Panel Overview

Moderator: An Overview of Energy Storage Applications (10 min)

1) Energy Storage for Microgrid, NC State University, Dr. Ning Lu (15 min)

2) ERCOT Pilot Project for Fast Responding Regulation Service, ERCOT, Dr. Perez, Henry (15 min)

3) Assessment of Energy Storage for Multiple Grid Applications, PNNL, Dr. Di Wu (15 min)

4) Managing Energy Storage for Providing Energy and Ancillary Services, ABB, Dr. Xiaoming Feng (15 min)

5) Energy Storage Integration in Alberta’s Energy Only Market, AESO, Kevin Dawson (15 min)
Outline

• An Overview of Energy Storage Applications
  – Energy Storage Applications
  – Energy Storage Use Case Development

• Energy Storage Applications in Microgrid Operation
  – NSF FREEDM systems center in North Carolina State
  – Modeling of Energy Storage Systems
  – Modeling of Grid Integration
  – Performance Evaluation
  – Economic Assessment

• What is the future?
  – Next steps
Developing Business Cases for Energy Storage Applications

Dr. Ning Lu
Electrical and Computer Engineering Dept.
North Carolina State University

Chair of the Working Group on the Economics of Energy Storage
Business Models for Energy Storage Systems (ESS)  
Performance-based

All Electric ESS

Electric-Thermal ESS

Other ESS

Load Shifting and Peak Shaving

- Sizing (Power and capacity)
- Location (central or distributed)
- Lifetime (charge/discharge cycles)
- Breakeven Cost ($/kw)
- Efficiency
- Performance

Fast Responding Regulation Service

- Sizing (Power and capacity)
- Location (central or distributed)
- Lifetime (charge/discharge cycles)
- Breakeven Cost ($/kw)
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Energy Storage Options

- Superconducting magnetic energy storage (SMES)
- Pumped-hydro power plants (PHP)
- Compressed air energy storage (CAES)
- Super capacitors
- Flywheels
- Batteries
  - NaS (sodium-sulfur), Li-ion, lead acid, flow batteries, etc.
  - Electric vehicles
- Thermal energy storage devices
  - Ice storage, water heaters, air conditioning units, etc.
  - Demand response programs using load with thermal storage capabilities
Energy Storage Options

Direct Storage
- Electrical charges: Capacitors, Superconducting, Magnetic ES

Indirect Storage (via 1-way or 2-way energy conversion)
- Potential
  - Pumped hydro
  - Compress air
- Kinetic
  - Flywheel
- Chemical
  - Batteries
- Thermal
  - Water heaters, air conditioners

Energy Storage Options Diagram

Time

One-directional energy conversion

Power

Yang, et al., Chemical Reviews, 111, 3577, 2011
Energy Storage Options

Direct Storage

- Electrical charges: Capacitors SEMS

Indirect Storage (via 1-way or 2-way energy conversion)

- Potential: Pumped hydro compress air
- Kinetic: Flywheel
- Chemical: Batteries
- Thermal: Water heaters, air conditioners

One-directional energy conversion

Time

Power

Electric-Thermal Storage
Electric-Thermal Storage

A Thermal “Battery”

Electricity → Ice at night

ICE Melting

Making ice

Ice → cool the building at noon

Electricity

Charging

Discharging
Applications

- **Traditional (Energy Markets)** (电能市场应用)
  - Backup (备用电源)
  - Peak shaving (削峰)
  - Energy shifting (负荷调整)
  - Arbitrage (高卖低买)

- **Advanced (Ancillary Services)** (电力市场辅助服务)
  - Regulation (负荷调节)
  - Load following service (负荷跟踪)
  - Frequency response (频率调节)
  - Spinning/non-spinning reserves (旋转和离线备用)
  - Reactive power support (无功补偿)
Applications

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An Example of Peak Load shifting

A normal energy consumption curve of end-use customers

Consumption is low during the night
Consumption is high during the daytime
An Example of Peak Load shifting

