Energy Storage as a Key Element in Smart Grids

Bill Muston
Oncor

Ross Baldick, Department of Electrical and Computer Engineering

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ONCOR

- 3.4^{+} M customers
- Largest regulated utility in Texas
- 4000 employees
- Transmission
- Distribution
- Metering
- Interconnections

Regulated, investor-owned, wires utility in ERCOT – does not generate, own, or sell electricity

– but delivers it –

Scope & Disclaimer

This presentation is intended to be broad in scope about the range of energy storage system (ESS) applications in the power grid.

The applications and examples cited in this presentation are not limited to the particular types of applications of direct interest to Oncor as a regulated utility within the market structure and regulatory rules that apply to Oncor.

Acknowledgements

Thanks to Oncor for allowing the use of slides and knowledge.

Thanks to Nathan Kassees and Mila Hunt at Oncor for partnership in developing the content, slides, and homework for the original 2017 presentation.

Outline

- Why Now?
- Energy Storage System (ESS) – Definition
- Roles – Bulk Power, Wires, Customer, DER
- Utility Distribution Systems
  - Meet reliability needs
  - Serve growing demand
  - Microgrids
- Multiple uses of a single ESS
- Regulatory & market construct considerations

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THEMES

Costs are declining

Experience is growing

Storage opens up new ways to address grid needs

WHY NOW?

- **Energy storage – to complement grid functions at substations and in distribution systems – has never been utilized widely**
  - Traditional equipment is economical and works well
  - Historically, high cost of storage for proven types of storage
  - Technical maturity of many newer storage technologies not yet proven, predictable, and known to be long-lived & reliable, as compared to traditional utility equipment
  - Commercial maturity – standardized performance needs for distribution applications have not been established, and, therefore, standardized products have not been widely available with standard warranty for standard performance expectations
- **HOWEVER –**
  - Costs and maturity are changing rapidly
  - Standardization thru common application types and functional specifications is underway

TYPES OF ENERGY STORAGE

For 'smart grid' applications, the discussion will be mainly about batteries, due to their present cost and deployment ease today

Energy storage takes many forms:

(a) electro-chemical batteries;
(b) chemical flow batteries;
(c) electrical potential storage, such as capacitors;
(d) mechanical inertia, such as flywheels; and
(e) potential energy, such as compressed air storage, liquid air storage, and pumped hydro

The choice of type of storage will be affected by the particular application and by commercial maturity

Lithium-Ion batteries have become the cost and deployment leader

Technical advancement of storage continues at a rapid pace throughout the world

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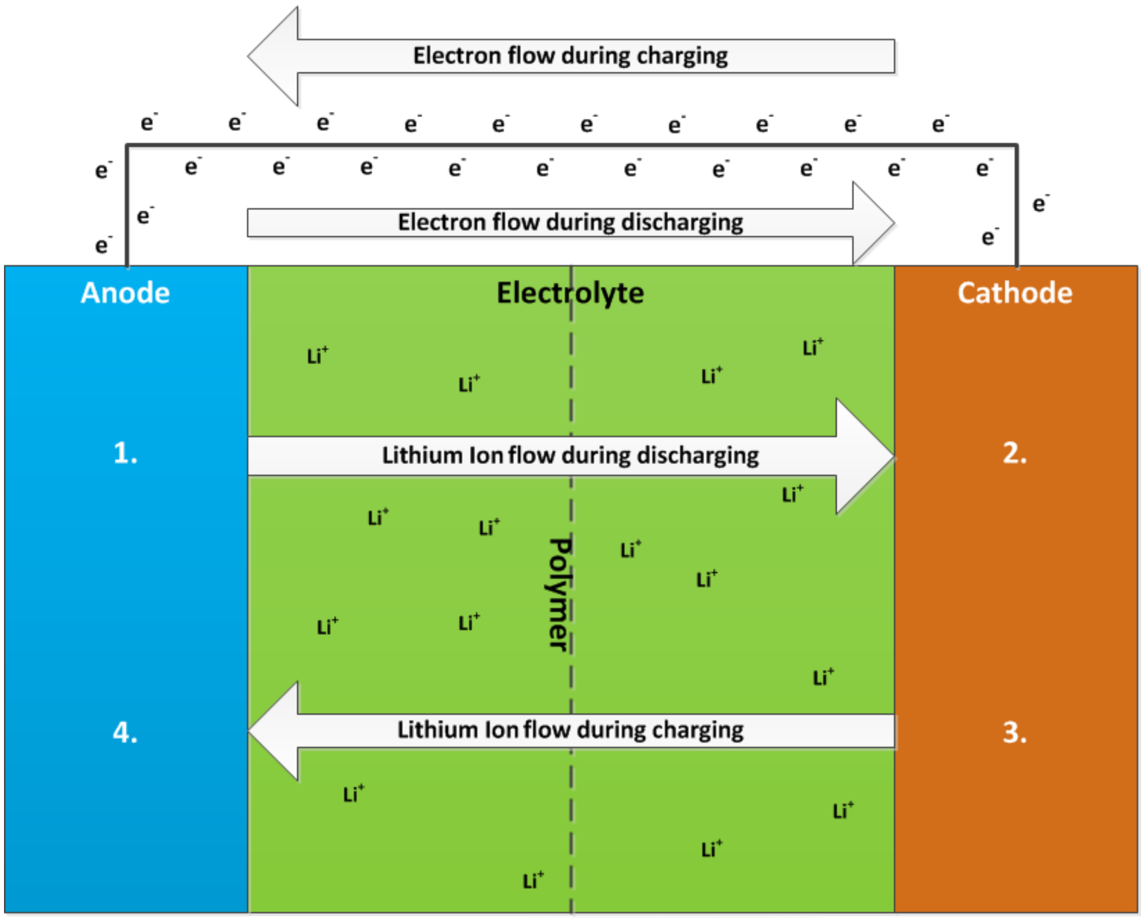
Lithium-Ion Battery

Anode - Copper conductor in Carbon, Titanium-Oxide, or Silicon-Tin structure
1 - Lithium Ions release electrons and dissolve into electrolyte
4 - Lithium Ions combine with electrons and layer onto anode

Cathode - Lithium-Metal-Oxide or Lithium-Metal-Phosphate structure
2 - Lithium Ions combine with electrons and integrate with cathode
3 - Lithium Ions release electrons and dissolve into electrolyte

Electrolyte
Liquid or Gel electrolyte of Lithium-Carbonate or Lithium-Flouride Compound
Conductive to Lithium Ions (Li^+)

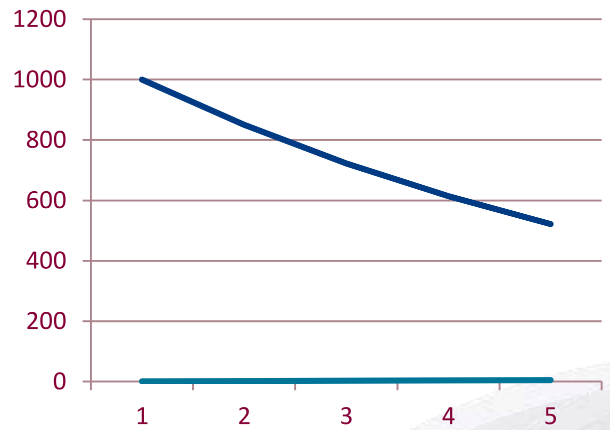
Polymer
Hydrocarbon barrier conductive to Lithium Ions (Li+)



COST DISCUSSION

- Costs for Li-Ion have declined rapidly
- Double-digit % cost reduction for several years
- Battery pack (dc) costs have declined ~80% from 2010 to 2018
- Progress in balance of plant costs

- ***Scale of manufacturing***
- ***Maturity of manufacturing processes***
- ***Supply chain economies***
- ***The # of manufacturers & production lines***



ELEMENTS OF COST

- Component Level
- Storage mechanism – eg. battery cells, packs, racks
- Power conversion ac/dc/ac
- Container – weight, footprint, safety, environmental
- Controls & monitoring

The challenge of stating costs versus the desire for simple comparisons among types & applications

- Macro Level
- By type of application
- $'s / kW
- $'s / kWh

Recommended:

EPRI Energy Storage Cost Analysis: Executive Summary

Technical Report 3002013958, December 2018

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ENERGY STORAGE SYSTEM – ESS

- **Energy stored in a form other than AC electricity**
- **Energy storage unit is 'filled' with energy from the grid**
- **Conversion from AC to stored energy and back to AC**
- **Grid tie & interface equipment and controls**
- **Internal storage unit internal controls to protect the asset**
  - Often called Battery Management System (BMS)
- **A set of equipment that can be 'placed'**
  - As used in these slides, an ESS is NOT locationally tied uniquely such as pumped hydro or compressed air energy storage where siting is driven by geology

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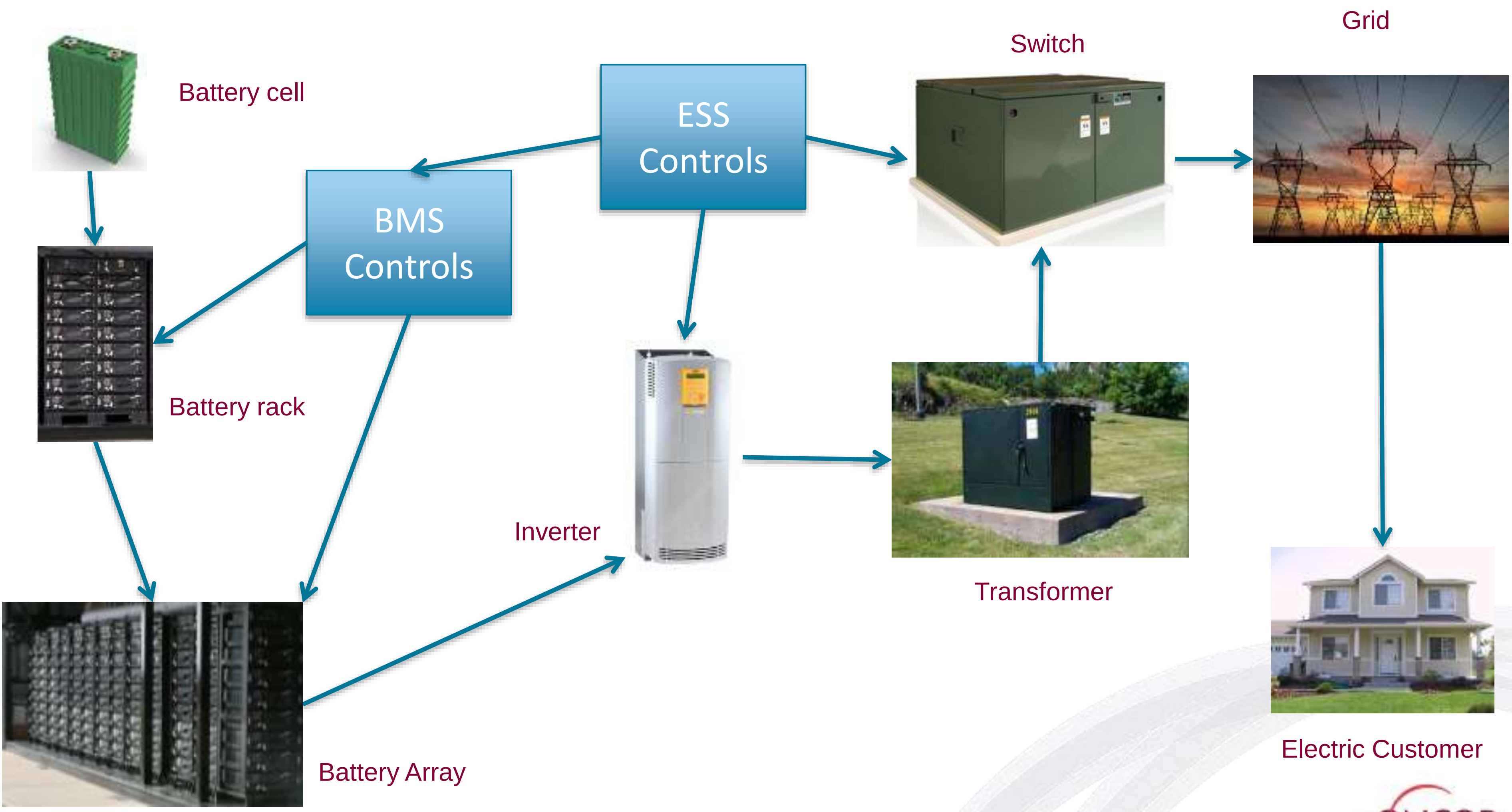
BATTERY STORAGE SYSTEMS



DESIGN FLEXIBILITY & CHOICES

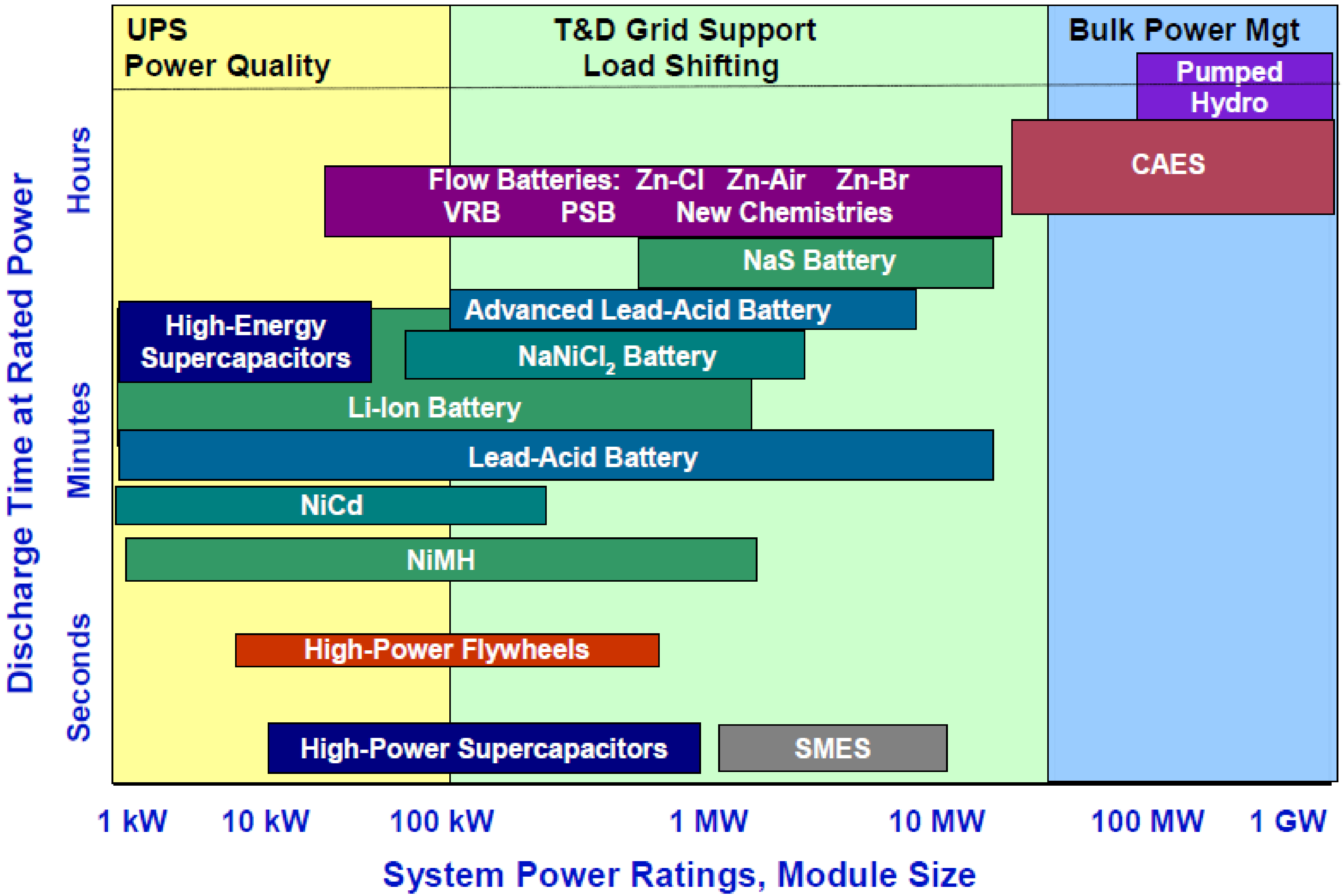
- **Power: Charge-discharge**
- **Energy: How much**
- **Rapid charge-discharge ➔ High C-rate**
- **Power conversion system (inverter)**
- **Container & systems**
- **Grid transformer & SCADA**
- **Site meteorological**
- **Site layout**

- **Efficiency –**

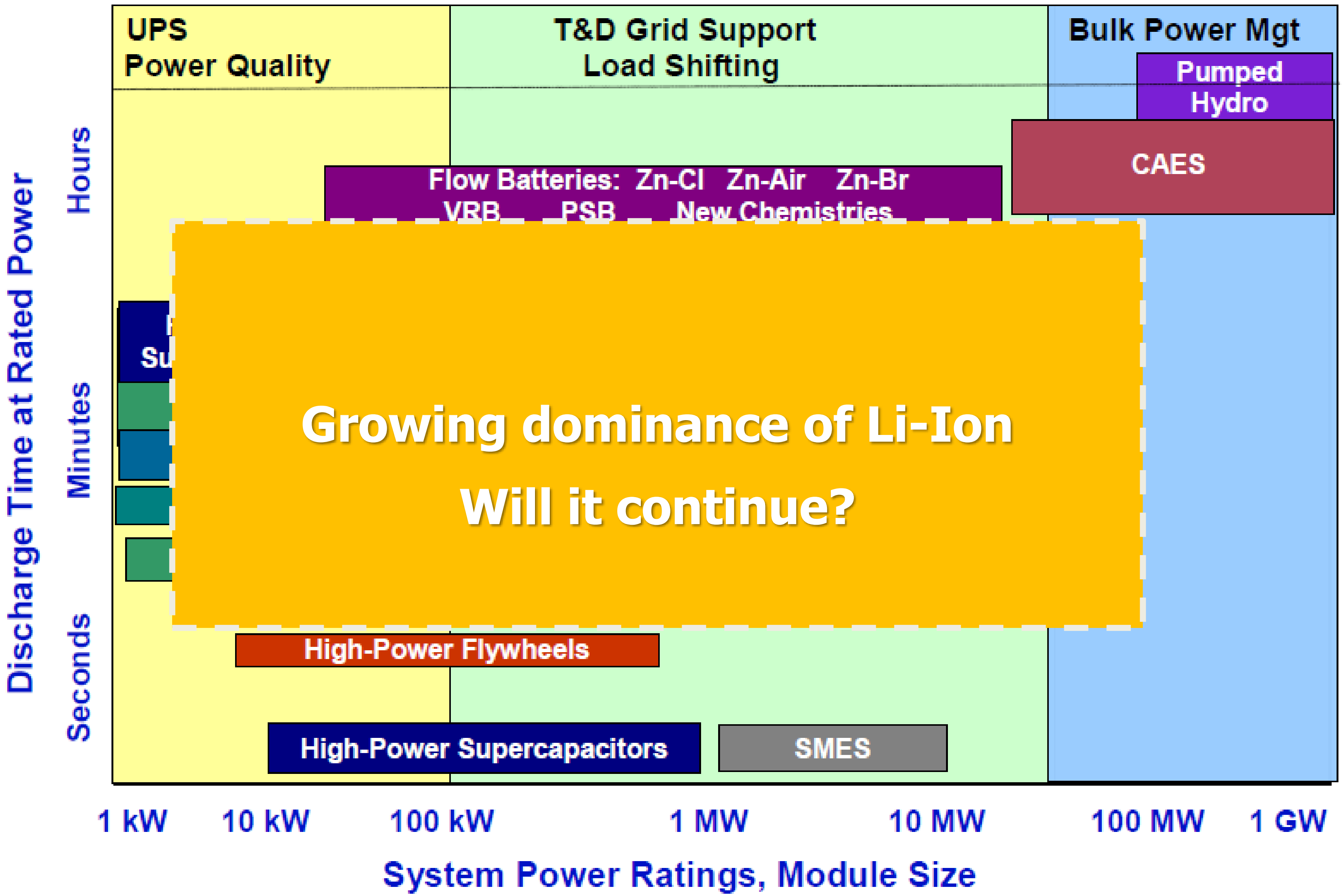
  $\mathbf{kWh_{AC}}\ \mathit{out}\ /\ \mathbf{kWh_{AC}}\ \mathit{in}$

- **Life – cycles & shelf life**

www.kaplanco.com



Source: DOE's Sandia National Laboratory, Energy Storage Systems Program – http://www.sandia.gov/ess/wp-content/uploads/2015/04/EsPositioningHandbook.png http://www.sandia.gov/ess/publication/doeepri-electricity-storage-handbook/



Lithium-ion batteries have achieved a cost, performance, and speed-of-deployment advantage today, which has led to their dominance in energy storage deployments the last few years.

