FEEDER
Industry Training Session

Microgrids

University of Central Florida
Orlando, Florida

Jim Reilly, Consultant
July 25, 2014



"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

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Microgrids
Concepts and Issues

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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***

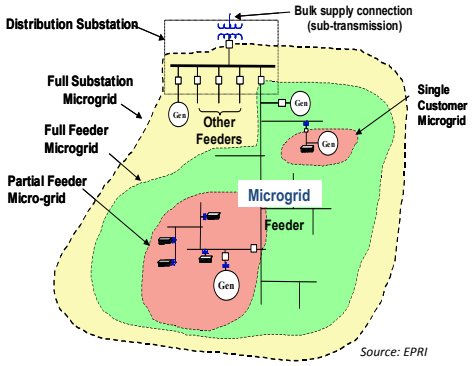


Source: EPRI

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.

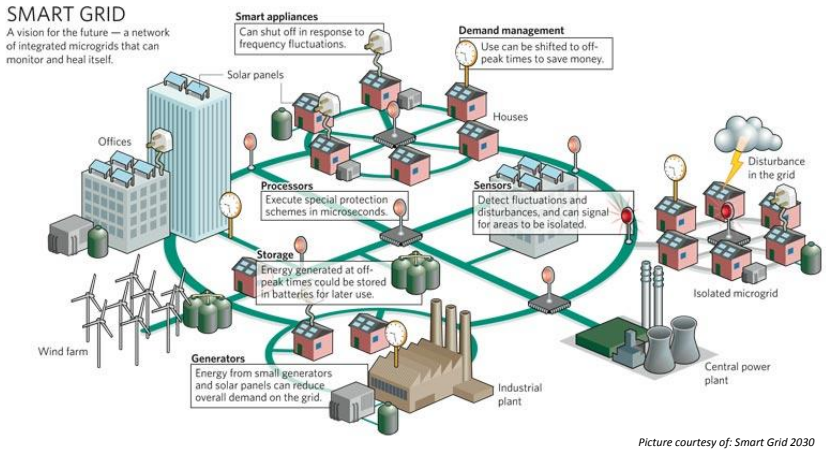
Residential	Less than 10-kW, single-phase
Small Commercial	From 10-kW to 50-kW, typically three-phase
Commercial	Greater than 50-kW up to 10MW



Source: EPRI

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Microgrids: Integral Part of a Smart Grid

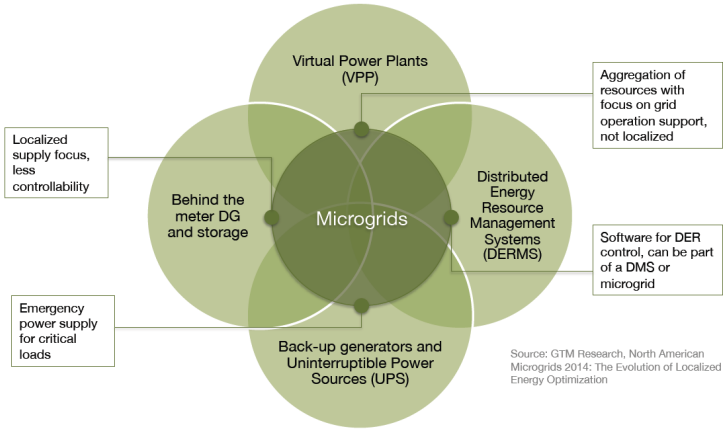


Picture courtesy of: Smart Grid 2030

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Microgrid and Distributed Energy Resources

Microgrid vs Related DER Concepts



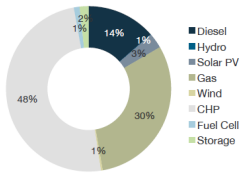
Source: GTM Research, North American Microgrids 2014: The Evolution of Localized Energy Optimization

Evolution of Microgrid Generation

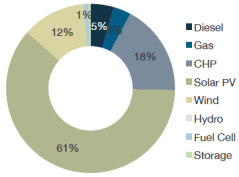
- **CHP Dominance**: Most operational and many planned microgrids are based on natural gas turbines and co-generation;
- **Reliable Diesel**: Diesel remains popular choice for back-up generation when cost efficiency is the most important optimization parameter;
- **Microgrids go Solar**: Integration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

Source: GTM Research, North American Microgrids 2014: The Evolution of Localized Energy Optimization

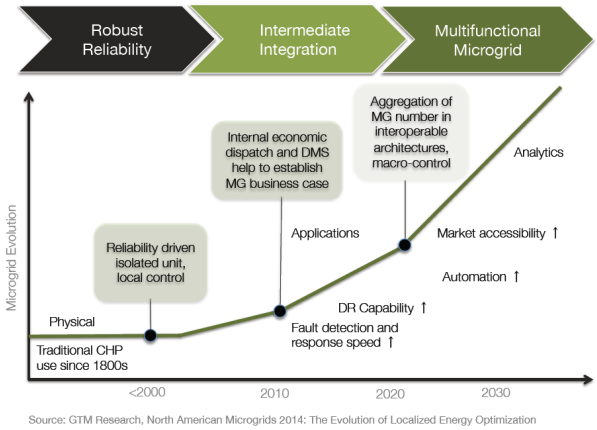
OPERATIONAL MICROGRID CAPACITY (MW)



PLANNED MICROGRID CAPACITY (MW)



Evolution of Microgrid Functionality



Source: GTM Research, North American Microgrids 2014: The Evolution of Localized Energy Optimization

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.

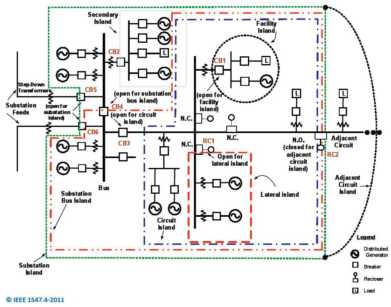
DR Island Systems

IEEE Std 1547.4™-2011, IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power 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.

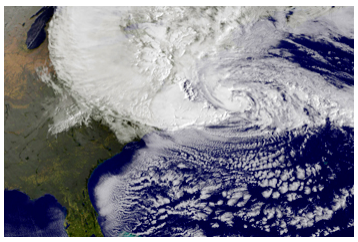
DR island systems can be either local EPS islands or area EPS islands.

