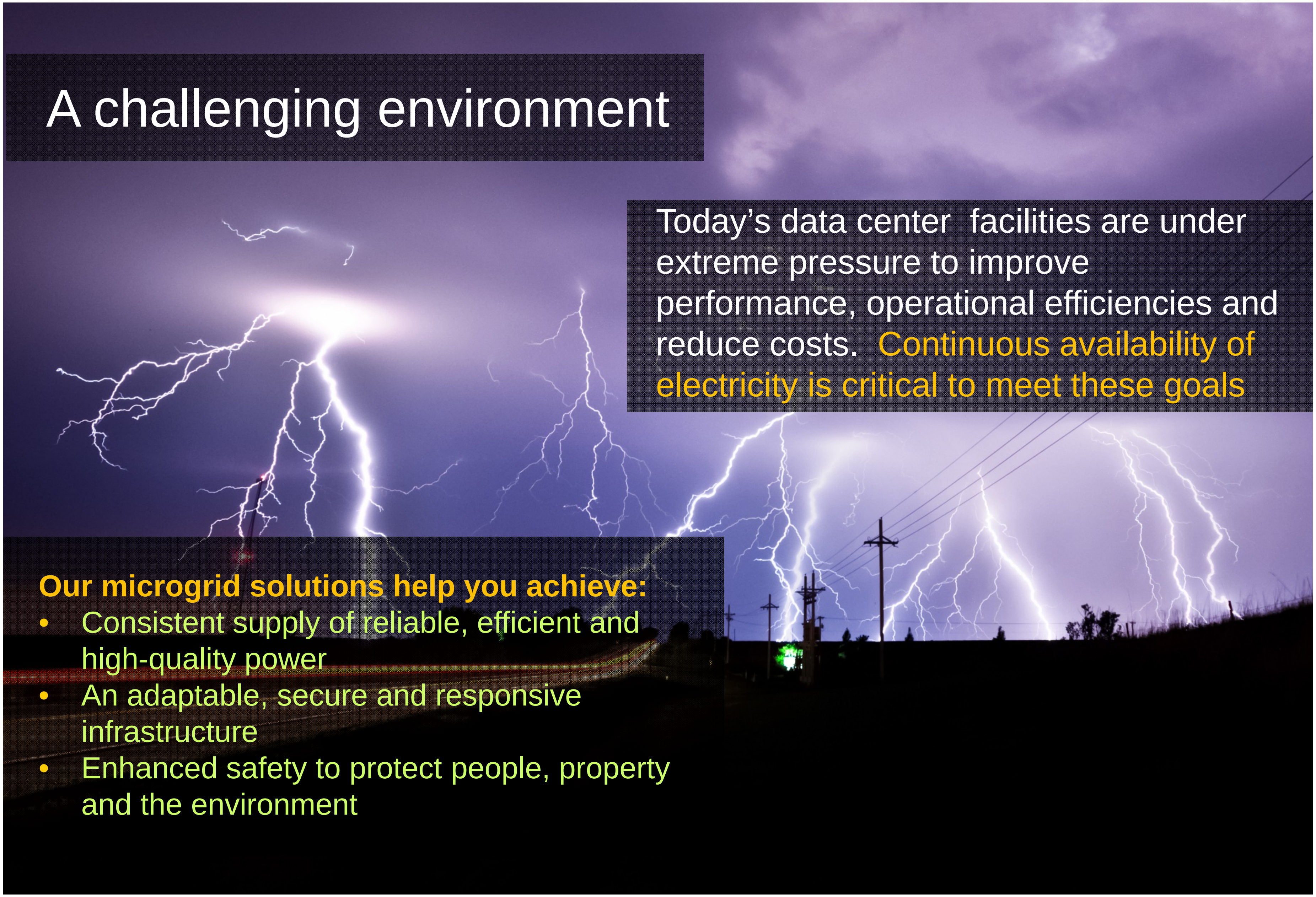
Eaton's Intelligent Grid Solutions Series
Microgrid & Energy Storage Systems for Data Center applications

7x24 Exchange New England Conference

June 1, 2016

Powering Business Worldwide

A challenging environment



Today's data center facilities are under extreme pressure to improve performance, operational efficiencies and reduce costs. Continuous availability of electricity is critical to meet these goals

Our microgrid solutions help you achieve:

- Consistent supply of reliable, efficient and high-quality power
- An adaptable, secure and responsive infrastructure
- Enhanced safety to protect people, property and the environment

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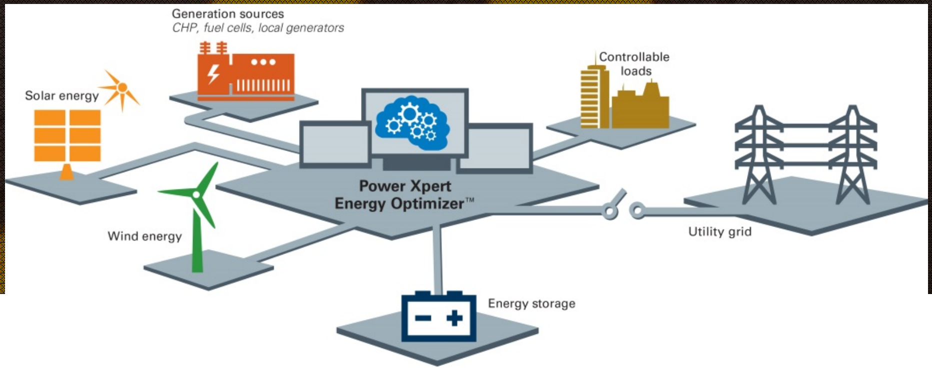
• Megatrends, MicroGrids & Segment Drivers



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Megatrends Impacting today's US power gird

Solar / Wind
Grid instability

Earthquakes

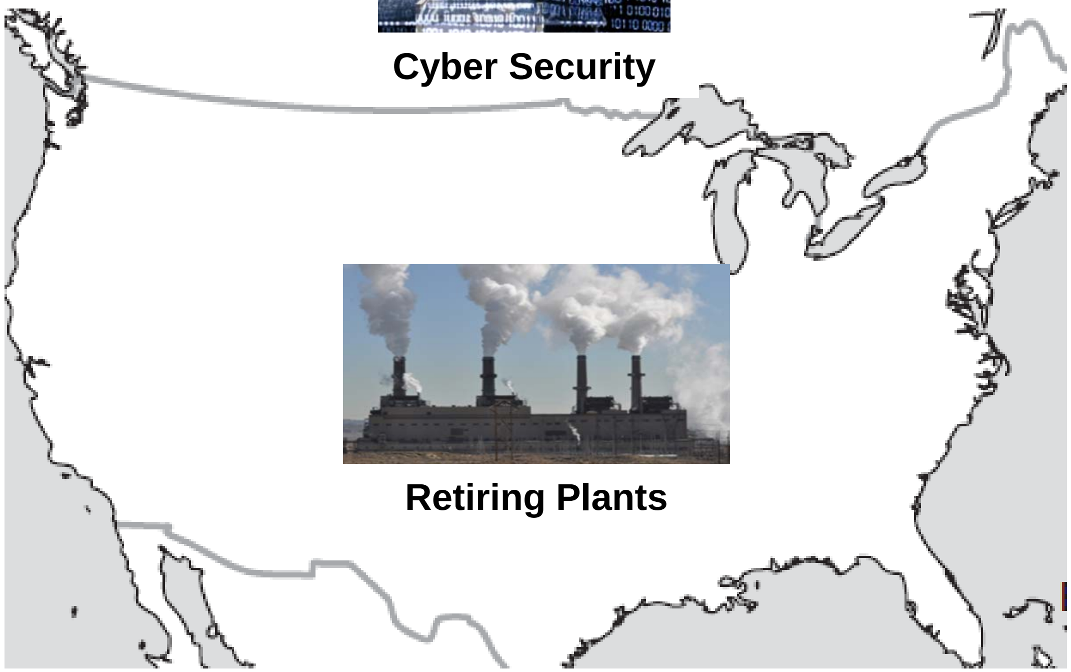
THE EVENING TELEGRAM

300,000 PEOPLE ARE HOMELESS

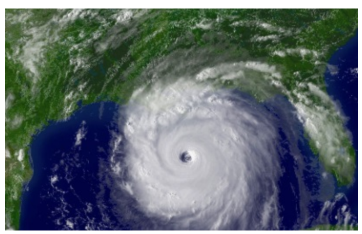
PORTLAND WILL SEND FOOD AND MONEY FOR DISTRESSED

Disasters

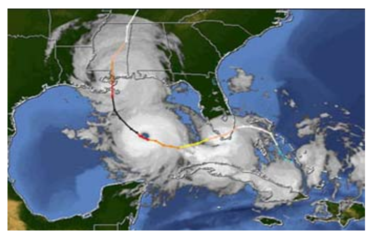
Cyber Security



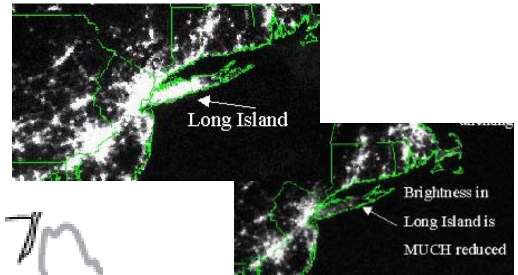
Retiring Plants



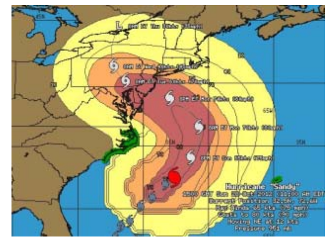
Storm Surge



Hurricanes



System Outages



Storm Surge

Aging Grid

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The last 5 Years: Summary…

“What happens if Hoboken goes dark? Mayor hopes a $50M microgrid will illuminate vital buildings”

HOBOKEN — Two years ago, all of Hoboken went dark, but city officials hope a $50 million microgrid will keep the city lit if another storm of Hurricane Sandy's caliber strikes.

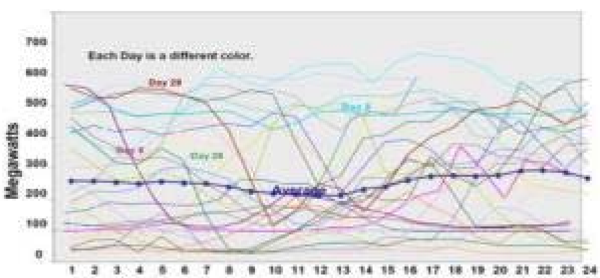
The city is hosting a series of expert panels Wednesday at Stevens Institute of Technology in hopes of sparking interest in financial backers for the $50 million project. The proposed microgrid would power roughly 50 buildings in the city in cases of mass outages.

Mayor Dawn Zimmer said that the microgrid would target emergency buildings— the police department, hospital and pharmacies— and the city's most vulnerable residents, such as senior citizens and the Hoboken Housing Authority.