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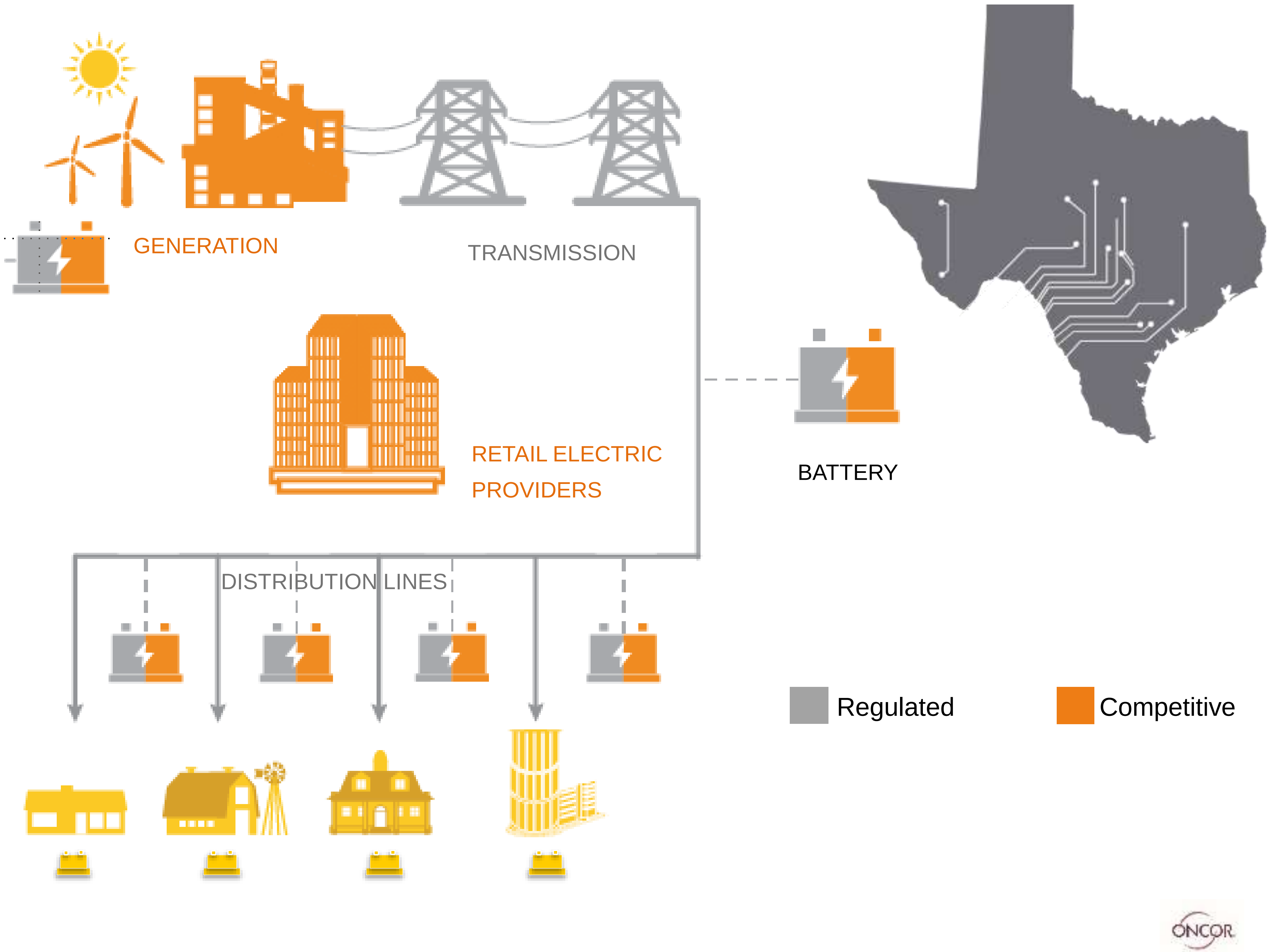
GENERATION
TRANSMISSION
RETAIL ELECTRIC PROVIDERS
BATTERY
DISTRIBUTION LINES
Regulated
Competitive
ONCOR

GRID ENERGY STORAGE VALUES

BULK GRID

Wind & solar firming, smoothing and dispatch

Time-shift energy supply vs. need to meet market needs

Grid reliability services

- Supply regulation
- Frequency regulation
- Responsive reserves for grid contingency
- Fast response

Time-shift to address transmission constraint

DISTRIBUTION FEEDERS & SUBSTATION

Support the local grid during upstream outages

Defer or substitute for traditional upgrades needed to support growing loads

Integrate distributed energy resources (DERs) to the local grid to maintain local grid stability & voltage control

Extend local operations with feeder-segment microgrids

CUSTOMER

Manage customer peak demand to limit demand charges

Smooth & firm customer-sited solar or wind

Time-shift energy from the grid or from customer-sited solar, such as to manage energy use under a time-of-use retail rate

Support islanded microgrid operation for critical services during grid outage

Focus of this lecture ⇧

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Electric Transmission Texas

Electric Transmission Texas energy storage project in Presidio, Texas.

- Commercial operation in 2010
- Serving transmission purposes
- http://www.ettexas.com/projects/presnas.asp

http://www.nytimes.com/2010/11/07/us/07ttbattery.html

PUC DOCKET NO. 35994

APPLICATION OF ELECTRIC	§	PUBLIC UTILITY COMMISSION
TRANSMISSION TEXAS, LLC	§	
FOR REGULATORY APPROVALS	§	of TEXAS
RELATED TO INSTALLATION	§	
OF A SODIUM SULFUR BATTERY	§	
AT PRESIDIO, TEXAS	§	

2009 APR -6 PM 4:29

ORDER

This Order addresses Electric Transmission Texas, LLC's (ETT's) application for regulatory approvals related to an installation of a sodium sulfur (NaS) battery at Presidio, Texas. For the reasons discussed in this Order, the Commission approves ETT's application subject to the limitations contained in this Order.

HOME SEARCH The New York Times

U.S. | THE TEXAS TRIBUNE

In Presidio, a Grasp at the Holy Grail of Energy Storage

By KATE GALBRAITH NOV. 6, 2010

Dozens of gray compartments, lined neatly in rows, inhabit a boxy concrete building on the edge of the impoverished border town of Presidio. The only sound, aside from occasional clanking, is the whirring of air-conditioners to keep the compartments cool.

This $25 million contraption is the largest battery system in the United States — locals have dubbed it Bob, for Big Ole Battery. It began operating earlier this year, and is the latest mark of the state's interest in a nascent but rapidly evolving industry: the storage of electricity.

Storage is often referred to as the holy grail of energy technology, because it can modernize the grid by more efficiently matching demand for power with the generation of electricity. A variety of early-stage technologies are being studied in Texas, ranging from the Presidio battery (which can power the town of about 4,000 people for up to eight hours in the event of a power failure) to superconducting magnets to caverns that would store and release air compressed by electricity.

Slide compiled by Oncor from public sources

Storage Week 2014

Jeff Gates – Managing Director, Commercial Transmission
Duke Energy

February 12, 2014

DUKE ENERGY.

Overview

- Developed by Duke Energy and Xtreme Power (XP)
- 36 MW / 24 MWh output
- Advanced lead-acid battery technology
- 24 Dynamic Power Modules with 1.5 MW / 1.0 MWh
- Modules housed in ~ 20,000 sq. ft. building
- Construction Oct 2011 to full operations December 2012
- Primary Commercial Market - ERCOT
  - ERCOT Freq Regulation
  - FRRS Pilot
- Potential future markets:
  - Energy Arbitrage
  - Voltage Support
  - Wind Firming
  - Curtailment Mitigation

U.S. DEPARTMENT OF ENERGY

- Acknowledgment: "This material is based upon work supported by the Department of Energy under Award Number(s) DE-OE0000195."

Storage Week 2014

Slide compiled by Oncor from public sources

Existing ERCOT Energy Storage Resources Projects

Type/Name	County	MW	~On-line date
Sodium Sulfur/ Presidio [Non-Market]	Presidio	4	Q1 2010
LI/ NWF	Ector/Winkler	36	Q4 2012
LI/ OCI_ALM1	Bexar	1	Q1 2016
LI/ BLSUMMIT	Wilbarger	30	Q3 2017
LI/ TOSBATT	Howard	2	Q4 2017
LI/ PYR	Nolan	10	Q1 2018
LI/ INDL	Nolan	10	Q1 2018
Total		**93**	

ERCOT Energy Storage Resources Projects
(per the GINR Project Details (as of 9-30-18) [Partial List]

Planned **:

Project Name	County	MW	Projected COD
Millhouse Storage	Jim Wells	38	11/15/2019
Chisholm Grid Battery Storage	Tarrant	200	03/01/2020
Longbow Storage	Brazoria	35	03/01/2020
Angus Storage	Bosque	63	08/31/2020
Stillwater Storage	Nueces	72	08/31/2020
Dusky Storage	Hill	83	12/30/2020
Robles Storage	Dimmit	100	12/31/2020
Prairie Point Battery	Grayson	41	12/01/2020
Zier Storage	Kinney	60	05/31/2021
El Zorro Storage	Webb	125	02/01/2021
Green Holly Storage	Dawson	50	08/01/2021
		867	

* COD from Interconnect Request
** Does not include a few Planned Resources 10 MW or less

STORAGE IN PURE TRANSMISSION ROLES – LIMITED INDUSTRY STUDY TO DATE

Bulk Grid – Networked Transmission – ESS in Lieu of Trans Line

- NERC governance of reliability
- n-1 Design & operating requirements
- Limited study to date

Radial Line to Load Center

- Example – Presidio, TX
- Reliability: ESS can supply power continuously over an eight-hour period
- Voltage regulation to address voltage drop along the radial line
- Address momentary outages
- Allows the radial line to be taken out of service for maintenance without loss of service to customers

Vertically - Integrated

- Mixed use capable
- Single utility
- Economy
- Reliability

Competitively Structured Regions ~ERCOT

- Economy uses – Market
- Ancillary svcs uses – Market
- Grid reliability uses in networked grid
  - **see left-most box**
- Radial line to load center
  - **center box at left**

DELIVERY OF POWER – SUBSTATIONS & DISTRIBUTION

DISTRIBUTION SYSTEM USE CASES FOR ESS

- **RELIABILITY – Supply local downstream loads when the upstream power is out**

- **SERVE GROWING DEMAND – An asset to meet a portion of growing local peak demand without requiring that traditional upstream facilities, such as feeders and substations, be upgraded to meet that demand**

- **INTEGRATE SOLAR – Maintain required feeder voltage & power factor during rapid feeder power changes for feeders with high solar penetration when clouds come and go**

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TODAY'S APPROACHES TO IMPROVE FEEDER RELIABILITY

Vegetation Management

Feeder Maintenance

Automation

- Autonomous communications and control
- Automated Feeder Switch
- Reclosing Fuses
- Faulted Circuit Indicator
- Fault Location, Isolation, Service Restoration/Reconfiguration

- **Operations**
  - Outage Management Systems (OMS)
  - Advanced Meter Systems (AMS) w outage notification

USING ENERGY STORAGE TO IMPROVE RELIABILITY

- **Energy Storage System (ESS)**
- **Automation**

DISTRIBUTION FEEDER – BASIS FOR DISCUSSION

CIRCUIT BREAKER AT SUBSTATION

Circuit Breaker for Each Feeder

Protective Relays

DISTRIBUTION FEEDER

Radial, not networked

Simplified diagram does not show reclosers, capacitor banks, voltage regulators and laterals

12.5 kV or 25 kV primary voltage at Oncor

NEIGHBORHOOD STORAGE RELIABILITY INITIATIVE

Purpose

- Evaluate effectiveness of deploying small-scale battery storage to bridge outages and improve local power quality

Details

- Six 25 kW lithium ion batteries
- Installation, testing and monitoring

Capacity

- These batteries are capable of bridging outages up to a few hours of duration

Deployed & operational by end of 2014

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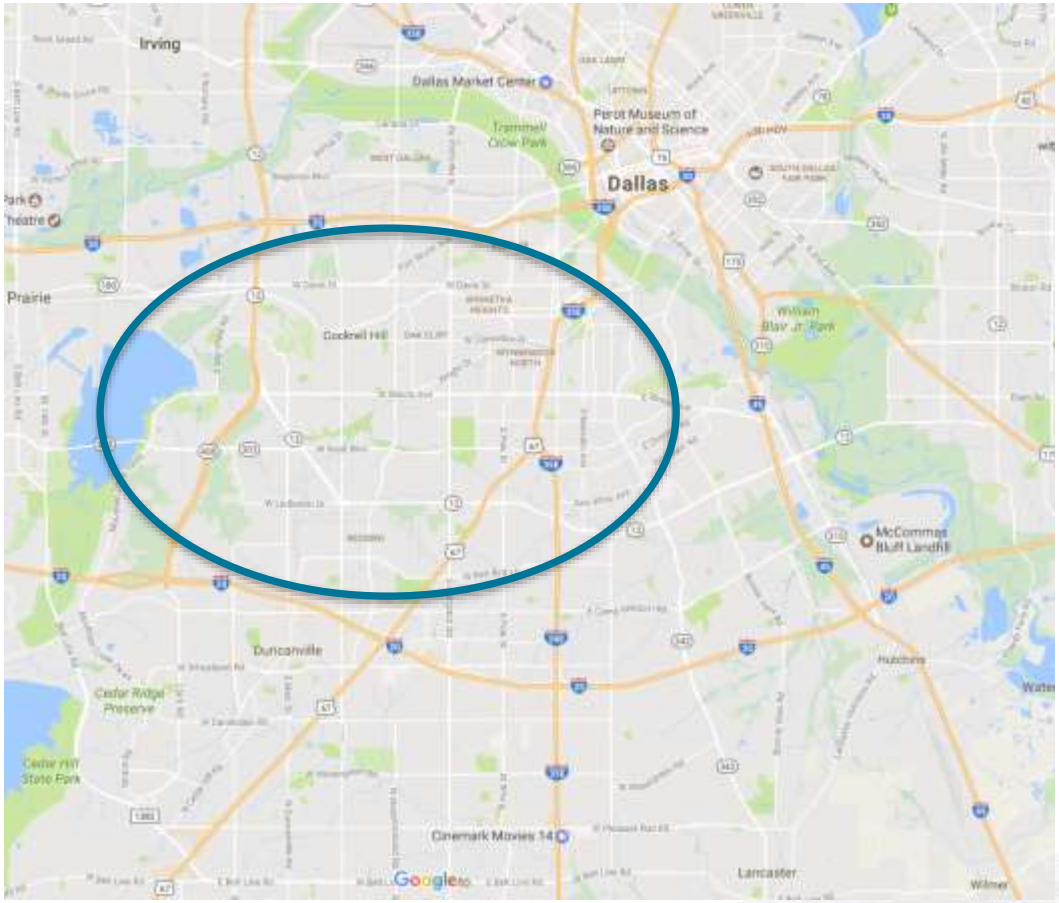
NEIGHBORHOOD STORAGE RELIABILITY INITIATIVE
Location Selection



120/240 Single Phase

Test Installation (SOSF)