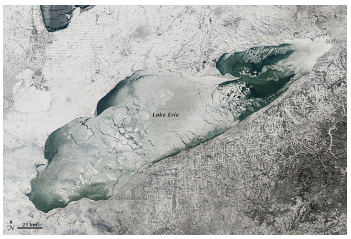


Source: IEEE Std 1547.4™-2011

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

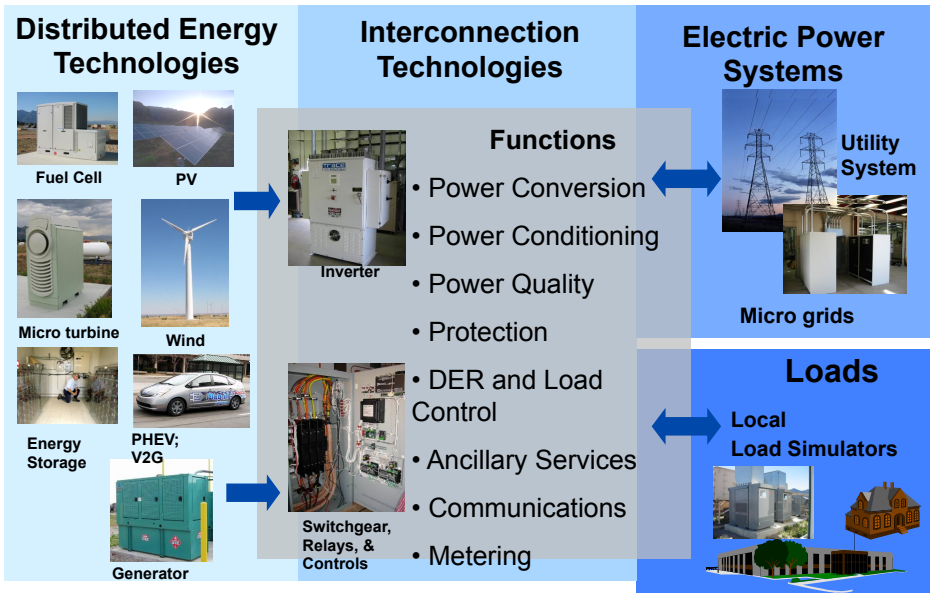
Power and information exchanges take place on both sides and across the PCC in real time.

Source: Dr. Geza Joos

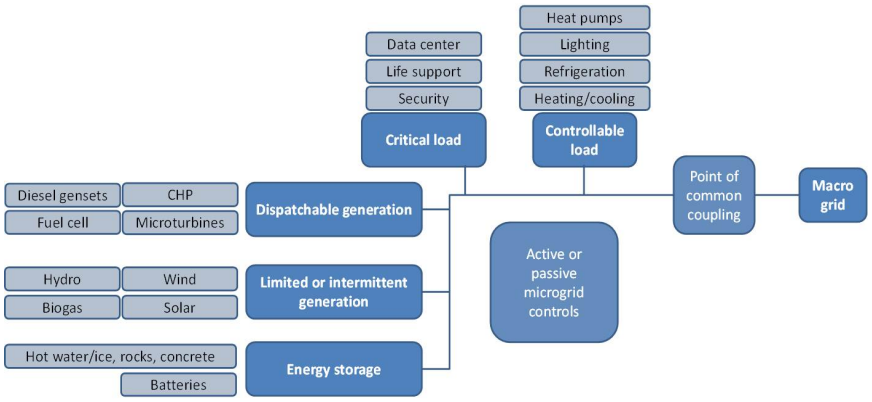
Rapid Changes Distribution

- 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)

DER Interconnection



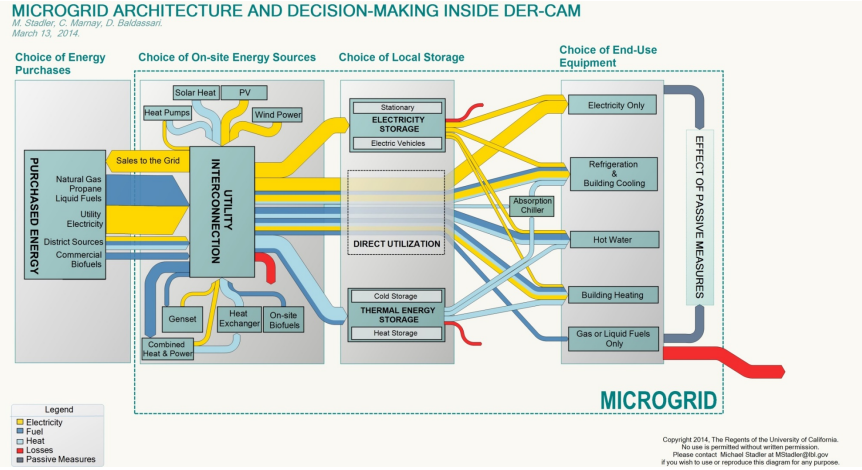
Microgrid Generic Configuration



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)

Microgrid Energy Sources



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Hierarchical Levels of Control

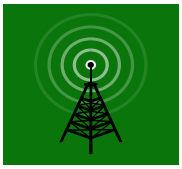
Hierarchical levels of control for microgrids may be categorized as primary, secondary, and tertiary.

- *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





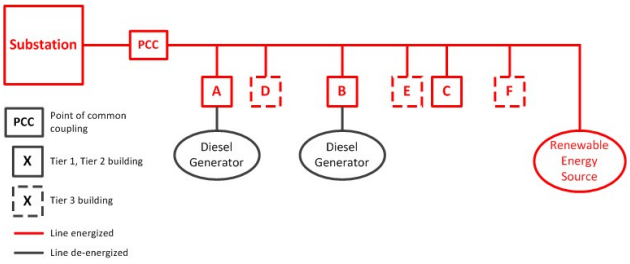
Syncrophasors can detect changes in the grid characteristics over long distances

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

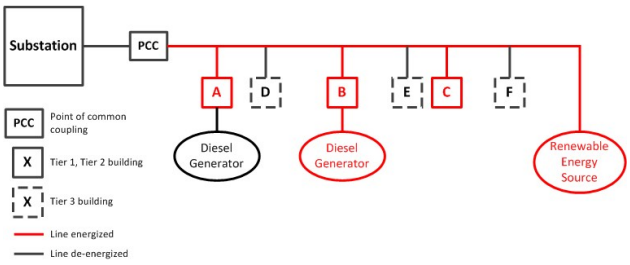
Microgrid Operating Modes
Normal day-to-day operations



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

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

Microgrid Operating Modes
Islanded, with connected DER

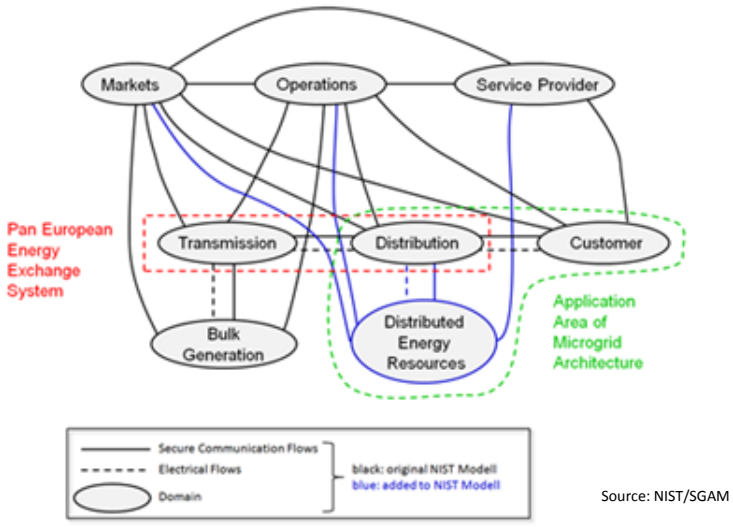


Islanded condition with connected renewable energy sources.

