Current State of Batteries and Next Generation Technologies

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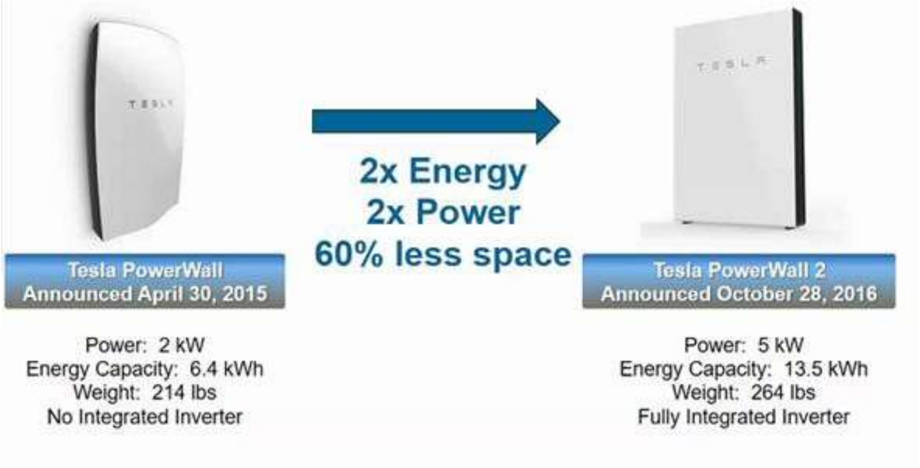
Current State of Energy Storage

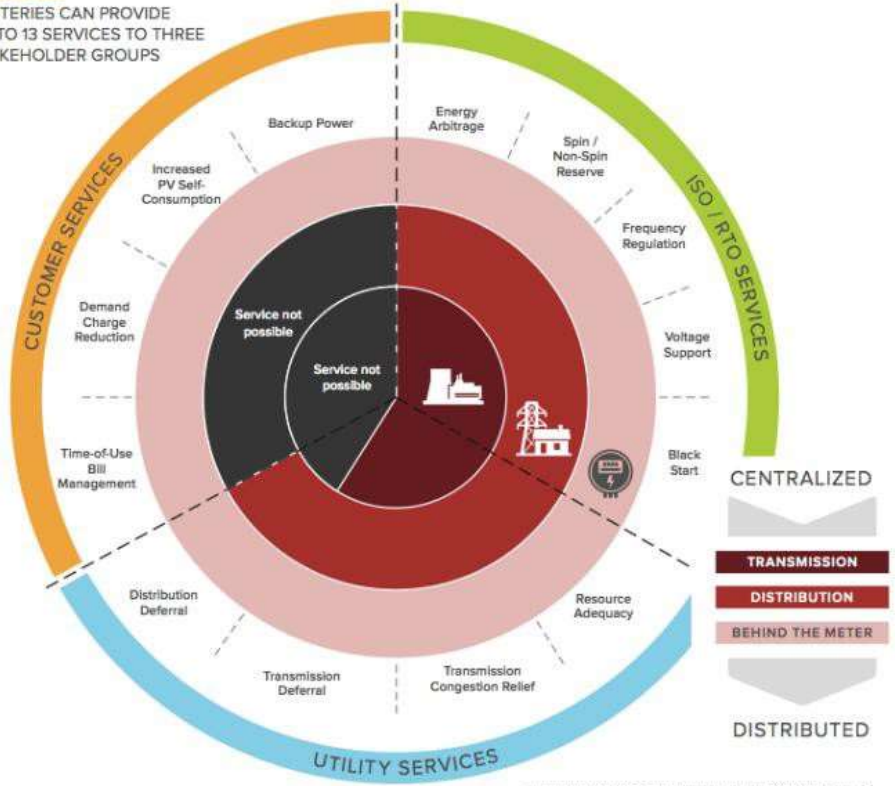
- Lithium-Ion energy storage prices continue to fall
  - EPRI estimates costs will fall to $350- 500/kWh by 2020
- Larger deployments leverage economies of scale
  - Tesla announced world's largest Li-Ion battery installation in Australia – 100 MW / 129 MWh
- New chemistries struggle to compete with large scale manufacturing of Li-Ion cells
  - Aquion, developer of a hybrid ion battery technology, filed for bankruptcy despite $190 million in funding
- Frequency regulation and peaker replacement are still most common applications for utility scale storage



Current State of Energy Storage

- Technical Challenges
  - Reliability
  - Efficiency
  - Performance
- Economic Challenges
  - Project Cost
  - Optimizing of Stacked Benefits
- Regulatory Challenges
  - ISO Markets
  - Valuation of Multiple Benefits