South Dallas Target Area

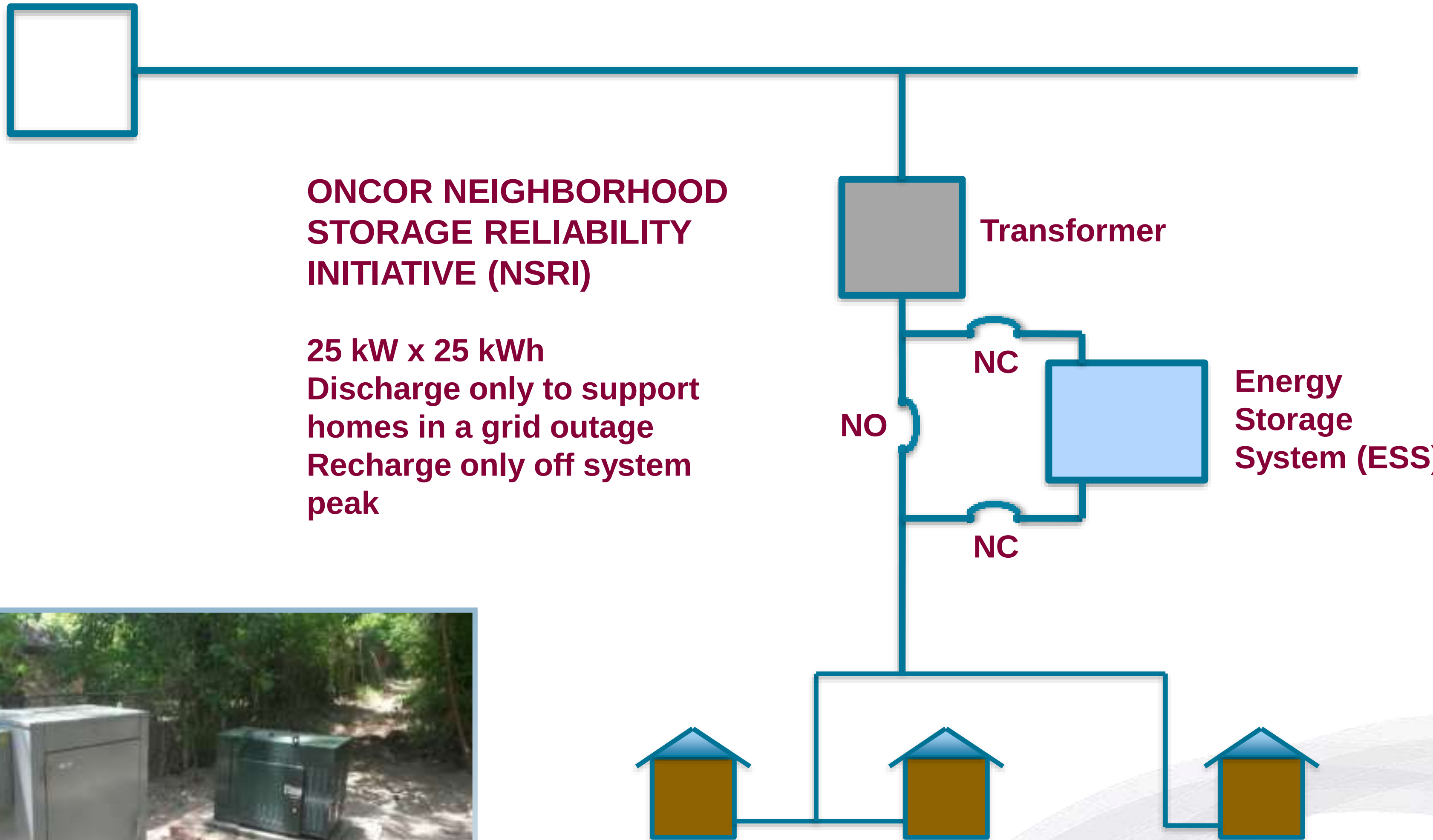
High SAIDI Feeders

Customer Verbal Approval

Available Space

SAIDI = System Average Interruption Duration Index

ESS PLACED AT LOAD-SERVING TRANSFORMER



ONCOR NEIGHBORHOOD STORAGE RELIABILITY INITIATIVE (NSRI)

25 kW x 25 kWh
Discharge only to support homes in a grid outage
Recharge only off system peak

NEIGHBORHOOD STORAGE RELIABILITY INITIATIVE
Distribution level outage backup, voltage regulation

25 kW x 25 kWh

Installed at single phase 120/240 secondary

1 at an Oncor facility

5 on Oncor System

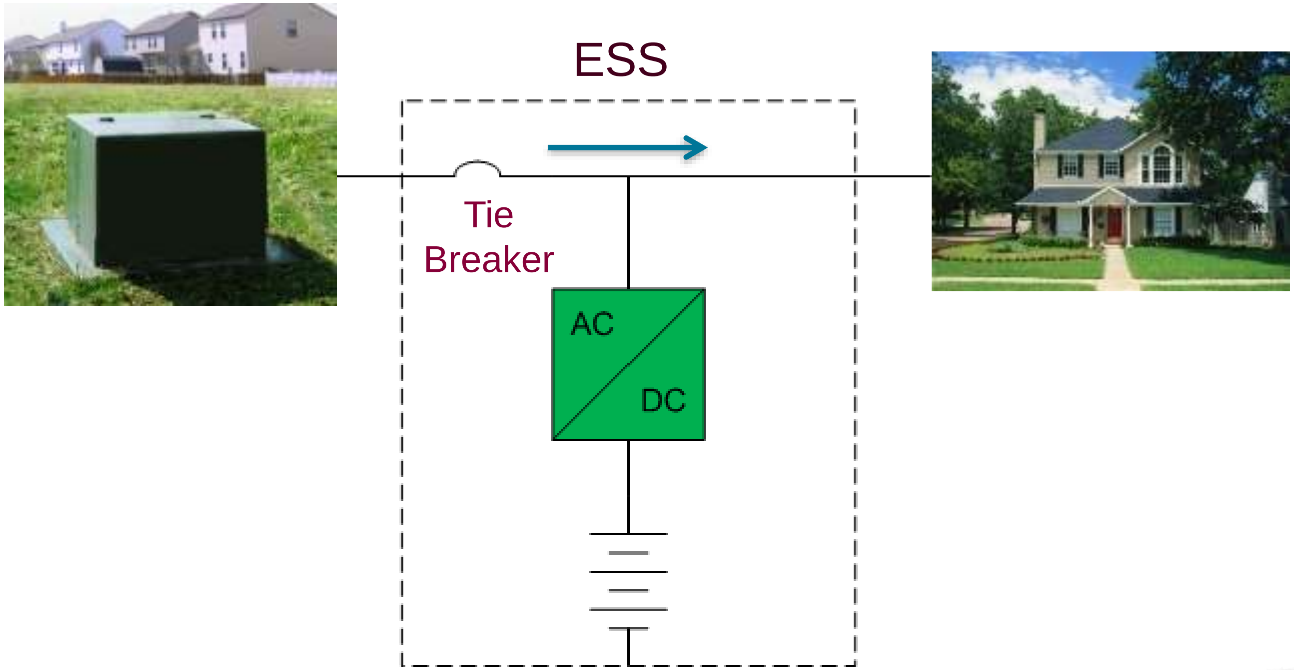
Supports residential homes during outages and maintains voltage within mandated levels (114 – 126 V)

Oncor Initial Installation at Oncor Facility

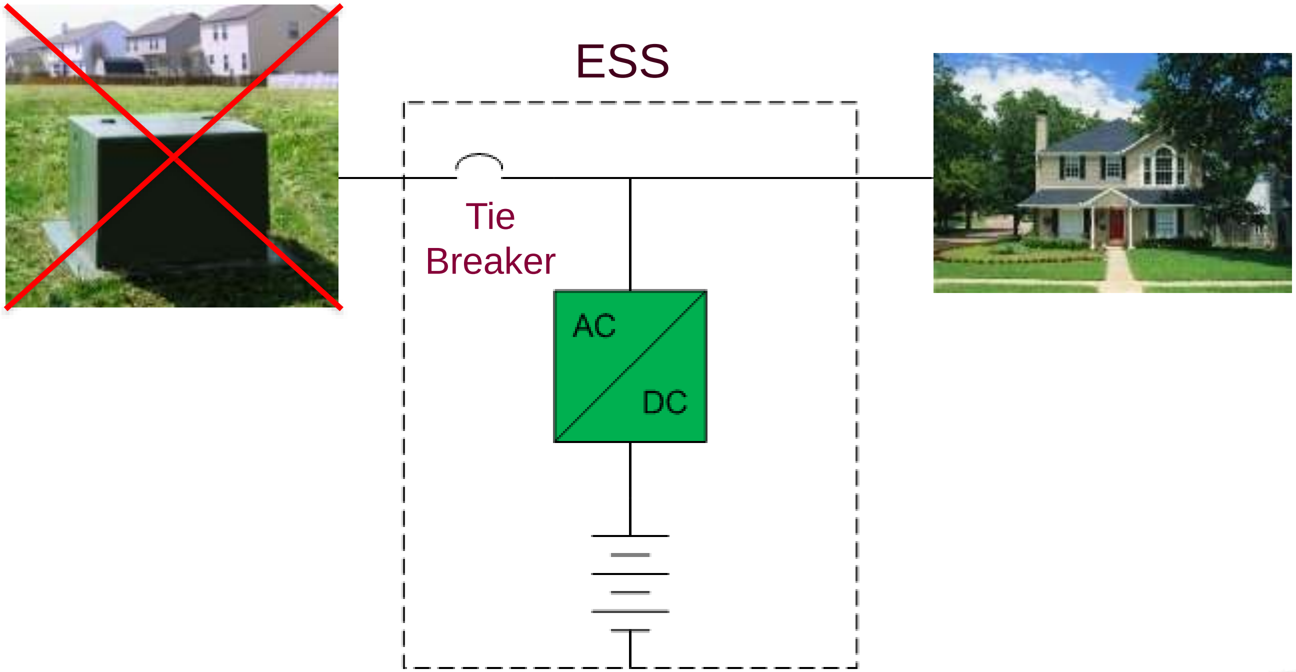
Neighborhood in South Dallas

ONCOR.

Example: Outage



Example: Outage



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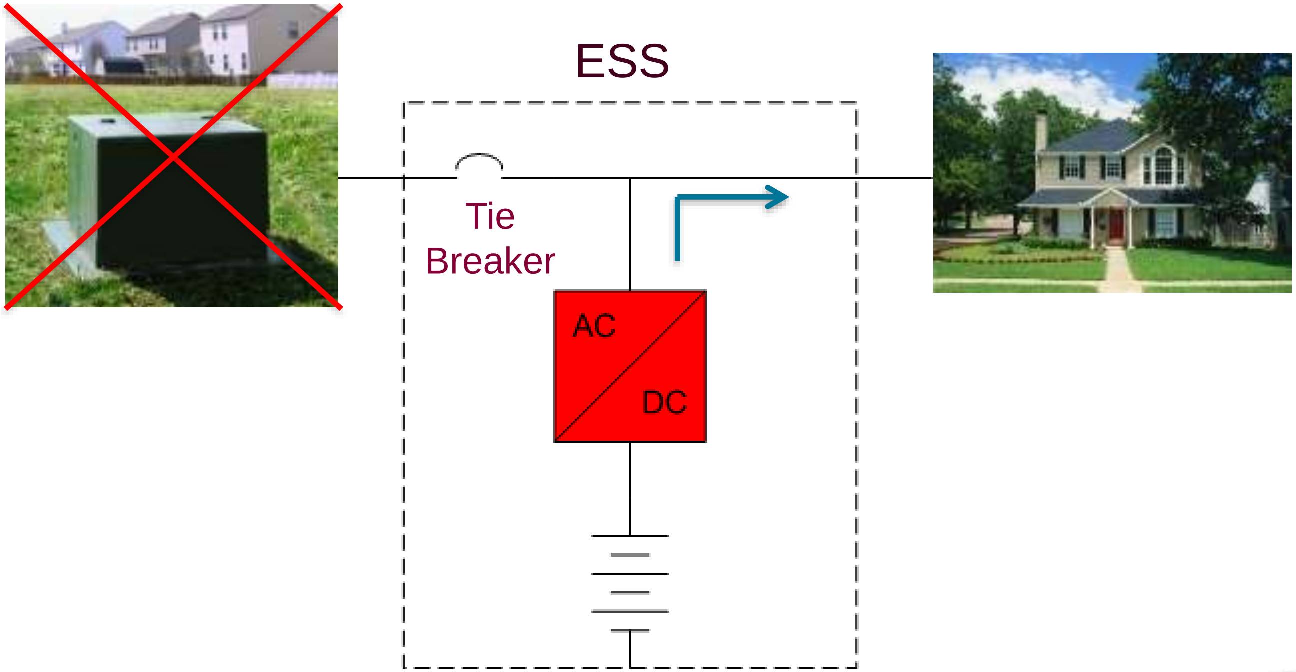
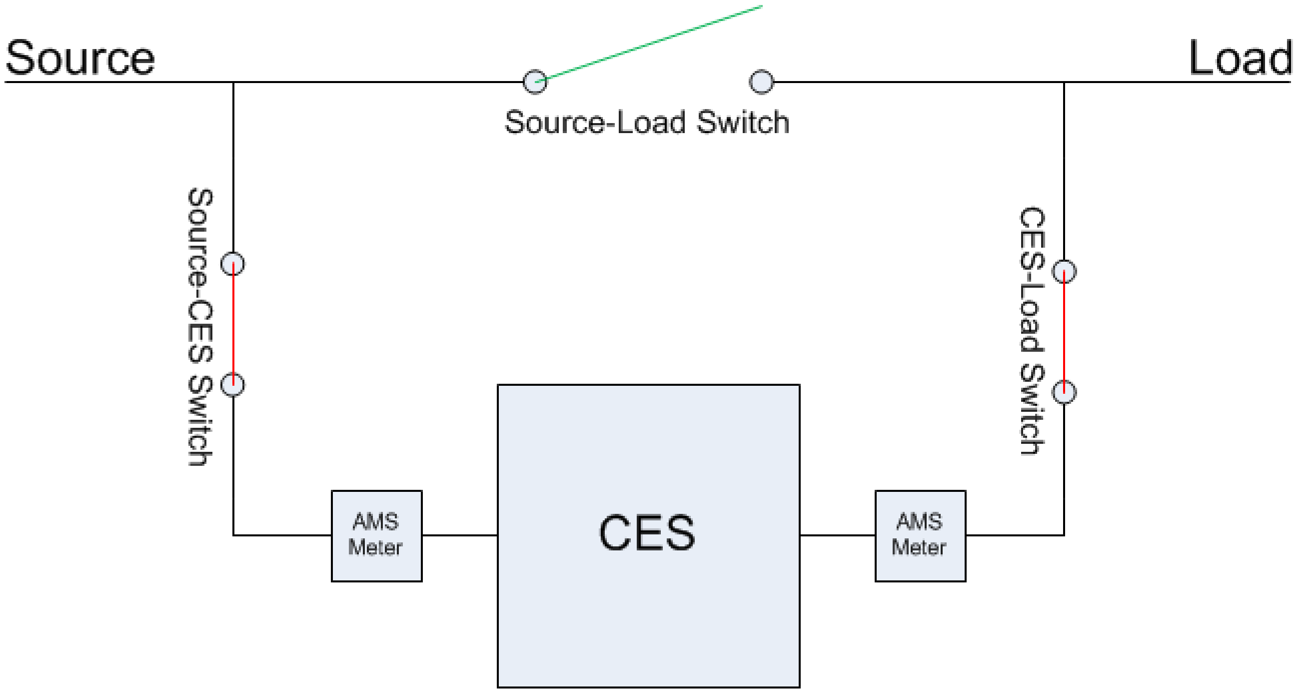
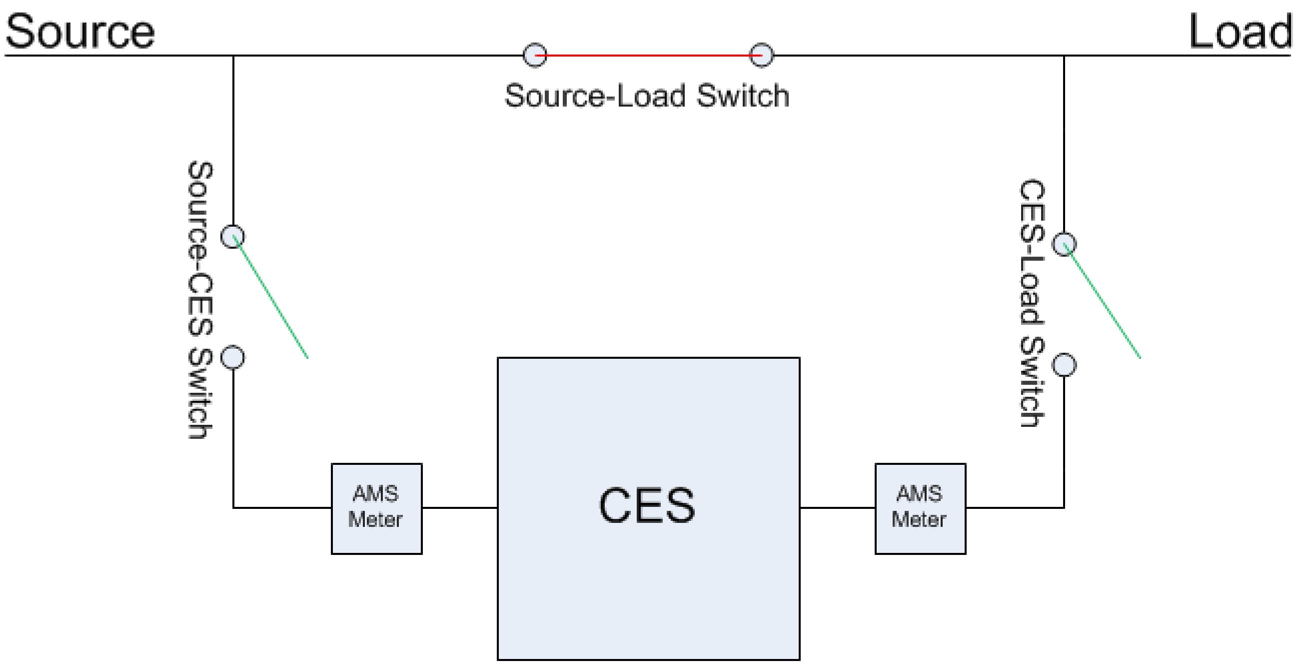


