Recent trends on the interconnection between power storage facilities and real systems in Japan and the United States.

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Japan Electric Power Information Center (JEPIC)
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Introduction

Advantages of renewable energy introduction to the grid

- Environment-friendly
- Low running costs
- Renewable energy introduction is expected to increase to realize a low-carbon society.

Problems of renewable energy introduction to the grid

- Intermittent power generation (Strongly depends on the weather conditions)
- Reducing reliability of the grid
- A solution is needed to increase renewable energy introduction to the grid.
**Introduction**

Example of reduced reliability of the grid #1

- A maximum (peak) volume of demand is observed around sunset.
- Potential of over-generation.
- Increased ramp up.
- Potential of over-generation.

(Comment)
- The results listed above cause a reduction in the value of the base load generation.
- A sudden increase of demand will be observed around dusk.

(Solution)
- Expansion of pumped Hydro.
- Reduction in the volume of interconnectivity.
Introduction

Example of reduced reliability of the grid #2

(Comment)
- Voltage fluctuation in a transformer bank increases with the introduction of massive PV current.
- Massive PV current increases the risk of deviating from the standard range of voltage.

(Conventional solution)
- Installation of additional transformers.
- Reduction in the volume of interconnectivity.

“Fluctuations” are caused by the attribute of electricity, therefore a new solution is needed to increase renewable energy development. And one of the solutions is “energy storage batteries” that make it possible to store electricity. We will introduce Japan and U.S. initiatives in energy storage batteries as case examples.
Purposes of interconnected energy storages

Interconnecting batteries to the grid has the following advantages.

- Batteries can be used for two purposes.
  - Charging and discharging are possible whenever you like.
- Less loss and more environmentally-friendly while charging and discharging.
  - Compared to other energy storage systems, the batteries have a small environmental load at charge and discharge.
- Added uses can be developed.
  - In addition to the use described above, batteries have other uses such as in virtual power plants which improves the performance and reliability of the grid.
Survey results

Electric power suppliers’ interests and concerns in Japan were surveyed by JEPIC.

**Suppliers’ interests**

- Generation assets: 17
- T&D assets: 15
- Customers’ assets: 15
- VPPs: 9
- Others: 1

**Suppliers’ concerns**

- Battery performance: 12
- Battery cost: 22
- Customers’ assets: 5
- Regulatory framework, rules: 12
- Others: 2

(N=28, multiple answers allowed)

- We surveyed participants’ interests on application of energy storage systems.
- They have interests in each application.
- They need various types of information about how to apply energy storage.
- We surveyed participant’s concerns when installing energy storage systems.
- We think performance and the cost of battery systems are in everyone’s interest.

These results indicate that suppliers have a strong interest in energy storage systems, and therefore we have reported recent trends on the interconnection between power storage batteries and real systems in Japan and the United States.
Recent demonstrations in Japan

Source: Japanese electric power companies’ web sites
Recent demonstrations in Japan

Hokkaido
EPCo

Legends
Symbols
○: Solution for Renewable Energies
Colors
Pink: Redox-Flow
Recent demonstration by Hokkaido EPCo.  
Minami-Hayakita Substation Large-Scale Storage Battery System Project

Project profile
- 60 MW of redox flow batteries has been installed in the Minami Hayakita substation.
- Development of the frequency control method by using BESS as a power supply for frequency adjustment
- Development of operational techniques against surplus electric power
- Performance evaluation of the redox-flow battery, etc.
- Test period FY 2013-2018.
  Demonstration: FY2015-FY2019
- Supported by METI
Recent demonstration by Hokkaido EPCo.
Minami-Hayakita Substation Large-Scale Storage Battery System Project

Overview of energy storage facility
• Tanks of electrolyte solutions are stored on the 1st floor.
• Cell stacks, and heat exchanger are stored on the 2nd floor.
  Footprint: 5,000 m²
  Output: 15 MW
  Capacity: 60 MWh
Recent demonstrations in Japan

Tohoku EPCo

Legends
Symbols
○: Solution for Renewable Energies
Colors
Red: Lithium-ion

Source: Japanese electric power companies’ web sites
Recent demonstration by Tohoku EPCo. #1
Nishisendai Battery Storage Verification Project

Objectives
The power system central center controls by power adjust instruction sent to the large scale BESS settled at the substation, in order to verify the BESS effect for frequency adjustment.