FIGURE ES2
BATTERIES CAN PROVIDE UP TO 13 SERVICES TO THREE STAKEHOLDER GROUPS



THE ECONOMICS OF BATTERY ENERGY STORAGE | 6

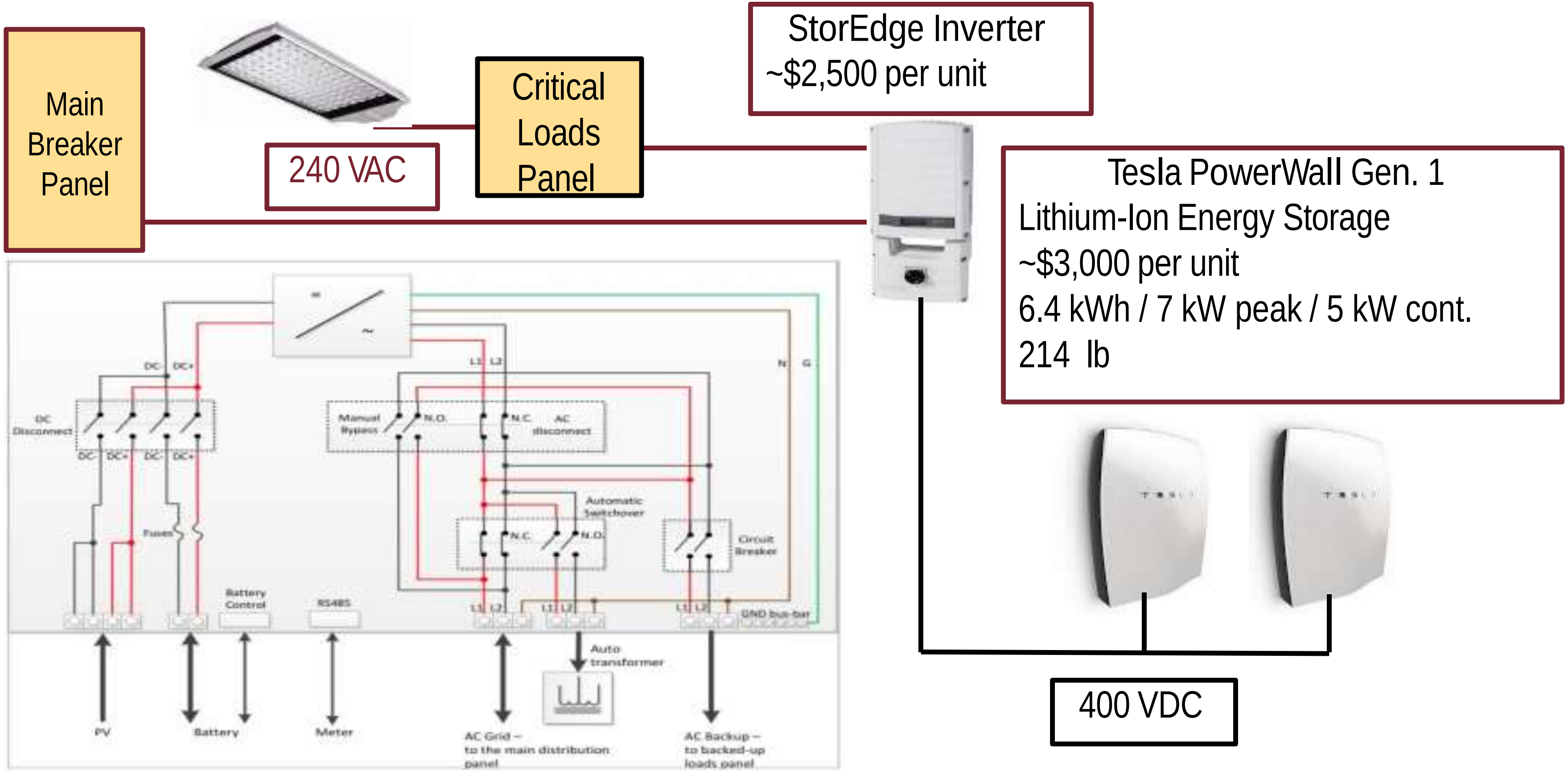
- Many companies entering market:

Mercedes-Benz LG Chem TESLA BYD sonnen

- Utility applications:
  - Virtual power plant, demand response and distribution deferral
- Customer applications:
  - Resiliency, TOU rate optimization and solar self consumption

Tesla PowerWall

Tesla PowerWall



Tesla PowerWall

- Requires certified Tesla installer to install
- Needs on site wiring of 400 VDC and 240 AC including critical loads panel
- Customer support isn't straightforward due to separate inverter and battery manufacturers
- Currently being used to demonstrate backup power capability, other modes require installed solar

Enphase AC Batteries

Enphase AC Batteries

Enphase AC Battery

Lithium-Ion Energy Storage

~ $2,000 per unit

1.2 kWh / 270 W peak / 260 kW cont.