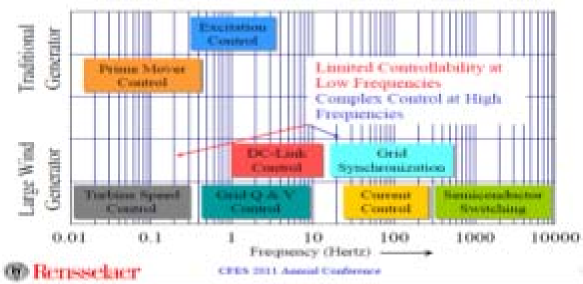
House Committee Meetings Started Sept. 10th, 2015

- 53 gained “Super-user” privileges on DOE computers.
- 19 successful attacks in 4 years on Nuclear Weapons Stockpile Computers

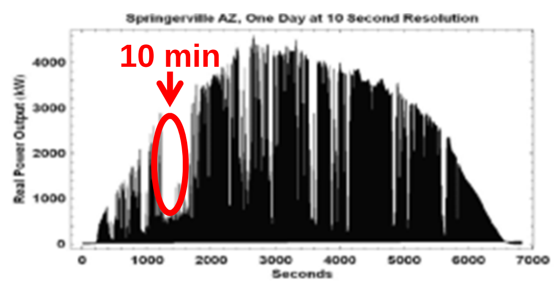
Renewables: Wind Profile



Wind Generator Control



Renewables: Solar Profile



http://www.rpi.edu/cfes/news-and-events/Seminars/06%20Sun.pdf

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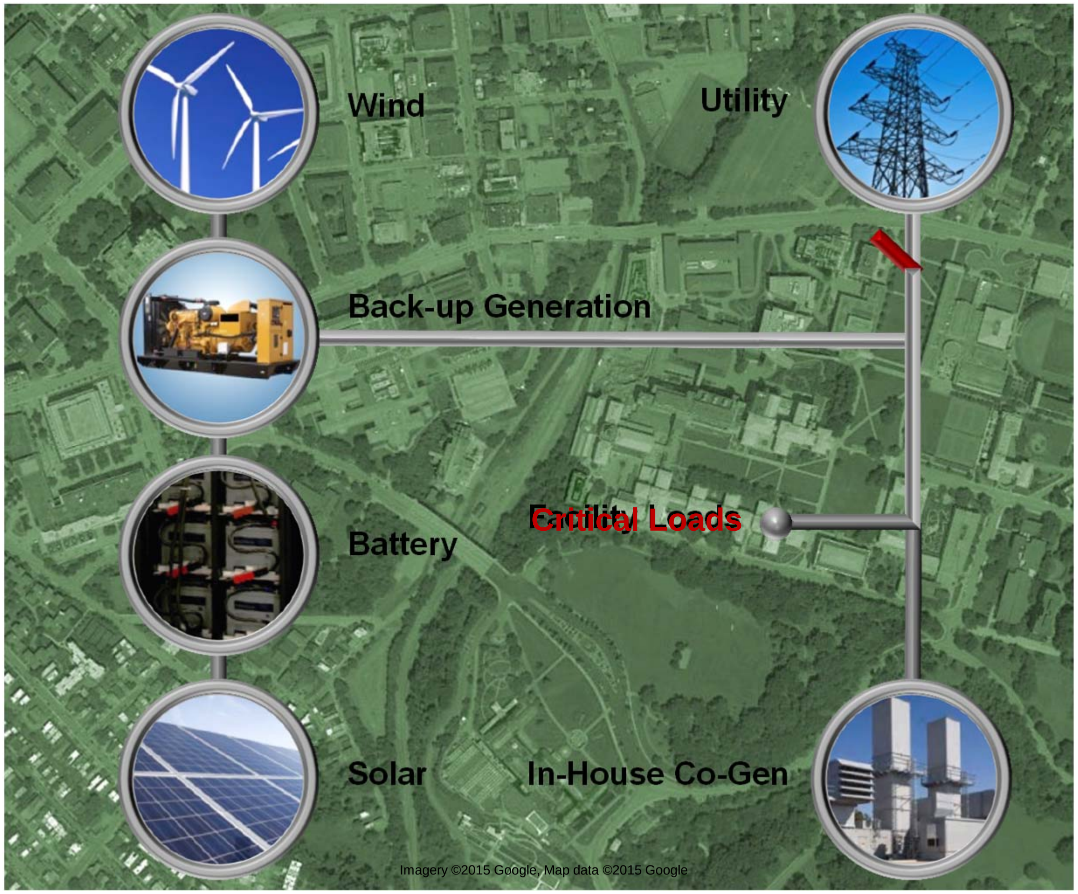
The microgrid energy system concept



A group of generating assets and defined loads that can operate within the utility grid or islanded from the grid, as a self-sufficient stand alone application

Local “Grid Within a Grid”

- Delivers Power Resilience, Reliability and Uptime

Distributed Energy Sources

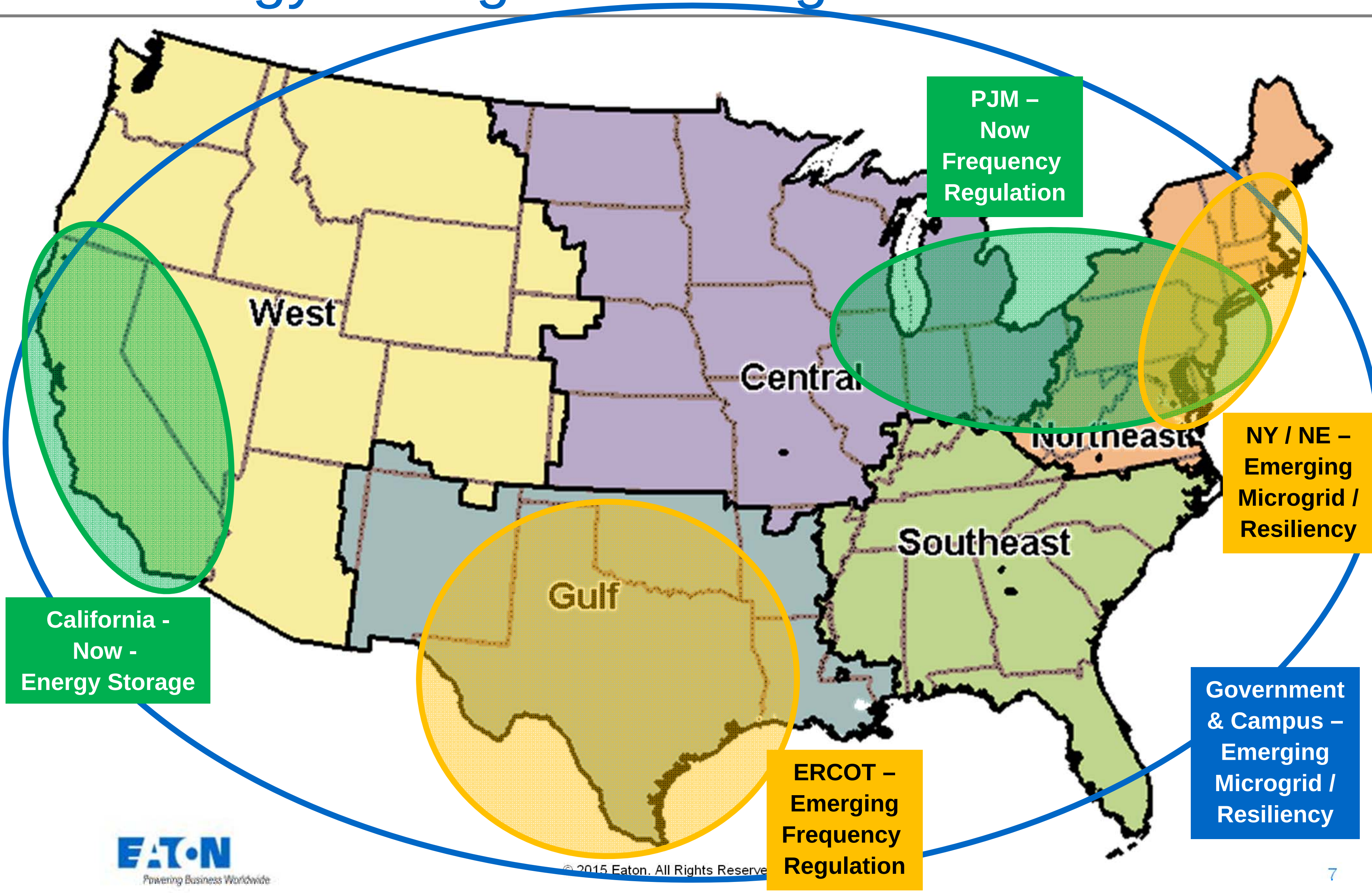
- Backup Generation
- In-House Co-Gen
- CHP (Combined Heat and Power)
- On-Site Renewables and Fuel Cells
- Energy Storage (Batteries)

Microgrid Applications

- Islanding & Synchronization
- Black Start
- Generation/Load Balance Control
- Battery Energy Storage & Frequency Regulation

Requires Control System “Glue” to Achieve System Performance

Other Applications: Early focus areas for energy storage & microgrids



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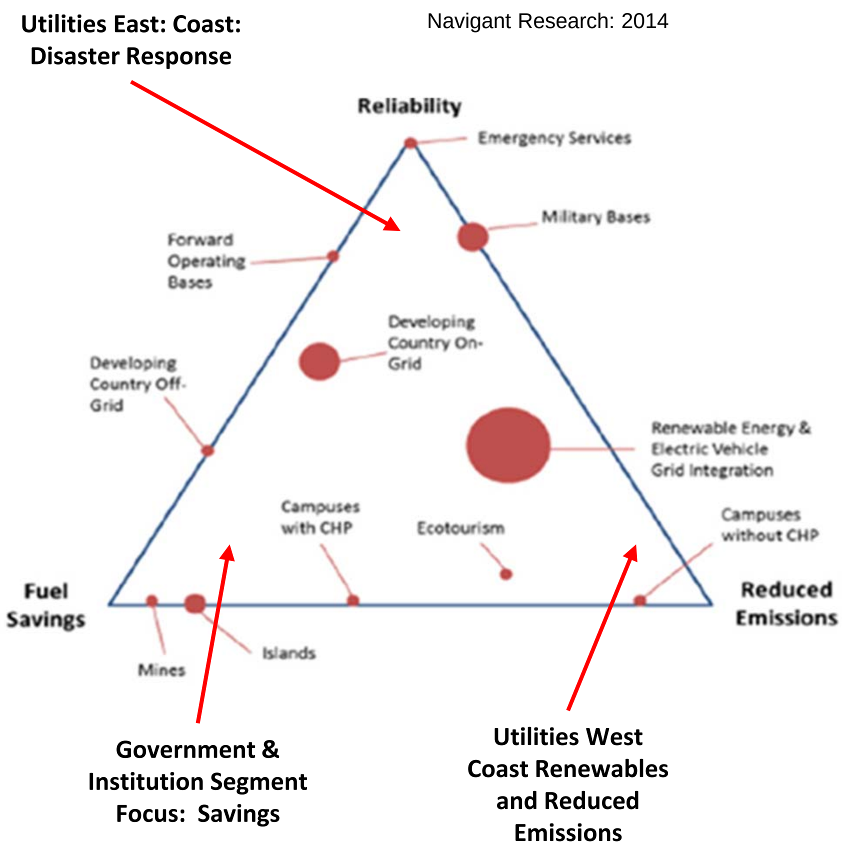
Market segments differ on their goals for microgrids and energy storage