Details
- Location: Nishisendai Substation (Sendai city, Miyagi Prefecture)
- Specifications:
  - Lithium-ion battery
  - Output: 20 MW (short term: 40 MW)
  - Capacity: 20 MWh
- Test period:
  - Construction: FY 2013-2014
  - Demonstration: FY 2014-2017
- Support: Associations

Output Fluctuations (Monitoring)
Central Load Dispatching Center
Transmission instructions for power control operations combining batteries with thermal power generators

Tohoku Electric Power Co., Inc. ANNUAL REPORT 2016
Utilizing pumping-up power and charging the batteries, at a time when a huge amount of generated output of renewables could lead to oversupply.

**Recent demonstration by Tohoku EPCo. #2**

**Minamisoma Battery Storage Verification Project**

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Improvement of balance of demand and power supply with large scale battery.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Details</strong></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Minamisoma Substation (Minamisoma city, Fukushima Prefecture)</td>
</tr>
<tr>
<td>Specifications</td>
<td>Lithium-ion battery</td>
</tr>
<tr>
<td></td>
<td>Output: 40 MW</td>
</tr>
<tr>
<td></td>
<td>Capacity: 40 MWh</td>
</tr>
<tr>
<td>Test period</td>
<td>FY 2016-2017</td>
</tr>
<tr>
<td>Support</td>
<td>Associations</td>
</tr>
</tbody>
</table>

**Test period:** FY 2016-2017

**Support:** Associations

**Location:** Minamisoma Substation (Minamisoma city, Fukushima Prefecture)

**Specifications:**
- Lithium-ion battery
  - Output: 40 MW
  - Capacity: 40 MWh

**Test period:** FY 2016-2017

**Support:** Associations

**Recent demonstration by Tohoku EPCo. #2**

**Minamisoma Battery Storage Verification Project**

- **Utilizing pumping-up power and charging the batteries,** at a time when a huge amount of generated output of renewables could lead to oversupply.
- **Demand (Power Usage)**
- **Wind**
- **Solar**
- **Base Generation Capacity**
- **Substation**
- **Gas**
- **Large Scale “BESS”**
- **Central Load Dispatching Center**
- **Instruction**
Recent demonstrations in Japan

Legends
Symbols
○: Solution for Renewable Energies
Colors
Red: Lithium-ion
Blue: Sodium-Sulfur (NAS)

Source: Japanese electric power companies’ web sites
Recent demonstration by Chugoku EPCo.

Demonstration Project utilizing Hybrid Storage Battery System on the Oki Islands

### Specifications of hybrid battery

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Output</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium sulfur (NAS)</td>
<td>4.2 MW</td>
<td>25.2 MWh</td>
</tr>
<tr>
<td>Li-ion</td>
<td>2.0 MW</td>
<td>0.7 MWh</td>
</tr>
</tbody>
</table>

- Under development

### Project profile

- In order to maximize renewable energy, a hybrid battery system will be installed, constructed with two types of batteries which have different characteristics.
- Charge-discharge management and control technology will be tested in the field.

EnerGia ANNUAL REPORT 2016
Recent demonstration by Chugoku EPCo.

Demonstration Project utilizing Hybrid Storage Battery System in the Oki Islands

1. Overview of the energy storage facility
   (1) Location
   Oki Islands (at the Nishino Shima substation)

   (2) Battery System (Hybrid System)
   Sodium sulfur battery: 4.2 MW (25.2 MWh)
   Lithium-ion battery: 2.0 MW      (0.7 MWh)

2. Test period
   Construction: FY2014-2015
   Demonstration: FY2015-FY2018

3. Supported by MOE
Recent demonstrations in Japan

Source: Japanese electric power companies’ web sites
Recent demonstration by Kyushu EPCo.