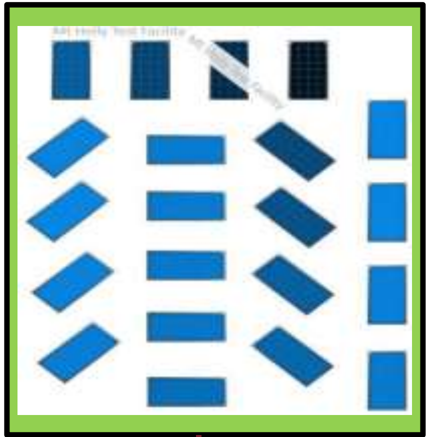
55 Lb per unit

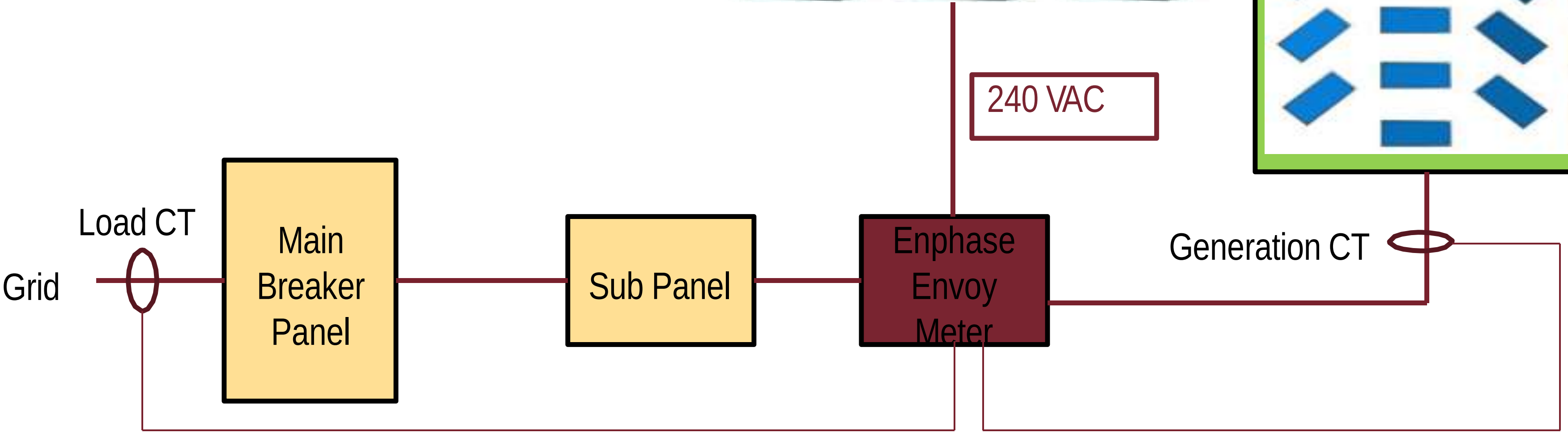
Modes: time of use bill management, solar self consumption, power export limiting