Normal Switching Scheme



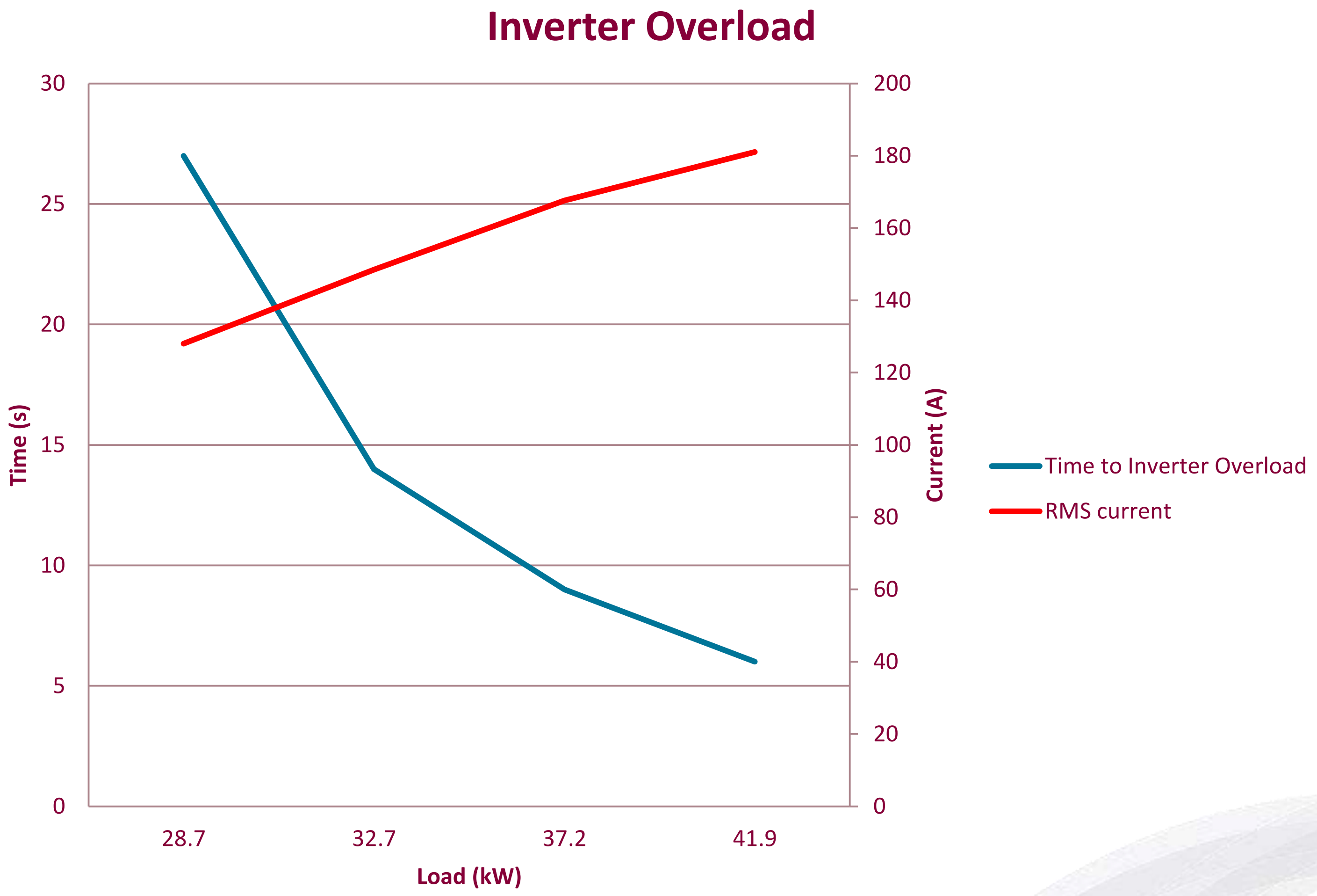
CES = Community Energy Storage

Bypass Switching Scheme

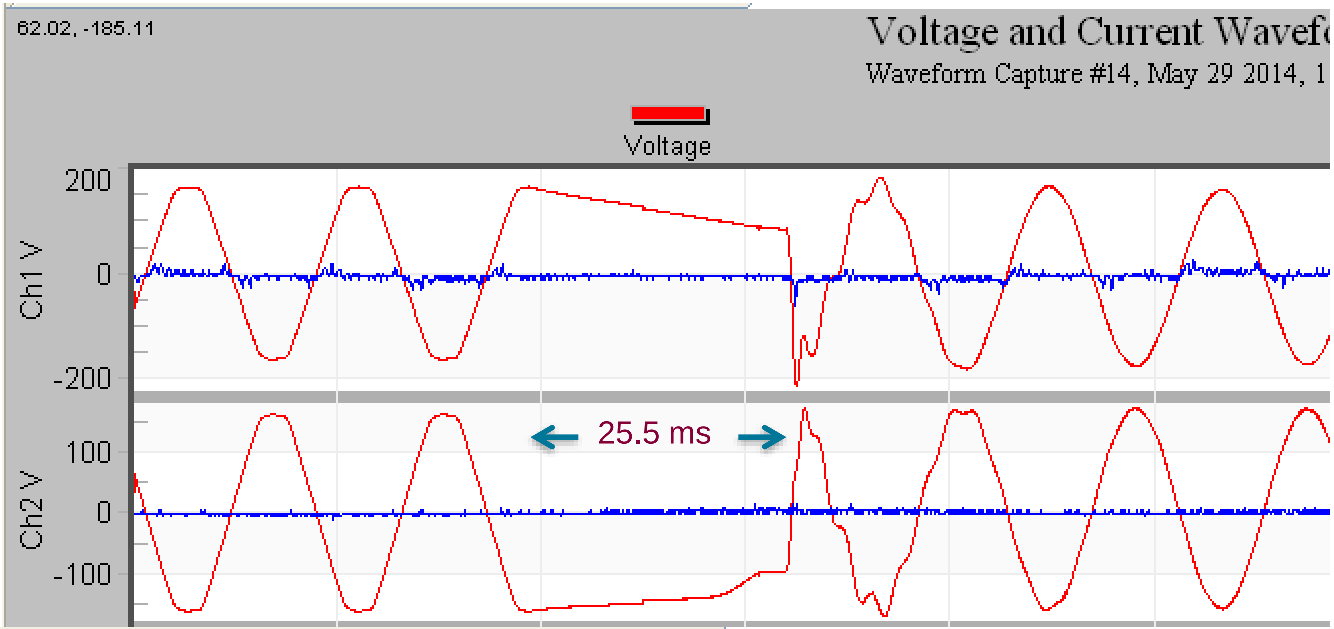


CES = Community Energy Storage

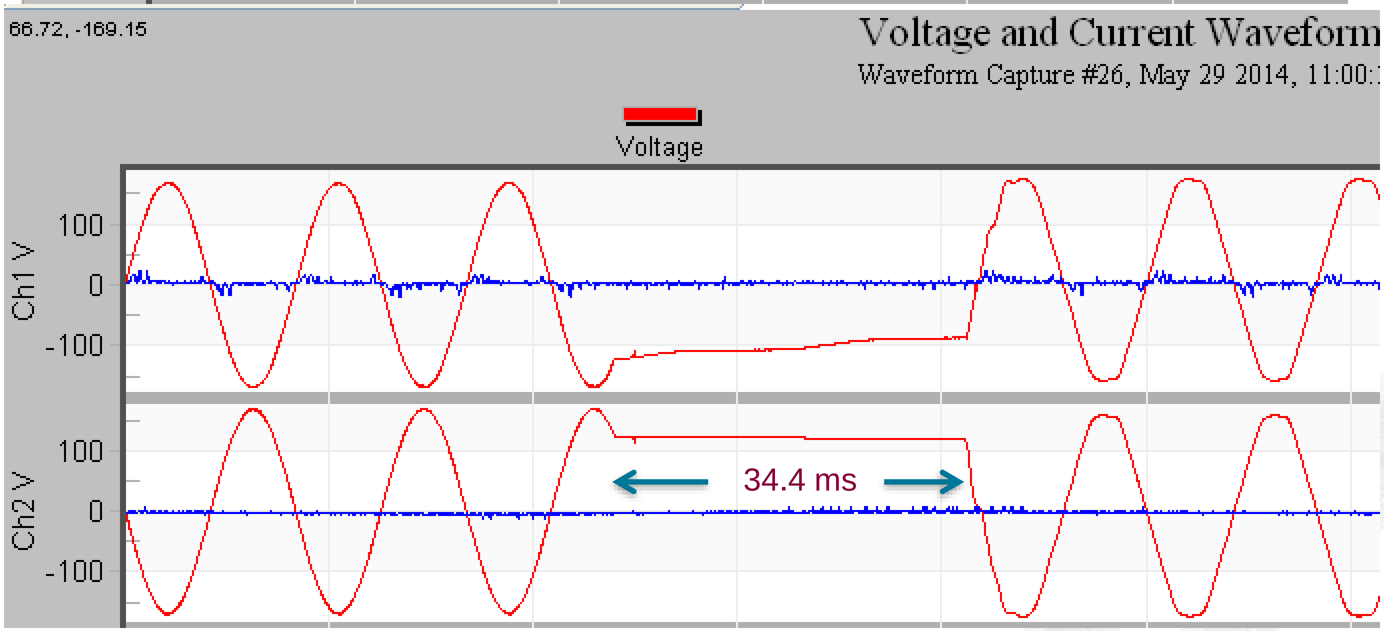
NSRI Testing
Inverter overload capability



NSRI Testing
Open circuit island test

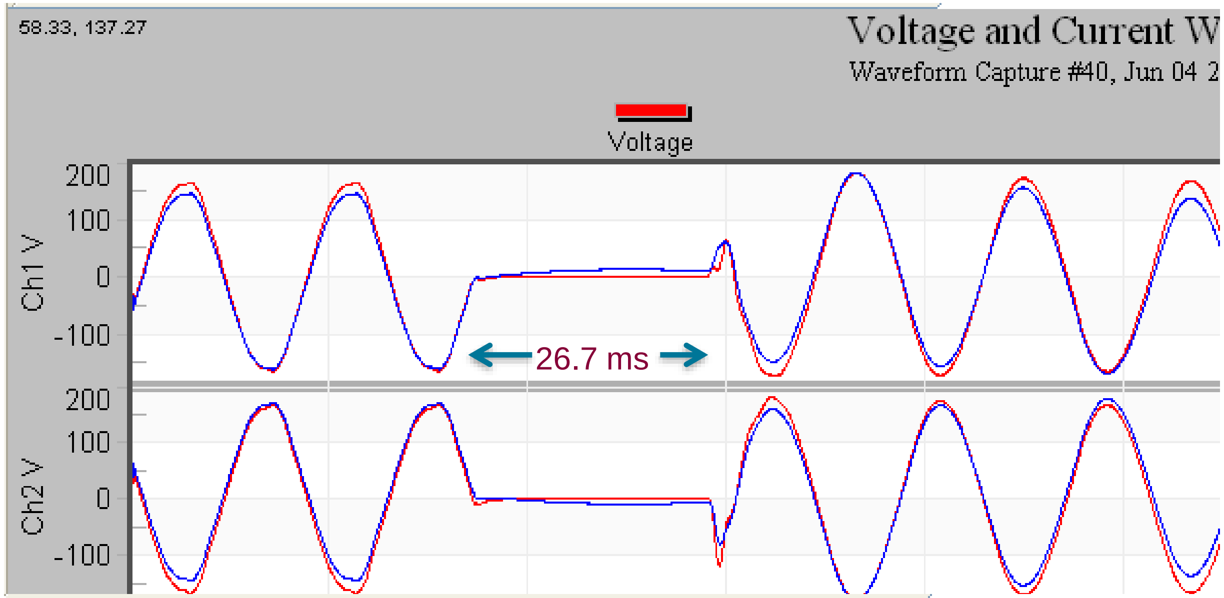


Transition to Inverter

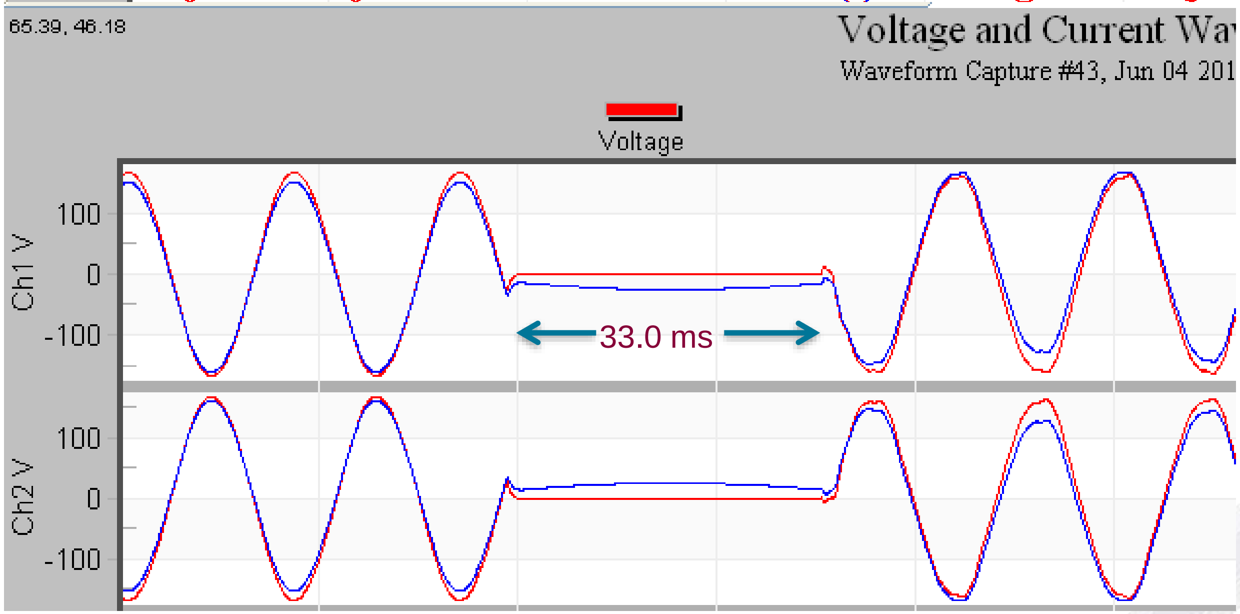


Transition to Grid

NSRI Testing
25 kW Load Island Test

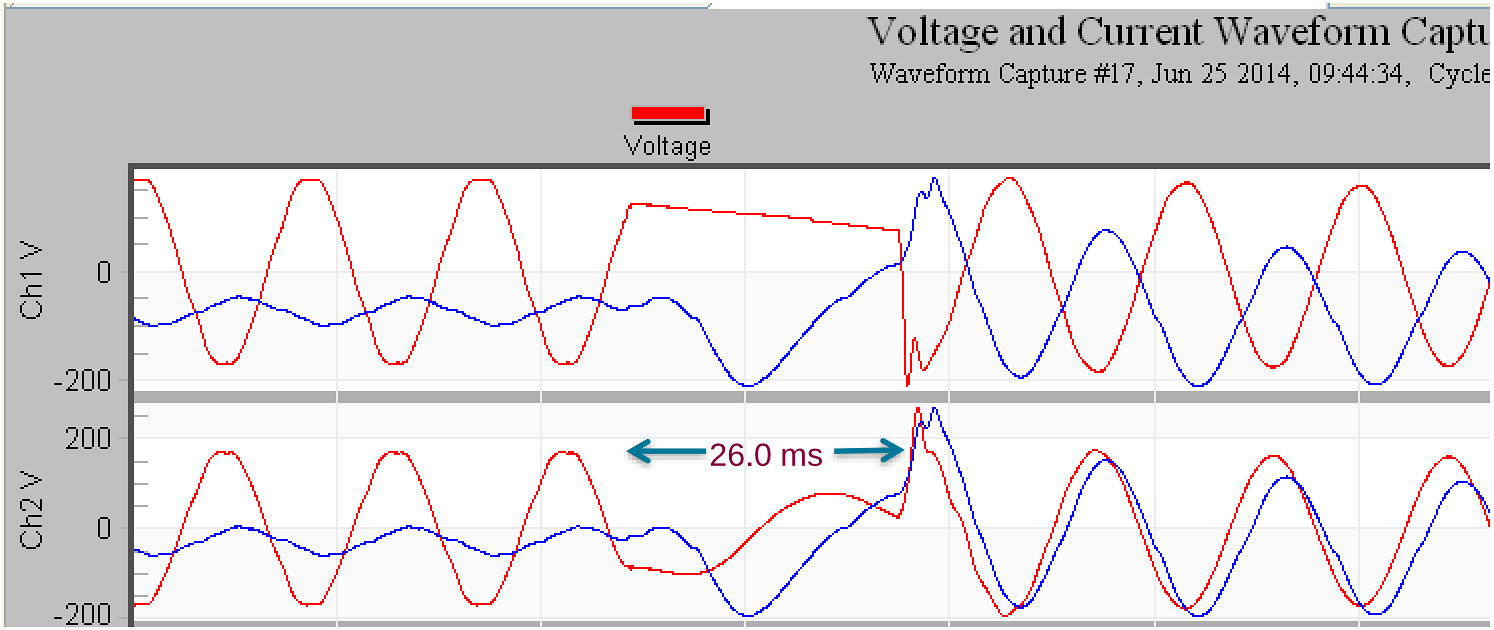


Transition to Inverter



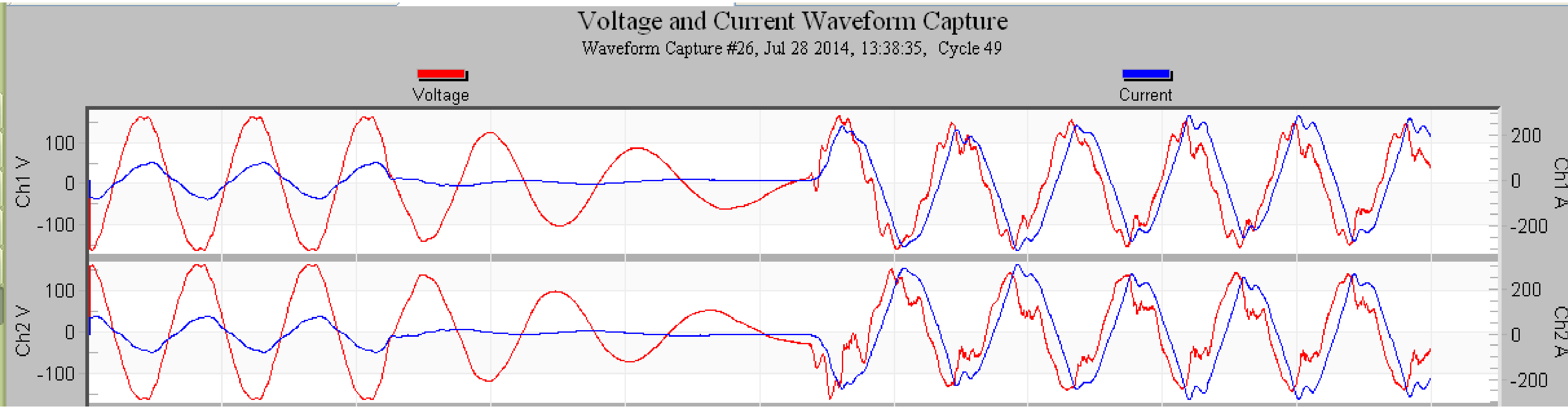
Transition to Grid

NSRI Testing
Small Fridge Island Test (2 amp motor)