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

Architecture

EU Extension of NIST Model



Source: NIST/SGAM

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:

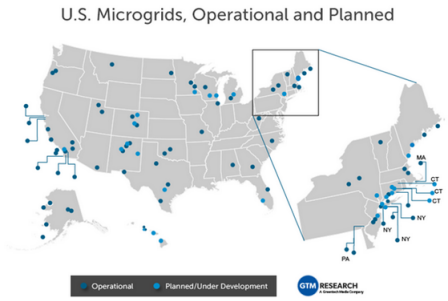
- Resiliency
- Reliability and power quality
- Economics
- Power system
- Environmental

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

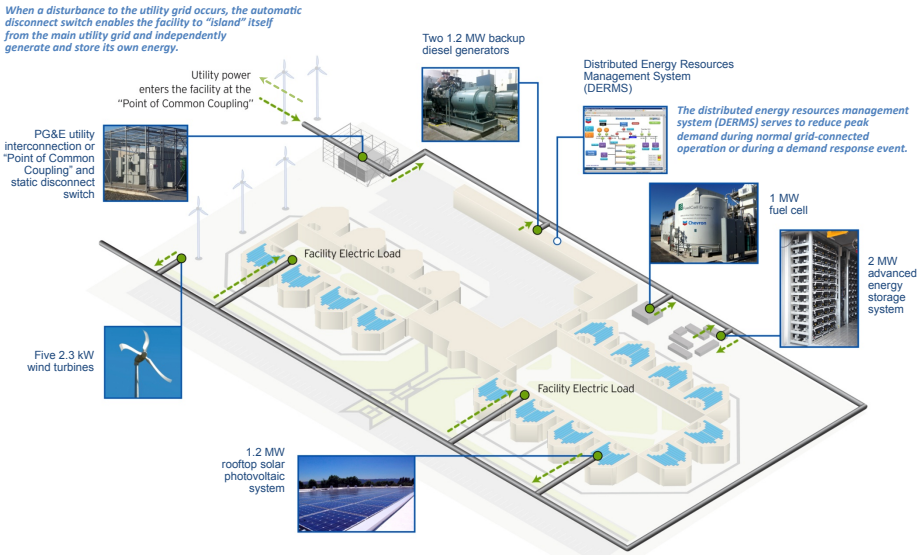
Microgrid Projects in the United States

Current Microgrid Landscape



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Santa Rita Jail



Energy Surety: SPIDERS



PEARL HARBOR / HICKAM AFB 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
- Islanded Installation
- High Penetration of Renewables
- Demand-Side Management
- Redundant Backup Power
- Makana Pahili Hurricane Exercise

TRANSITION
- Template for DoD-wide implementation
- CONOPS
- TTPs
- 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/WtjIj91imSQ

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

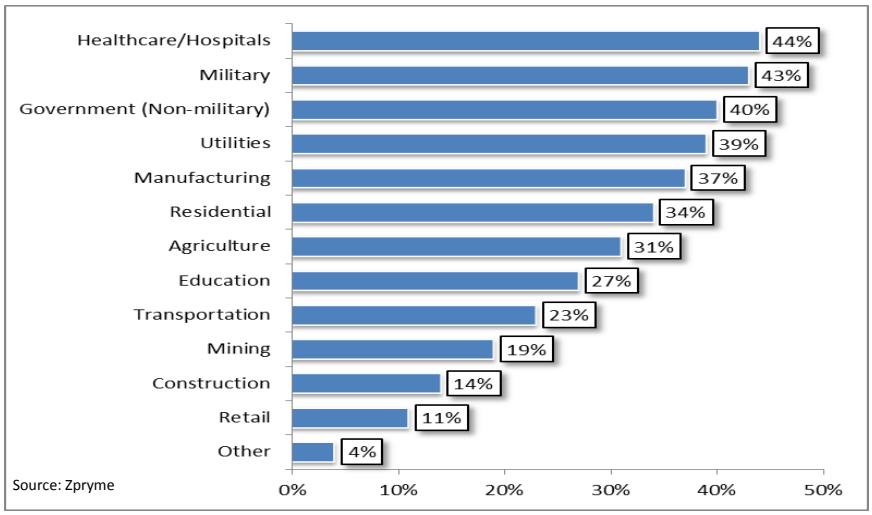
Reliability Metrics

- 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

	Microgrid Cost Components				
Component	Energy Resources	Switchgear Protection & Transformers	Communications & Controls	Site Engineering & Construction	Operations & Markets
Cost Ratio	30-40%	20%	10-20%	30%	
Description	Energy storage; controllable loads, DG; renewable generation; CHP	Switchgear utility interconnection (incl. low-cost switches, interconnection study, protection schemes, and protectino studies)	Standards & Protocols; Control & protection technologies; Real-time signals; Local SCADA access; power electronics (smart inverters, DC bus)	A&E (System design and analysis); System Integration, testing & validation	Market (and utility) acceptance; communications; O&M

Industries Most Likely to Deploy Microgrids over the next 5 years



Challenges for Microgrid Deployment

Challenges

Technical / Economic

- Microcontrollers
- Energy Management Systems
- Interoperability
- Costs
- Business case