Segment Goals



Microgrid/ES Business Cases

Driver	Description	Detail	Business Focus
Energy Storage Regulations	Fills need for grid storage to complement intermittent renewables	California AB 2514- IOUs to install 1400 MW by 2020 to mate with 33% RPS reg. 400 MW in 2015	California- Battery installations
Resiliency Regulations	Limits outages due to natural events (weather)	NY REV, numerous state programs & regs to implement microgrids	East Coast Sandy States- CT, Mass., NJ, NY, MD
Frequency Regulation	Supplants loss of coal-fired base load power plants	PJM- Wholesale price creates viable business case for short duration ES. ERCOT emerging	PJM territory- OH, PA, KY WV, VA, NJ; Ontario; ERCOT- TX
Dependency on imported fossil fuels	Need to embrace renewables to offset high fossil cost & environmental impact	Impacts remote and island grid environments using renewables and ES to minimize diesel use	HI, PR, AK, Canada
Need for energy surety and independence	Military and government drive for energy surety at key bases and facilities	Military bases and mission-critical facilities critical to national defense	DOD bases and key facilities

When looking for a microgrid solution

Integrated Solutions

Application Expertise

Foundation

Advanced Microgrid Energy System

- Scalable system across applications and segments
- Versatile interface & global high-speed communications standards
- Minimize custom engineering and support through system lifecycle
- Suite of optimization strategies meets microgrid goals across many segments
- Leverage existing utility-proven hardware/software platforms
- Ability to retrofit and embrace legacy infrastructure
- Full microgrid field support & consultation services

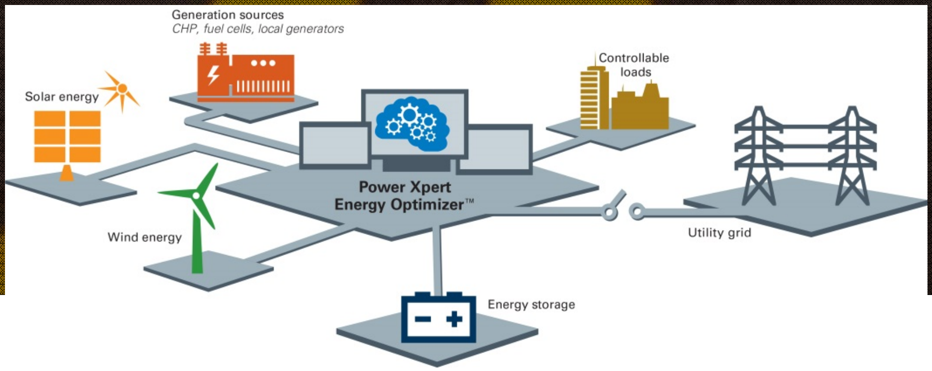
Extensive Utility Experience & Capability

- Deep microgrid application knowledge
- Power system engineering, advanced automation, and control
- Utility distribution and generation system design and planning expertise
- Project management and turn-key implementation
- National service organization & presence
- Extensive generation and distribution installed base

Full Product & Service Supplier

- Ability to leverage wide Eaton product scope into microgrid
- Utility distribution automation hardware, software, systems, services & planning
- Power transformers, reclosers, full utility distribution equipment line
- Low and medium-voltage switchgear, panelboards/switchboards, assemblies
- Generator paralleling switchgear
- PV and storage smart inverters

- MicroGrid Functions & Capabilities



Data Center industry drivers:

- Battery Grid Storage: energy stored in batteries can be used for benefits beyond traditional UPS applications, supporting behind-the-meter applications such as demand management, and utility ancillary services such as frequency regulation
- Islanding Capabilities: allow microgrid-protected commercial data centers to maintain power when the larger grid fails
- Reliability: Combined Heat and Power (CHP) as the scale of cooling requirements increases, additional reliable uninterrupted operation through extended periods of grid disruption is proving to be beneficial for long-range resilience.
- Power outages becoming alarmingly more frequent and widespread

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Microgrid Design and Use Cases

- Key Features

System Design

- Open Comm standards
- SCADA & enterprise interface
- Modular, Pre-engineered templates
- Legacy asset compatible
- Adaptable to future asset changes

Seamless islanding

- Unintentional (Seamless) islanding
- Fast grid-fault detection, isolation and safety interlocks
- Load shedding
- Source management
- Grid reconnection

Black Start

- Safety interlock for grid isolation
- Gen and renewable source start-up
- Paralleling sources
- Power Quality stabilization
- Load sequencing & management

Frequency & voltage control

- Islanded generator Freq. control
- Generation-demand balancing
- Supporting renewable dynamics
- Ramp rate control
- Ancillary services
- Energy storage

System Balance

- Generation and demand priority management
- Fast load shedding
- Dynamic demand response
- Dynamic energy storage management
- Protection and fault

Renewable optimization

- Smart inverter controls
- Energy storage integration
- Adaptive system to weather and price forecast
- Renewables maximization option to save fossil fuel

Lowest cost

- Utility Demand Response functionality
- Energy arbitrage
- TCO optimization
- Fossil fuel conservation
- Peak shaving
- Load shifting
- Conservative voltage regulation

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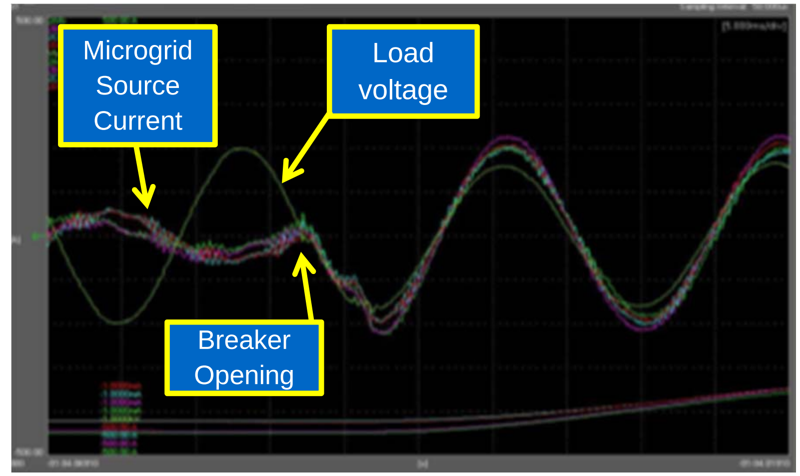
Microgrid Design and Use Cases
- Key Features

Seamless islanding

Immediate response to grid separation
- High-speed isolation from grid
- Block inadvertent reconnection
- Microgrid source outputs change to carry internal load
- Microgrid sources regulate voltage & frequency
- Excess load is shed to maintain stability



Sustained control
- Manage sources and loads to optimize stability and meet secondary targets (maximize renewables, minimize fuel consumption, etc.)

Return to grid
- Ensure stable grid supply
- Coordinate microgrid voltage and frequency to match grid
- Supervise resynchronization
- Re-balance sources & loads to achieve grid-connected targets

Intentional Islanding
Under certain conditions (e.g. severe weather) the microgrid may be islanded intentionally
- Microgrid sources and loads varied to achieve net-zero power flow from utility
- Microgrid intentionally isolates from the grid
- Microgrid sources provide voltage and frequency control

Microgrid Design and Use Cases

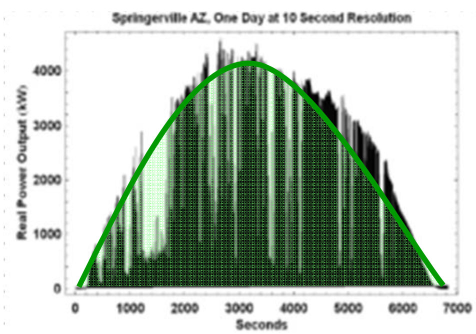
- Key Features

Black Start

Start Microgrid from “Black” state (no sources)

- Isolate from grid
- Block inadvertent reconnection
- Loads disconnected from sources
- First source started & connected, providing stable voltage & frequency to a portion of the microgrid
- Intelligent sequencing of additional microgrid sources and loads to maintain stability
- Transition to standard islanded operation

Renewable optimization



Renewable Optimization

- Sources within the microgrid (esp. energy storage) smooth variations in renewables
- Combined with storage and conventional generation, variable renewables become viable sources in islanded applications
- Smart inverter controls enable inverters to be used for Var / Voltage control

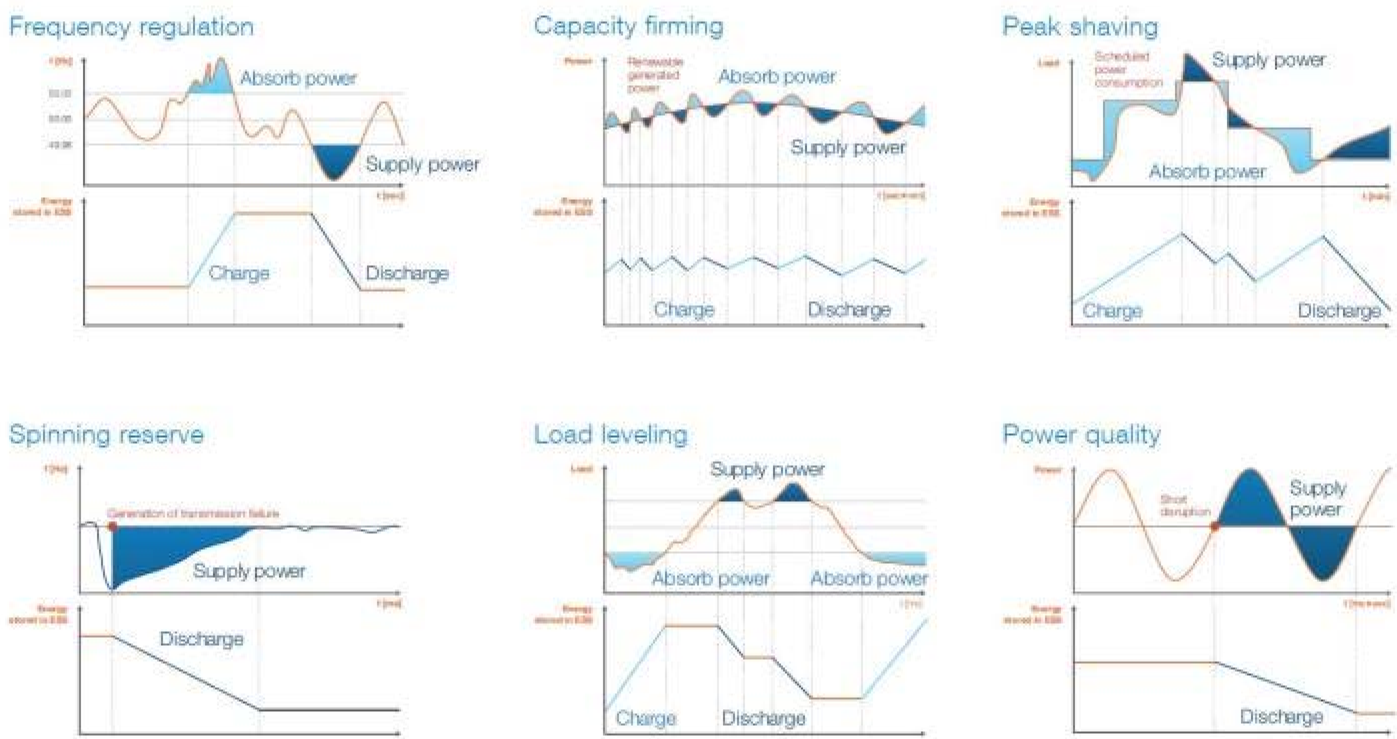
Microgrid Design and Use Cases
- Key Features

- Ancillary services
- Demand response
- Energy arbitrage
- Peak shaving
- Load shifting

A variety of sources combined with intelligent source and load control provides grid-tied functionality