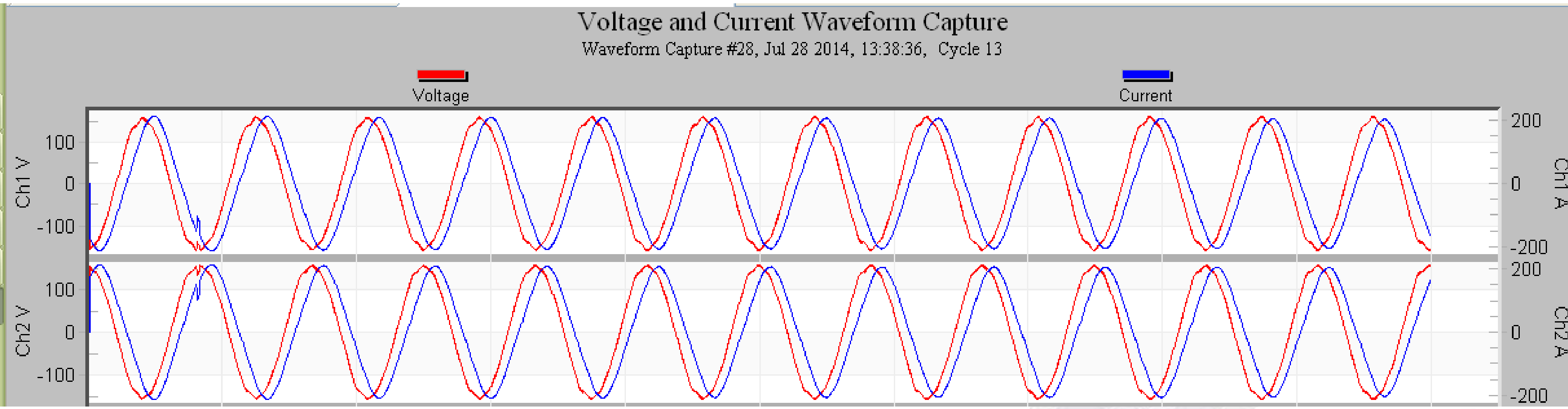


Transition to Inverter

Large A/C Load Island Test



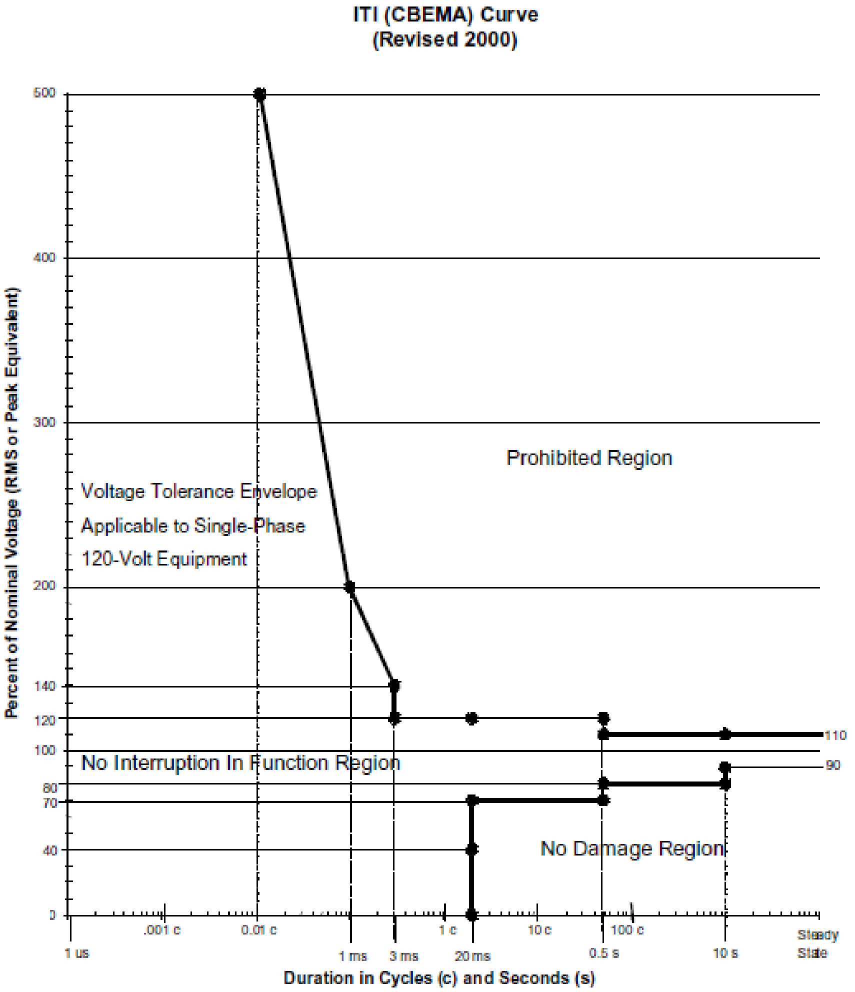
1 second later



Operational Settings

Based on ITI (CBEMA) curve defining voltage tolerance thresholds of power supplies

NSRI islanding settings based on this curve



NSRI Results: Inception to January 2019

Location	Number of Operations	Total Island Minutes	Average	CIM	Efficiency
1	16	921	58	2763	95.1%
2	9	267	30	1068	98.9%
3	13	506	39	2024	98.0%
4	26	483	19	966	96.9%
5	7	428	61	1712	99.1%
All	71	2605	37	8533	

Efficiency measured as energy in vs. energy out over the life of the system

DISTRIBUTION FEEDER – BASIS FOR DISCUSSION

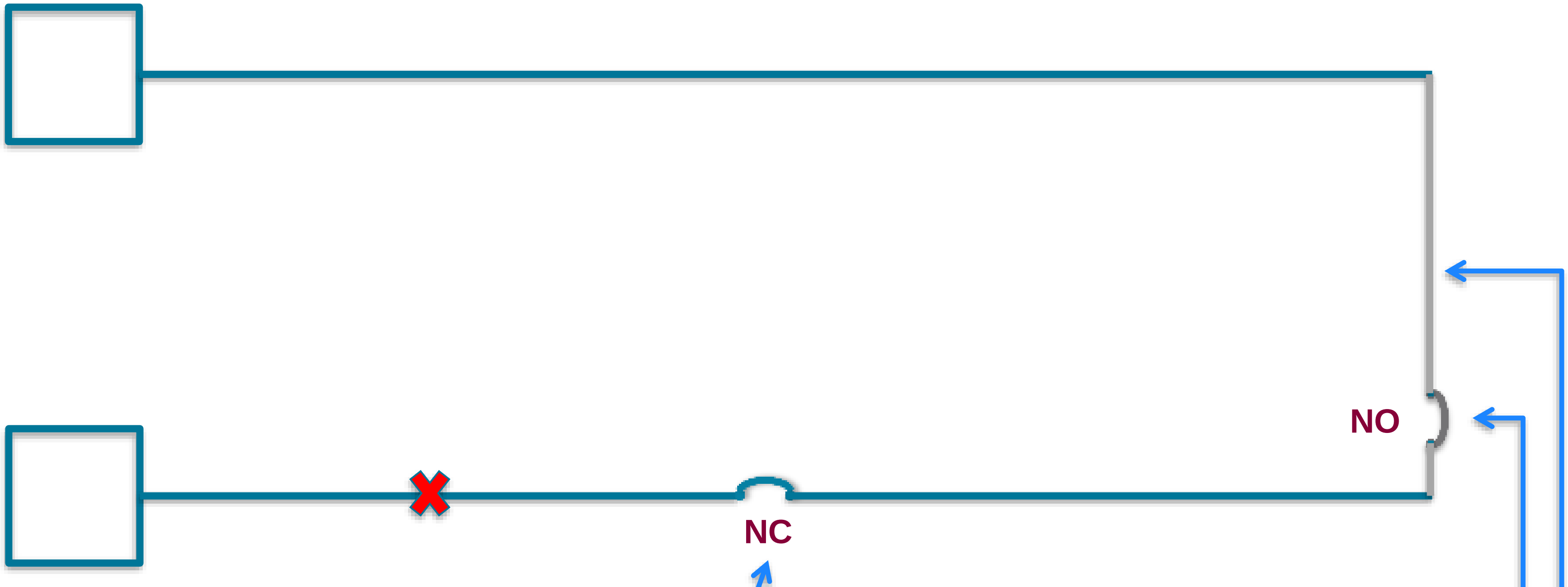
CIRCUIT BREAKER AT SUBSTATION

- Circuit Breaker for Each Feeder
- Protective Relays

DISTRIBUTION FEEDER

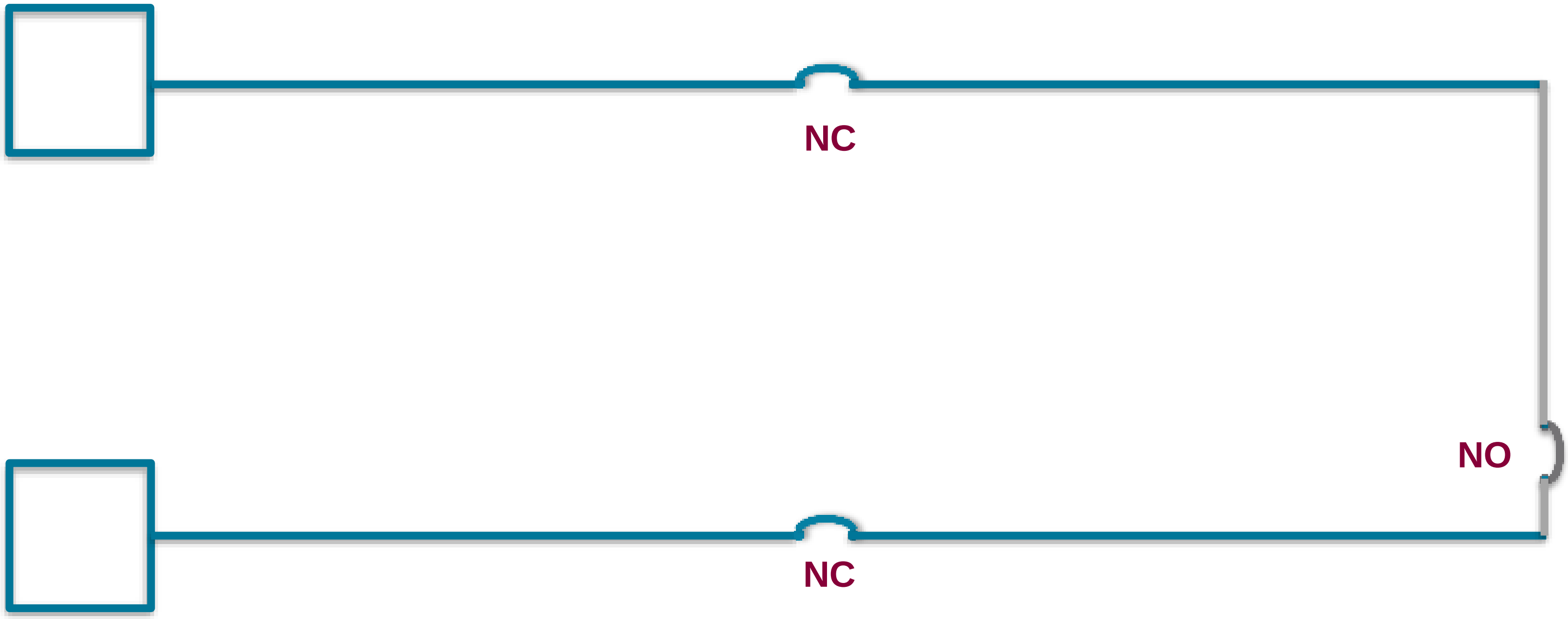
- Radial, not networked
- Diagram is simplified and does not show reclosers, capacitor banks, voltage regulators and laterals
- 12.5 kV or 25 kV primary voltage at Oncor

SECTIONALIZE & BACKFEED TO IMPROVE RELIABILITY (FLISR)



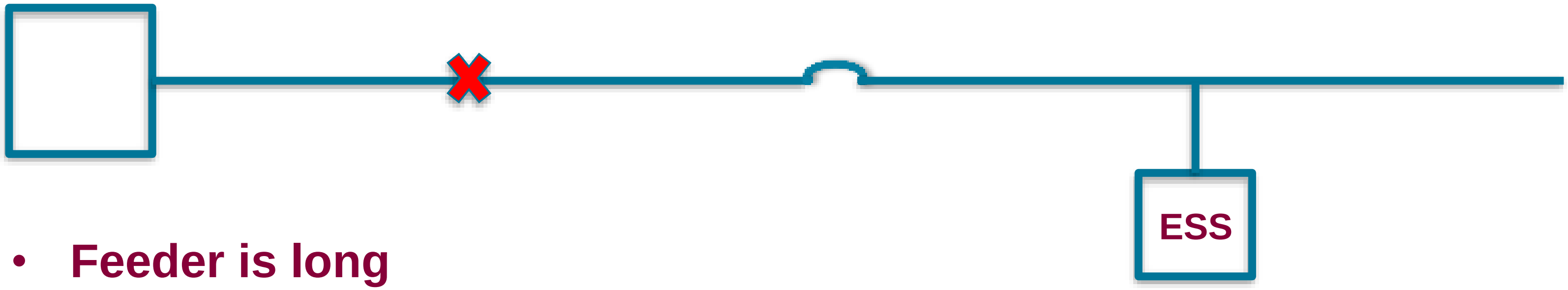
- Add sectionalizing to the feeder
- Connect end of feeder to nearby feeder
- Breaker opens and locks. Locate fault
- Open NC Normally Closed switch
- Close NO Normally Open switch to feed healthy segment of the circuit

SECTIONALIZING & BACKFEED TO IMPROVE RELIABILITY – TYPICAL INSTALLATION



- Capability to backfeed to either feeder
- Construction of tie between the two
- Adding 3 automated switches
- May also require some upgrade of circuit to carry the added load
- Utilized in urban & suburban areas

RURAL FEEDER – UTILIZE ESS VS BACKFEED



- Feeder is long
- Distance to another feeder for backfeed is large
- Upper portion of feeder experiences an outage (eg. local storm)
- All customers are out

- Add sectionalizing
- Add storage downstream
- Size storage to support customers for ~2 hours
- Allow time for crews to restore power upstream
- Improve SAIDI on the feeder

- ESS must have grid-forming capability
- Energy source
- Voltage & frequency control
- Supply in-rush current when initially restore

ESS – REQUIREMENTS FOR FEEDER RELIABILITY

- Operate ESS only during a grid outage
- Designed to serve load ~2 hours during restoration of grid ➔ increase reliability by improving SAIDI
- Brief outage – Wait until breaker locks out. Isolate downstream load from upstream faulted grid with sectionalizing switch. Start the ESS
- ESS designed to provide in-rush current
- ESS designed to support faults on the feeder to allow existing fusing or other protective devices to work
- Inverter must be grid-forming
- Controller must maintain appropriate voltage & frequency using only the ESS during this operation of a small electrical island until upstream grid power is restored

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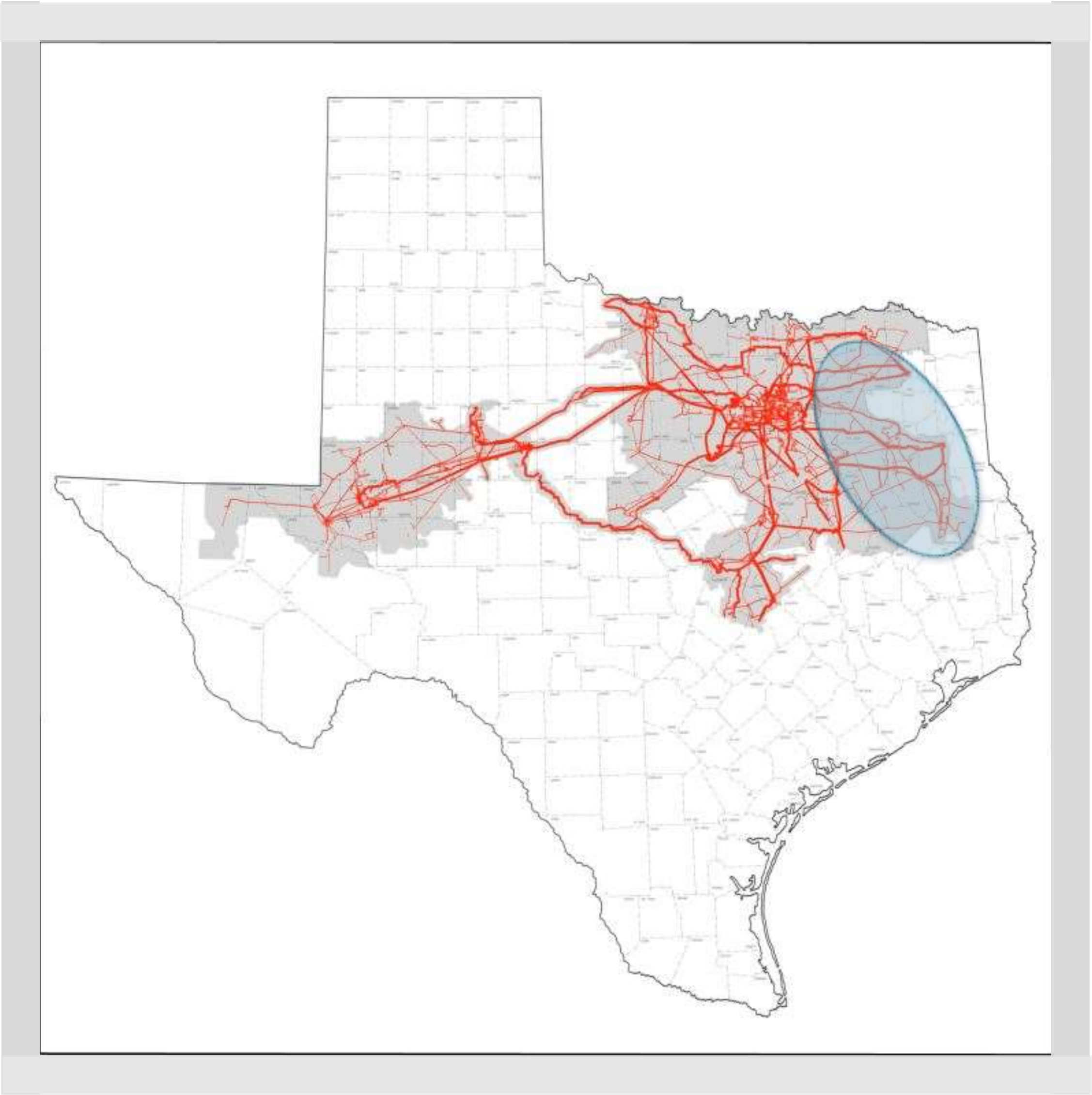
GEOGRAPHIC REGION FOR THIS PROJECT



