Energy Storage at Duke Energy

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Emerging Technology Office

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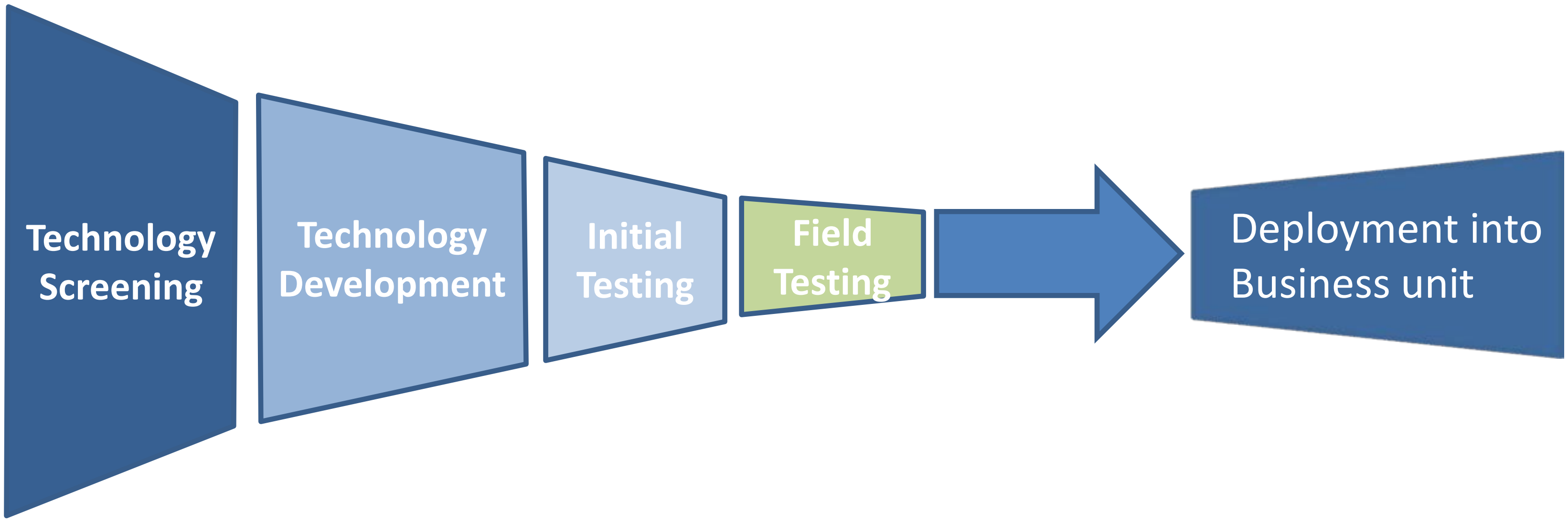
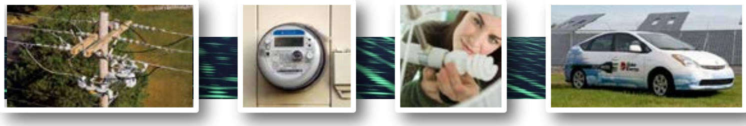
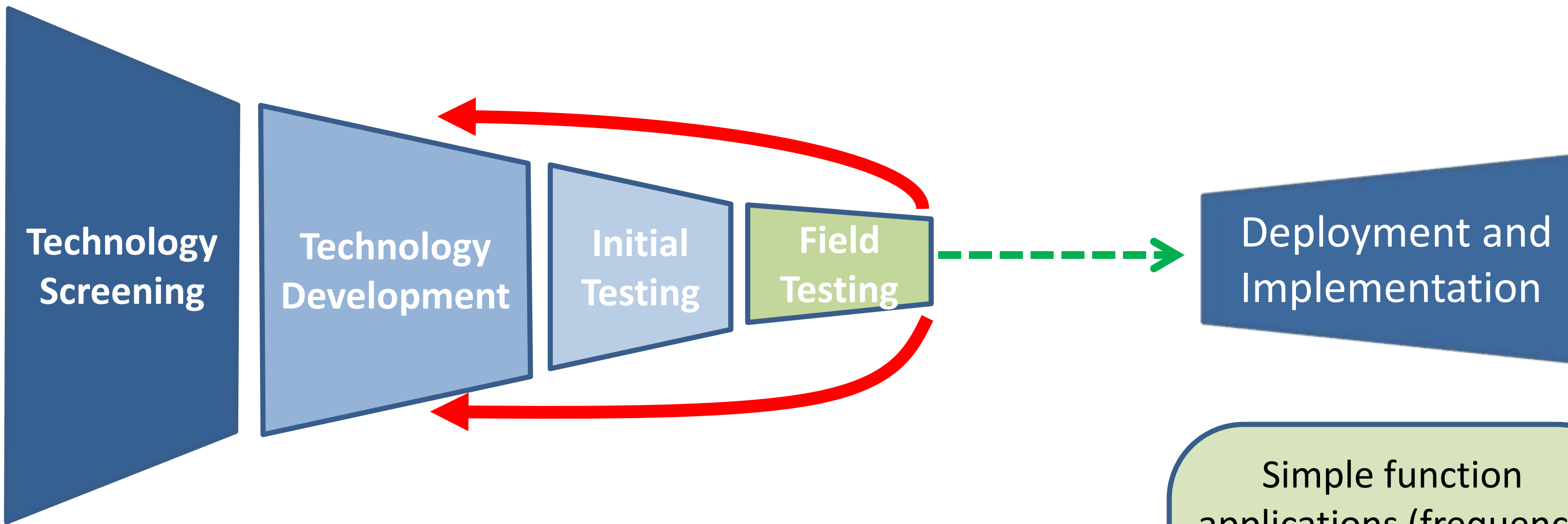
ETO Technology Screening Funnel



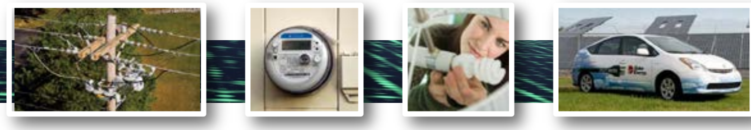


Energy Storage Current State



Integration of Energy Storage into the vertically integrated utility ecosystem to maximize value is still <u>under development</u>