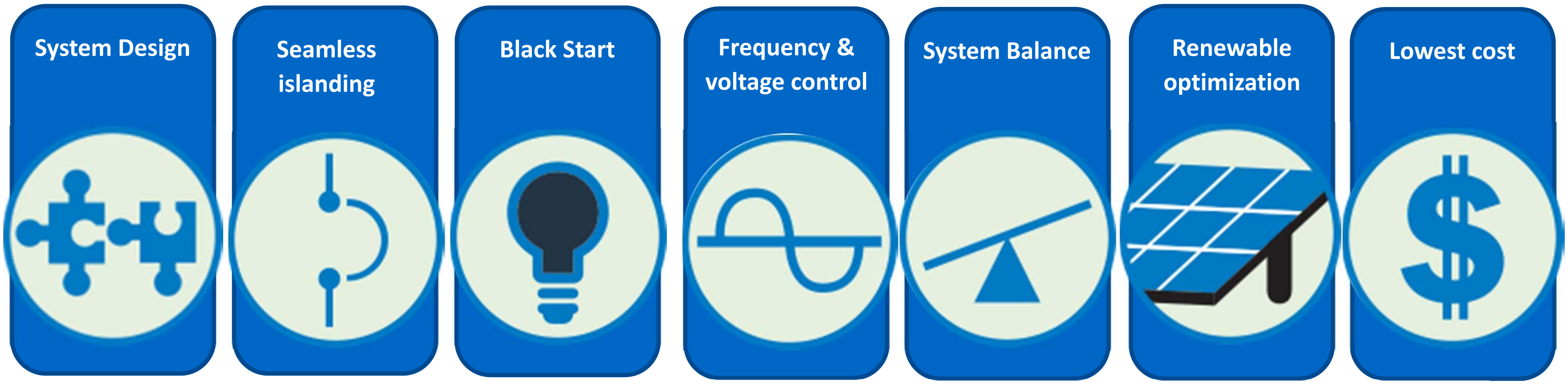
- Net Demand Response (combination of load shedding and generation sources)
- Net Demand Management (peak shaving, load shifting, load shedding)
- Energy cost optimization

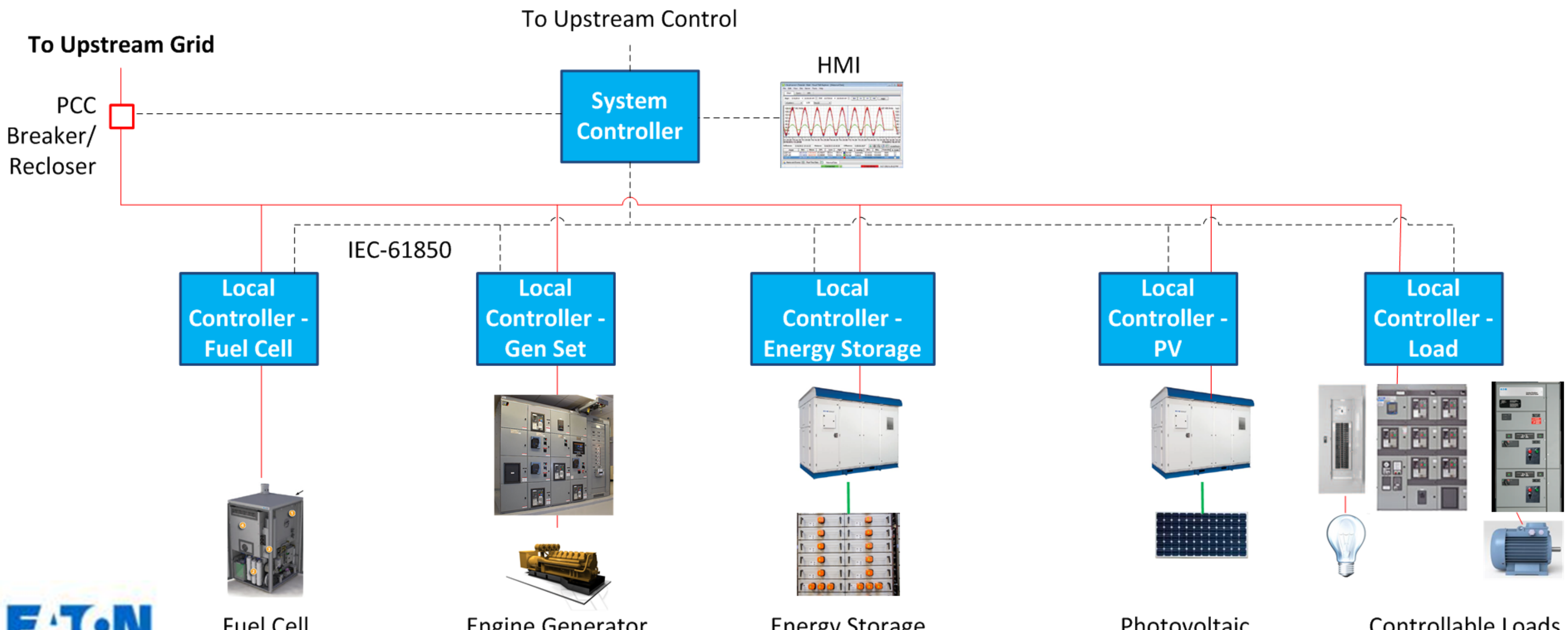
Microgrid sources, especially energy storage, have additional use cases:



Source: DOE Storage Handbook 2014

Microgrid Energy System (MES)



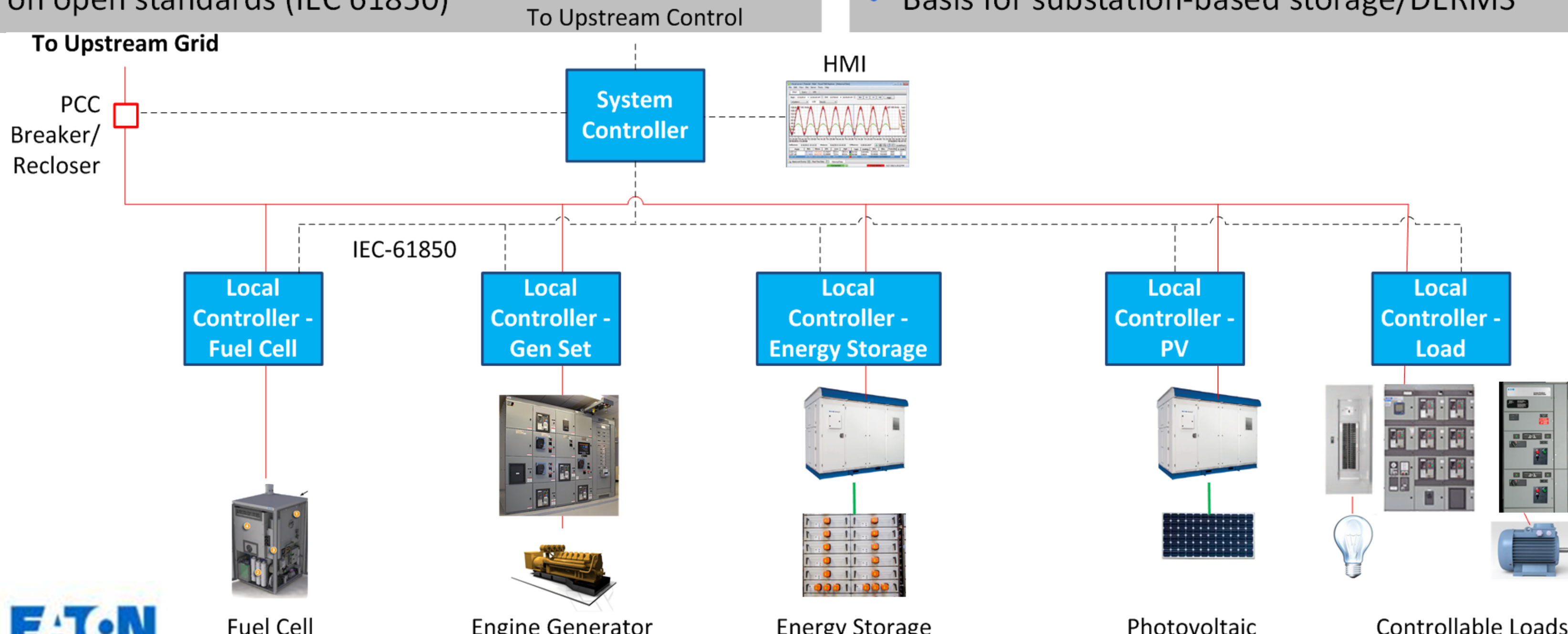


Microgrid Energy System (MES)

MES Design Basis

- Utilizes modular systems design
  - Repeatable gen. modules (templates)
  - Pre-format load options
  - Suit of pre-engineered optimization strategies
  - Standard set of displays / reports
  - Scale templates to match application
- Build on open standards (IEC 61850)

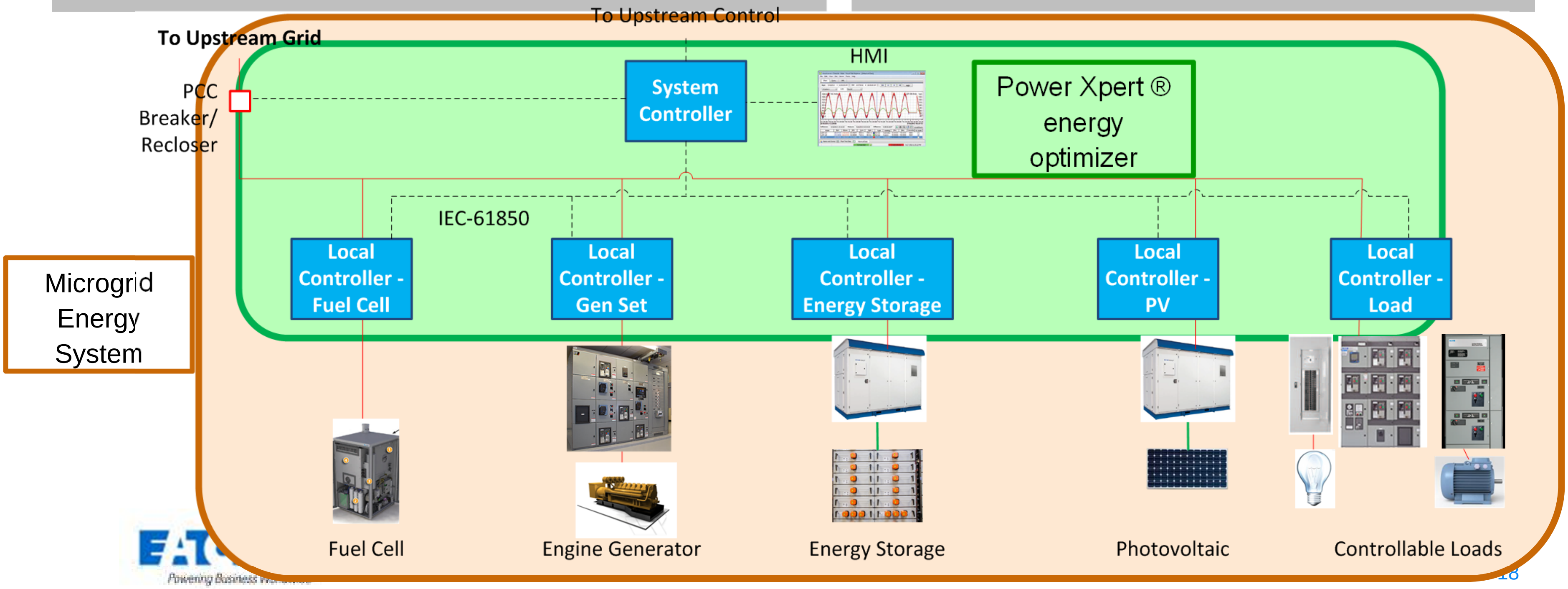
- Achieve a system architecture that's
  - 75% Pre-engineered
  - 15% App. configured
  - 10% Custom
- Offer customization as desired
- Full system simulation testing
- Basis for substation-based storage/DERMS