Area of interest is in blue oval

Characteristics of the area

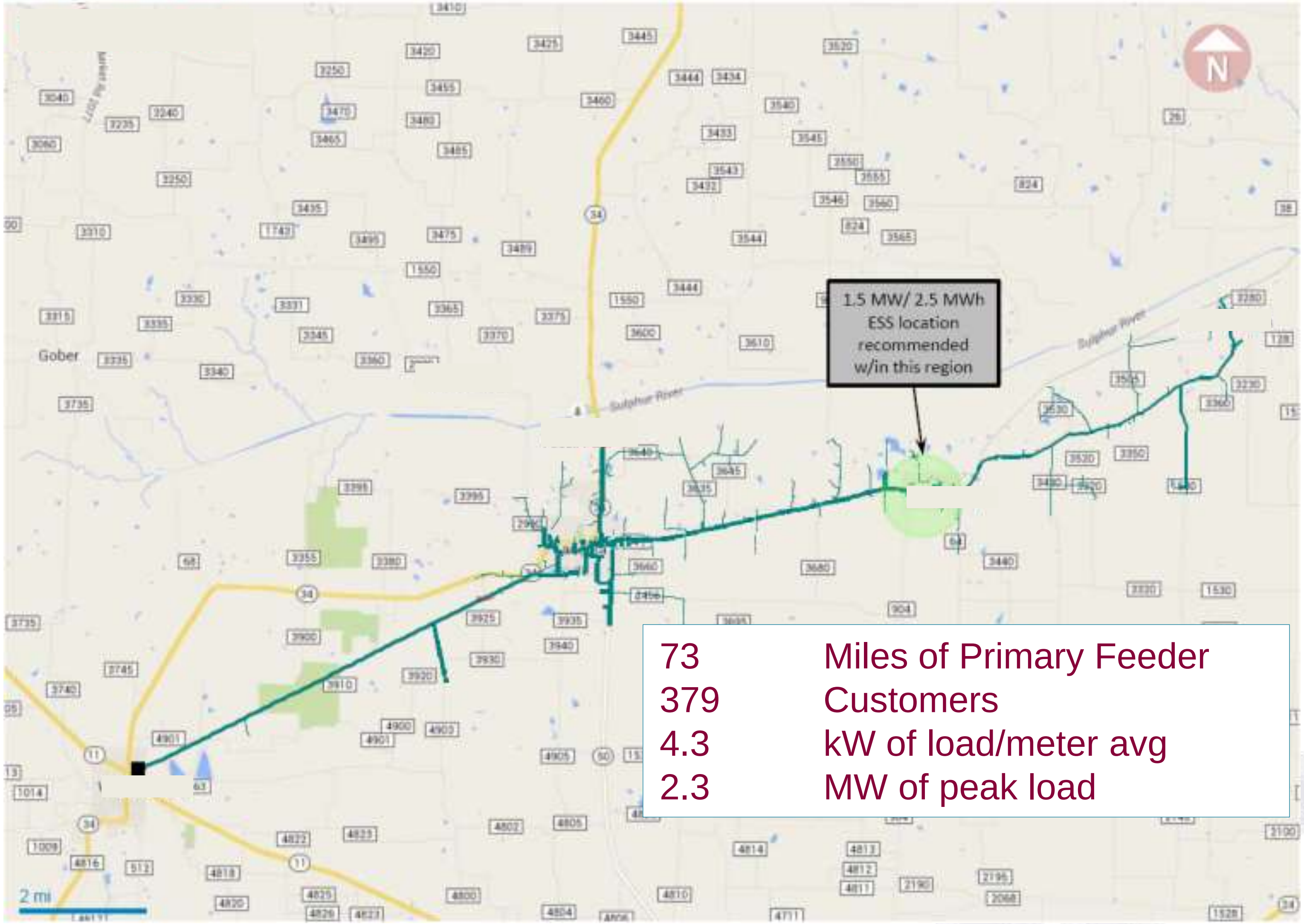
- Agriculture
- Forestry
- Sparse population

FEEDER SELECTION CRITERIA

1. Consistently high SAIDI
2. Majority of faults along feeder backbone
3. Ties to other feeders not easily accessible
4. Minimum of a few hundred customers
5. No heavy industrial customers
6. Feeder length >40 miles primary 3-phase
7. Pockets of load located toward the end of the line

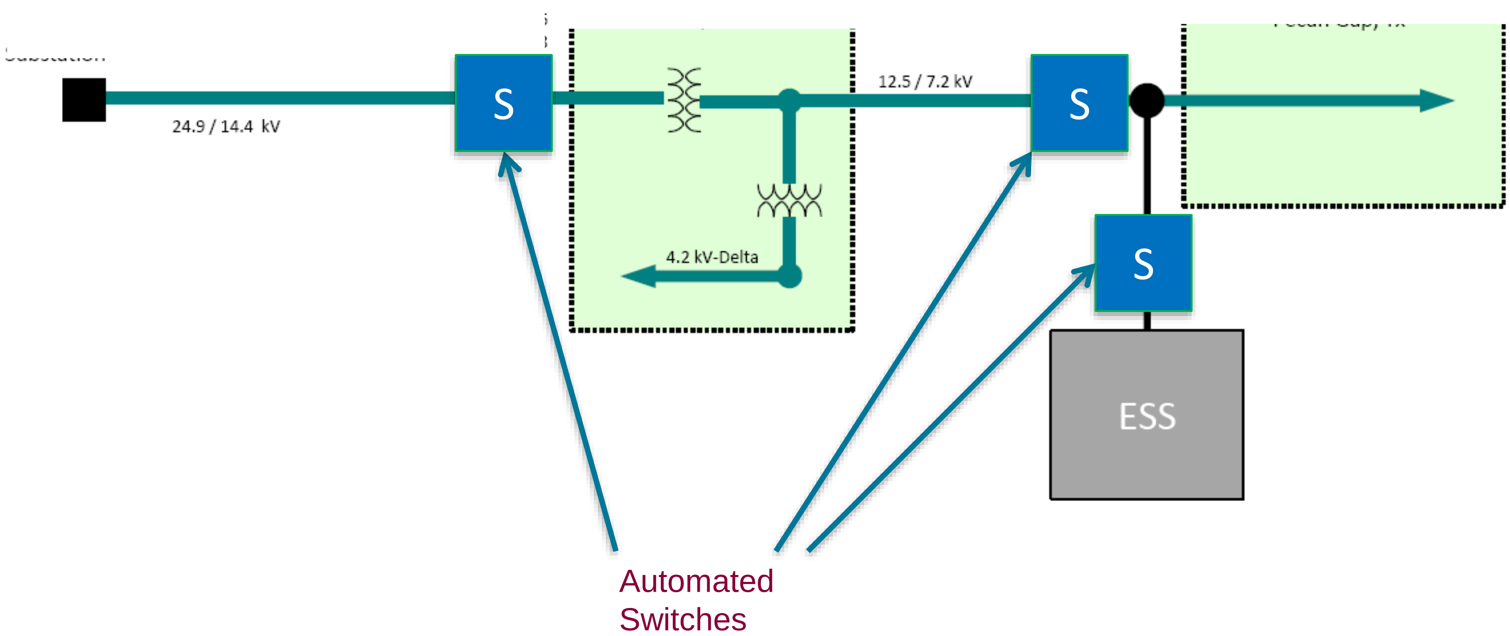
SAIDI = System Average Interruption Duration Index

Feeder B

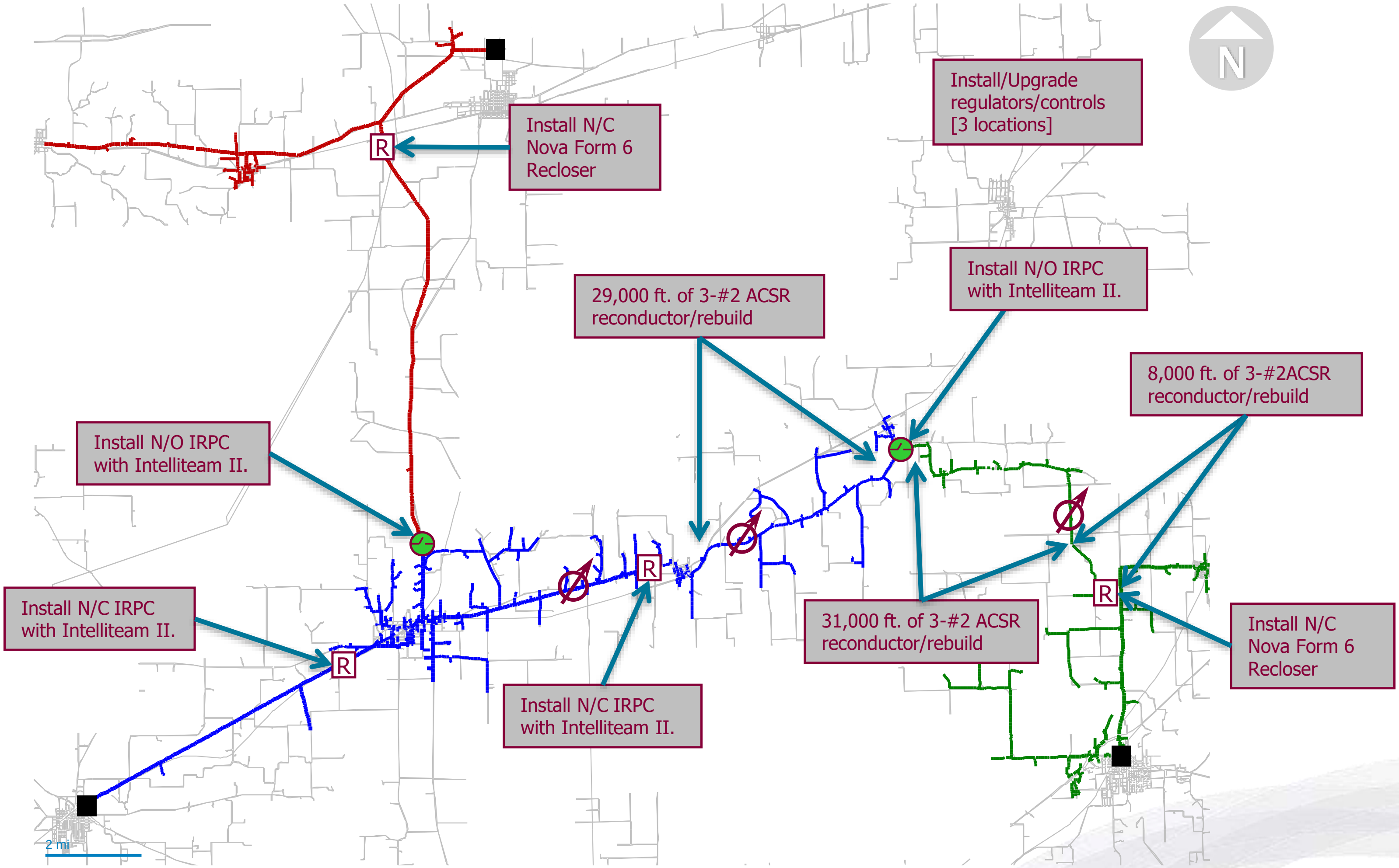


73	Miles of Primary Feeder
379	Customers
4.3	kW of load/meter avg
2.3	MW of peak load

Feeder B Battery Solution



Feeder B Alternative Solution



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RURAL FEEDER – Lessons Learned

- Feeder in-rush current on blackstart via ESS imposes additional specification and design needs, in order to procure an ESS today for this specific application
- System protection requires adequate fault current from an ESS to blow fuses on feeder lateral lines. This also imposes additional specification and design needs
- Suggests to vendors of ESS a need to develop standard options for ESS that incorporate in-rush current and fault current needs

Outline

- Why Now?
- Energy Storage System (ESS) – Definition
- Roles – Bulk Power, Wires, Customer, DER
- Utility Distribution Systems
  - Meet reliability needs
  - Serve growing demand
  - Microgrids
- Multiple uses of a single ESS
- Regulatory & market construct considerations

SERVE GROWING LOAD

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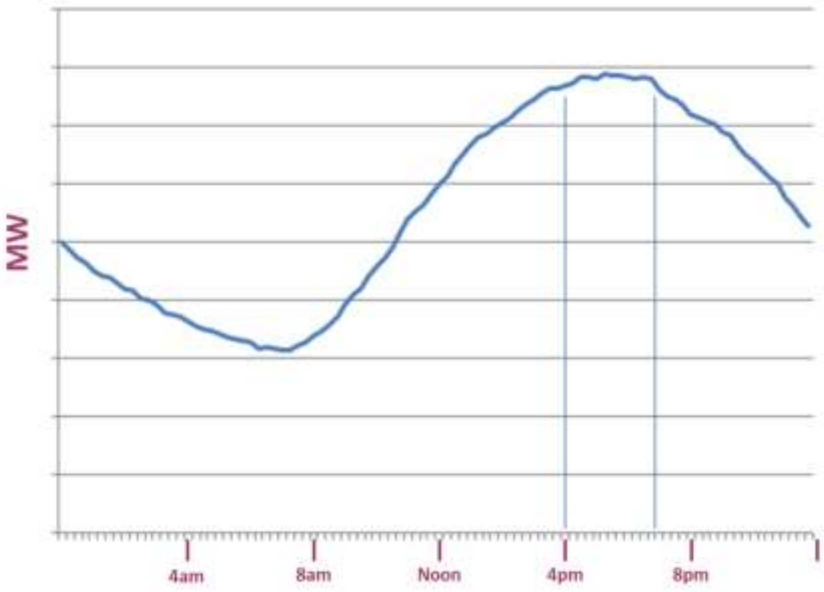
RELIEVE OVER-DUTIED SUBSTATION EQUIPMENT

- **For a fully loaded substation transformer, could an ESS serve incremental peak load growth to avoid overloading the transformer?**
- **Defer a substation expansion with new transformer for a year or two or three?**

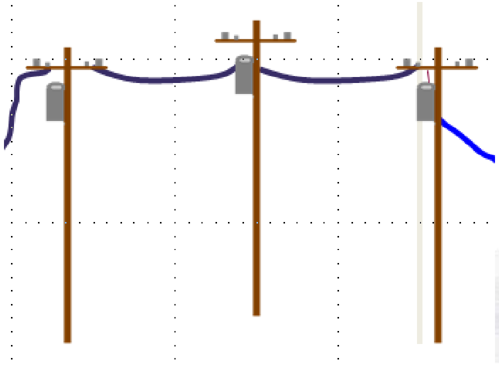


SERVE GROWING LOAD – Substation

- **Meet the incremental peak demand on a substation**
  - When that incremental demand would create total substation demand that is greater than what the substation equipment can support
- **Case 1 – The peak demand on substation equipment is growing slowly**
  - A storage system can meet peak hour needs, and thereby avoid or defer a major substation upgrade or expansion
- **Case 2 – The peak demand on substation equipment is expected to grow very rapidly**
  - Storage can be deployed more to defer the traditional upgrade if more timely or more cost-effective

SERVE GROWING LOAD – Distribution Feeder

- Meet the local demand growth downstream on a feeder
- The demand growth will otherwise require that a portion of the feeder that is upstream of the demand growth will need to be upgraded
- The cost or lead time or community impact might be limiting factors in upgrading the feeder
- Siting is available for a storage facility



INTEGRATE DER ON A DISTRIBUTION FEEDER

- Maintain required feeder voltage & power factor during rapid feeder power changes – eg. when clouds come and go for feeders with high penetration of solar PV systems
- Utilize ESS to complement deployed voltage & power factor control such as load tap changers (LTC), capacitor banks, and voltage regulators, all of which are electromechanical and not designed for frequent operation
  - Utilize energy, power, and reactive capabilities of the ESS
  - Frequent use of LTC's, capacitor banks and voltage regulators will wear them out, requiring higher maintenance
  - Inverter is utilized for feeder voltage & reactive power management
  - ESS help balance downstream and upstream power flow

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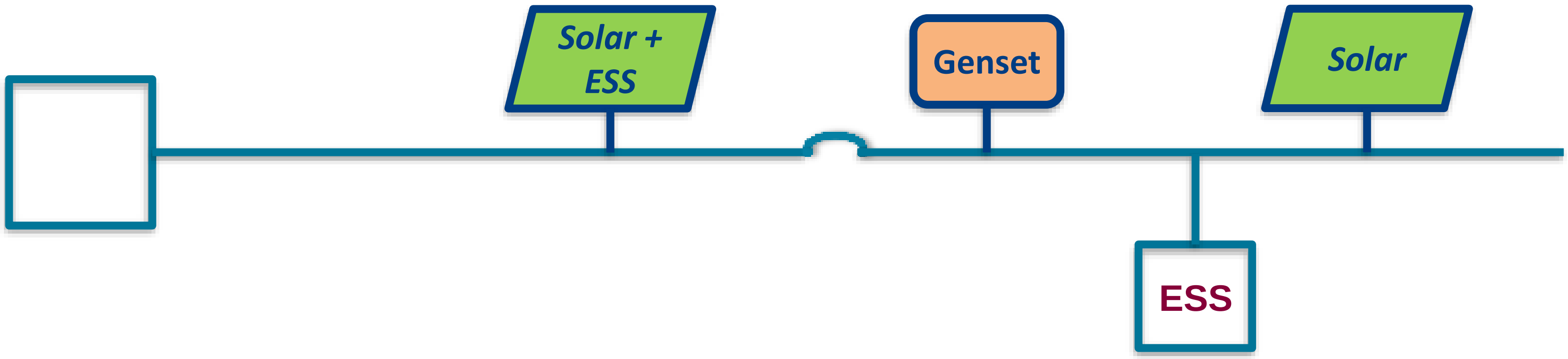
STORAGE + DISTRIBUTED ENERGY RESOURCES



Role of Storage to Integrate DER?