Simple function applications (frequency regulation) have started to be deployed in certain markets (ie. PJM, ERCOT, CAISO) – Duke Energy's Notrees' Project



Energy Storage Benefits

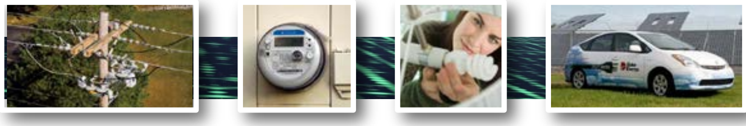
Generation	T & D	End User
Frequency Regulation	Defer System Upgrades	Provide Back Up Power
Renewable Smoothing	Improve Reliability	Utilize lower retail rates
Energy Shifting	Renewable Smoothing	
Spinning and Non-spinning Reserves	Improve Power Quality (Volt / VAR management)	
Limit Peaker Plant Builds		

Through pilots we understand…

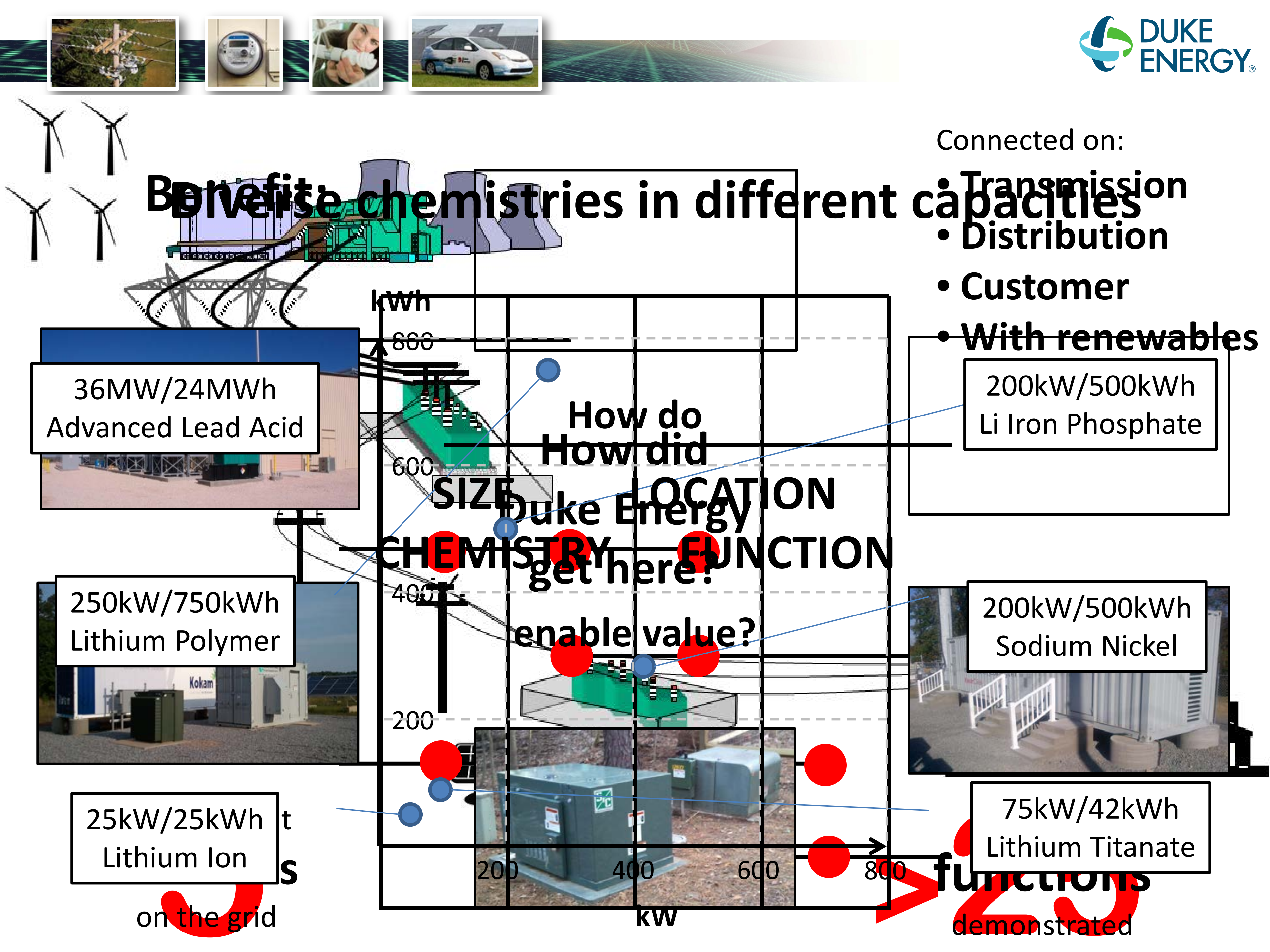
Capital Costs
O & M Costs
Installation Hurdles
Operational Issues
Value Streams

…to develop

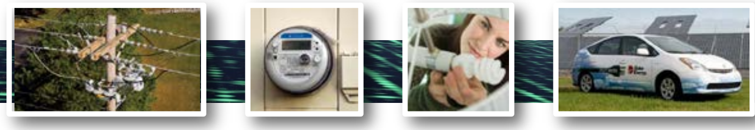
Business models
Regulatory models
Understand benefits



How did Duke Energy get here?