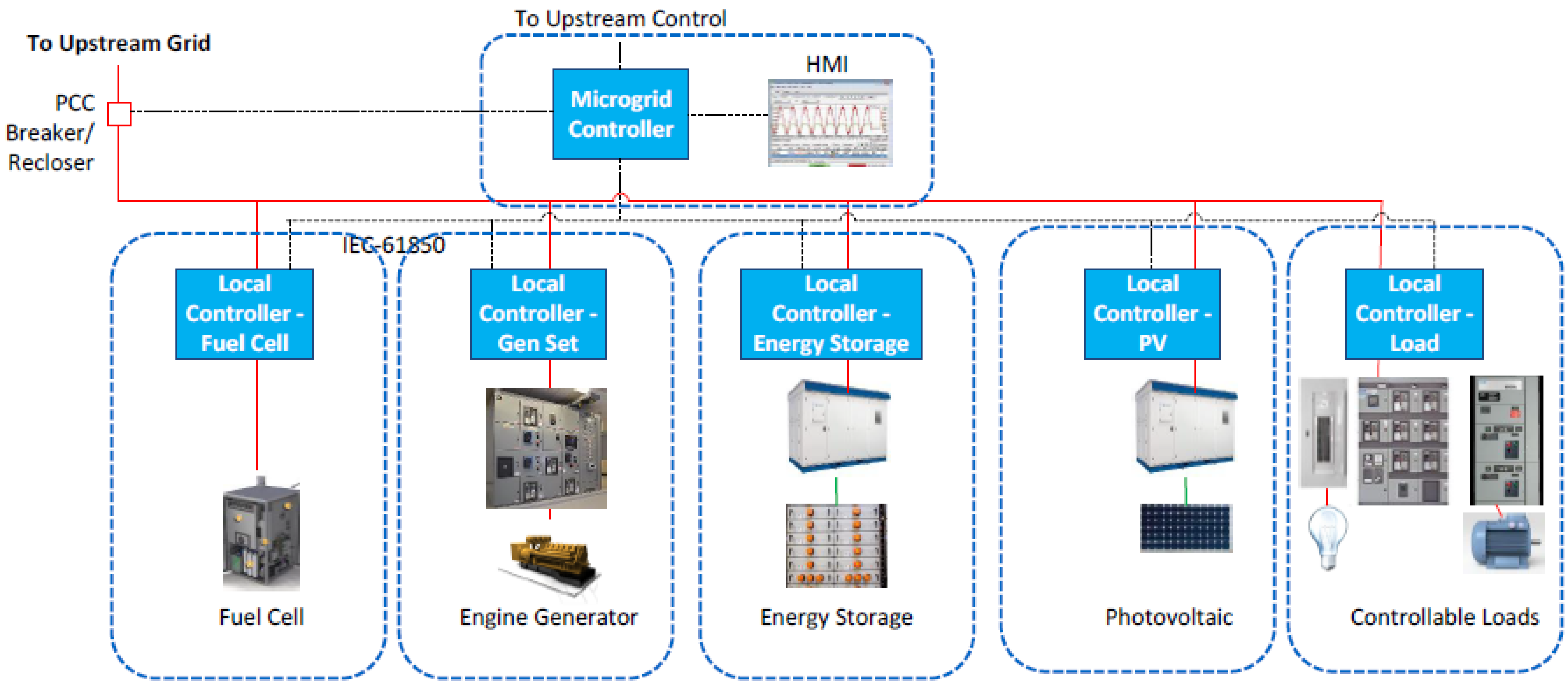
Benefits are significant

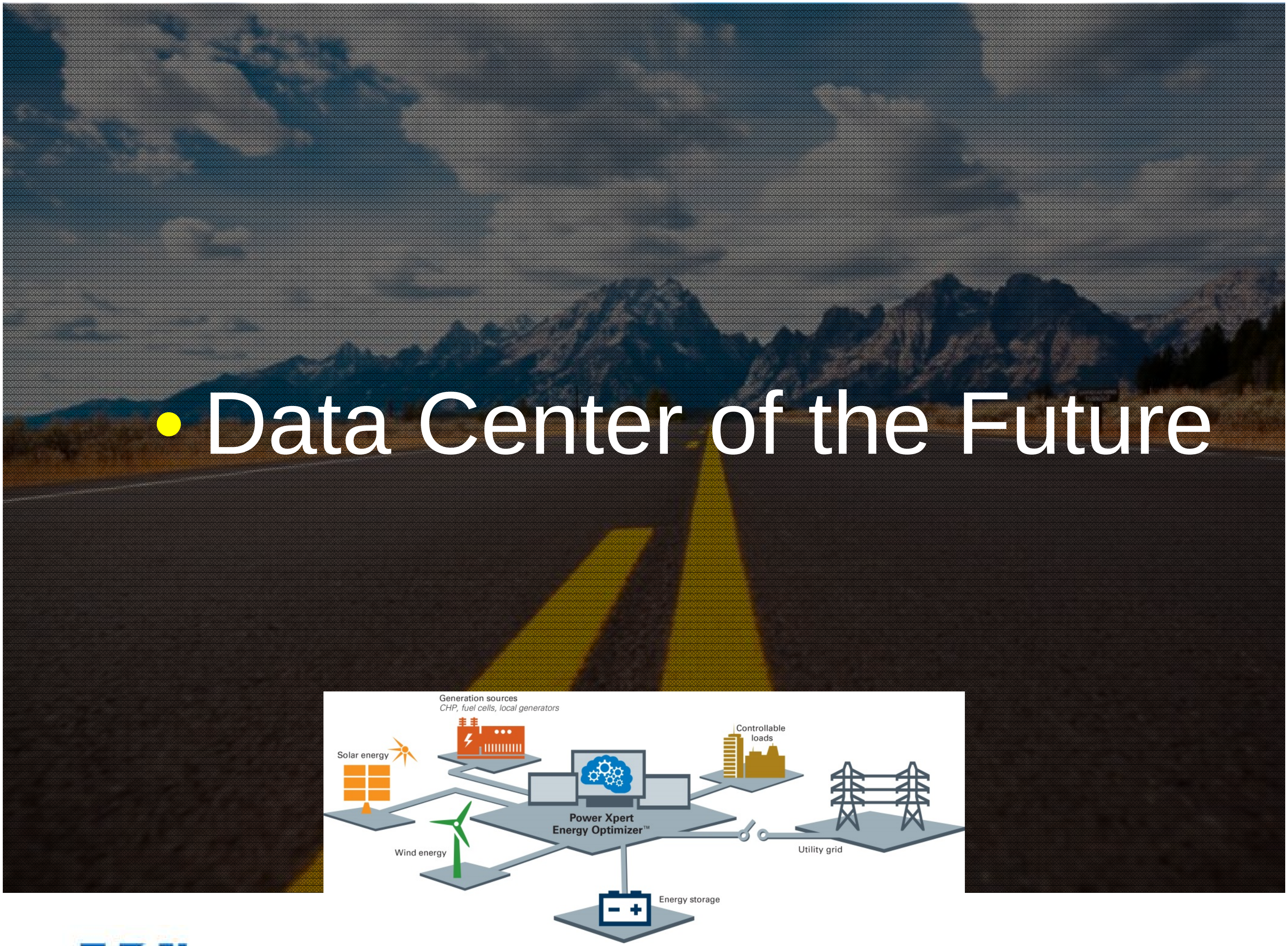
Customer Benefits

- Repeatable modules require less engineering, implementation and testing
- Improved overall cost effectiveness
- Shorter project cycles – Faster Turnkey Project
- High system quality and functional assurance from comprehensive system simulation & test
- Improved project confidence with less risk
- Flexible to be more easily reconfigured to reflect changing generation & load assets
- Easier to troubleshoot
- More efficient system support documentation & training
- Single point of responsibility
- Turnkey and full lifecycle support



modular approach supports the Cybersecurity Required Zones of Protection



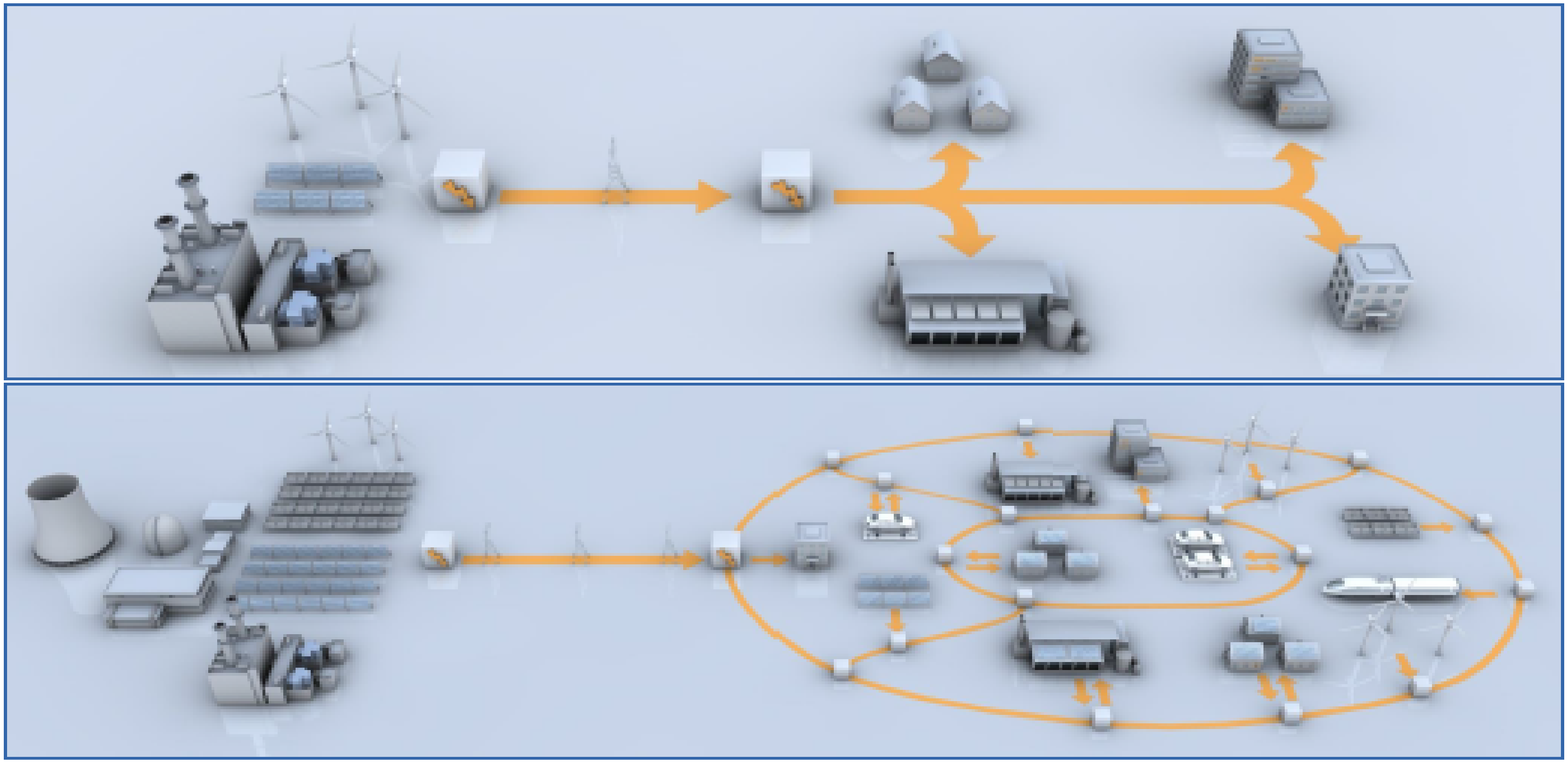

Data Center of the Future
Generation sources
CHP, fuel cells, local generators
Solar energy
Controllable loads
Power Xpert Energy Optimizer™
Wind energy
Utility grid
Energy storage