Regulatory / Policy

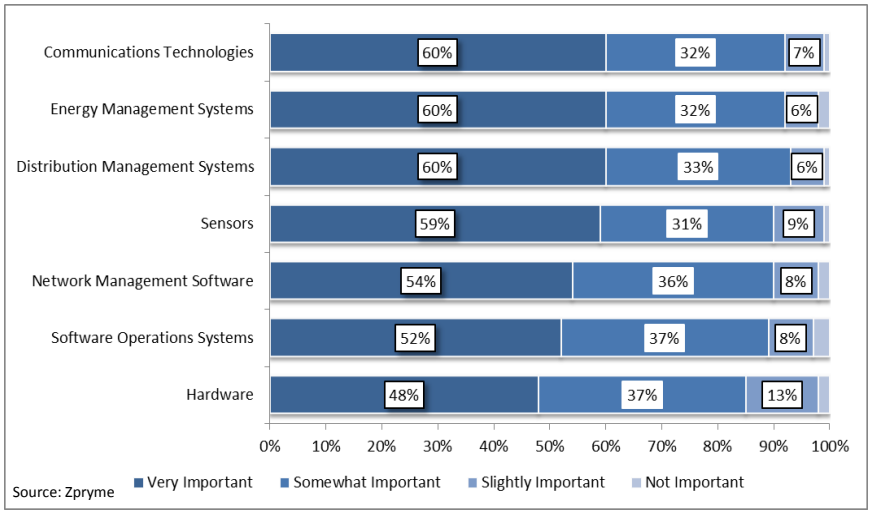
- Markets
- Tariffs
- Interconnection standards
- CHP portfolio standards
- Investment incentives

Integration microgrid integrated into power delivery system
Operations relationship of microgrid to distribution utility
Standards 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

Technologies to Integrate Microgrids



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

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



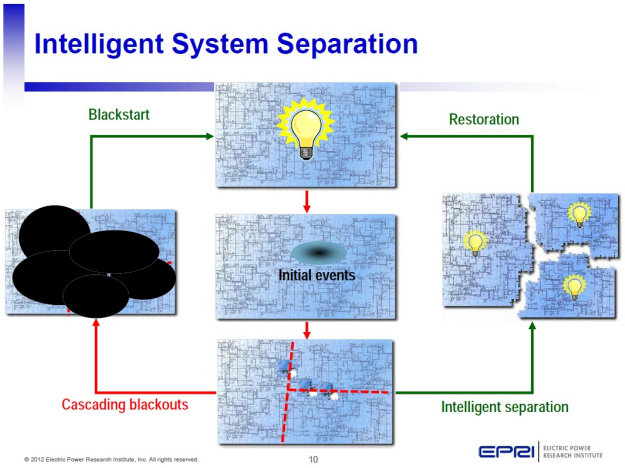
Power System:
Collection of Microgrids

"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."

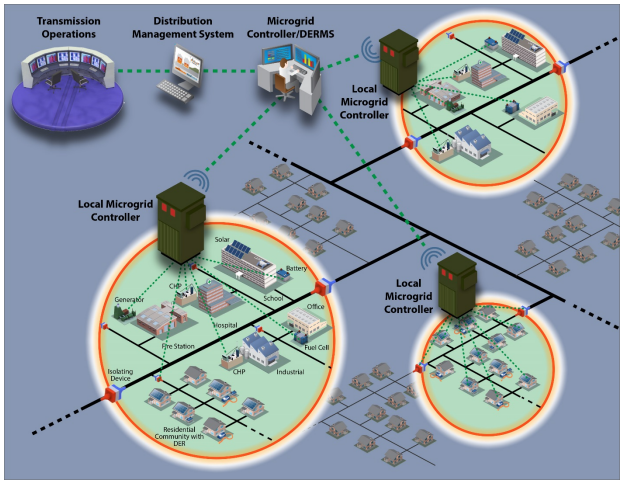
- *The Distribution System of the Future*, John D. Kueck and Brendan J. Kirbye, The Electricity Journal. 2003.

Intentional Islanding



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

July 25, 2014

Topics

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

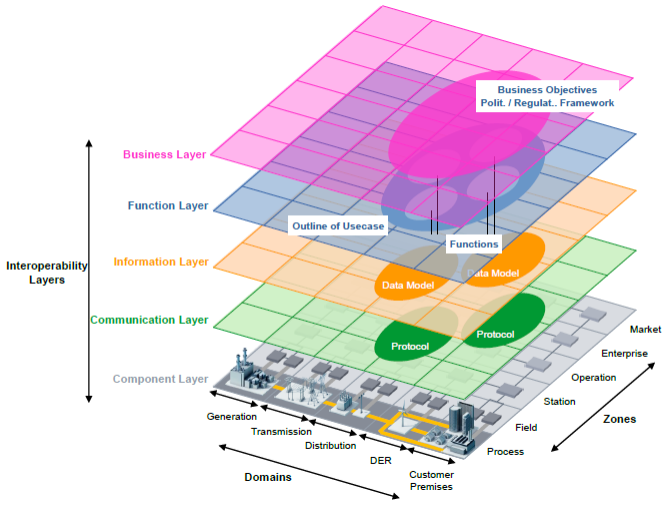
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Microgrid Functional Model

Smart Grid Architectural Model

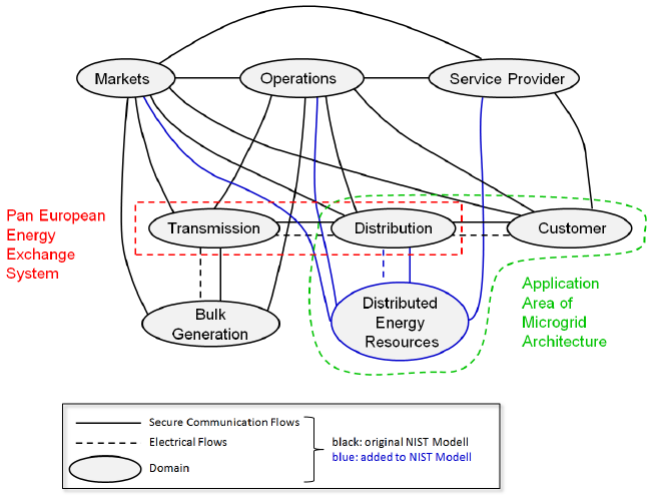
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Smart Grid Architecture Model



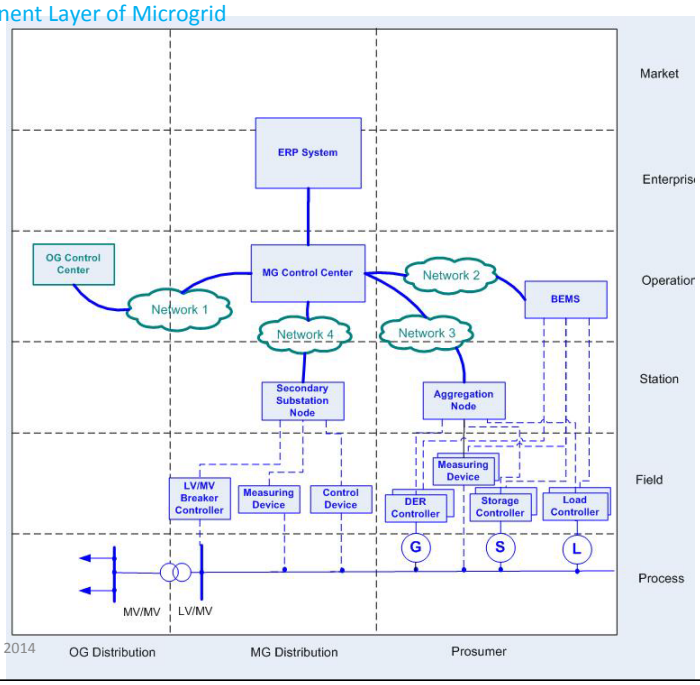
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EU Extension of NIST Model