DUKE ENERGY
Benefits:
Diverse chemistries in different capacities
Connected on:
• Transmission
• Distribution
• Customer
• With renewables
36MW/24MWh
Advanced Lead Acid
250kW/750kWh
Lithium Polymer
25kW/25kWh
Lithium Ion
on the grid
200kW/500kWh
Li Iron Phosphate
200kW/500kWh
Sodium Nickel
75kW/42kWh
Lithium Titanate
functions
demonstrated
kWh
800
600
400
200
200
400
600
800
kW
How do
How did
Duke Energy
get here?
enable value?
SIZE
LOCATION
CHEMISTRY
FUNCTION



Notrees Wind Farm Project

Notrees, TX

Major system components:

- 36 MW / 24 MWh
- Xtreme Power Advanced Lead Acid Technology
- Co-located at site of 156 MW Wind Farm in Notrees, Texas
- Began commercial operation in December 2012
- 50:50 Cost share with DOE

Applications being tested

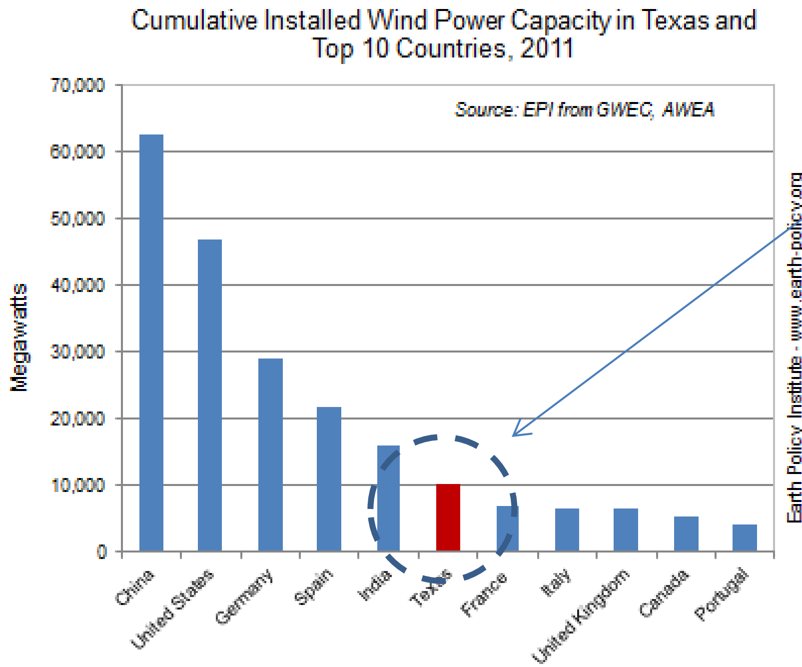
1 – Ancillary Services: participating in a series of ERCOT (Texas ISO) market tests to learn how to structure an efficient market that enables energy storage to provide ancillary services to the grid.

2 – Energy Shifting: Charging and discharging to maximize the value of energy delivered to the grid based on timing.

3-Avoiding Wind Curtailment : Using storage to store wind energy in order to avoid orders to cease providing power to the grid.

Example: Texas and ERCOT (Electric Reliability Council of Texas)

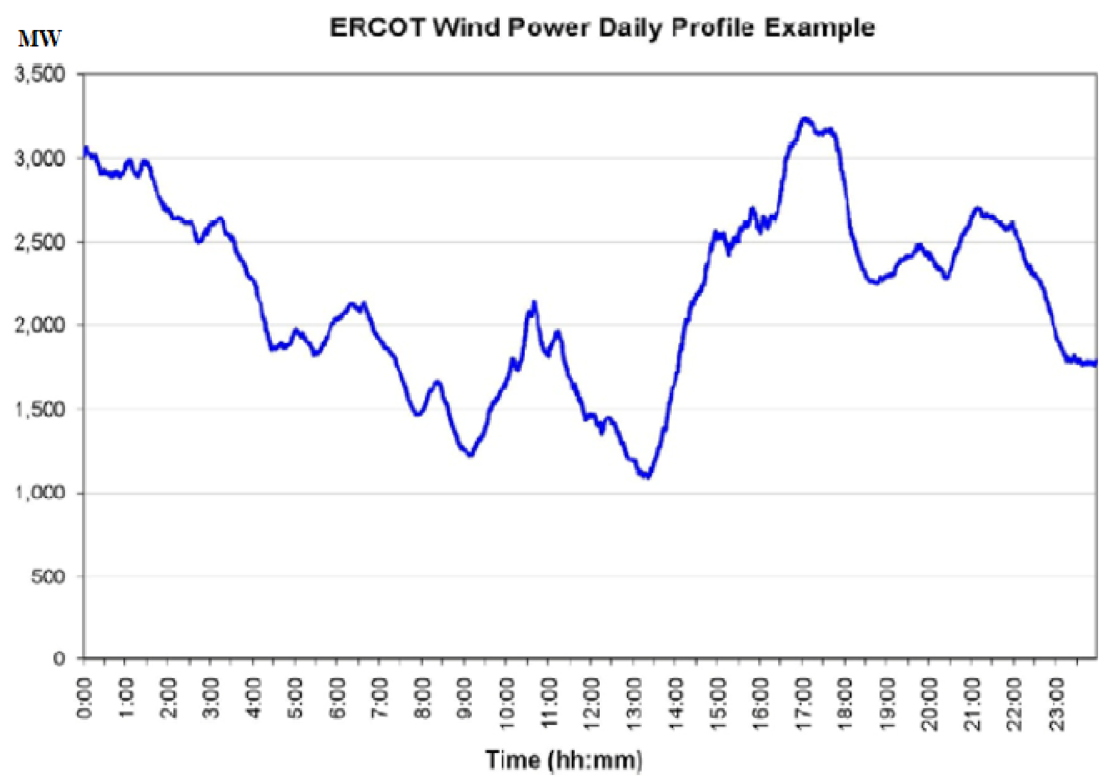
- Texas has seen a large amount of wind growth over the past 10 years.
- This has the created the need for fast responding resources such as energy storage to help stabilize the grid



Texas alone has more wind than France.

