Energy Storage and its Application in Smart Grid

Shijie Cheng
Huazhong University of Science and Technology
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1. Introduction
Renewable energy, such as the wind power and/or solar power, can be fully used, so that the problems of energy crisis and climate change can be solved.

Benefits of the Smart Grid

Improve efficiency, reliability and safety of power delivery and use

Renewable energy, such as the wind power and/or solar power, can be fully used, so that the problems of energy crisis and climate change can be solved.
Large scale centralized utilization of the renewable energy is the main characteristic in China. Accordingly, wind power generation has got a rapid development in China in the recent years.
Wind power development in China
However, Random fluctuation, the inherent property existed in the wind power generation, presents difficulties for power system security operation.

Both the theoretical research and the experiment results show that the energy storage technique is able to provide significant contributions in overcoming such difficulties.
This presentation will briefly:

Introduce the potential applications of the energy storage in smart grid,

summarize some commonly used energy storage techniques,

give a few examples and suggestions for the research of applying ES in smart grid.
2. Applications of Energy Storage in Smart Grid
wide Applications of ES in Smart Grid
# Applications of ES in Smart Grid

## (ESA classification)

<table>
<thead>
<tr>
<th>Category</th>
<th>Applications</th>
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</thead>
<tbody>
<tr>
<td><strong>Generation</strong></td>
<td>energy management, peak generation, load following, load leveling</td>
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<tr>
<td><strong>Transmission And Distribution</strong></td>
<td>voltage control, power quality, system reliability, asset utilization</td>
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<tr>
<td><strong>Ancillary Services</strong></td>
<td>frequency response, spinning reserve, standby reserve, long term reserve</td>
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<td><strong>Renewable</strong></td>
<td>time shifting generation, control and integration, reserve</td>
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<tr>
<td><strong>End–user</strong></td>
<td>UPS/Ride through, energy purchase optimization, VAR support</td>
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Providing active and reactive high power support, energy storage can be used in the energy management applications such as load leveling, peak shaving, load shifting and commodity storage where electricity storage technologies are used in daily cycles for economic gain.
By providing uninterrupted power supply (UPS), energy storage technologies can increasing power grid reliability.
Providing “prompt” spinning reserve (or load) for mitigating load-generation imbalance with the energy storage of discharging real power for a duration up to 30 minutes, grid frequency excursion can be suppressed.
By the injection and the absorption of real power at periods of 1 to 2 seconds, energy storage technology has ability to keep all components in the system in synchronous with each other and prevent system collapse.
By providing additional reactive power plus injection of real power for duration up to 2 seconds, energy storage technology has the ability to maintain the voltages of the generation and load ends within the normal values.
By providing "ride-through" for momentary outages, and extended protection from longer outages, coupled with advanced power electronics, energy storage systems can reduce harmonic distortions, and eliminate voltage sags and surges. Power quality can then be improved.
In combination with renewable resources, energy storage can increase the value of photovoltaic (PV) and wind-generated electricity, making supply coincident with consumer demands.
Energy storage can dispatch energy stored during off-peak or low cost times to manage demand on utility-sourced power.
3. Commonly Used Energy Storage Techniques
Pumped hydro
Flywheel
CAES

Mechanical

Batteries
Fuel cells

Electro-chemical

SMES
Capacitors
Super capacitors

Electrical
Pumped Hydro Energy Storage

Principle: Use up level water reservoir to store energy

Advantage: very large energy storage
Long lifetime

Drawback: Slow response speed
Geographic limitation

Applications: Energy management
Frequency control
Reserve provision
A Large pumped hydro energy storage
Flywheels Energy Storage

Principle: Store energy in massive rotating cylinder

Advantage: Fast respond speed
Long lifetime
Less maintenance cost

Drawback: Relatively small storage

Applications: Active and reactive stability control
A High Speed Flywheel
Compress Air Energy Storage (CAES)

Principle: Use pre-compressed air to store energy, 40% less gas fuel for gas turbine generator

Advantage: Similar to pumped hydro

Drawback: Similar to pumped hydro

Applications: Similar to pumped hydro
A CAES Power Plant
Batteries

Principle: Customer–side energy storage devices
Vanadium Redox Flow (VRB), NAS, Li-ion.