Charge the battery during the night hours

Discharge the battery to supply the peak load
Applications

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An Example of Load Balancing

Intra-hour Applications

Daily Load Profile
An Example of Load Balancing

Balance the mismatches between the load forecast and the actual load

Figure by Craig Taylor and Don DeBerry, presented at 2002 OSIsoft T&D Users Conference
Time and Service Considerations

Power System Stability
- Power balance
- Frequency regulation
- Regulation
- Load balance

Power System Economics
- Energy balance
- Transmission/distribution congestion
- Price volatility
- Hedge energy price

Ancillary Services
- Energy Market

Time Scale:
- 0
- 1ms
- 1s
- 1 minute
- 1 hr
- 1 day
- 1 week
- 1 month
Energy Storage Applications – Time Scales

Seconds to Minutes
Ancillary Services

Regulation

Minutes - One Hour
Ramping

Several Hours - One Day
Energy Services

Peak shaving, load leveling

Different time regimes will require different storage solutions.
Different services will have different service requirements and be paid differently.

Courtesy of Imre Gyuk
Economic Considerations

Value Streams

Ancillary service market:
- Capacity market
- Time resolution: intra-hour
- Fast, controllable, measurable

Energy market:
- Energy sales and carbon credits
- Time resolution > 1 hour
- Strategy: buy low and sell high

Power Intensive Applications
(higher price $/MW)

For Ancillary Service Applications

Energy Intensive Applications

For Energy Market Applications

$$$$$

$$

P (kW)

200MW

1 hour

1GW

Time (hour)
An Example of Revenue Streams

- A 1 MW/4MWh NaS battery

If it serves for 1 MW regulation service at 35 $/MW for 24 hours, it is paid by （提供24 小时1 MW 的负荷追踪服务的收入，假定35 $/MW 为其价格）

\[ Revenue = 1 \times 35 \times 24 = 840 \$ \]

If it buys in 1 MWh at 10 $/MWh for 4 hours and sells 1 MWh at 60 $/MWh for 3 hours, its revenue is （峰谷买入4 小时电，峰值卖出 3小时电，收入如下）

\[ Revenue = 1 \times 60 \times 3 - 1 \times 10 \times 4 = 140 \$ \]

- Arbitrage is normally not as profitable as offering ancillary services.
Placement and Size

**National level**: Fuel storage for years

- **House/Building**: Batteries, Thermal Storage
- **Community**: Batteries
- **Substations**: Batteries, Flywheel, Capacitor, Superconductor
- **Area and Regional Level**: Virtual energy storage via power exchanges, Pumped-hydro, Compressed-air
Placement and Service

**Distribution**
- Wind/solar integration
  - Energy shifting: solar and wind
  - Smoothing: solar and wind
  - Regulation and load following
- Reliability
  - Spinning reserves
  - Voltage support
- Distribution congestion relief
- Market
  - Arbitrage
- Others
  - Demand response coordination
  - Power quality
  - Black start
  - Reduce losses

**Transmission**
- Wind/solar integration
  - Energy shifting: solar and wind
  - Smoothing: solar and wind
  - Regulation and load following
- Reliability
  - Spinning reserves
  - Voltage support
- Transmission congestion relief
- Market
  - Arbitrage
- Others
  - Demand response coordination
  - Power quality
  - Black start
  - Reduce losses
Summary of Multiple Values

Enhancing system stability
- Reduces peak load
- Reduces infrastructure requirements
- Minimizes congestion
- Improves base-load capacity factor
- Defers transmission and distribution investment
- Provides VAR support
- Can provide black start capability

Enabling large-scale/utility renewable energy (RE) integration
- Reduce variability
- Ramp rate control
- Load shifting
- Firms RE to improve dispatchability

Enabling DG and EV deployment
- Reduces variability
- Interacts and supplements vehicle-based storage
- Improves power quality
- Provides voltage support
Energy Storage Applications in Microgrid Operation

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http://www.freedm.ncsu.edu/
Vision of the NC State FREEDM Microgrid

Today
Centralized Generation

Future
Distributed Renewable Energy Resources

Plug-and-Play Energy Storage plays a critical role.