Example of Daily Wind Output in ERCOT

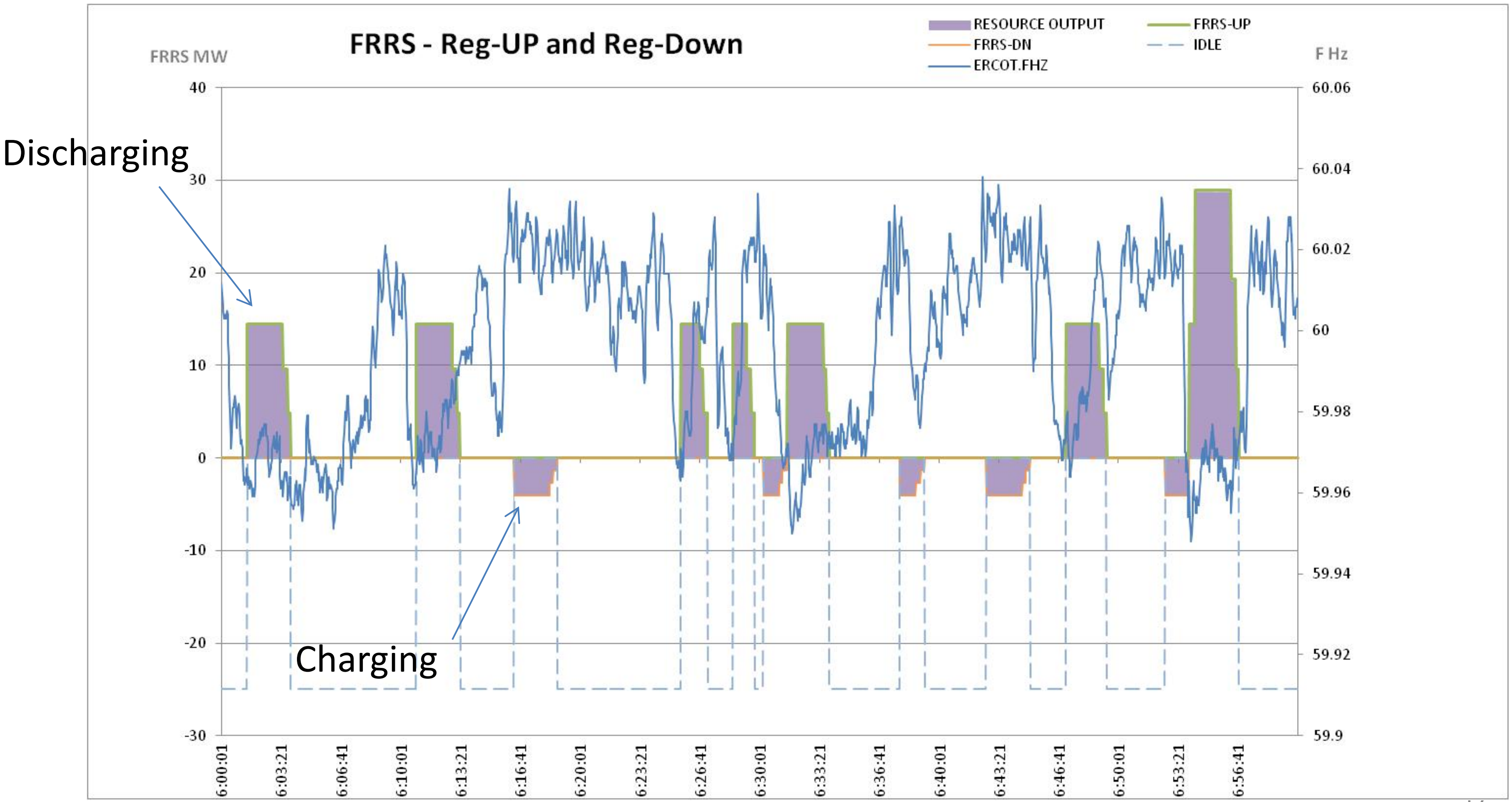
Wind is highly variable (the graph to the right shows a daily wind profile in Texas) which makes balancing supply and demand very difficult. Fast responding resources such as battery energy storage can help solve this problem.



(from NREL's *Analysis of Wind Power Ramping Behavior…*)

Example of Battery's Output and Response Time

Duke Energy's 36 MW / 24 MWh battery charging and discharging based off market signals to help with grid stability



McAlpine Energy Storage System

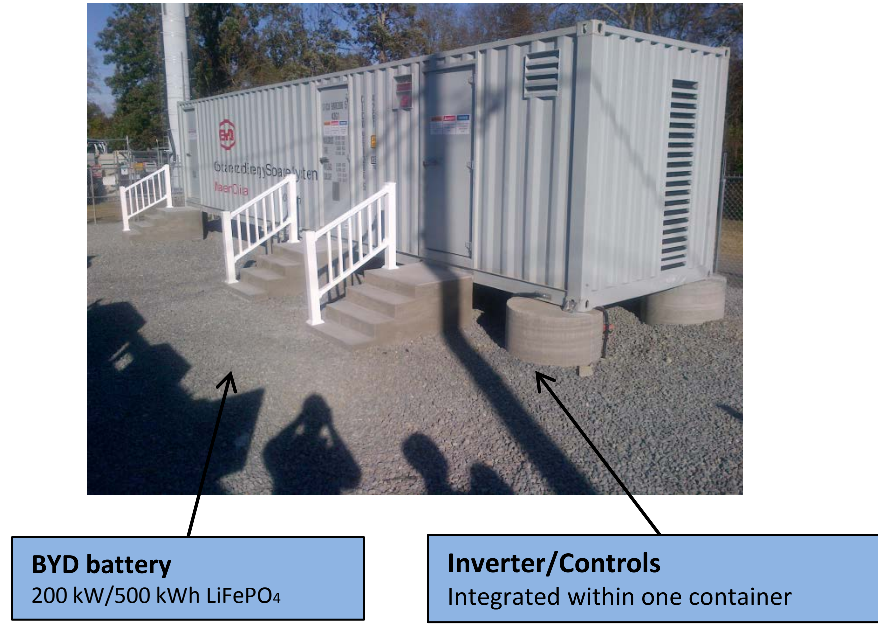
McAlpine Creek Retail Substation, Charlotte, NC

Major system components:

- 200 kW / 500 kWh system capacity
- BYD battery and inverter system
    - All components integrated within on container
- Lithium-iron-phosphate battery (BYD)

Interconnection:

- Located on a 24 kV distribution circuit
- Interconnected immediately outside of the substation
- Adjacent to 50 kW solar facility on McAlpine test circuit



System attributes

- In service 4Q 2012

- Interconnected next to a 50 kW solar facility in a planned islandable micro-grid scheme that will use the battery for grid frequency/voltage regulation.