Demonstration at Buzen Battery Substation

Project profile
1. Location
Buzen coalfire power plant
(Buzen city, Fukuoka Prefecture)

2. Objectives
✓ To improve the balance of supply & demand
✓ To control grid voltage/frequency
✓ To evaluate the battery system

3. Battery specification
Sodium-Sulfur battery
Output: 50 MW
Capacity: 300 MWh
Footprint: 14,000 m²

4. Test period
FY 2015-2017

5. Supported by METI

Kyushu Electric Power Group Medium-term Management Policy
http://www.kyuden.co.jp/var/rev0/0053/7385/ji06d57xm764dh7.pdf
MITSUBISHI ELECTRIC Co. Press Release
Recent demonstration by Kyushu EPCo.
Demonstration at Buzen Battery Substation

Features of the battery system
1. The facility offers energy-storage capabilities similar to those of pumped hydro facilities while helping to improve the balance of supply and demand when renewable energy sources are used.
2. The energy storage system achieves effective overall control and improved operational efficiency through the use of battery systems to monitor and control modules in a multiple module system.
3. Containerized, compact (double stacked) battery modules help to reduce the facility footprint, installation time and construction costs.
# Recent demonstrations in Japan

<table>
<thead>
<tr>
<th>Company</th>
<th>Project</th>
<th>Battery (Output, Capacity)</th>
<th>Note (Targets of the project, etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hokkaido</strong></td>
<td>Minami-Hayakita</td>
<td>Redox flow (15 MW, 60 MWh)</td>
<td>Renewables (demand/supply balancing)</td>
</tr>
<tr>
<td><strong>Tohoku</strong></td>
<td>Minami-Soma</td>
<td>Lithium-ion (40 MW, 40 MWh)</td>
<td>Renewables (demand/supply balancing)</td>
</tr>
<tr>
<td></td>
<td>Nishi-Sendai</td>
<td>Lithium-ion (40 MW, 20 MWh)</td>
<td>Renewables (frequency control)</td>
</tr>
<tr>
<td><strong>Tokyo</strong></td>
<td>Yokohama Smart City</td>
<td>Lithium-ion (300 kW, 100 kWh)</td>
<td>Renewables (frequency control, spinning reserve)</td>
</tr>
<tr>
<td></td>
<td>Virtual Power Plant (VPP)</td>
<td>Unconfirmed (10 kWhx18)</td>
<td>Demand/supply balancing (normal times) Emergency power supply (disaster times)</td>
</tr>
<tr>
<td><strong>Chubu</strong></td>
<td>Simose</td>
<td>Lithium-ion (25 kWh)</td>
<td>Renewables (voltage control)</td>
</tr>
<tr>
<td><strong>Hokuriku</strong></td>
<td>Shika</td>
<td>Lithium-ion (50 kWhx2)</td>
<td>Renewables (overall performance test)</td>
</tr>
<tr>
<td><strong>Kansai</strong></td>
<td>Amagasaki</td>
<td>Lithium-ion (100 kW, 300 kWh)</td>
<td>Overall performance test</td>
</tr>
<tr>
<td><strong>Chugoku</strong></td>
<td>Oki Islands</td>
<td>Lithium-ion (2 MW, 0.7 MWh) Sodium-Sulfur (4.2 MW, 25.2 MWh)</td>
<td>Renewables (demand/supply balancing), Island</td>
</tr>
<tr>
<td><strong>Kyushu</strong></td>
<td>Buzen</td>
<td>Sodium-Sulfur (50 MW, 300 MWh)</td>
<td>Demand/supply balancing</td>
</tr>
<tr>
<td></td>
<td>Isolated islands*</td>
<td>Lithium-ion (2<del>4 MW, 774 k</del>1.6 MWh)</td>
<td>*4 islands; Iki-shima, Tsu-shima, Tanega-shima, and Amami-ooshima</td>
</tr>
<tr>
<td><strong>Okinawa</strong></td>
<td>Miyakojima Islands</td>
<td>Lithium-ion + Sodium-Sulfur (100 kW, 176 kWhx2)</td>
<td>Renewables (demand/supply balancing), islands</td>
</tr>
</tbody>
</table>

Source: Japanese electric power companies’ web sites
Recent installation examples in the Americas & Europe

Source: Power Distribution Utilities Retail web site
AES Energy Storage web site
Recent installation example in Chile.