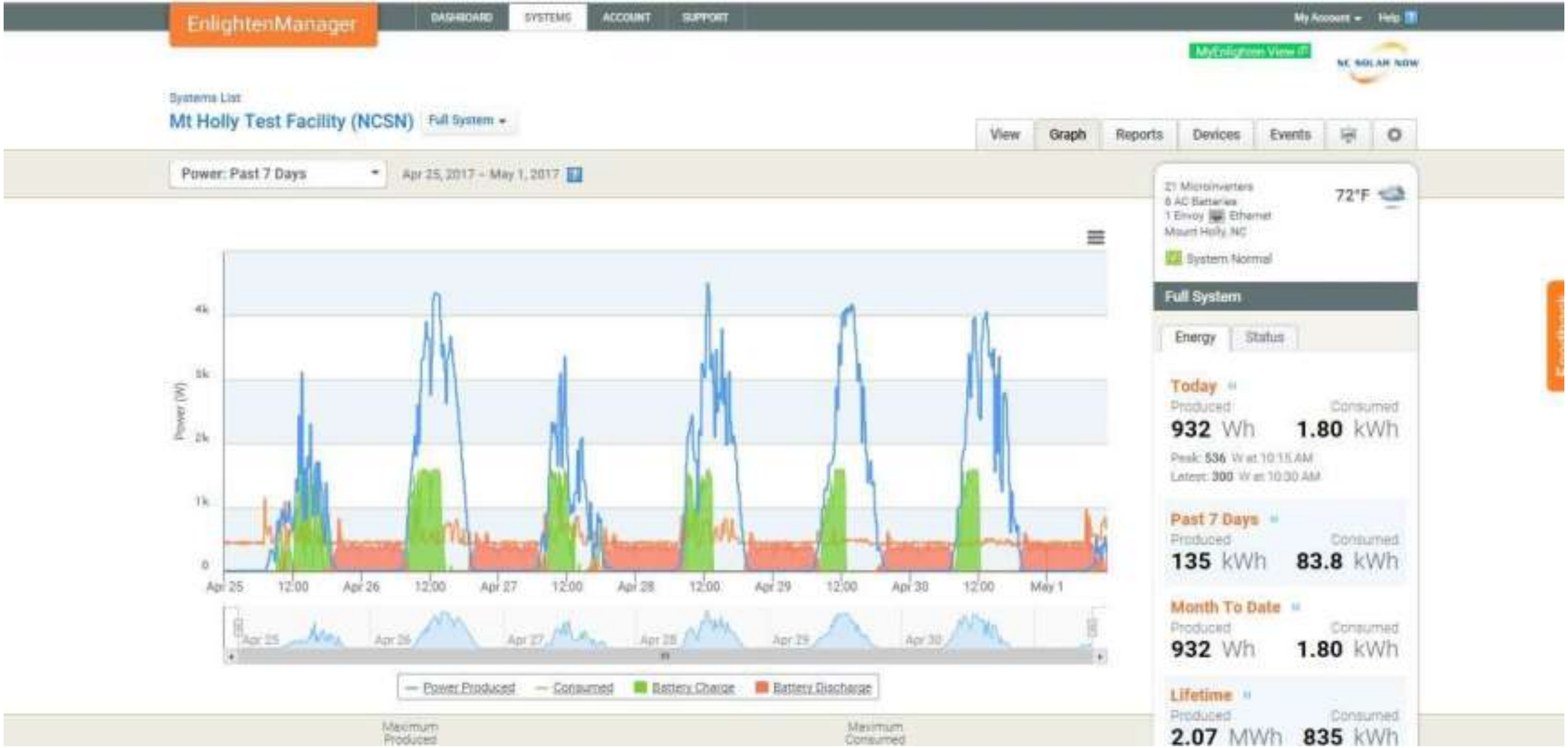
Enphase Solar

21 solar panels

Max Output: 5.67 kW







EnlightenManager
DASHBOARD
SYSTEMS
ACCOUNT
SUPPORT
My Account
Help
Systems List
Mt Holly Test Facility (NCSN)
Full System
View
Graph
Reports
Devices
Events
Power: Past 7 Days
Apr 25, 2017 - May 1, 2017
21 Microinverters
1 Envoy
Ethernet
Mount Holly, NC
System Normal
72°F
Full System
Energy
Status
Today
Produced
Consumed
932 Wh
1.80 kWh
Past 7 Days
Produced
Consumed
135 kWh
83.8 kWh
Month To Date
Produced
Consumed
932 Wh
1.80 kWh
Lifetime
Produced
Consumed
2.07 MWh
835 kWh
Power (W)
4k
3k
2k
1k
0
Apr 25
12:00
Apr 26
12:00
Apr 27
12:00
Apr 28
12:00
Apr 29
12:00
Apr 30
12:00
May 1
Power Produced
Consumed
Battery Charge
Battery Discharge
Maximum Produced
Maximum Consumed

Enphase AC Batteries

- Intuitive interface for customer, limited for utility
- Great support and customer service
- Enphase microinverters do not support backup power
- Battery modules have standard AC output and can be wired by any electrician
- Initial hardware is more expensive than other technologies

- Utilities and customers have different needs from a vendor's GUI
- Some technologies require pre-approved installers, adding to installed cost
- Customer support for a utility incentivized program needs to be handled delicately
- Business model for ownership, dispatch and financing is not yet clear

Fire Station 24 (McAlpine Creek Substation) - microgrid field test

How can a microgrid benefit a customer and the grid?

- Provide resiliency to a critical facility
    - Fire station will be able to operate during periods of prolong grid outages.
- Utilize utility-owned, utility sited assets
    - All equipment is owned and operated by Duke Energy. No alterations behind the customer meter.
    - Utilize “off the shelf” components where possible to allow more integrated support
- Demonstrate ancillary and grid stability services:
    - Frequency regulation
    - Circuit voltage support (VAR dispatch)
    - Demand response through islanding
    - Mitigating solar intermittency at the source

McAlpine Energy Storage System

McAlpine Creek Retail Substation, Charlotte, NC

Major system components:

- 200 kW / 500 kWh system capacity
- Containerized battery and inverter system
- Lithium-iron-phosphate battery

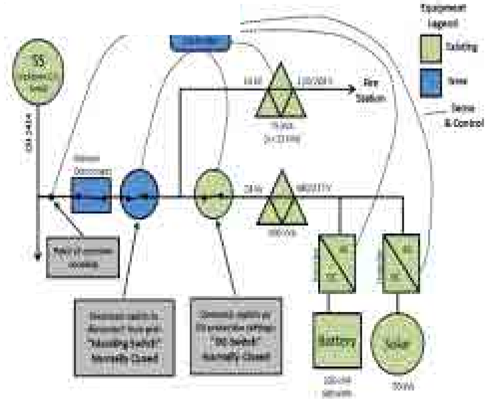
Interconnection:

- Located on a 24 kV distribution circuit near the substation
- Adjacent to 50 kW solar facility on test circuit