Applications being tested

1 – consolidated inverter/battery construction at a low price

2 – energy shifting applications

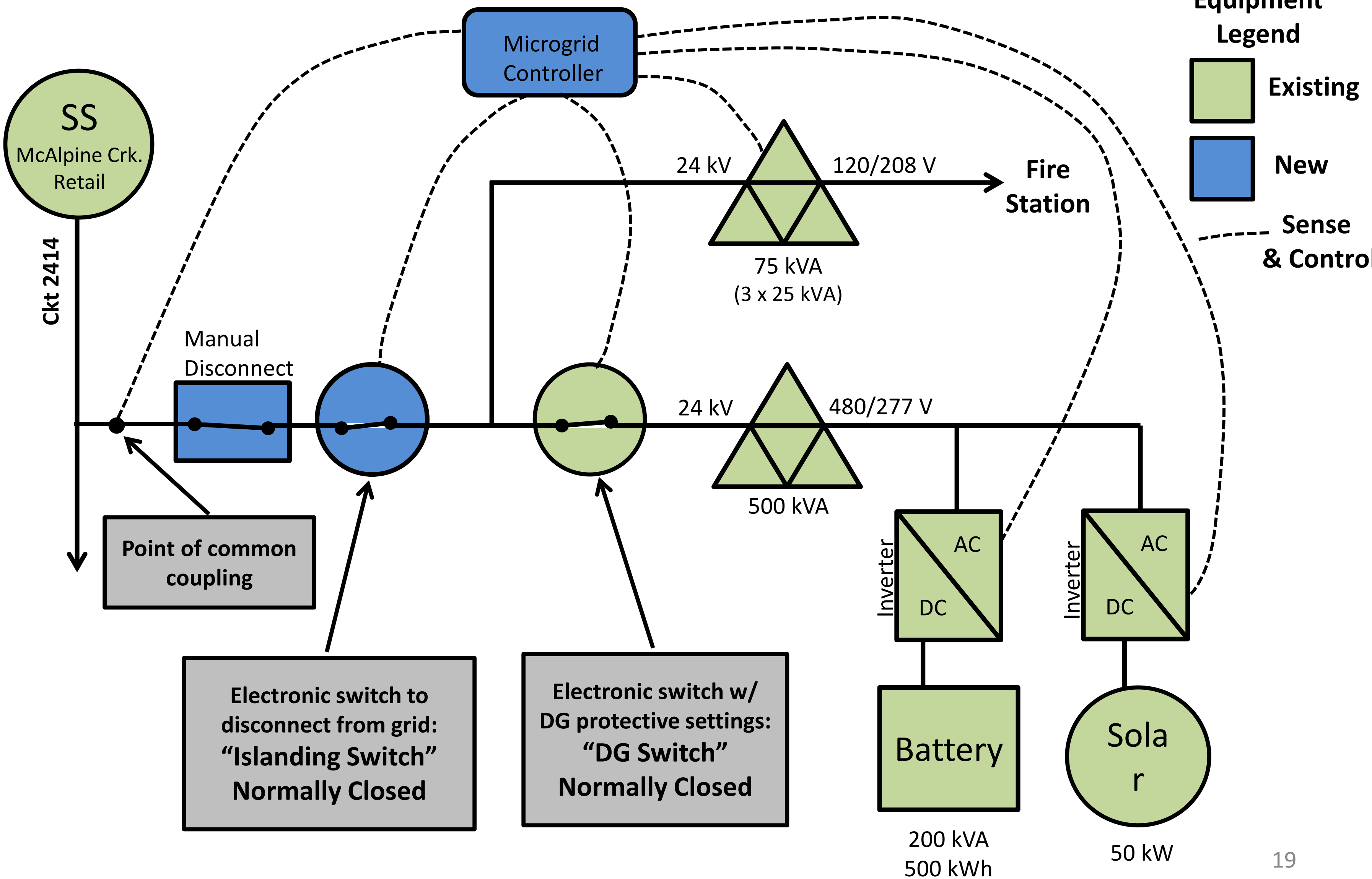
a) dispatched based on schedule, local load peaks, etc

3 – integration with solar in a microgrid

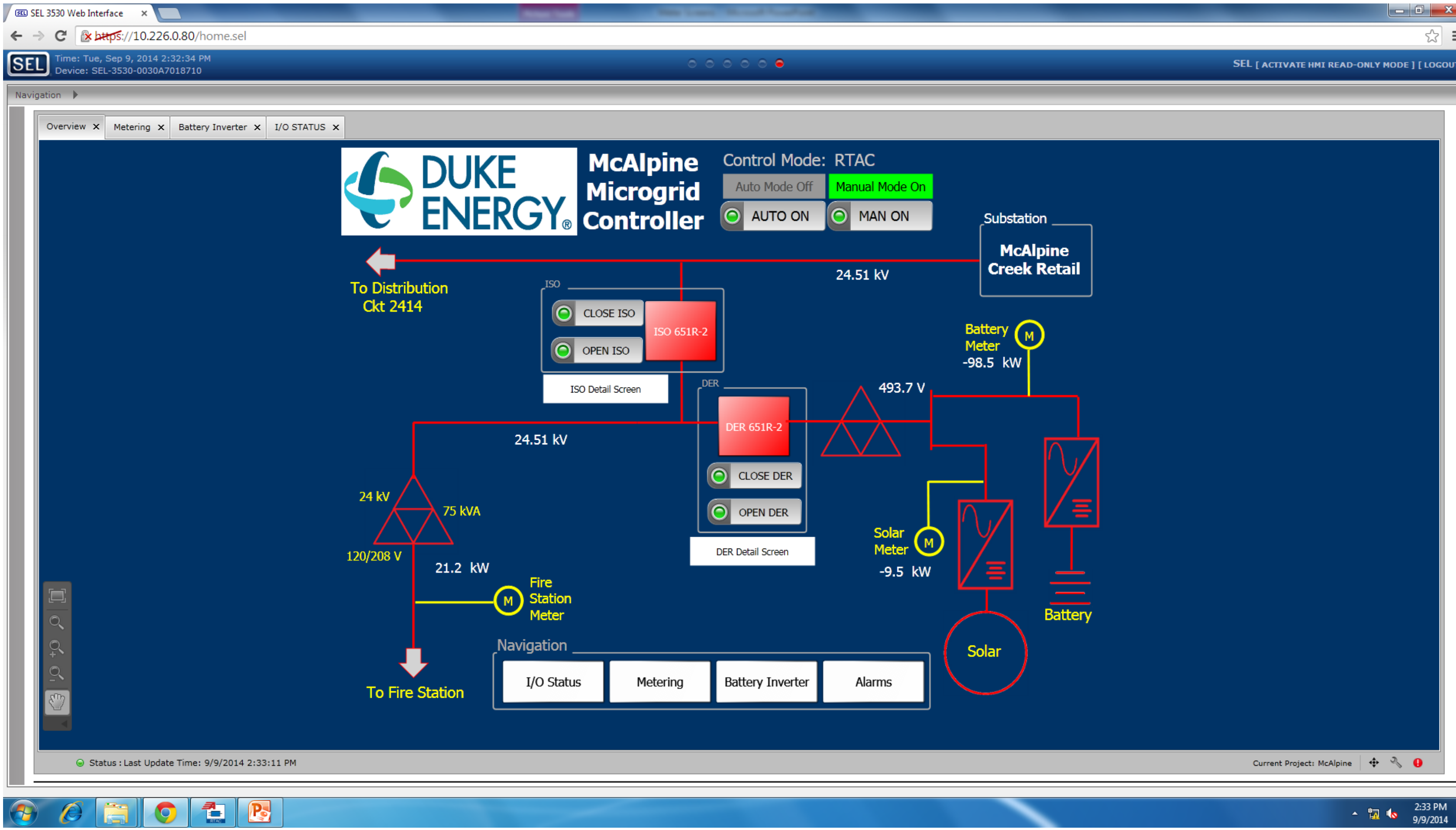
a) will be configured with switches, solar, and load to create an autonomous microgrid that disconnects from the circuit