Advantage: Relatively large storage
Fast response speed

drawback: High cost, Short lifetime

Applications: Load leveling, Stability control, Voltage support
Vanadium Redox Flow Battery (VRB)
Superconductive Magnetic Energy Storage (SMES)

**Principle:** Store energy in DC magnetic field.

**Advantages:**
- Very high efficiency
- Fast response speed
- Relatively Long lifetime

**Drawbacks:**
- Very high cost
- Related small storage

**Applications:**
- Power quality improvement
- Angular stability control
- Voltage support
Super Capacitor Energy Storage

Principle: A new kind of energy storage device with very high capacitance, Thousands of times larger than that of the conventional capacitors.

advantage: High density energy storage
Fast response speed

drawback: Cost high, limited lifetime

applications: Power quality
Stability control
Voltage support
Super Capacitor

Double Layer Capacitors
(Adsorbed layers of ions and solvated ions)
4. Examples
100kJ/10kW Flywheel Energy Storage For Power System Stability Control
System configuration

- large rotating inertia flywheel energy storage
- doubly-fed induction generator
- rectifier-inverter pair
- monitoring and control system
Parameter of the prototype

- Rated power $PN = 4\text{kW}$,
- Stator rated voltage $UsN = 380\text{V}$, $f = 50\text{Hz}$,
- Number of pole pairs $p = 3$, Synchronous speed $n1 = 1000\text{rpm}$, Rated speed $nN = 976.2\text{rpm}$,
- Range of slip $-0.5 < s < 0.5$,
- Rated power factor $\phi N = 0.816$,
- Stator resistance $Rs = 1.5818\ \Omega$,
- Rotor resistance $Rr = 1.4797\ \Omega$,
- Stator inductance $Ls\sigma = 0.00855\text{H}$, Mutual inductance $Lm = 0.31395\text{H}$,
- Moment of inertia $J = 19\text{kg}$.
Dynamic Operation Characteristic Tests

Diagram of the test system
Power Regulation Test

$P$ regulation

$Q$ regulation
Dynamic Response Test

- $P$ ramp time is less than 100ms and $Q$ less than 60ms.
- The response is sensitive.
The prototype can realize rapid regulation of active power and reactive power in bi-directions. The prototype has met the design requirement on power regulation for improving the grid stability.
Damping The Power System Oscillation Test

Parameters of the test power system

- $S_{gN} = 5\text{kVA}$, $P_{gN} = 4\text{kW}$, $\phi_{gN} = 0.8$, $X_{gd} = 0.666\text{p.u.}$, $X_{gd'} = 0.126\text{p.u.}$, $X_{gd''} = 0.063\text{p.u.}$,
- $R_{L1} = 1.26\ \Omega$, $R_{L2} = 1.26\ \Omega$, $X_{L1} = 17.45\ \Omega$, $X_{L2} = 17.45\ \Omega$,
- Grid voltage 800V, Grid Frequency 50Hz,
- Transformer 1 turns ratio 220:800, Transformer 2 turns ratio 220:380
the FPC prototype can effectively damp out power system oscillation
35kJ/7kW Conduct Cooling High Temperature SMES
System configuration

Utility System

Transformer

Reactive Power Compensation

Converter

PWM Pulse Trigger

Cryogenic Subsystem

SMES Coil

Monitoring Subsystem

Coil Protection
A Single Machine Infinite Bus Power System with SMES
Laboratory Environment Test Results
Laboratory Environment Test Results
Movable Conduction-cooling HT-SMES for Field Test
Field Test System
Field Test Results

System Response with 3-Phase Fault
5. Research Interests
Development of high performance energy storage device

Development of advanced energy conversion technique and equipment

Development of effective energy management system for smart grid
6. Conclusions
Application of energy storage technology provides multiple benefits to the smart grid leading to two important goals: effectively using the energy sources and reducing the environment impact of power system. More attention should be given to it.
Thank You for your attention!

Questions or comments?