Battery
200 kW/500 kWh $LiFePO_4$

Inverter/Controls
Integrated within one container

System attributes

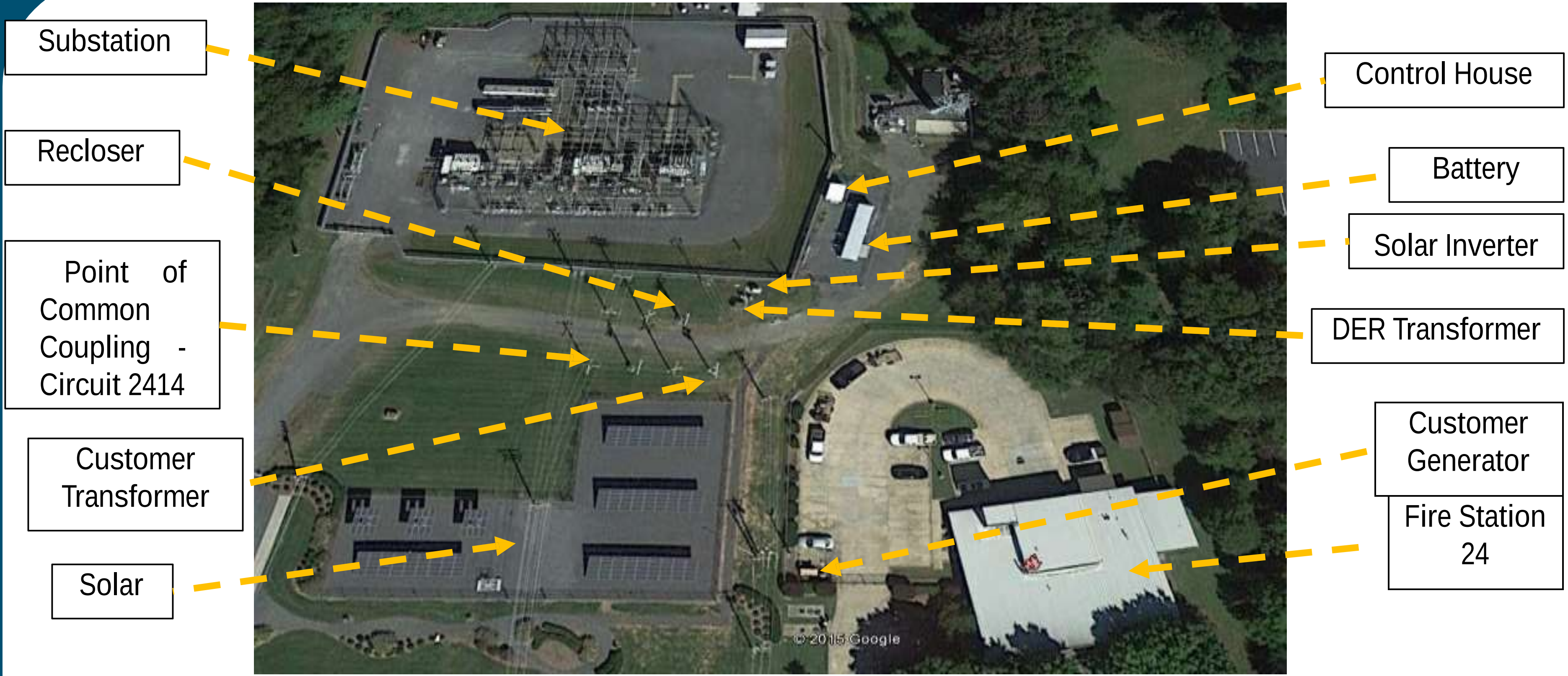


Applications being tested

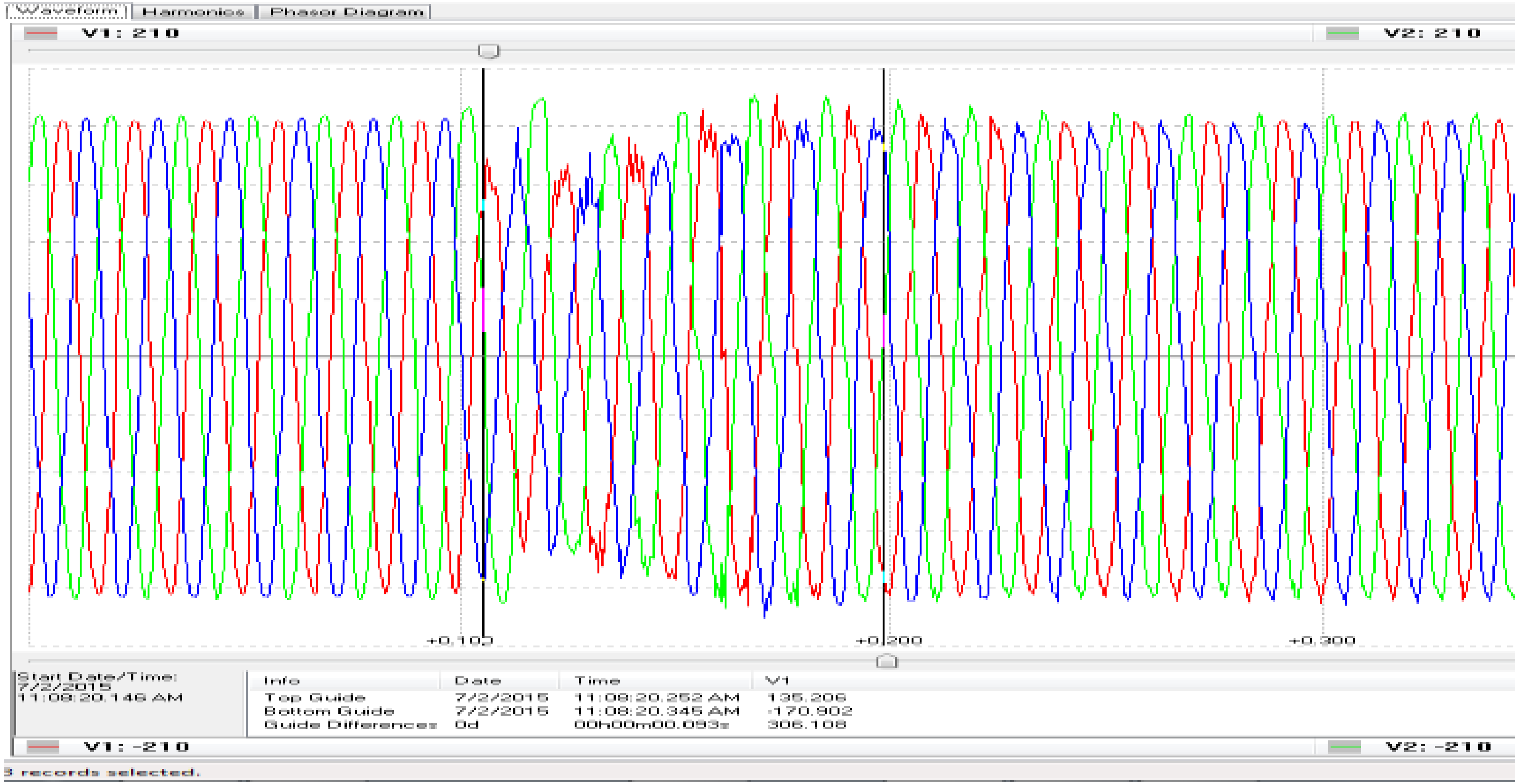
1. <u>Distribution Circuit located Microgrid</u>

a) Develop switching schemes with standard reclosers
b) Develop P&C strategy
c) Understand benefits of microgrid technology on Utility side of the meter