Energy storage supplying critical spinning reserves.
Initial 2009 project leading to over 100MW of energy storage in Chile.

PURPOSES
- Primary & secondary reserves
- Contingency management

IMPACT
- Avoided load shedding and contingency curtailment
- Increased energy production and reduced costs
- Increased system security
- Inertia-like performance

I thank AES for permission to use their articles.
Recent installation example in United States. #1

Energy storage frequency regulation from a wind farm since 2011
Serving US PJM Interconnection; integrated with eight power systems

PURPOSES
- Frequency Regulation
- Renewable ramp control

IMPACT
- Saving $20m/year
- Competitive bid, wins every hour vs. traditional
- Reduces regulation by ~1.7x
- Saves 62,000t of CO2, 329t of SO2 & 97t of NOx / year

I thank AES for permission to use their articles.
The 17th IERE General Meeting & Canada Forum

Recent installation example in United States. #2

**PURPOSES**
- Capacity, local reliability
- Peak power mitigation
- Ramping/flexibility
- Ancillary services

**IMPACT**
- Rapid deployment
- Competitive & cost effective
- Meets flexibility (duck curve)

Battery storage devices were installed in the city that can not be installed with conventional thermal power generation facilities.

Early operation was possible without strict environmental regulations being applied.

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Recent installation example in United States. #3

Frequency control and capacity using 1 hour battery

20MW array is the first of its kind in the Midwestern US.

PURPOSES
- Frequency response
- Capacity
- Voltage control

IMPACT
- Meet control/reliability regulations
- Reduce cost of capacity
- Potential black start

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Recent installation example in United States. #4

Distribution Alternative

Embedding storage in the distribution network for reliability
Two Arizona arrays totaling 4MW/4MWh installed at substations for solar integration

PURPOSES
- Peak demand management
- Renewable integration

IMPACT
- Support rooftop solar growth
- Manage local feeder reliability
- Alternative to substation upgrades

2MW Buckeye Advancion Array
Buckeye, Arizona

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Recent installation example in United States. #5

Solving peaking demand through solar + storage on Hawaii

28MW PV with 20MW, 5 hour duration energy storage to take full advantage of renewable power

Hawaii co-op signs deal for solar + storage project at 11¢/kWh

- The state of Hawaii aims to make the ratio of renewable energy to the total power generation to 100% in the future.
- To compensate for the variability of renewable energy, the power storage system is necessary to achieve the target.

I thank AES for permission to use their articles.
<table>
<thead>
<tr>
<th>Country</th>
<th>City (State)</th>
<th>Battery (Output, Capacity)</th>
<th>Note (Targets of the project, etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>Los Andes (Atacama)</td>
<td>Lithium-ion (12 MW)</td>
<td>Primary &amp; secondary reserves</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Independent grid</td>
</tr>
<tr>
<td></td>
<td>Laurel Mountain (WV)</td>
<td>Lithium-ion (32 MW)</td>
<td>Renewables (frequency regulation)</td>
</tr>
<tr>
<td></td>
<td>San Diego (CA)</td>
<td>Lithium-ion (37.5 MW,150 MWh)</td>
<td>Renewables (capacity, local reliability)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Installed in 6 months</td>
</tr>
<tr>
<td></td>
<td>Buckeye (CA)</td>
<td>Lithium-ion (4 MW,4 MWh)</td>
<td>Renewables (peak demand management)</td>
</tr>
<tr>
<td></td>
<td>Long Beach (CA)</td>
<td>Lithium-ion (100 MW,400 MWh)</td>
<td>Renewables</td>
</tr>
<tr>
<td></td>
<td>Pomona (CA)</td>
<td>Lithium-ion (20 MW,80 MWh)</td>
<td>Construction of the system in less than 4 months</td>
</tr>
<tr>
<td>United States</td>
<td>Mira Loma (CA)</td>
<td>Lithium-ion (20 MW,80 MWh)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Notrees (TX)</td>
<td>Lithium-ion (36 MW,24 MWh)</td>
<td>Renewables</td>
</tr>
<tr>
<td></td>
<td>Grand Ridge, LaSalle (IL)</td>
<td>Unconfirmed (68 MW)</td>
<td>Renewables</td>
</tr>
<tr>
<td></td>
<td>Indianapolis (IN)</td>
<td>Lithium-ion (20 MW,100 MWh)</td>
<td>Renewables (grid and transmission reliability)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Built in under 12 months from groundbreaking to commissioning.</td>
</tr>
<tr>
<td></td>
<td>Hawaii</td>
<td>Lithium-ion (20 MW,100 MWh)</td>
<td>Renewables (peak demand management)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>West Burton (Nottinghamshire)</td>
<td>Unconfirmed (49 MW)</td>
<td>Renewables (frequency regulation)</td>
</tr>
<tr>
<td></td>
<td>Barrow-in-Furness (Cumbria)</td>
<td>Lithium-ion (49 MW)</td>
<td>Capacity</td>
</tr>
</tbody>
</table>