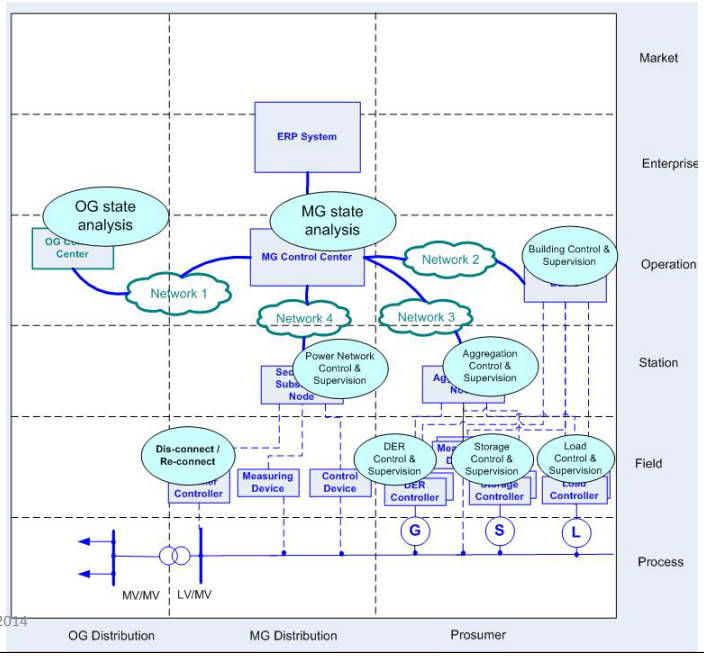
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Component Layer of Microgrid

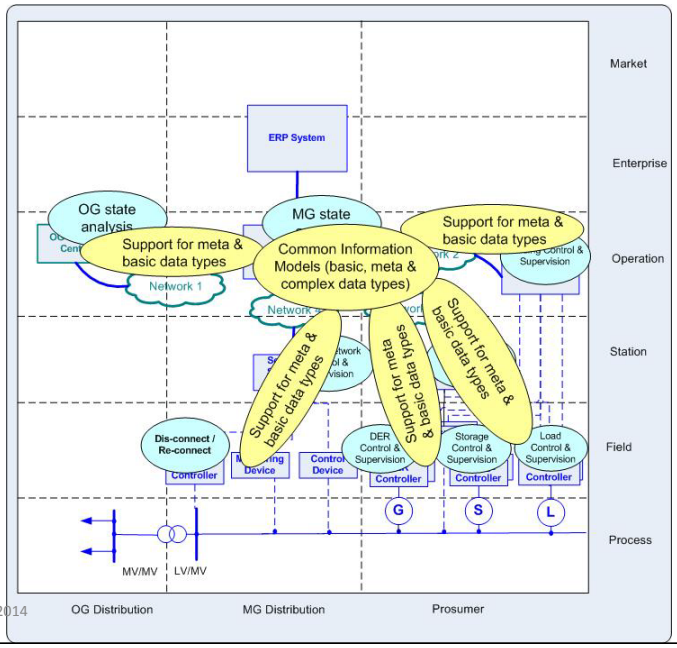


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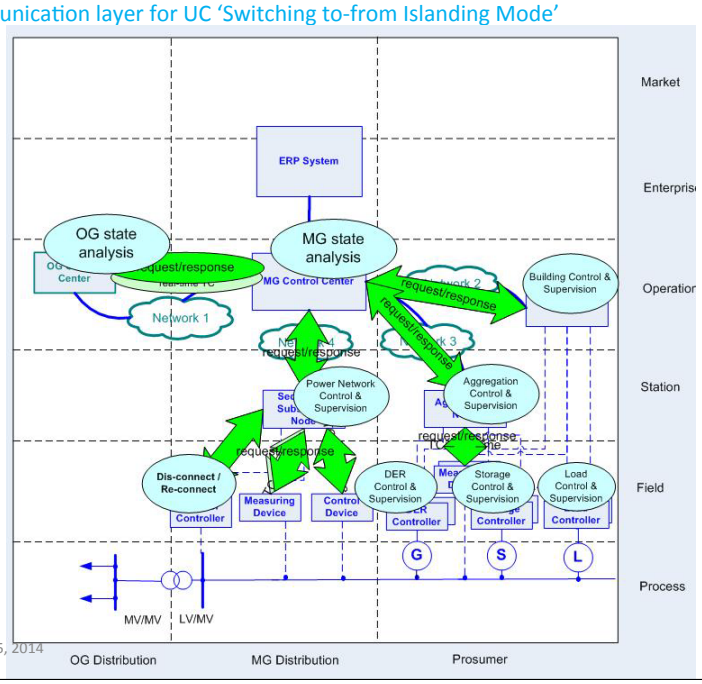
Functional layer for the UC 'Switching to-from Islanding Mode'



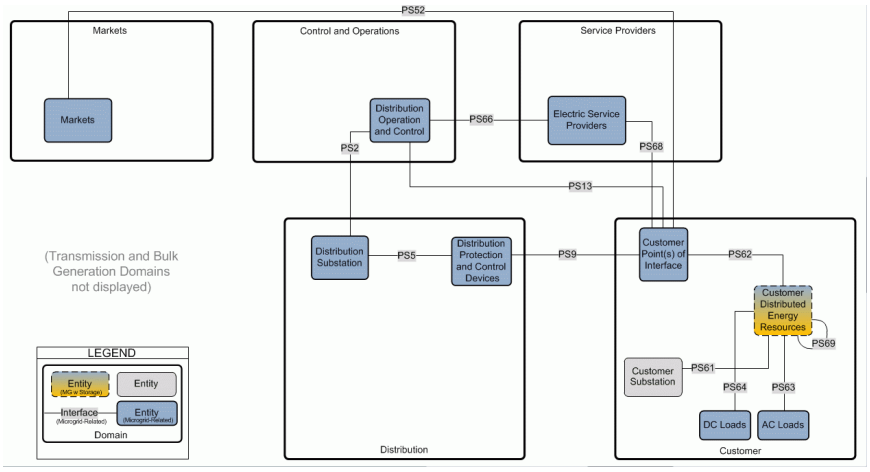
Information layer for UC 'Switching to-from Islanding Mode'



Communication layer for UC 'Switching to-from Islanding Mode'



IEEE Std 2030.2™ – Microgrid Architecture



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.