McAlpine Microgrid – Site Overview

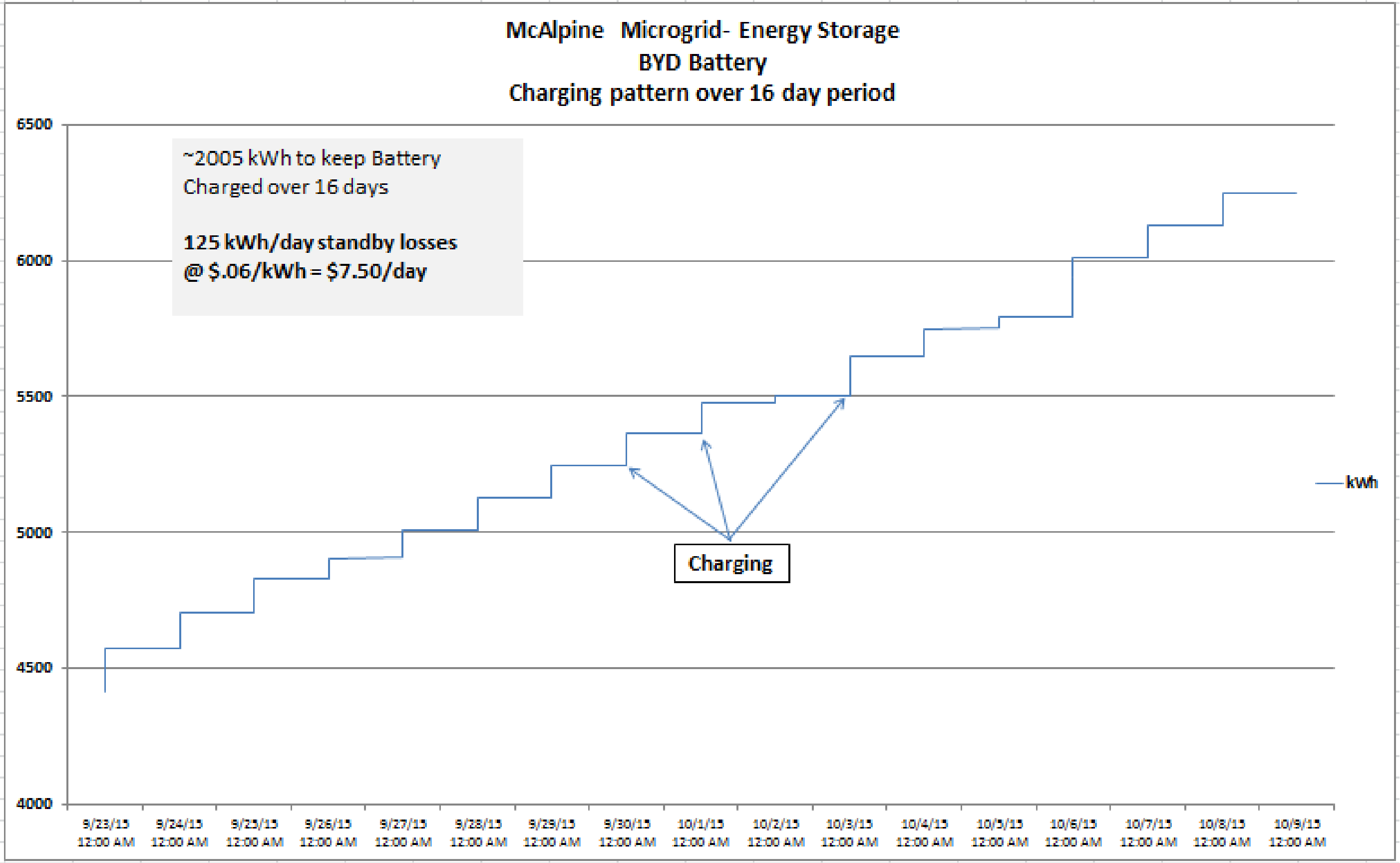


Fire Station Meter, Islanding Event – Battery Discharging @100 kW

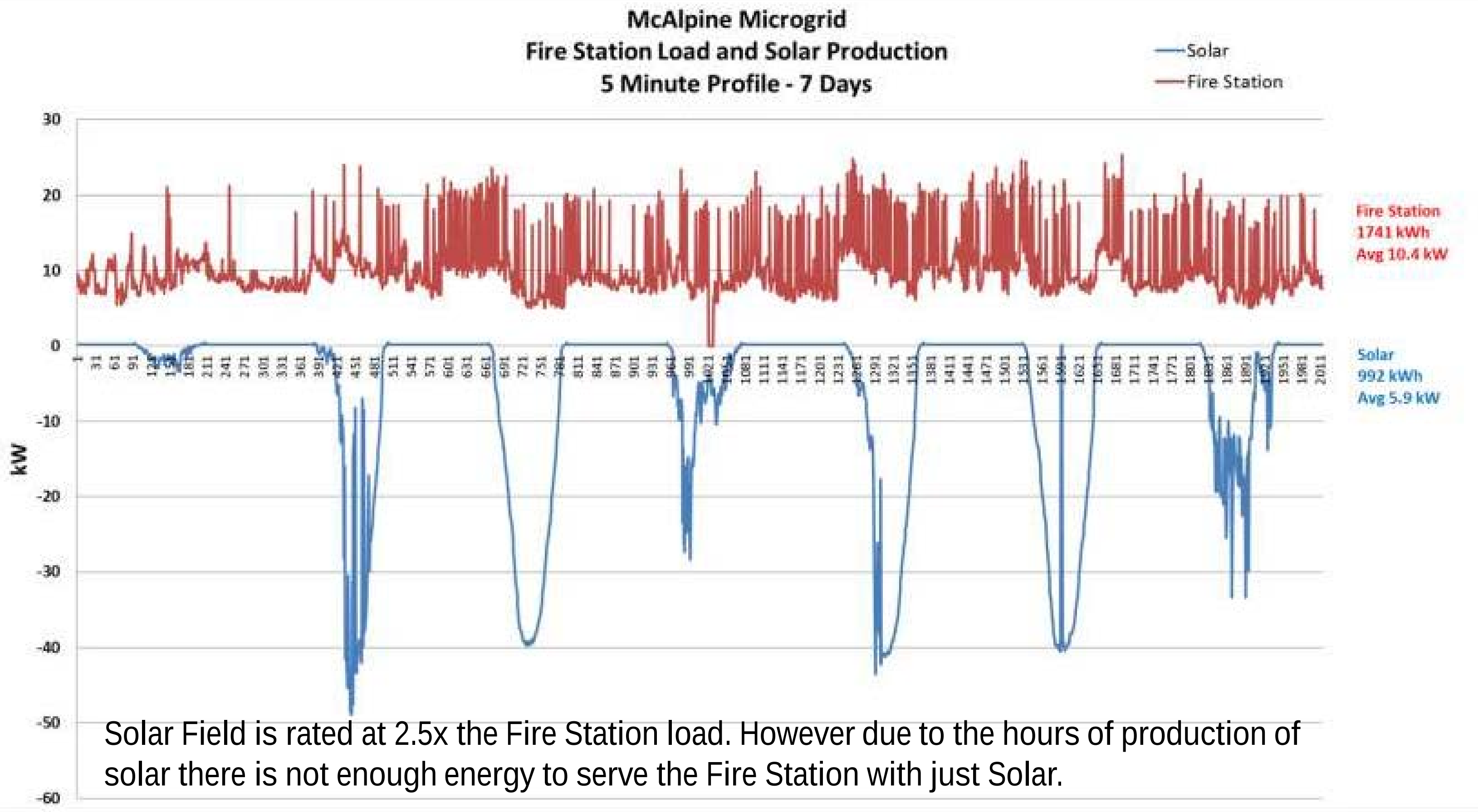


Transition from Grid Connected to Islanded takes ~5 cycles (90 ms)

Battery Charging – Standby Losses



Fire Station 24 - Load Analysis



Solar Field is rated at 2.5x the Fire Station load. However due to the hours of production of solar there is not enough energy to serve the Fire Station with just Solar.

McAlpine Microgrid – Lessons Learned

- Distribution System based Microgrid Advantages:
  - Microgrid can potentially serve a larger number of business cases making them more financially viable.
  - Assets on the Duke side of the meter have higher potential availability for grid services

- Distribution System based Microgrid Challenges:
  - Microgrid components must be supportable by Utility personnel
  - Increasing resiliency for one customer may decrease reliability for other customers
  - Energy storage systems are hands-on assets that require O&M.
  - Auxiliary power support systems must be well understood.

Beckjord Phase I and II Energy Storage System

W.J . Beckjord Station, New Richmond, Ohio

Major system components:

- Phase I = 2 MW/ 725 kWh Li Ion Batteries
- Phase II = 2 MW/ 800 kWh Li Ion Batteries