- Mitigate rapid power level change on feeder voltage (solar smoothing)
- Time-shift energy to more useful periods
- Keep local energy at local level, especially if an upgrade of upstream feeder is needed
- Avoid two-way flow

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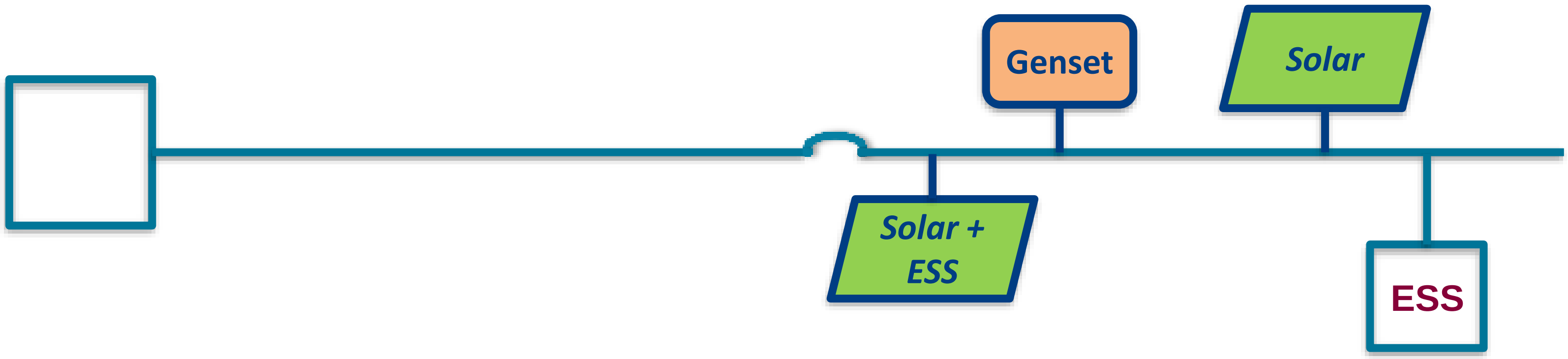
- Multiple uses of a single ESS
- Regulatory & market construct considerations

LOCAL MICROGRID – FUTURE CONSTRUCT



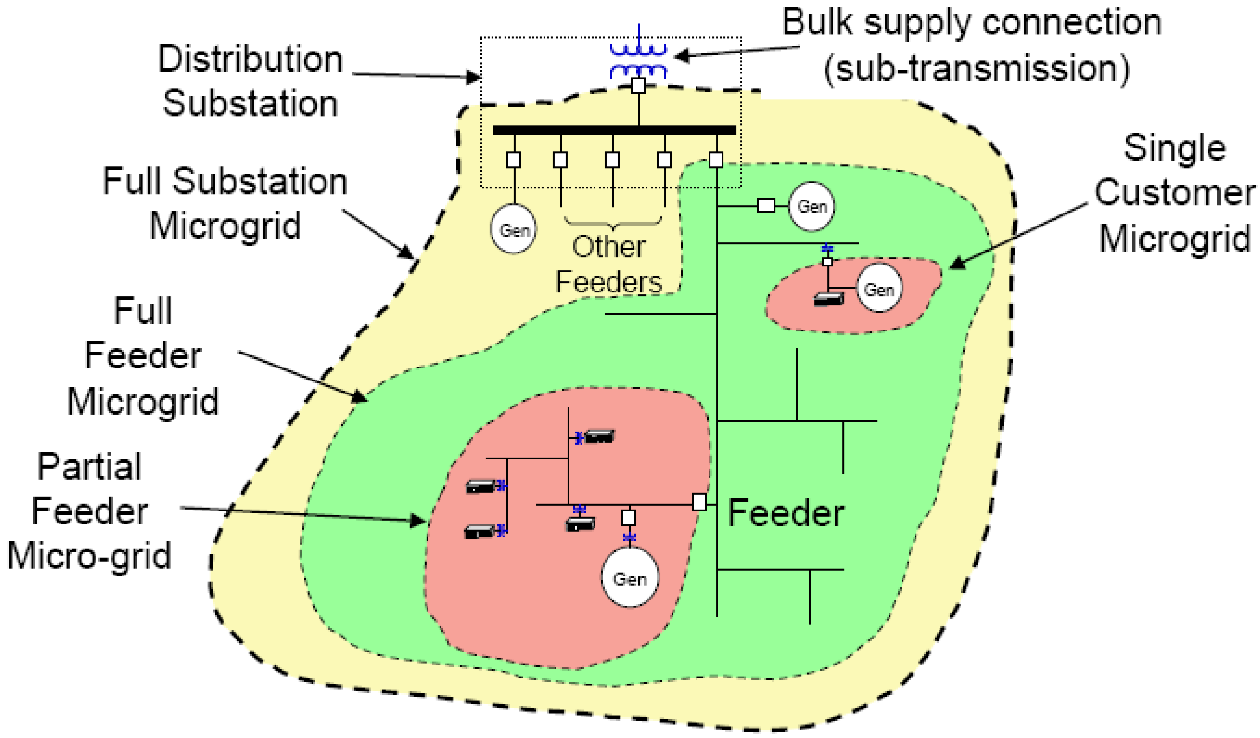
ESS on Feeder with DER

- Feeder segment with storage
- Grid-connected and islanded operations
- Grid-connected: Limit abrupt changes of power level on feeder/support voltage stability
- Islanded: ESS as grid-forming element / Controller dispatches supply and ESS to balance with load during island

Reliability → Resilience

- Utilize ESS to support feeder segment in an outage
- Distributed energy resources (DER) extend the electrical island operation
- Local controller to maintain frequency & voltage, resynchronize to the grid
- Controller dispatches supply and ESS to balance with load
- Reliability → Resilience if designed for robust events

What is a Microgrid?



"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 and that connects and disconnects from such grid to enable it to operate in both grid-connected or 'island' mode"

Outline

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MORE THAN A SINGLE USE FOR AN ESS

- A common theme in energy storage is to find ways to maximize the value of the ESS by using it for more than one purpose
- Define the primary use
- Examine secondary use: 1. contemporaneous with primary use; 2. at times primary use is not needed
- Avoid degrading capability for the primary application when designing additional uses
- Rigorous control scheme required
- Avoid reducing life of the ESS unless higher value overall is achieved

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MULTIPLE USE – MULTIPLE USERS

- When the primary and secondary uses benefit two different parties, then business model and possibly regulatory model come into play
  - maintain accountability for ESS health
  - serve the respective needs
  - provide proportional value & risk to each entity

Utility & customer

Customer & ISO

Utility & ISO

CUSTOMER-SITED ESS SERVING GRID NEEDS

- Several storage business entities are engaging in customer-sited storage to serve specific customer needs and to support utility or ISO needs or pursue revenue opportunities thru ancillary services
- Each ESS performs two or three functions, such as demand charge management for the customer, and a grid need for the grid operator
- Aggregation across several customer-sited ESS may be necessary to reach scale needed for grid support

Outline

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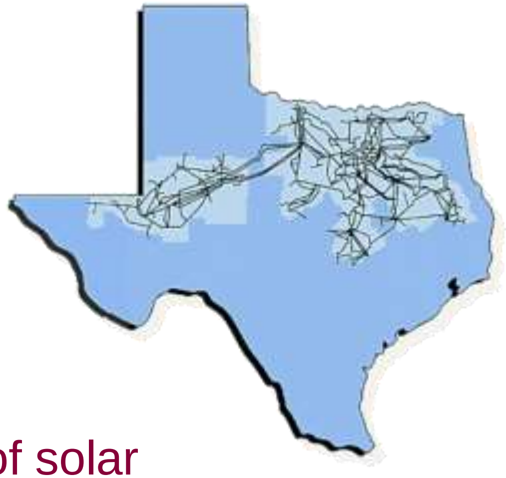
CONTACT

Bill Muston

Oncor Electric Delivery Company LLC

bill.muston@oncor.com

214-486-3015



How do we reduce the length & frequency of power outages?

How do we increase the efficiency of the grid?

How do we create a more resilient, secure and even self-healing power grid?

How do we integrate increasing amounts of solar and wind power into the grid?

How do we support customers who choose rooftop solar and electric vehicles?

How do we achieve all this and still keep your monthly bill affordable?

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References

TERMS

SAIDI – System Average Interruption Duration Index

- **Quantitative measure of the reliability of power service**
- **Measured in minutes/year**

ESS – Energy Storage System

PCS – Power Conversion System

SCADA – Supervisory Control and Data Acquisition

BES – Bulk Electric System – definition
http://www.nerc.com/pa/RAPA/BES%20DL/BES%20Definition%20Approved%20by%20FERC%203-20-14.pdf

Battery Terminology Reference –
mit.edu/evt/summary_battery_specifications.pdf

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TERMS

Smoothing & Firming for Solar & Wind –

The terms ‘smoothing’ and ‘firming’ are used to describe means to address the variations and intermittency from individual solar site or wind site installations.

In particular, ‘firming’ refers to bringing predictability and reliability. As such, it may address pure grid reliability for grid needs, or may address financial certainty for the owner/operator of the solar or wind facility, or perhaps both.

TERMS

Interconnection –

An interconnection agreement is required for any party connecting a generation or storage resource to the grid. During the application process, engineering studies are conducted to determine what design requirements are needed to assure safety of people and equipment and to assure compatibility with grid reliability and operations.

Within ERCOT, for large resources expecting to serve ERCOT energy and ancillary services markets, the ERCOT process combines all requests to create a queue that is publicly listed. Being in the queue does not necessarily mean each project will be completed. Degrees of financial commitment are required during the process, and those reaching the highest stage of financial commitment typically will be completed.

Utilities also have interconnection agreements for customer-site generation resources, including emergency gensets, solar PV systems, and energy storage.

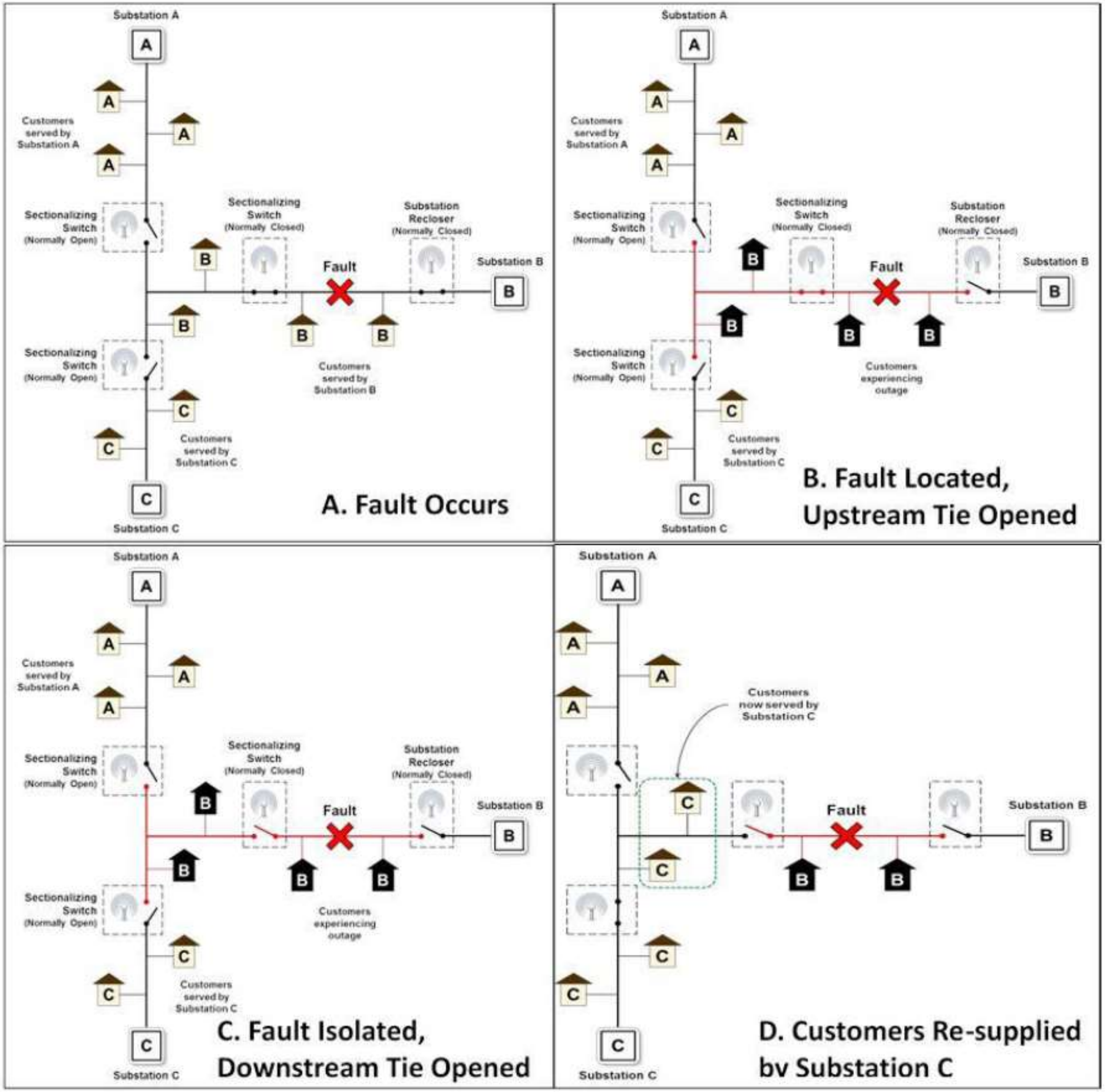

Figure 1. Schematics Illustrating FLISR Operations.

Fault Location, Isolation, and Service Restoration (FLISR)

From U.S. Department of Energy report Fault Location, Isolation, and Service Restoration Technologies Reduce Outage Impact and Duration

https://www.smartgrid.gov/files/B5_draft_report-12-18-2014.pdf

An essential component for successful FLISR operations is the communications network for remote monitoring and control of technologies and systems. FLISR communication networks require increased resilience because they must operate under conditions where the grid itself is damaged or not functioning properly. The two-way communications network must have sufficient coverage and capacity to interface and interoperate with a wide variety of technologies and systems, including various field devices and DMS, OMS, and SCADA systems.

References – Page 1

EPRI

Energy Storage Technology and Cost Assessment: Executive Summary

Technical Report 3002013958, December 2018

https://www.epri.com/#/pages/product/000000003002013958/?lang=en-US

Energy Storage Integration Council (ESIC), hosted by EPRI, focused on utility distribution applications https://www.epri.com/#/pages/sa/epri-energy-storage-integration-council-esic?lang=en-US

MESA – Modular Energy Storage Association – 'Open Standards for Energy Storage' – http://mesastandards.org/

Sandia National Laboratory – Energy Storage Systems Program – facilitates and publishes a variety of DOE-sponsored studies and reports related to the application of ESS –

https://www.sandia.gov/ess-ssl/

Sandia Energy Storage Safety Collaborative

https://www.sandia.gov/energystoragesafety-ssl/

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References – Page 2

Fault Location, Isolation, and Service Restoration (FLISR)

https://www.smartgrid.gov/files/B5_draft_report-12-18-2014.pdf

Northern Power Low Carbon Network Fund Youtube Video

http://www.youtube.com/watch?v=KUGpUaA4D5k&index=1&list=UUx_iDK8VCyKqYmAkORAhNzw

AEP Filing with PUCT on storage for specific reliability and asset deferral projects

- **PUCT 46368 – find on http://interchange.puc.texas.gov/ , and open or download Item 2 – APPLICATION OF AEP TEXAS NORTH COMPANY FOR REGULATORY APPROVALS RELATED TO THE INSTALLATION OF UTILITY-SCALE BATTERY FACILITIES**
- **Despite being a legal document with a regulatory agency, it contains very readable descriptions of the proposed projects, one being reliability for a rural community on the end of a radial line, and the other being an alternative to traditional methods to serve growing load in a community at the end of a radial line**

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References – Page 3

Austin Energy's DOE SHINES Project

https://austinenergy.com/ae/green-power/austin-shines/austin-shines-innovations-energy-storage

Arizona Public Service 'Solar Partners' Energy Storage

http://www.tdworld.com/energy-storage/aps-aes-bring-energy-storage-arizona-customers

San Diego Gas & Electric Unveils Worlds Largest Lithium-Ion Energy Storage

http://www.tdworld.com/renewables/sdge-unveils-worlds-largest-lithium-ion-battery-energy-storage-facility?NL=TDW-01&Issue=TDW-01_20170301_TDW-01_946&sfvc4enews=42&cl=article_4_b&utm_rid=CPG04000000116581&utm_campaign=12763&utm_medium=email&elq2=55c63a250535471ea5d6c1a4195b2961

References – Page 4

Brattle Report Examining Dual Technical Uses of Battery wherein the Users Are Utility and Market Participants, Respectively

- Brattle Press Release – a good summary of the report
- http://www.brattle.com/news-and-knowledge/news/749
-
- Link to Full-Length Technical Report Released in 2015
- http://www.brattle.com/system/publications/pdfs/000/005/126/original/The_Value_of_Distributed_Electricity_Storage_in_Texas_-_Proposed_Policy_for_Enabling_Grid-Integrated_Storage_Investments_Full_Technical_Report.pdf?1426377384

- Presentation
- http://www.brattle.com/system/publications/pdfs/000/005/119/original/The_Value_of_Distributed_Electrical_Energy_Storage_in_Texas.pdf?1423513210

ENERGY STORAGE USE CASES

- **Publicly available use cases are generally high-level descriptions and ESS performance expectations**

- **The DOE/EPRI/NRECA "Handbook" from 2013 provides many use cases. A more recent version has been rumored, but is not yet available.**
  - https://www.sandia.gov/ess-ssl/lab_pubs/doeepri-electricity-storage-handbook/

- **The use cases within the Lazard Levelized Cost of Storage v2.0 also provide a good summary introduction**
  - https://www.lazard.com/perspective/levelized-cost-of-storage-analysis-20/?utm_content=buffer7978d&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer

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Use Case Overview—Grid-Scale

Lazard's Levelized Cost of Storage ("LCOS") study examines the cost of energy storage in the context of its specific applications on the grid and behind the meter; each Use Case specified herein represents an application of energy storage that market participants are utilizing now or in the near future

	USE CASE DESCRIPTION
TRANSMISSION SYSTEM	■ Large-scale energy storage system to improve transmission grid performance and assist in the integration of large-scale variable energy resource generation (e.g., utility-scale wind, solar, etc.) ■ Specific operational uses: provide voltage support and grid stabilization; decrease transmission losses; diminish congestion; increase system reliability; defer transmission investment; optimize renewable-related transmission; provide system capacity and resources adequacy; and shift renewable generation output
PEAKER REPLACEMENT	■ Large-scale energy storage system designed to replace peaking gas turbine facilities ■ Specific operational uses include: capacity, energy sales (e.g., time-shift/arbitrage, etc.), spinning reserve and non-spinning reserve ■ Brought online quickly to meet the rapidly increasing demand for power at peak; can be quickly taken offline as power demand diminishes ■ Results shown in $/kW-year as well as standard LCOS ($/MWh)
FREQUENCY REGULATION	■ Energy storage system designed to balance power by raising or lowering output to follow the moment-by-moment changes in load to maintain frequency to be held within a tolerance bound ■ Specific Use Case parameters modeled to reflect PJM Interconnection requirements ■ Results shown in $/kW-year as well as standard LCOS ($/MWh)
DISTRIBUTION SUBSTATION	■ Energy storage systems placed at substations controlled by utilities to provide flexible peaking capacity while also mitigating stability problems ■ Typically integrated into utility distribution management systems
DISTRIBUTION FEEDER	■ Energy storage systems placed along distribution feeders controlled by utilities to mitigate stability problems and enhance system reliability and resiliency ■ Typically integrated into utility distribution management systems

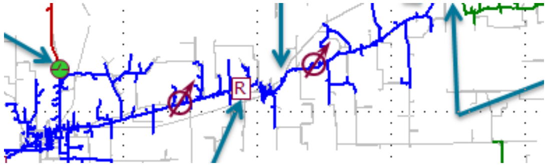
Use Case Overview—Behind-the-Meter

Lazard's Levelized Cost of Storage ("LCOS") study examines the cost of energy storage in the context of its specific applications on the grid and behind the meter; each Use Case specified herein represents an application of energy storage that market participants are utilizing now or in the near future

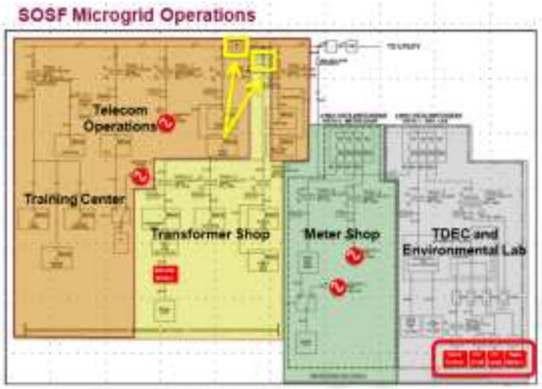
	USE CASE DESCRIPTION
MICROGRID	▪ Energy storage systems that support small power systems that can "island" or otherwise disconnect from the broader power grid (e.g., military bases, universities, etc.) ▪ Provides ramping support to enhance system stability and increase reliability of service; emphasis is on short-term power output (vs. load shifting, etc.)
ISLAND GRID	▪ Energy storage system that supports physically isolated electricity system (e.g., islands, etc.) by supporting stability and reliability, in addition to integrating renewable/intermittent resources; may also provide balancing service for isolated power grids that integrate multiple distributed resources (i.e., fast ramping) ▪ Relative emphasis on discharge endurance vs. simply short-term power output (as in Microgrid Use Case) ▪ Scale may vary widely across variations on Use Case (e.g., island nations vs. relatively smaller off-grid, energy-intensive commercial operations, etc.)
COMMERCIAL & INDUSTRIAL	▪ Energy storage system that provides behind-the-meter peak shaving and demand charge reduction services for commercial and industrial energy users ▪ Units typically sized to have sufficient power and energy to support multiple C&I energy management strategies, and provide option of system providing grid services to utility or wholesale market
COMMERCIAL APPLIANCE	▪ Energy storage system that provides behind-the-meter demand charge reduction services for commercial and industrial energy users ▪ Unit contains limited energy and power vs. Commercial & Industrial Use Case—geared toward more modest "peak clipping" to reduce demand charges
RESIDENTIAL	▪ Energy storage system for behind-the-meter residential home use—provides backup power, power quality improvements and extends usefulness of self-generation (e.g., "solar plus storage") ▪ Regulates the power supply and smooths the quantity of electricity sold back to the grid from distributed PV applications

ONCOR STORAGE PROJECTS

NSRI – Neighborhood Storage Reliability Initiative



Rural Feeder Reliability – Study – Can a battery located on long rural feeder support customers when the upstream portion of a feeder is out?