Capital Cost Shifting

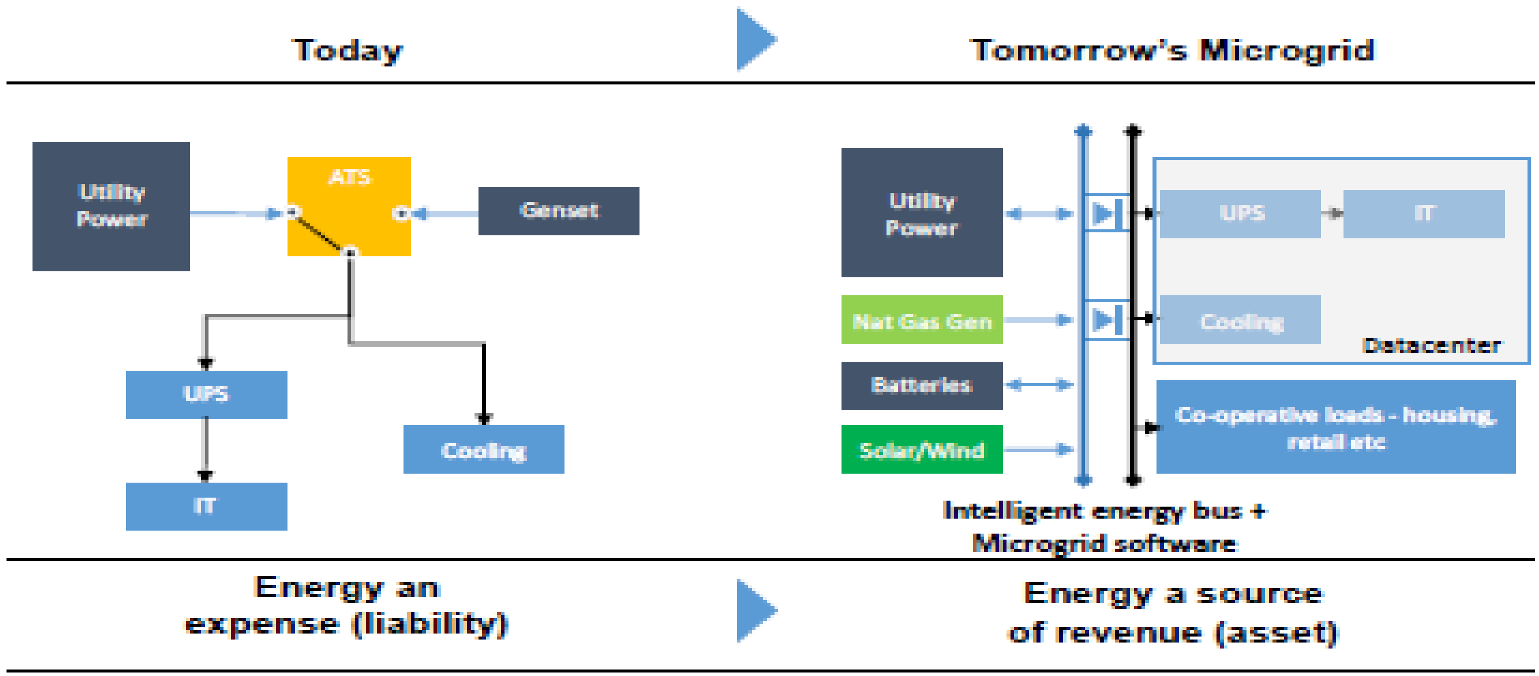
Traditional System	kWh Production	Proposed System	kWh Production	Green / Regulatory Compliance
Utility	Yes	Utility *Peak demand $$ *Load Shedding $$	Yes	Yes
UPS	No	PV / Inverter	Yes	Yes
Battery Plant	No	Advanced Batteries / Energy Storage	No*	Maybe
Standby Generator	No	Continuous Duty NG Generator / Turbine, Fuel Cell	Yes	Maybe (CHP)
Other	No	Wind Turbine	Yes	Yes

*Energy storage systems can be used for arbitrage, effectively offsetting utility costs during peak demand periods

Energy and Grid Transformation



So…. what does it look like



4 key benefits:

- Energy Security
- Power Quality
- Environmentally responsible
- Grid participation / revenue opportunity

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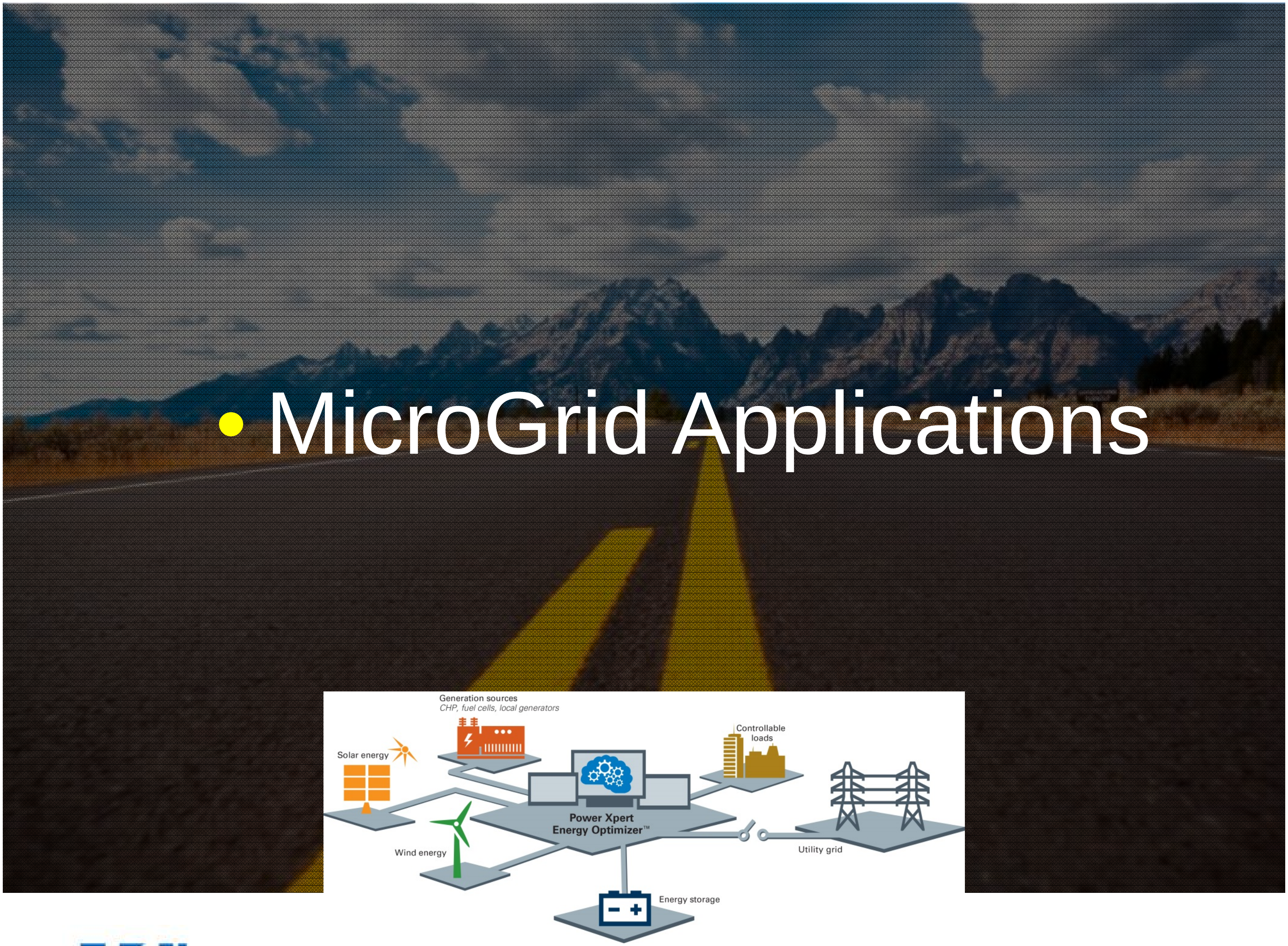
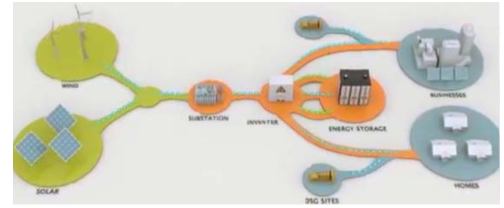
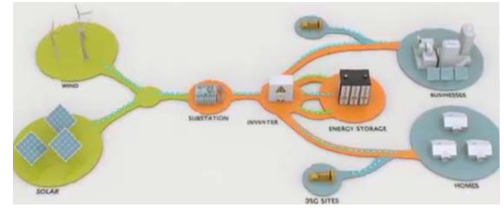
• MicroGrid Applications