Source: [Power Distribution Utilities Retail web site](http://www.pdu-retail.com)  
[AES Energy Storage web site](http://www.aesenergystorage.com)
Conclusion

Recent demonstrations of grid batteries in Japan

- The projects in Japan are mainly implemented in collaboration with the central or local governments.
- Usually, multiple goals are set for each project.
- There are some other projects that municipalities, companies and other entities have implemented.

Recent installation examples in the Americas & Europe

- In the U.S., there are several examples of installing batteries in real systems.
- Usually, the limited goal is set for each installation.
- Especially in urban areas, it is difficult to start operating conventional power plants in a short period of time. Therefore applying storage battery systems has a great advantage in this respect.
# List of batteries

<table>
<thead>
<tr>
<th>Battery type</th>
<th>Lead-acid</th>
<th>Nickel-metal Hydride</th>
<th>Lithium-ion</th>
<th>Sodium-Sulfur</th>
<th>Redox-flow</th>
<th>Molten-salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact (Energy Density : Wh/kg)</td>
<td>X 35</td>
<td>△ 60</td>
<td>◎ 200</td>
<td>◎ 130</td>
<td>× 10</td>
<td>◎ 290</td>
</tr>
<tr>
<td>Cost (JPY/kWh)</td>
<td>50,000</td>
<td>100,000</td>
<td>200,000</td>
<td>40,000</td>
<td>Evaluating</td>
<td>Evaluating</td>
</tr>
<tr>
<td>Capacity Enlargement</td>
<td>◎ - MW Class</td>
<td>◎ - MW Class</td>
<td>◎ - MW Class</td>
<td>◎ Over MW Class</td>
<td>◎ Over MW Class</td>
<td>Evaluating</td>
</tr>
<tr>
<td>Measurement Accuracy of State of Charge</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>◎</td>
<td>△</td>
</tr>
<tr>
<td>Safety</td>
<td>◎</td>
<td>◎</td>
<td>△</td>
<td>△</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Material Resource</td>
<td>◎</td>
<td>△</td>
<td>◎</td>
<td>◎</td>
<td>△</td>
<td>◎</td>
</tr>
<tr>
<td>Heat-up during Operation</td>
<td>Not Need</td>
<td>Not Need</td>
<td>Not Need</td>
<td>Need (&gt; 300°C)</td>
<td>Not Need</td>
<td>Need (&gt; 50°C)</td>
</tr>
<tr>
<td>Life time (Charge-discharge Cycle)</td>
<td>17 Yrs. 3,150 Cyc.</td>
<td>5 - 7 Yrs. 2,000 Cyc.</td>
<td>6 - 10 Yrs. 3,500 Cyc.</td>
<td>15 Yrs. 4,500 Cyc.</td>
<td>6 - 10 Yrs. Non-limit</td>
<td>Evaluating</td>
</tr>
</tbody>
</table>

Source: METI(2012)