- 2- 2.2 MVA inverter systems

Interconnection:

- Connected to 138 KV switchyard
- Utilizes brown field location of retired 1.4 GW mixed fuel plant

System attributes

- COD January 2015 /November 2015
- Owned and operated by Duke Energy's commercial group
- Availability (> 98%)
- Perf. Score (> 97 %)

Commercial Application

1. <u>Market opportunity for Frequency regulation</u>
   - Units are dispatched remotely based on PJM Reg D signal
   - Major equipment is designed and warrantied for 10 years of commercial operation.

PJM Rule Changes

- Changes in the benefit factor of RegD vs RegA resulting in less market participation for fast response assets
- Market constraints were removed, requiring RegD participants to engage in longer duration frequency regulation services
- Impacts:
  - Impacts revenue from RegD services
  - Average range of SoC of energy storage systems increased
  - Changes in market signals have increased internal battery cell temperatures affecting overall performance

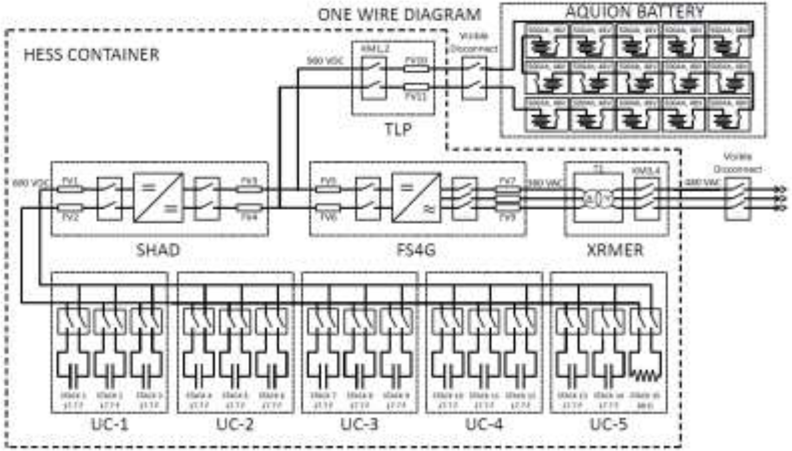
Beckjord I & II – Lessons Learned

- Retiring older generation provides an opportunity for new energy storage
- Energy storage markets are still in their infancy and the future is not certain
- Changes in operational paradigms can have unforeseen secondary impacts to energy storage performance