- IEEE P2030.2 Draft Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure

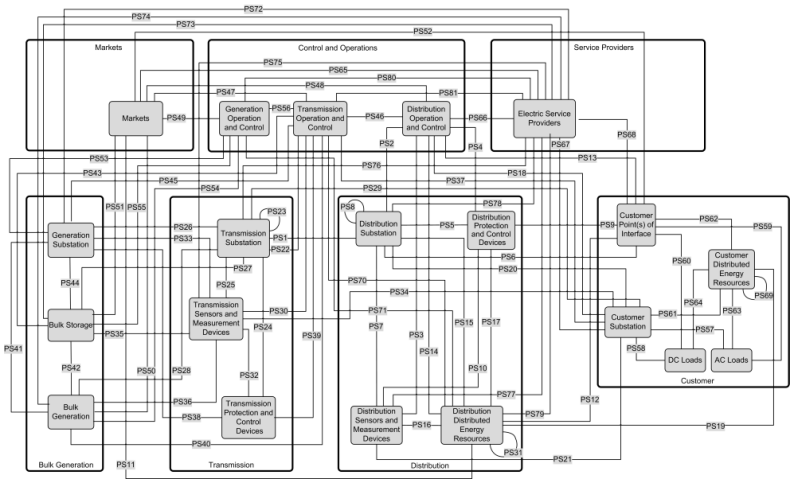
  This document provides guidelines for discrete and hybrid energy storage systems that are integrated with the electric power infrastructure, including end-use applications and loads. This guide builds upon IEEE Std 2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology 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.

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IEEE Std 2030™ – Architecture



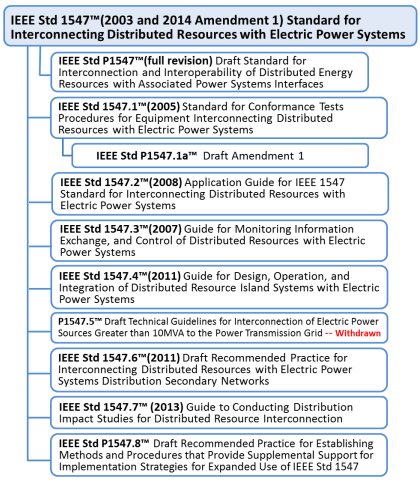
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IEEE 1547 Series

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IEEE Std 1547™

IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems



The Federal Energy Policy Act of 2005 calls for state commissions to consider certain standards for electric utilities.

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.

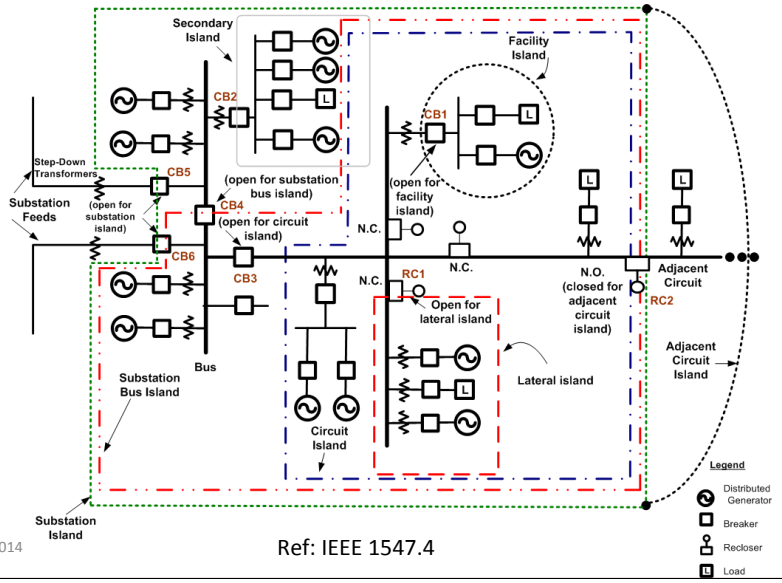
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IEEE 1547.4

IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

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DR Island System Configurations



Ref: IEEE 1547.4

Point of Common Coupling

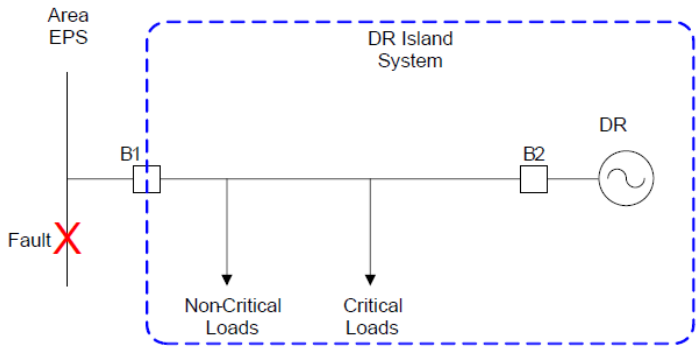
IEEE 1547:

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)

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IEEE 1547a

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

July 25, 2014

IEEE 1547a

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

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IEEE 1547a

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.

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IEEE 1547a

Under/Over frequency ride through

DR size	Frequency range (Hz)	Clearing time(s)[a]
≤ 30 kW	> 60.5	0.16
	< 59.3	0.16
> 30 kW	> 60.5	0.16
	< (59.8 – 57.0) (adjustable set point)	Adjustable 0.16 to 300
	< 57.0	0.16

Table 2—Interconnection system default response to abnormal frequencies

	Default settings		Ranges of adjustability	
Function	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s) adjustable up to and including
UF1	< 57	0.16	56 – 60	10
UF2	< 59.5	2	56 – 60	300
OF1	> 60.5	2	60 – 64	300
OF2	> 62	0.16	60 – 64	10

IEEE 1547a

Under/Over voltage ride through

Voltage range (% of base voltage[a])	Clearing time(s)[b]
V < 50	0.16
50 ≤ V < 88	2.00
110 < V < 120	1.00
V ≥ 120	0.16

Table 1—Interconnection system default response to abnormal voltages

Default settings[a]		
Voltage range (% of base voltage[b])	Clearing time (s)	Clearing time: adjustable up to and including (s)
V < 45	0.16	0.16
45 ≤ V < 60	1	11
60 ≤ V < 88	2	21
110 < V < 120	1	13
V ≥ 120	0.16	0.16

[a] Under mutual agreement between the EPS and DR operators, other static or dynamic voltage and clearing time trip settings shall be permitted
[b] 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

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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.

