintentional
5. Islanding to grid-connected transition
6. Energy management (grid-connected & islanding)
7. Protection
8. Ancillary services (Grid-connected)
9. Black start
10. User interface and data management

Interactive Use Cases for Control and Operations of Advanced Microgrids

There are seven (7) use cases related to information support between the area Electric Power System (EPS) and advanced microgrids in the connected mode. The objectives of the use cases is to determine the actors, the logical interfaces, and the step-by-step actions involved in this information support.

The Use Cases for Information Support of the Interactions between Area EPS and Advanced Microgrids are
1. Coordination of EPS and microgrid load shedding schemes (based on UFLS)
2. Volt/VAR control in connected mode under Normal Operating Conditions
3. Update aggregated at PCC real and reactive load-to-voltage and load-to-frequency dependencies
4. Updates of aggregated capability curves at the microgrid’s PCC
5. Updates of information on microgrid dispatchable load
6. Updates of the information on overlaps of different load management means within microgrids
7. Updates of dependencies of the components of the microgrid operational model on external conditions
**Operational Priorities**

**Utility and Microgrid Operators**

### Changing Priorities of RAS and DER Protection for Microgrids

<table>
<thead>
<tr>
<th>Load-generation balance of the Microgrid</th>
<th>EPS Operator’s Interest under emergency conditions</th>
<th>Microgrid operator’s interest under emergency conditions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microgrid is load-rich</td>
<td>Assign higher priorities to the UFLS within the microgrid and lower ones to the PCC. Keep the DER protection priorities even lower.</td>
<td>Assign higher priorities to the UFLS within the microgrid and lower ones to the PCC. Have another load-shedding RAS for balancing load under island conditions.</td>
<td>Objectives coincide. Microgrid needs to inform the EPS about the situation. EPS needs to confirm its settings.</td>
</tr>
<tr>
<td>Microgrid is generation-rich</td>
<td>Assign priorities to the UFLS within the microgrid according to the EPS rules (interconnection contracts) and no UFLS for the PCC (after UFLS the microgrid may inject in the EPS).</td>
<td>Assign higher priorities to the UFLS for the PCC and lower for the UFLS within the microgrid (the MG may lose load).</td>
<td>Objectives are different; Microgrid can trade its support to EPS. Needs to inform the EPS about the situation. EPS needs to confirm its settings.</td>
</tr>
</tbody>
</table>

IEEE p2030.7  
Standard for the Specification of Microgrid Controllers

On June 11, 2014 the IEEE SA Board approved the PAR (IEEE P2030.7),  

Scope: A key element of microgrid operation is the Microgrid Energy  
Management System (MEMS). It includes the control functions that  
define the microgrid as system that can manage itself, and operate  
automonomously or grid connected, and seamlessly connect to and  
disconnect from the main distribution grid for the exchange of power  
and the supply of ancillary services. The scope of this standard is to  
address the technical issues and challenges associated with the proper  
operation of the MEMS that are common to all microgrids, regardless  
of topology, configuration or jurisdiction, and to present the control  
approaches required from the distribution system operator and the  
microgrid operator. Testing procedures are addressed.
Microgrid Case Study

University of Central Florida
Orlando, Florida

Jim Reilly, Consultant
July 25, 2014

Multi-power Quality Microgrid
Multi-power Quality Microgrid

Definition
- The Multi Power Quality Microgrid (MPQM) enables the supply of power to critical loads at multiple levels of power quality at higher levels than are supplied normally by the distribution utility.
- The MPQM does this by utilizing Distributed Energy Resources (DER) and power from the distribution utility (grid) in a mutually complementary manner.

Functions
- The MPQM can continue to supply power at a high power quality level, when grid connected, when the DER is grid-connected, or when the grid suffers from an outage and the DER is in an islanding operation mode.

Simplified Model MPQM
- Focuses on the functionality of “Multiple Power Quality Supply”
- Describes the supply of classes of power quality

Sendai Microgrid
Multiple Power Quality Microgrid

Overview of Sendai Microgrid

Geographical location of Sendai City

Sendai City

PV Panels 50 kWp

Gas Gen- sets 350 kW X 2

(DPS) Integrated Power Supply

MCFC 250 kW

DVRs 200 kVA 600 kVA

Offered by Jim Reilly, Reilly Associates
Simplified MPQM Model
Configuration

Generation Facility
- Multiple DER
- Two operational modes
  - Grid Connection Mode
  - Islanding Mode

Switches
- Switch 1 – PCC between MPQM and commercial grid
- Switch 2 – Boundary point of microgrid islanding mode

Configuration of the microgrid in the diagram above shows three classes of power quality. The Sendai Microgrid offers five classes of power quality (DC Supply, A, B1, B2 & B3) defined according to user needs.