Microgrid at Oncor operational facility

Homework Exercises: Thursday, March 28.

1. ESS specifications for distribution feeders depend on the applications they must serve (kVA capacity of inverter and kWh capacity of battery)

- Peak Shaving (kVA and kWh requirement)
- Islanding (kVA and kWh requirement)
- System Protection (kVA requirement)

Background

- Today, the maximum kVA of load on a feeder is 2750 kVA without overloading the substation transformer
- The peak load on that feeder is projected to grow in a year from 2750 kVA to 2951 kVA
- On peak load day the load is expected to go above 2750 kVA limit for 2.5 hours, as shown in the graph
- The first parts of the question will be to specify an ESS to support this increased peak load in lieu of a substation upgrade that would require a new substation transformer and bus
- Assumption: assume the area of the peak load curve above the level of 2750 kVA is an isosceles triangle to simplify the calculation

Background

- The next parts of the question will be, for the same feeder, specify an ESS to support the downstream half of the feeder with the ESS during an upstream outage
- The outage is over the same future peak hours load curve as the prior problem
- The last part of the question will be to size the ESS to support fault current for fuses serving a 3-phase load for a fault during islanded operation:
  - A fault is assumed to occur on a feeder lateral during islanded operation, requiring the inverter to provide fault current through the fuse on the lateral.

Additional assumptions

- Assume the ESS is a perfectly efficient unit, with no losses through the inverter and no losses in the battery through charging or discharging
  - A kWh ac is the same as a kWh dc
- Assume the feeder is operating at unity (1.0) power factor
- Assume the load shape during those peak hours (for the portion above 2750 kVA) is an isoceles triangle with the base being the segment along 2750 kVA
- Assume the ESS performance is not affected by ambient temperature
- Assume the feeder load curve is precisely halved for the A.2 problem

Questions

1. Refer to Feeder Load Curve

A. To serve the growing load, what kVA capacity ESS can prevent feeder overload?

B. Approximately how many kWh of energy storage would be needed to support the peaking period?

C. To support the downstream half of the feeder with ESS during an outage on the other half of the feeder, approximately what kVA capacity would the ESS need to be able to island half of the feeder load during peaking time? Assume the load shape curve is precisely half for the half of the feeder to be supported by the ESS during an outage

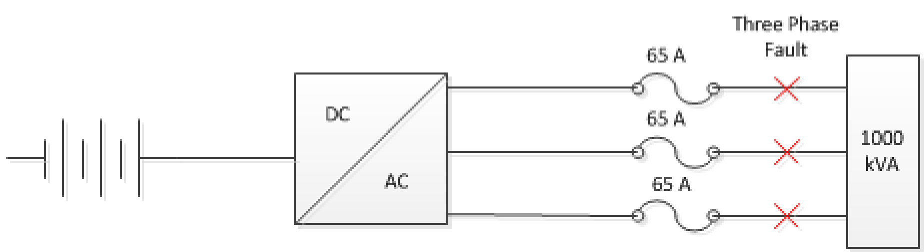
D. How many kWh are needed? Assume the shape is a rectangle on the bottom and a triangle on the top

Questions

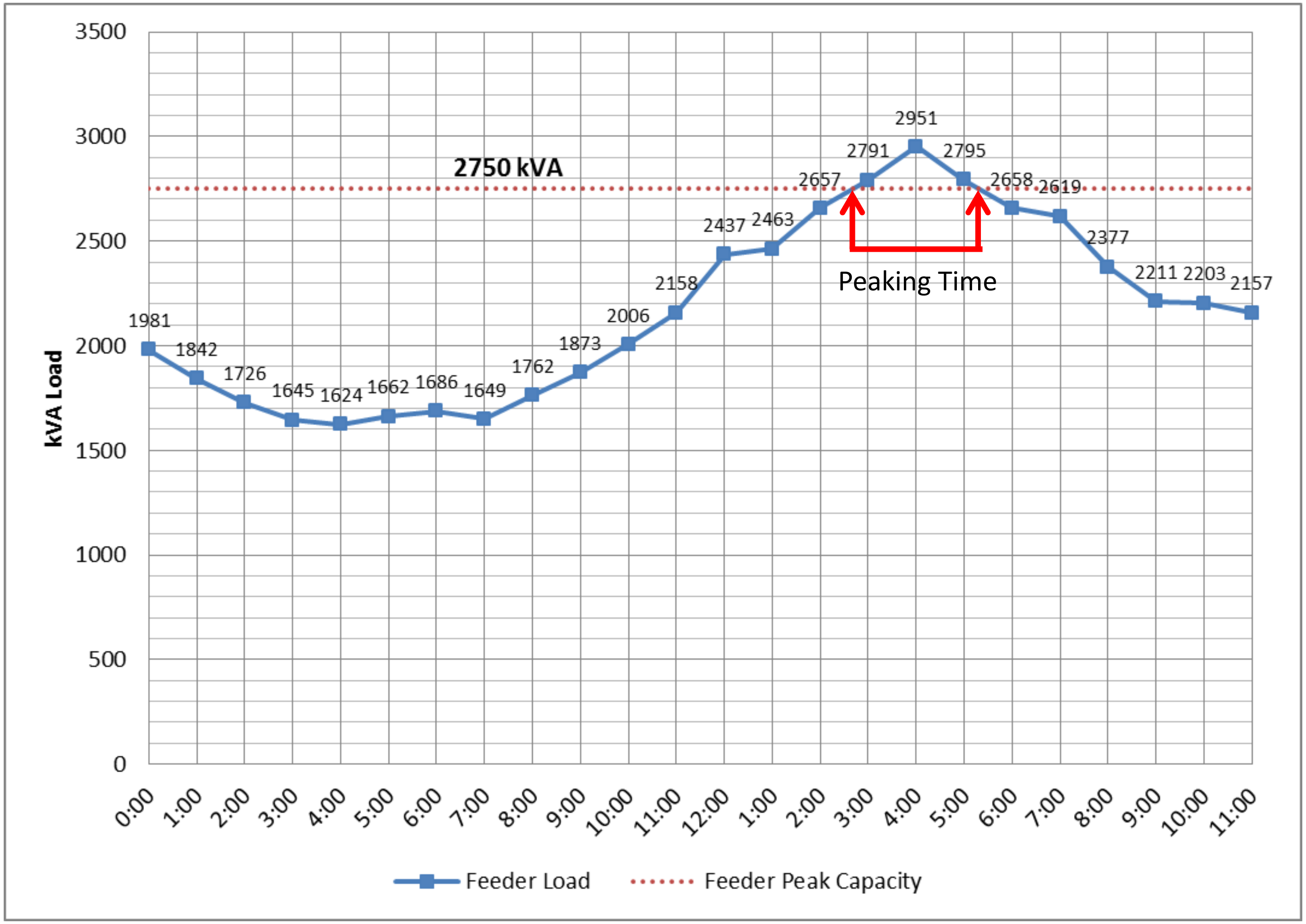
1.

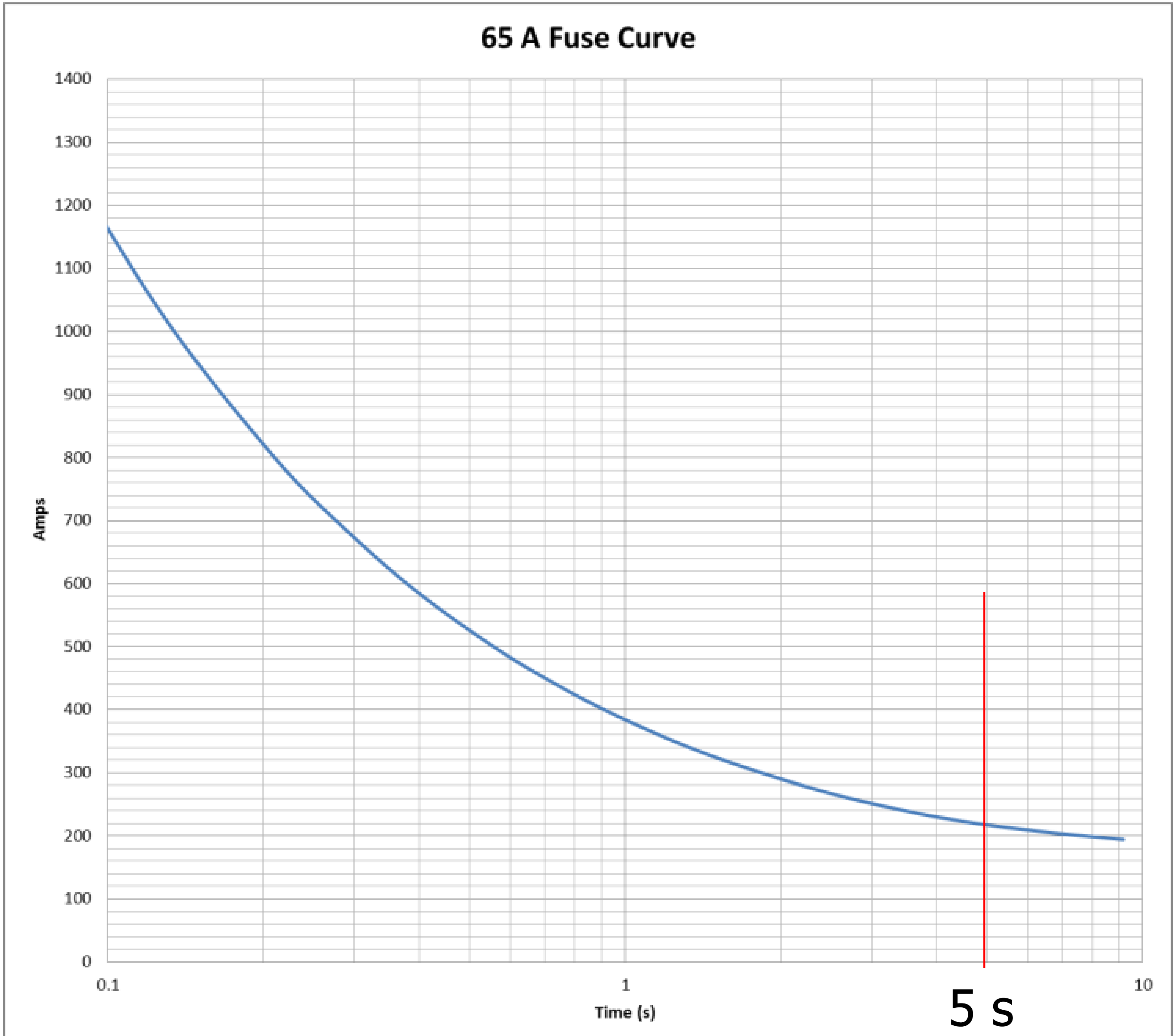
Refer to Fuse Curve

E. A 1000 kVA 3-phase load is attached to the half of the feeder on island protected by 65 A primary fuses (12.5 kV phase-to-phase). Assume the ESS inverter can provide 150% of its continuous kVA rating for 10 seconds. Approximately what continuous kVA capacity would the ESS need to be able to operate all three fuses in under 5 seconds?



Feeder Load – 1 day





65 A Fuse Curve
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Amps
0.1
1
10
Time (s)
5 s

Problem Statement 2
Customer-Sited Storage

- The commercial customer decides to install an ESS to limit its peak load, in order to reduce demand charges
- The demand charge is based on the peak load over a 15-minute interval each month, and is reflected in a monthly charge on the utility bill

A. How large should the ESS be to reduce the demand incurred in the three hourly blocks of time of 14:00 thru 16:00 blocks to the level shown for the 08:00 thru 13:00 hour blocks?

B. What does the discharge and recharge profile look like, if a slow recharge is conducted over hours not being discharged? What is the customer's new maximum demand on the grid?

C. What should the recharge profile be to avoid increasing total demand above the amount shown for the 08:00 thru 13:00 hour blocks? What would the customer's new maximum demand be in this case?

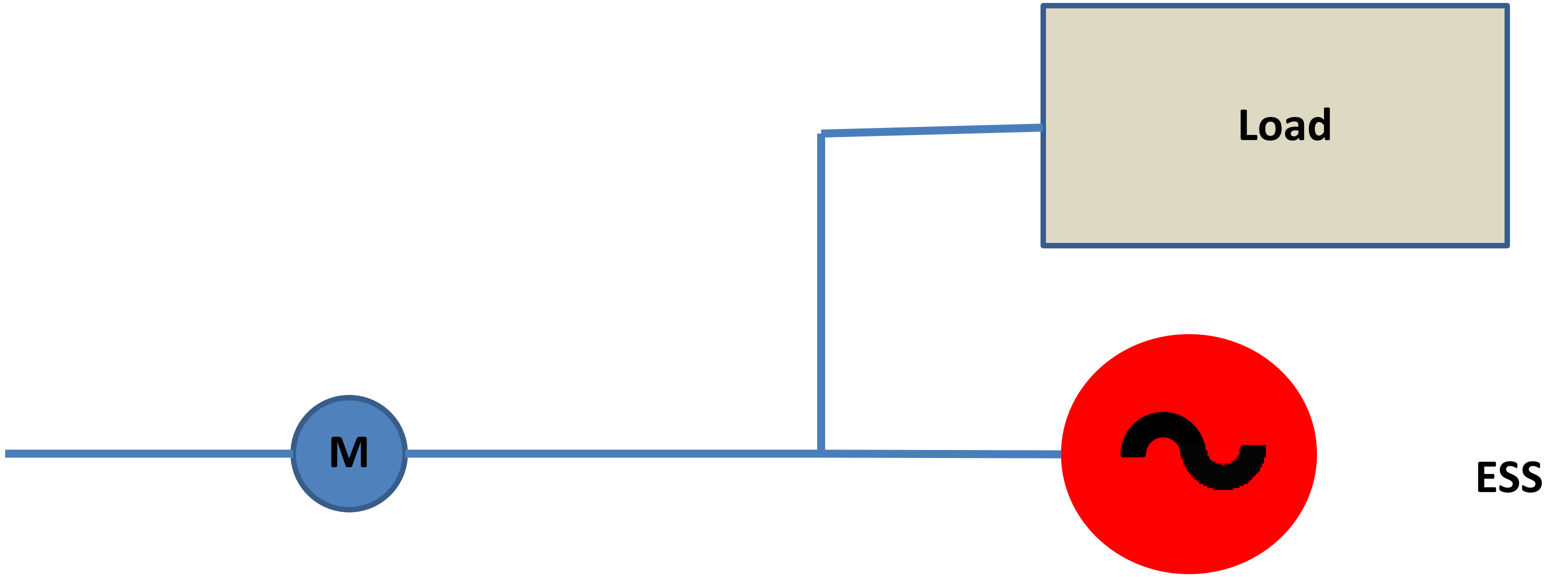
Utility Customer

Commercial Customer

Meter

- kWh – Total each 15-minute interval
- kW – Demand
- Time stamp

Utility Customer Adds Storage



Customer Load Profile

Description

The load profile is shown numerically at right

Hour 0 = midnight, 24-hour clock time

For simplicity, assume the load increases instantaneously at the start of the hour and continues at that level for the full hour

Assume this load profile is the same for all work days, M-F

Assume the load profile for Saturday & Sunday is always less kW demand at each hour, as compared to M-F profile

Assume this load is not sensitive to weather changes

Hour	kW load
0	100
1	100
2	100
3	100
4	100
5	100
6	100
7	175
8	300
9	300
10	300
11	300
12	300
13	300
14	400
15	400
16	400
17	300
18	300
19	250
20	100
21	100
22	100
23	100
0	100

Example: At 7:00 hours (for a 24-hour clock) (7:00 a.m. for a 12-hour clock), as shown above, the load moves instantly from 100 kW in the prior hour to 175 kW. The load then remains at 175 kW through that 7:00 hour, until it moves up to 300 kW instantly at 8:00 hours.

Demand Charge Mgt

- Differential demand at peak = peak hours kW less mid-level demand = ESS kW capability
- Peak duration is over the peak hours shown above
- Energy in ESS needed = ESS kW x hours of discharge
- Recharge Rate – Case #1
  - Over 24 hours less the hours being discharged
- Recharge Rate – Case #2
  - 24 hours less all hours 300 kW or higher

Recharge Rate = kW for the period of recharging the battery

Problem Statement 3 – AEP Projects Proposed

- Read the AEP filing at the PUCT, which is Item 2, as noted in the References
- Read the summary and the section of testimony by the Director of Distribution Engineering

AEP Projects Proposed

A. For the Woodson project, how many outages has the community experienced in the last 5 years?
B. Of those, how many were of a duration of 2 hours or less?
C. For a battery designed to serve the full community for 2 hours, how many outages would be eliminated?
D. For the outages not eliminated, what is the value to the customers from the battery? (A word answer, not a quantitative answer)

AEP Projects Proposed

1. For the Paint Rock proposal, what is the present peak demand on the substation?
2. What is the rated capacity of the substation?
3. What is the battery power capability that is proposed?
4. What is the battery energy capability that is proposed?