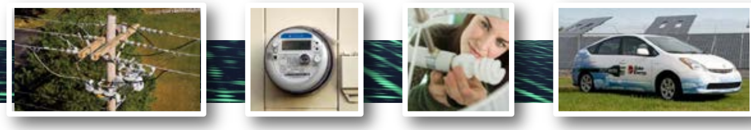
4 – solar output smoothing/firming

Islandable Microgrid Schematic



Microgrid Controller HMI





Rankin Energy Storage System

Rankin Ave. Retail Substation, Mount Holly, NC

Major system components:

- 402 kW / 282 kWh system capacity
- FIAMM sodium nickel chloride battery
    - 12 Zebra bus batteries connected in parallel
- 1.25 MVA S&C Electric Company Inverter (SMS)

Interconnection:

- Located on a 12.47 kV distribution circuit
- Interconnected immediately outside of the substation
- Circuit contains a 1.2 MW solar facility ~3 miles away

System attributes

- Installed Dec 2011, in service Mar 2012

- Remotely operable
- ZEBRA bus batteries by FIAMM for stationary application development
- Contains fiber connection to substation relaying; no connection to the solar facility on the circuit

Applications being tested

<u>1 – centralized solar-induced power swing mitigation</u>

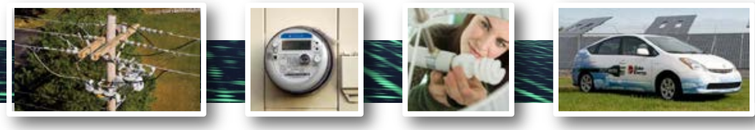
a) senses substation real power loading and uses battery to “smooth” rapid ramp rates caused by cloud-induced solar intermittency

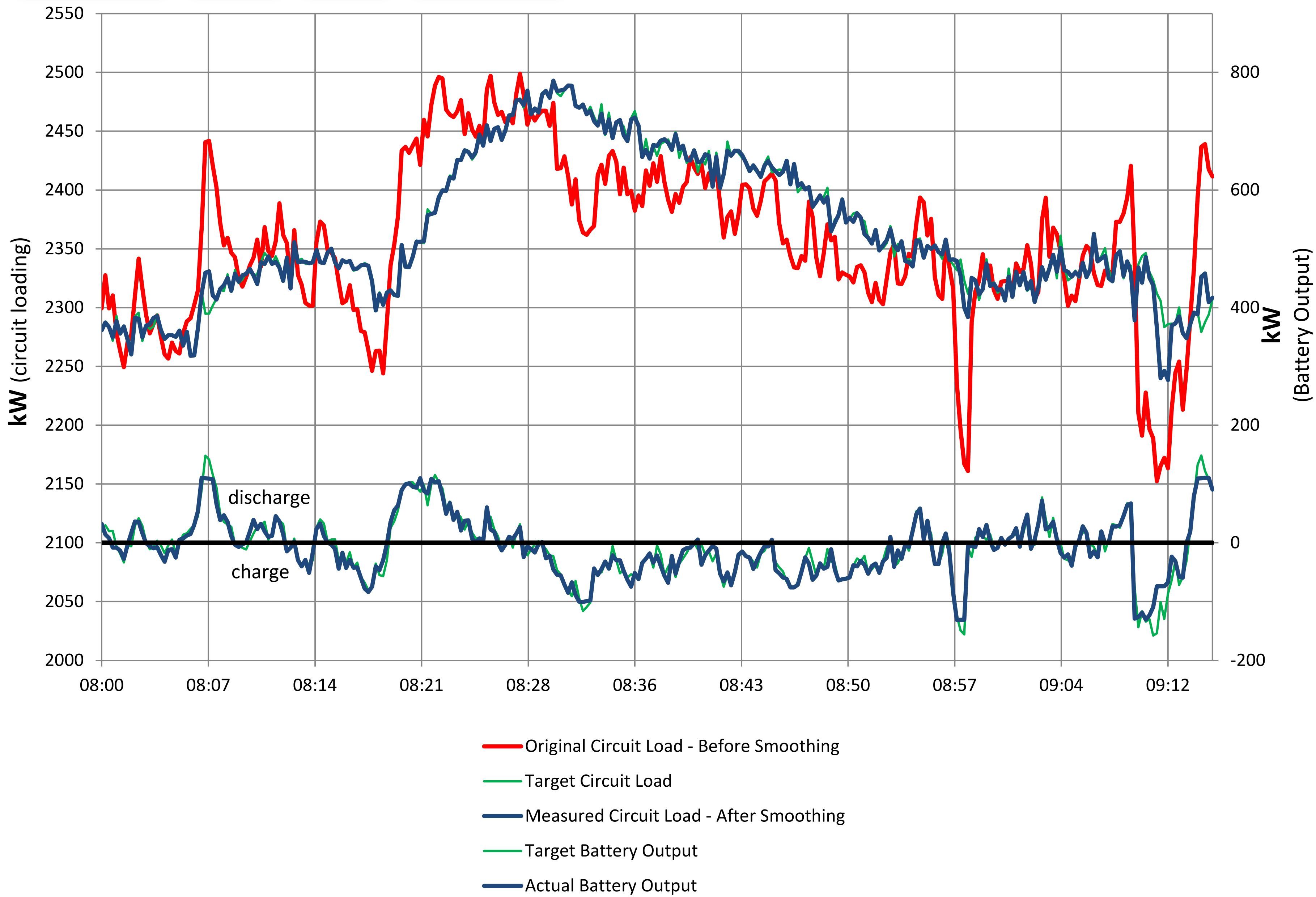
b) no direct connection to the solar – designed to smooth power swings from multiple dispersed solar sites on a circuit