DUKE ENERGY

Rankin Substation Hybrid Energy Storage System

- Major system components:
  - 50 kW / 200 kWh Aquion Battery
  - 250 kW / 7.5 kWh Maxwell Ultracaps
  - WinIntertia DC/DC converter and inverter
- Interconnection:
  - Located on a 12 kV distribution circuit near the substation
  - Same circuit as Mt Holly microgrid and 1.2 MW solar



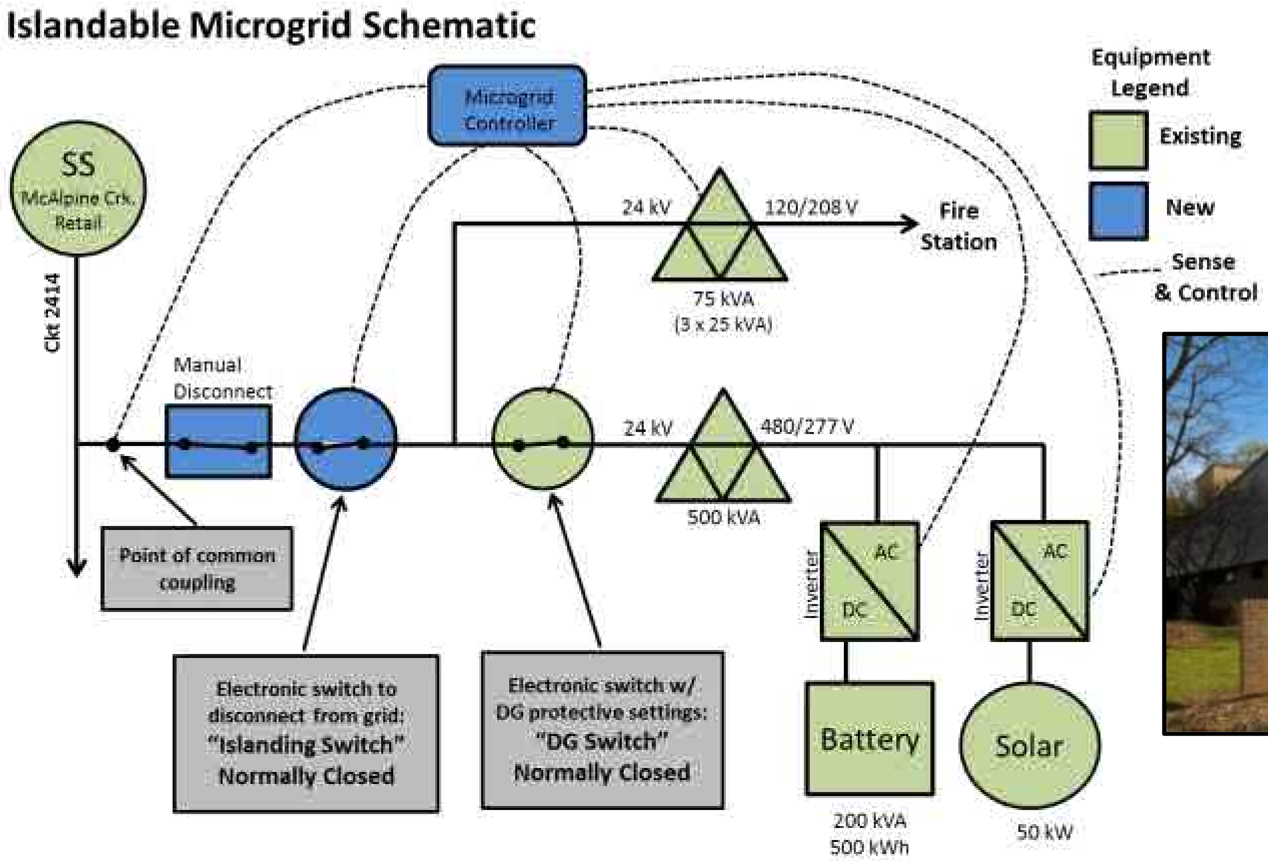
- Applications
  - Joint dispatch of battery and ultracaps to simultaneously support solar smoothing and energy time shift of 1.2 MW solar
  - Expand lifetime of traditional battery technologies by dispatching ultracaps for short duration power needs instead of relying on battery
  - Demonstrate ability to effectively couple two different chemistries on a DC bus

- Control systems must be fast and reliable to allow for simultaneous dispatch of collocated assets
- Correct modeling of the power electronics and energy storage systems are essential for proper operation of the system
- As complexity increases so does the O&M

Thank You!

Appendix

Schematic


Islandable Microgrid Schematic
Microgrid Controller
SS
McAlpine Crk. Retail
Ckt 2414
Manual Disconnect
Point of common coupling
24 kV
120/208 V
Fire Station
75 kVA
(3 x 25 kVA)
24 kV
480/277 V
500 kVA
Inverter
AC
DC
Inverter
AC
DC
Battery
Solar
200 kVA
500 kWh
50 kW
Electronic switch to disconnect from grid: "Islanding Switch" Normally Closed
Electronic switch w/ DG protective settings: "DG Switch" Normally Closed
Equipment Legend
Existing
New
Sense & Control

Microgrid Controller - Functions