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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.

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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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IEEE p1547.8:

Functionality of the DR island system

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.

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IEEE p1547.8:

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.

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IEEE p1547.8:

Functionality of the DR island system

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.

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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.

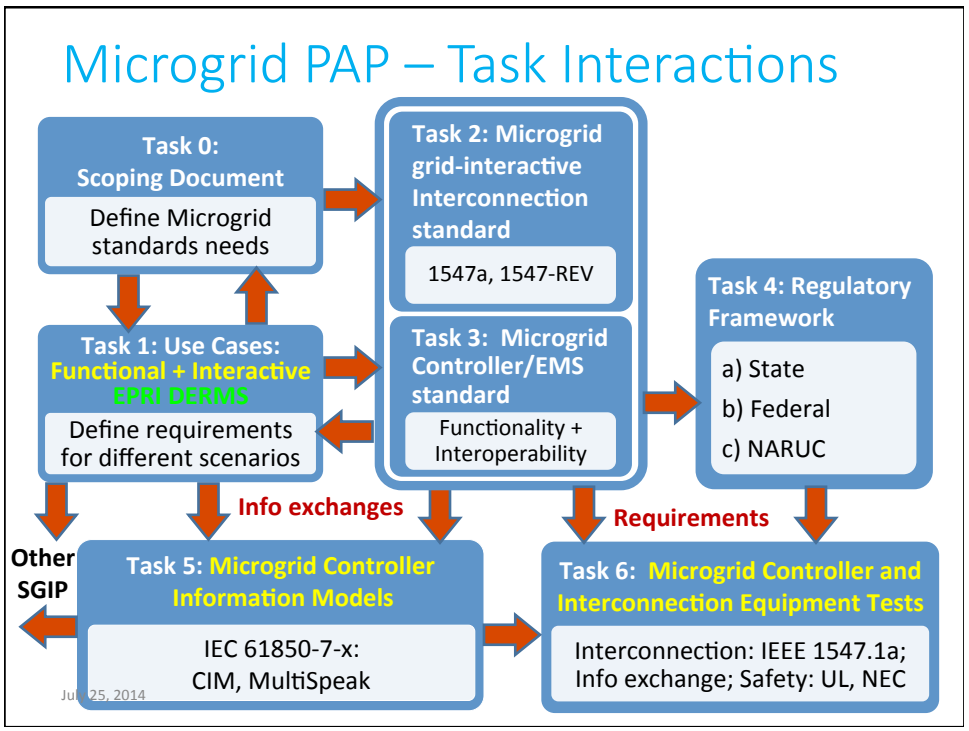
2) Start up series reactance or impedance is recommended to be installed to limit the inrush current. In order to avoid additional system losses, the installed reactance or impedance must be bypassed during normal system operation when the inrush current is diminished.

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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.

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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.

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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

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Interactive Use Cases for Control and Operations of Advanced Microgrids

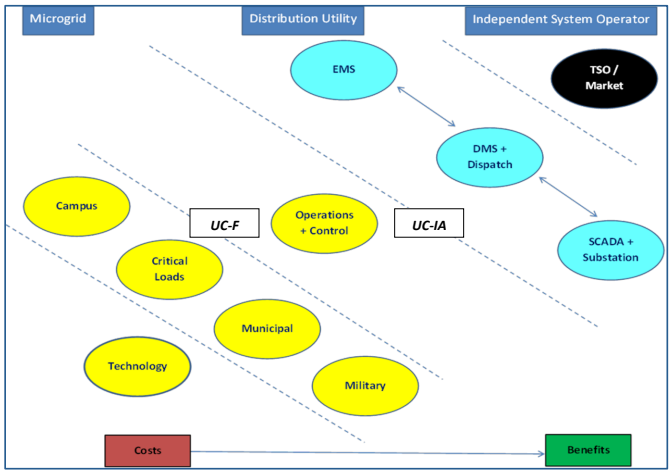
There are seven (7) use cases related to information support between the area Electric Power System (EPS) and advanced microgrids in the connected mode. The objectives of the use cases is to determine the actors, the logical interfaces, and the step-by step actions involved in this information support.

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

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UC-Inter Relationship UC-F + UC-IA



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Operational Priorities

Utility and Microgrid Operators

Changing Priorities of RAS and DER Protection for Microgrids

Load-generation balance of the Microgrid		EPS Operator's interest under emergency conditions	Microgrid operator's interest under emergency conditions	Comments
Microgrid is load-rich	Microgrid is connected to EPS. The load import is greater than the Under Frequency Load Shedding (UFLS) in the microgrid (in the ranges of EPS UFLS)	Assign higher priorities to the UFLS within the microgrid and lower ones to the PCC. Keep the DER protection priorities even lower.	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	Objectives coincide. Microgrid needs to inform the EPS about the situation. EPS needs to confirm its settings.
	Microgrid is connected to EPS. The load import is smaller than the UFLS in the microgrid	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)	Assign higher priorities to the UFLS for the PCC and lower for the UFLS within the microgrid (the MG may lose less load)	Objectives are different; Microgrid can trade its support to EPS. Needs to inform the EPS about the situation. EPS needs to confirm its settings.
Microgrid is generation-rich	Microgrid is connected to EPS. The microgrid injects power into EPS.	Assign priorities to the UFLS within the microgrid with higher priorities than the DER frequency protection. No UFLS for the PCC.	UFLS for the PCC only with higher priority than the DER frequency protection.	Objectives are different; Microgrid can trade its support to EPS. Needs to inform the EPS about the situation. EPS needs to confirm its settings.

Source: *Narratives for use cases with integration of microgrids into EPS operations*, White Paper, Nokhum Markushevich, Smart Grid Operations Consulting (SGOC). February 2014.

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IEEE p2030.7

Standard for the Specification of Microgrid Controllers

On June 11, 2014 the IEEE SA Board approved the PAR (IEEE P2030.7), *Standard for the Specification of Microgrid Controllers*.

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 autonomously 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.