<u>2 – active VAR/power factor management</u>

<u>3 – combined watt/VAR voltage control</u>

a) compensation for rapid solar-induced voltage changes





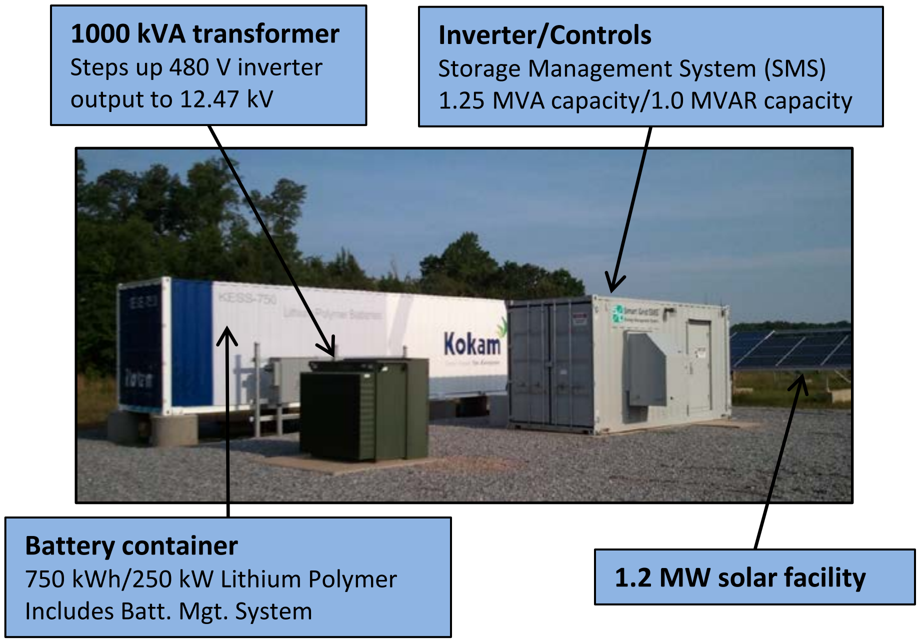
kW (circuit loading)
kW (Battery Output)
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
2000
800
600
400
200
0
-200
discharge
charge
08:00
08:07
08:14
08:21
08:28
08:36
08:43
08:50
08:57
09:04
09:12
Original Circuit Load - Before Smoothing
Target Circuit Load
Measured Circuit Load - After Smoothing
Target Battery Output
Actual Battery Output

Marshall Energy Storage System

Marshall Steam Station, Sherrills Ford, NC

Major system components:
- 750 kWh / 250 kW system capacity
- Kokam Superior Lithium Polymer Batteries
- 1.25 MVA S&C Electric Company Inverter (SMS)

Interconnection:
- Located on a 12.47 kV distribution circuit
- Separate but adjacent medium-voltage interconnection from 1.0 MW solar facility
- Located at the end of a distribution feeder



System attributes

- Installed May 2012, in service July 2012
- Remotely operable
- Battery and inverter independently sourced (both vendors to Duke)
- Located at the Marshall solar test site where multiple solar technologies are being field tested on a sealed coal-ash landfill

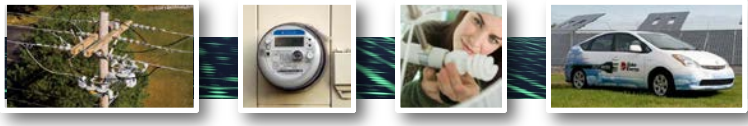
Applications being tested

<u>**1 – energy shifting**</u>
- a) for system-level arbitrage
- b) for local operational constraint management
- c) based on forward-looking economic algorithm

<u>**2 – solar output smoothing and firming**</u>
- a) for local feeder voltage management
- b) solar-induced power swing mitigation

<u>**3 – active VAR/power factor management**</u>

<u>**4 – combined algorithms / optimization**</u>
- a) combined energy shifting and smoothing algorithm
- b) use of distributed logic with economic, substation, and local input parameters



Clay Terrace Energy Storage System

Clay Terrace Mall, IN

Major system components:
- 75 kW / 42 kWh system capacity
- Toshiba lithium titanate battery
- 10 kW roof-mounted solar
- Eaton 50 kW, Siemens 3.3 kW PEV charging stations

Interconnection:
- Behind a commercial meter (customer sited)
- Interconnected at 480V, 3-phase transformer
- Located in the parking lot of a shopping mall

System attributes

- Installed 3Q 2012, in service 4Q 2012

- Designed to manage and optimize the combined energy profile of solar, PEV charging, and storage.