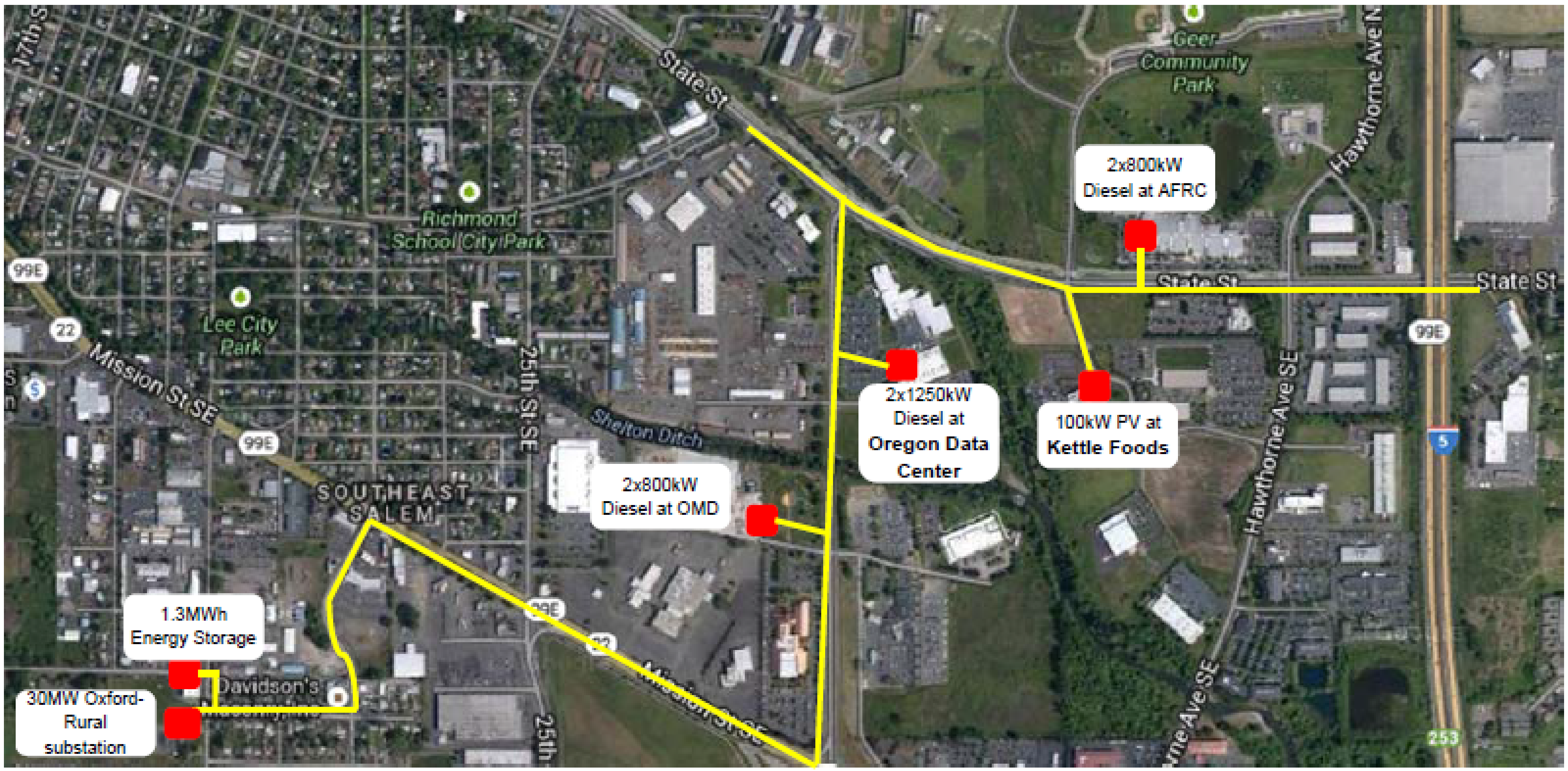
Portland General Electric MicroGrid



Portland General Electric MicroGrid



PGE Salem High Reliability Zone



The Yellow line is a 2.5 mile 12kV over head line

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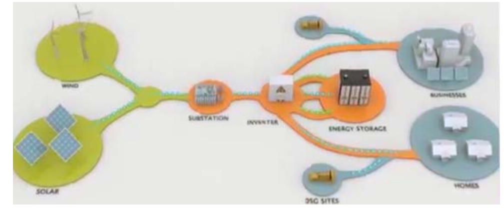
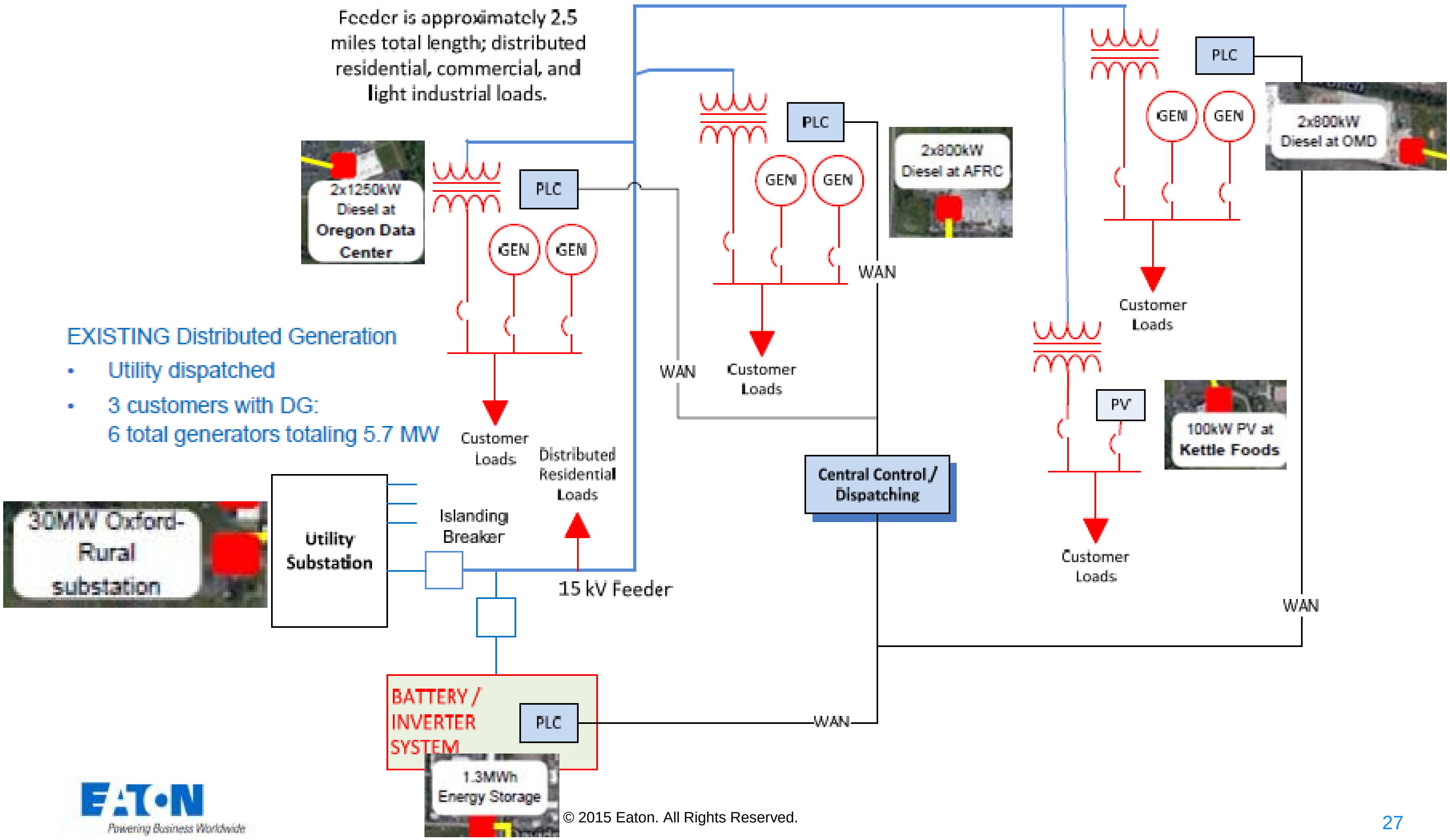
Portland General Electric MicroGrid



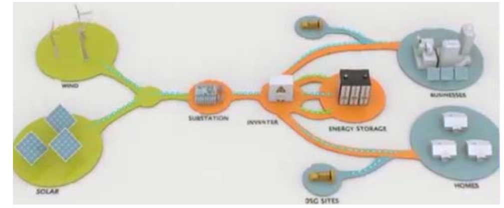
PGE High-Reliability Zone

EXISTING Distributed Generation

- Utility dispatched
- 3 customers with DG:
  6 total generators totaling 5.7 MW



Portland General Electric MicroGrid



PGE Battery Storage System

Batteries

- 1 MW / 1.25 MWh EnerDel Lithium-Ion Battery system with associated battery management system

Inverters

- 20 Eaton PowerXpert 250 kW PV inverters, adapted for battery storage application

Associated AC Power System

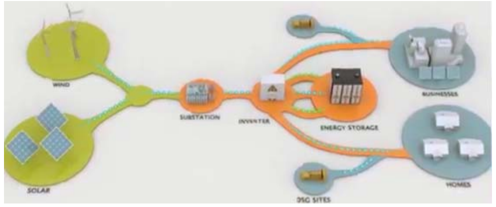
- Low-Voltage switchboards
- Step-up transformers
- Medium-voltage switchgear, metering, protection
- UPS (for control)

Storage Master Control System

- PLC-based control to coordinate and regulate operation of multiple inverters and battery banks and interface with utility control system

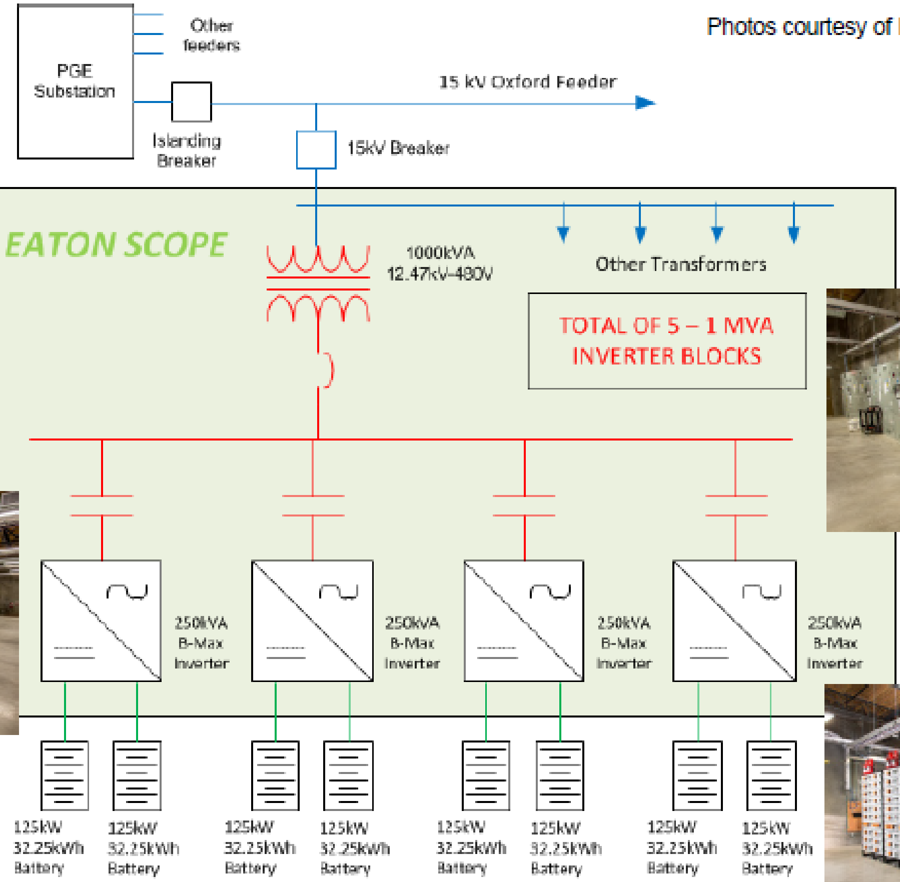
Photos courtesy of Portland General Electric

Portland General Electric MicroGrid



PGE Battery Storage System Architecture – Power

Photos courtesy of Portland General Electric



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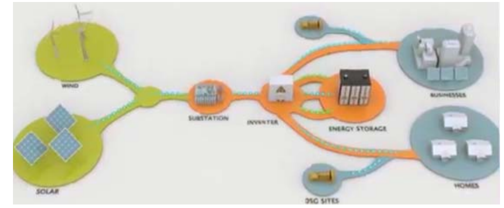
Portland General Electric MicroGrid



PGE Feeder Advanced Storage Transaction

5MW Inverter System

5MW Li-ion Batteries

Focus: High reliability (ability to detect faults and island a medium voltage feeder)

Breakthroughs:

1. Seamless transition from utility to battery with standard medium voltages switches (No static switch as in a UPS).
2. A dynamic load sharing of a number inverters (20) and transitioning to the island