Innovation
Our Vision of Developing Microgrid Technologies

• Develop efficient, stable, and reliable Microgrid Technologies
• Make it scalable and can be seamlessly integrated into the existing power system infrastructure
• A hierarchical energy management system
  – Manage microgrid resources and load
  – Coordinate the operation of the microgrid with the main grid
NC State FREEDM Microgrid Configuration

Legacy grid

FREEDM Substation

Distributed Grid Intelligence (DGI)

User Interface

Market & Economics

LOAD

DRER

DESD

IEM

IFM

IEM

IFM

IEM

IFM

69kV

1 MVA

120 V

3Φ 480V

RSC

FREEDM

69kV

12kV

10 kVA

100 kVA

LOAD

DRER

DESD

IEM: Intelligent Energy Management

IFM: Intelligent Fault Management

DRER: Distributed Renewable Energy Resource

DESD: Distributed Energy Storage Device
Load Emulator

Main Grid

Solid state transformer

Household level energy storage

Community level energy storage
Aggregation of Distributed Energy Storage Devices

Considering Communication Delays and Errors

- Uncertainties
  - Drive patterns
  - Hot water consumptions
  - Ambient temperature changes

Cost Methodology

- Calculated breakeven costs using standard levelized cost approach.

Breakeven Cost / kWh =
Annualized Capital Cost / kWh + Annual Operating Cost / kWh

Annualized Capital Cost / kWh = Capital Cost × Recovery Factor

\[
RecoveryFactor = \frac{i \times (i + 1)^n}{(i + 1)^{n-1}}
\]

where

- \( n = \) Battery life;
- \( i = \) Discount Rate

Annual Operating Cost / kWh = Annualized Operating Cost / annual kWh

For example: 10% × Capital Cost/Annual kWh
Wide-area Energy Storage Management Systems

A WAESMS is a centralized control system that operates energy storage devices located in different places to provide services so that they can be shared among balancing areas.

Can also be a conventional generator

Hydro
Energy storage

Can be flywheel, batteries, and demand response programs

A Hierarchical Energy Management System

Distributed Energy Storage
- MW Level
- Thermal Storage
- Electric Vehicles

kW Level

Traditional Generation Units
- Coal
- Hydro
- Natural Gas

Energy and Ancillary Services

Method A: Load Balancing Signal Separation: fast and slow

Load Balancing Signals

Control Algorithms

Energy Storage
- MW Level
  - Thermal Storage
  - Electric Vehicles

Traditional Regulating Units
- Coal
- Hydro
- Natural Gas
Method B: **Priority Based Dispatch**: Always Dispatch ES First

- **Load Balancing Signals**
- **Control Algorithms**

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<td><strong>MW Level</strong></td>
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An Example of Method A: Flywheel for Regulation Services

State of charge well maintained

Modeling flywheel performance:
- State-of-charge
- Mileage

An Example of Method B: Coordination Between ES and Conventional Regulation Resources

1) Reduced mileage for hydro
2) Even a very slow conventional generator can provide fast regulation if it works with a fast regulating unit such as flywheels or Li-ion batteries.
Energy Storage: Future Opportunities
Future Opportunities

• From the above results, we concluded that opportunities for energy storage technologies lie in the following areas:
  – Provide **multiple services** to claim revenues from multiple markets
  – **Share** energy storage among utilities to increase the value and utilization rates of the energy storage
  – Operate energy storage **in conjunction with conventional generators** to improve the generators’ efficiency and performance, reduce the generators’ wear-and-tear, and provide compatible services that do not require much modification of the existing operating system
  – **Aggregate** small energy storage resources to shift energy consumption
    • Thermal storage
    • Electric vehicles
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Papers Referenced
References


References