Applications being tested

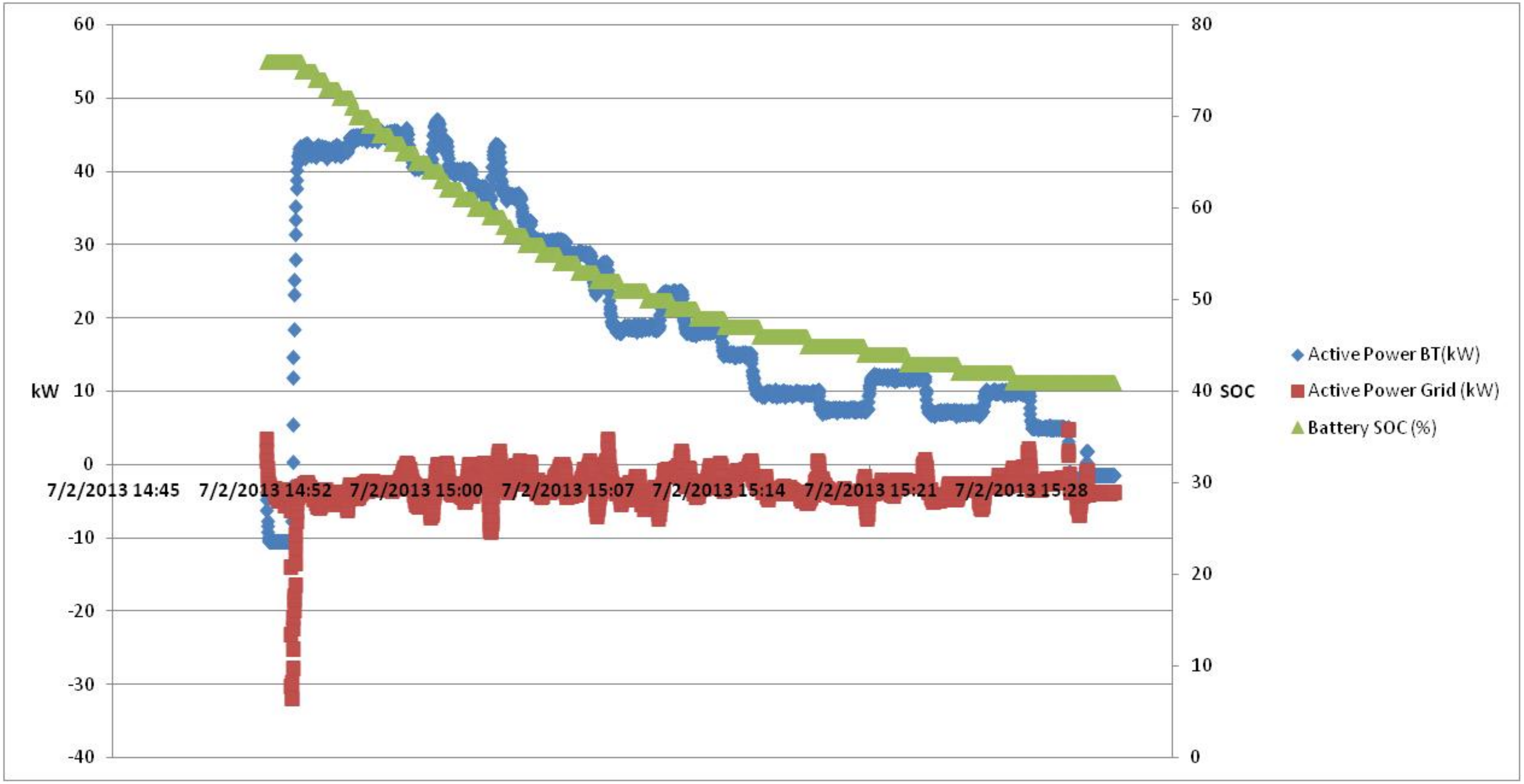
1 – active management of combined solar, storage and PEV charging

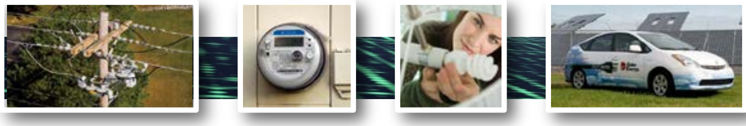
a) testing energy management system and sizing of a behind-the-meter system

2 – energy shifting

3 – customer-sited installation aspects

Battery Responding to DC Charge Event





Community Energy Storage Systems

Two units installed

McAlpine 24 kV circuits, Charlotte, NC

Major system components:

- 25 kVA inverter system – S&C Electric Company
- Kokam 25 kWh / 25 kW lithium ion battery
    - Battery located in underground vault

Interconnection:

- Interconnected at 120V/240V split single phase
- Configured to serve up to five customers on 50 – 75 kVA padmount transformers
    - Initially connected to one customer each for testing

Inverter/control unit
25 kVA connected at 120V/240V

50 kVA secondary transformer

Battery vault
4-feet deep, open bottom

Battery (underground in vault)
25 kW / 25 kWh Kokam Li-ion battery pack

System attributes

- Installation: unit 1 - Oct 2011; unit 2 - Dec 2011

- Remotely operable and monitored via DMS
- Demonstrating underground battery vault configuration

Applications being tested

1 – automatic voltage managment

a) automatically injects/consumes VARs to maintain voltage within a specified setpoint

2 – islanding/back-up power

a) automatic islanding during a grid outage

3 – distributed energy shifting

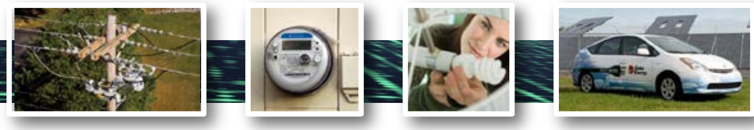
a) various energy shifting applications using a network of distributed batteries

4 – control system for distributed storage

a) using distributed communications network to monitor and dispatch the battery

Need to Consider

- Physical vs. Virtual Energy Storage
- How will energy storage compete / work together with:
  - Smart Invertors
  - Demand Response
  - Devices which perform autonomous frequency regulation



Conclusions

- The electric grid is changing: Electric generation is becoming more "de-centralized" – moving closer to the end user
- Balancing supply and demand requires a highly interconnected ecosystem with constant communication between assets
- Understanding how energy storage can seamlessly be integrated in this ecosystem is still under development