Service Territory

Offered by Jim Reilly, Reilly Associates
Power Quality Definition and Loads

<table>
<thead>
<tr>
<th>Requirements</th>
<th>DC Power</th>
<th>AC Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B1</td>
</tr>
<tr>
<td>Interruption</td>
<td>NI</td>
<td>NI</td>
</tr>
<tr>
<td>Voltage Dip</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Outage</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Voltage Fluctuations</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Voltage Harmonics</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Voltage Unbalance</td>
<td>N/A</td>
<td>Y</td>
</tr>
<tr>
<td>Frequency Variation</td>
<td>N/A</td>
<td>Y</td>
</tr>
</tbody>
</table>

Note. NI: No Interruption, Y: With compensation, -: Without compensation, Y*: When Gas engine sets generated

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Load</th>
<th>Consumers (Load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>180 kW</td>
<td>Research Center (MRIs) Laboratory (servers)</td>
</tr>
<tr>
<td>B1</td>
<td>18 kW</td>
<td>Nursing Care Facilities (lighting, PCs)</td>
</tr>
<tr>
<td>C</td>
<td>170 kW</td>
<td>Newly-built Hospital (Emergency Power)</td>
</tr>
<tr>
<td>B3</td>
<td>130 kW</td>
<td>Nursing Care Facilities (lighting, clinic equipment)</td>
</tr>
<tr>
<td>DC</td>
<td>20 kW</td>
<td>Energy Center (servers, lighting, fans)</td>
</tr>
<tr>
<td>Normal</td>
<td>N/A</td>
<td>Nursing Care Facilities Training Center Dormitories</td>
</tr>
</tbody>
</table>

Power quality classes

Great East Japan Earthquake

March 11, 2011

Characteristics:
- N: 0 quake (March 11)
- N: 7 class 5 times
- N: 6 class 71 times
- N: 5 class 140 times

(As of May 16th)
## Power Supply Following Earthquake

<table>
<thead>
<tr>
<th>Date in 2011</th>
<th>March 11</th>
<th>March 12</th>
<th>March 13</th>
<th>March 14</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utility Grid</strong></td>
<td>Grid Connection</td>
<td>Voltage collapse</td>
<td>Grid Outage</td>
<td>Grid Connection</td>
</tr>
<tr>
<td><strong>AC C</strong></td>
<td>Grid Connection</td>
<td>Disconnect</td>
<td>About 12:00</td>
<td>Grid Connection</td>
</tr>
<tr>
<td><strong>DC</strong></td>
<td>Grid Connection</td>
<td>Supply from GasG</td>
<td>Supply from GasG</td>
<td>Grid Connection</td>
</tr>
<tr>
<td><strong>AC A</strong></td>
<td>Grid Connection</td>
<td>Battery</td>
<td>Stop</td>
<td>Grid Connection</td>
</tr>
<tr>
<td><strong>AC B1</strong></td>
<td>Grid Connection</td>
<td>Battery</td>
<td>Stop</td>
<td>Grid Connection</td>
</tr>
<tr>
<td><strong>AC B3</strong></td>
<td>Grid Connection</td>
<td>Outage</td>
<td>Supply from GasG</td>
<td>Grid Connection</td>
</tr>
<tr>
<td><strong>PV</strong></td>
<td>Outage</td>
<td>Outage</td>
<td>Outage</td>
<td>Outage</td>
</tr>
</tbody>
</table>

### Outline of the Gas Lines

- **Port Plant** (Main Tank)
- **Saiwaityou Plant** (Reserve Tank)
- **Energy Center**
- **Area of gas supply**

Gas Supply in SENDAI

Source: City bureau, City of SENDAI Web Site

Low-pressure gas for domestic use was stopped in the whole SENDAI area two hours after the earthquake. 25 days after the disaster, supply was resumed in almost the whole area.

Devastated by the great earthquake and Tsunami.
Evolution of the Microgrid Roadmap

University of Central Florida
Orlando, Florida

Jim Reilly, Consultant
July 25, 2014

Genesis of the Evolution of the Microgrid

The genesis of the evolution of the microgrid can be seen in many regions of the world.

Europe – MORE Microgrids, FI-PPP (FINSENY, FINESCE), eEnergy

USA – R&D in microcontrollers; advanced and dynamic microgrid concepts; community microgrids; DOE demonstration projects; DOD pilots

Japan – demonstration projects; smart Community; DC microgrid demonstration projects
Microgrid Readiness

- μGrid components must be ready to be integrated
  - Interoperable
  - Standards
- μGrids are site-specific and require “mitigation” for interconnection with area EPS
  - Not necessarily “plug and play”
  - “Mix and match”? 
- Cost reduction
  - Amortized cost for engineering development
  - Reasonable commissioning times

Integrated Distributed Electricity System

- DSO is responsible for providing reliable real-time distribution service
- A complementary mix of centralized and distributed resources including
  - generation, energy storage, power flow and stability control devices
  - control systems

Future “Integrated Distributed” Electricity System

[Caltech Resnick Institute. May 2014]
Roadmap – Timeline

Learning Opportunities

Standards Working Groups (P2030.7; P1547-REV)
Tools Workshops (DER-CAM)
Microgrids & Power System Restoration (Pilots)
DOE Microgrid Workshop (2015)
Cooperative Control (Demonstration Projects)