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FEEDER
Industry Training Session

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

Simplified MPQM Model

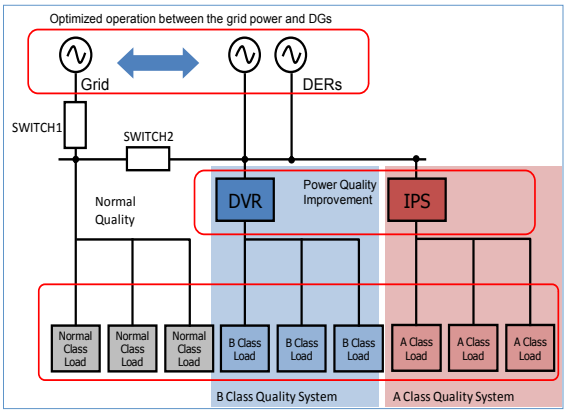
Configuration

Generation Facility

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

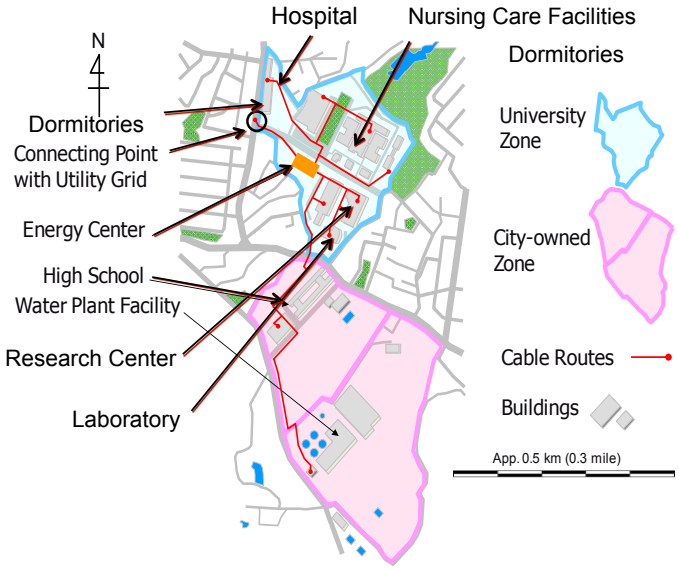
Switches

- 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



Power Quality Definition and Loads

Requirements	CLASS				
	DC Power	AC Power			
		A	B1	C	B3
Interruption	*NI*	*NI*	*< 15 ms*	*< 15 ms*	*< 15 ms*
Voltage Dip	*Y*	*Y*	*Y*	-	*Y*
Outage	*Y*	*Y*	*Y*	*Y**	-
Voltage Fluctuations	*Y*	*Y*	-	-	-
Voltage Harmonics	*Y*	*Y*	-	-	-
Voltage Unbalance	*N/A*	*Y*	-	-	-
Frequency Variation	*N/A*	*Y*	-	-	-

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

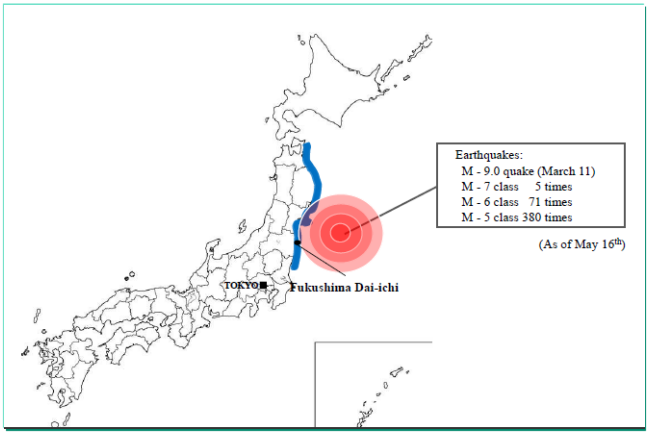
Power quality classes

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

Power quality classes and Loads

Great East Japan Earthquake

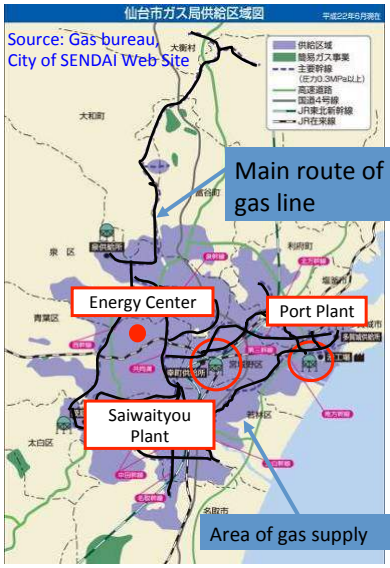
March 11, 2011



Power Supply Following Earthquake

Date in 2011	March 11	March 12	March 13	March 14
Utility Grid	▼14:47:10 Voltage collapse ⇨ Grid Outage			▼8:16:43 Grid Recover
	Grid Connection	Outage		Grid Connection
AC C	▼Disconnect	▼About 12:00 GE started. (Islanding operation)		
	Grid Connection	Stop	Islanding operation	Grid Connection
DC	Grid Connection	Supply from Battery	Supply from GasG	Grid Connection
AC A	▼02:06 Stopped manually			
	Grid Connection	Battery / Outage	Supply from GasG	Grid Connection
AC B1	▼02:06 Stopped manually			
	Grid Connection	Battery / Outage	Supply from GasG	Grid Connection
AC B3	▼About 14:00 Dispatch Start (for customer needs)			
	Grid Connection	Outage	Supply from GasG	Grid Connection
PV				

Gas Supply in SENDAI



Outline of the Gas Lines

~~Port Plant (Main Tank)~~ Devastated by the great earthquake and Tsunami.

Saiwaityou Plant (Reserve Tank)

[Medium-pressure Gas]

Loop style supply route

Energy Center

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.

FEEDER
Industry Training Session

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

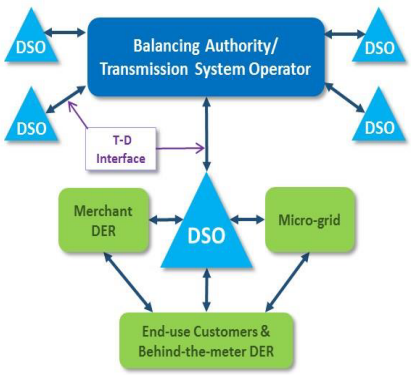
Microgrid Readiness

- 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

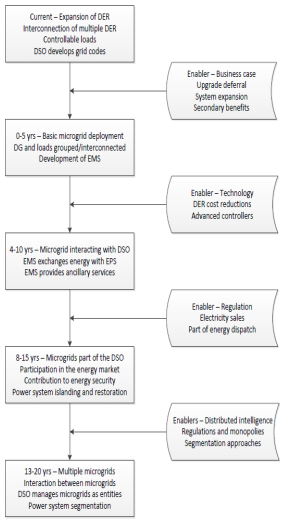
- DSO is responsible for providing reliable real-time distribution service
- A complementary mix of centralized and distributed resources including
  - generation, energy storage, power flow and stability control devices
  - control systems

Future "Integrated Distributed" Electricity System
(High-DER, Multi-directional energy flows & Multi-level optimizations)



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)