Some highlights of the project:

1. Testing and evaluating the Li Ion batteries with rapid charge discharge cycles operating within limits
2. Understanding safe management of batteries and inverters
3. Communications between a large number of batteries and inverters

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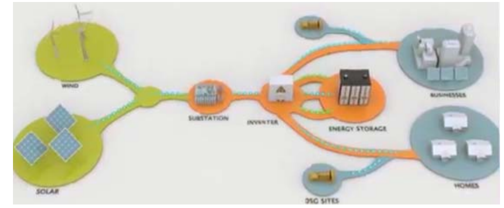
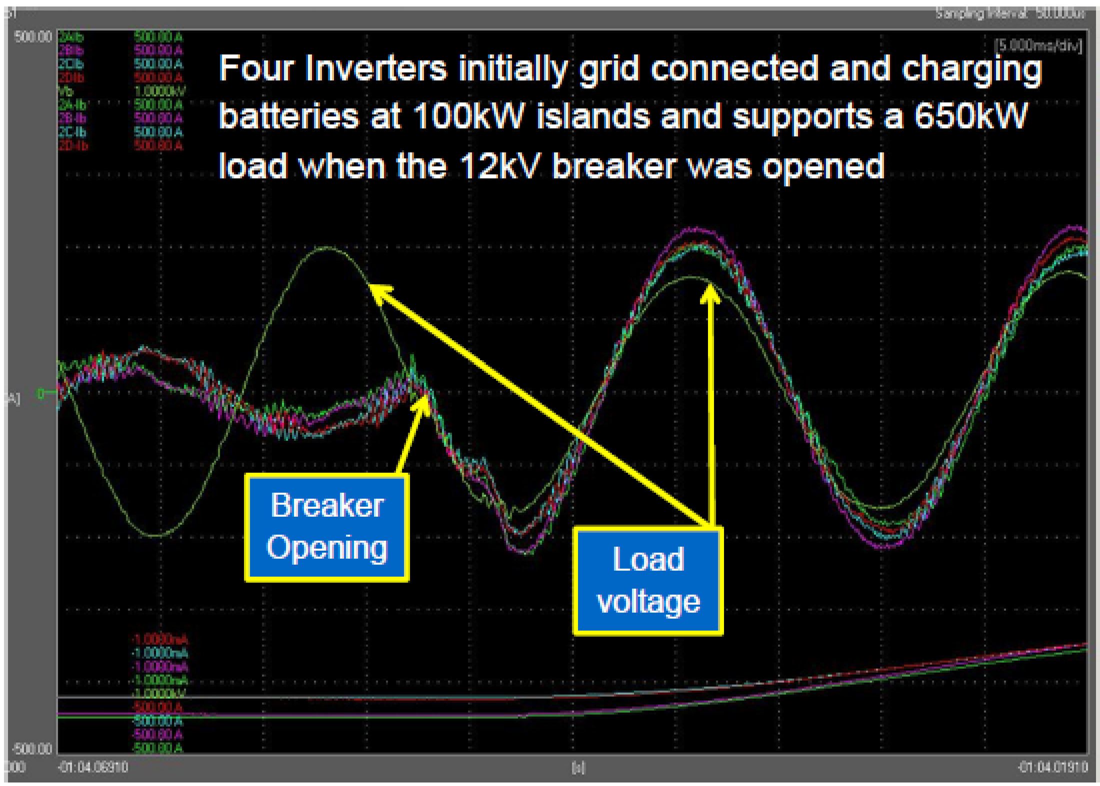
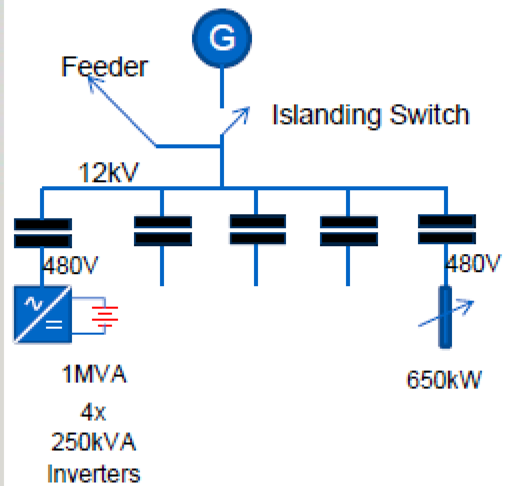
Portland General Electric MicroGrid



Islanding – Captured Waveforms





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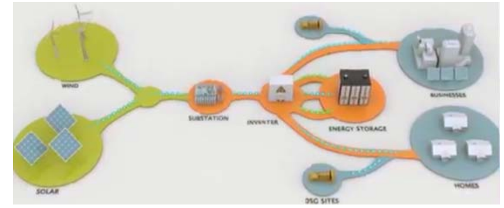
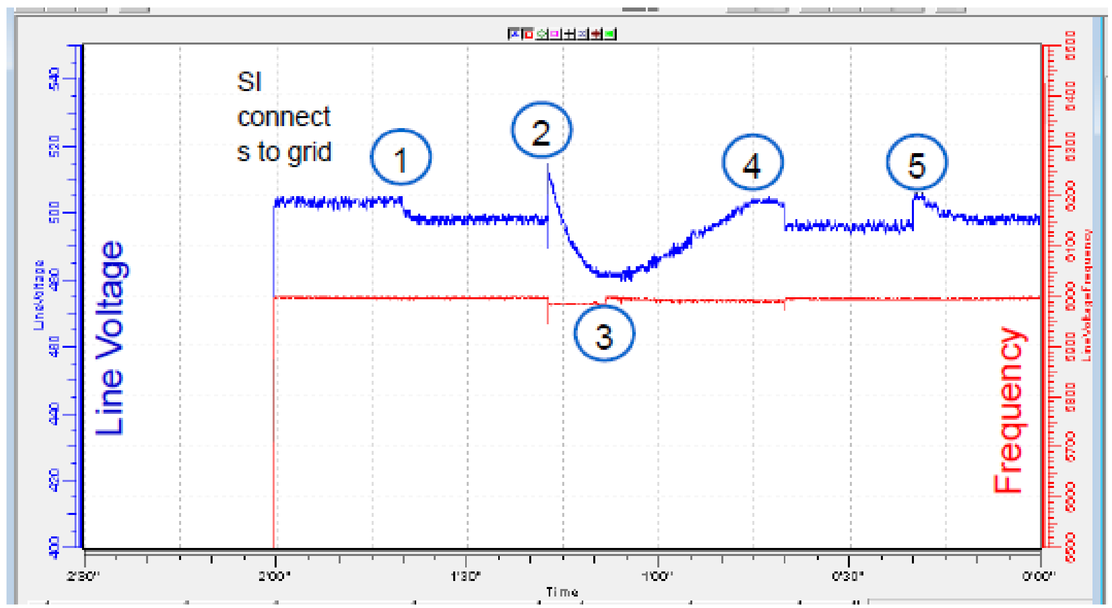
Portland General Electric MicroGrid



Un-intentional Islanding and Return to Grid

1. SI connects to grid and charges battery
2. A grid-loss event occurs and MISS opens. SI maintains frequency and voltage
3. Utility returns and ISO controller provides frequency and voltage correction signals to SI
4. SI with ISO synch to grid and close MISS
5. SI charges battery

Voltage and Frequency Data Captured During an Storage Inverter Unintentional Islanding



SI: Storage Inverter
MISS: Microgrid Interconnection Static Switch
ISO: Intelligent Switchgear Organization

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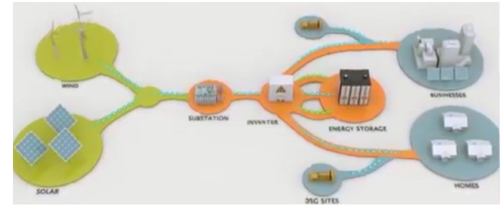
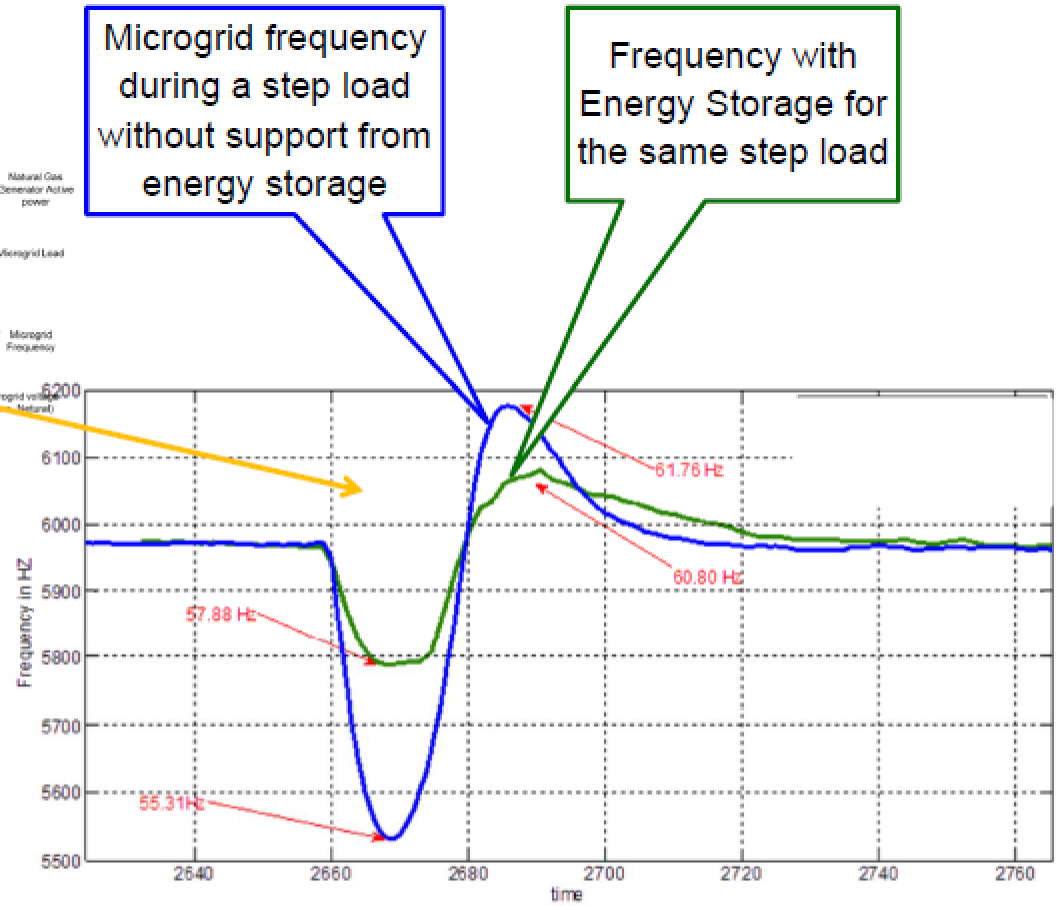
Portland General Electric MicroGrid



Frequency Support in Microgrids



Without support

Frequency drop 4.41Hz

Frequency overshoot 2.02Hz

With Support

Frequency drop 1.84Hz

Frequency overshoot 0.8Hz

MicroGrid example chiller plant

Project Focus: Energy Surety / Resiliency for a military campus

Solution developments:

1. Manage multiple generation sources – natural gas generators, solar pv, wind, battery storage
2. Optimized capital and operating costs via microgrid system design
3. Seamless islanding and reconnection to the grid

Eaton provides the "glue" to seamlessly connect and island the microgrid

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