Modeling, Simulation, and Applications of Distributed Battery Energy Storage Systems in Power Systems

Xiaokang Xu, Martin Bishop, Edgar Casale, Donna Oikarinen, and Michael J.S. Edmonds

S & C Electric Company

CIGRE US 2013 Grid of the Future Symposium
Boston, MA, USA, October 20-22, 2013
Energy Storage Projects and Capacity in US (from DOE Database as of August 2012)

Total = 58 Projects
- Thermal Storage: 14
- Pumped Hydro: 3
- Flywheel: 1
- Compressed Air: 4

Total = 5,305 MW
- Battery: 206 MW (4%)
- Compressed Air: 709 MW (13%)
- Flywheel: 0.01 MW (0%)
- Pumped Hydro: 4,370 MW (83%)
# Major Applications of Battery Energy Storage System (BESS)

<table>
<thead>
<tr>
<th>Generation Applications</th>
<th>Transmission and Distribution Applications</th>
<th>End-User Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Provide renewable sources governor response and system frequency regulation. (Renewable generation typically lacks governor response and frequency regulation capability.)</td>
<td>• Increase transmission capacity factor for renewable sources.</td>
<td>• Store renewable generation production.</td>
</tr>
<tr>
<td>• Balance energy needs such as peaking shaving/valley filling. (Renewable generation non-controllable variability increases balance energy needs.)</td>
<td>• Relieve transmission congestion and relax transmission reliability limits.</td>
<td>• Provide time-shifting, load-following and load-leveling of demand to avoid peak prices.</td>
</tr>
<tr>
<td>• Provide short-term and quick start reserves.</td>
<td>• Defer transmission, distribution or transformer upgrades, capital expenditure due to congestion, or peak load growth.</td>
<td>• Provide reliability enhancement to avoid power interruptions.</td>
</tr>
<tr>
<td>• Provide renewable energy production shifting, smoothing and leveling.</td>
<td>• Provide voltage and VAR support and reliability enhancement to manage the fluctuations of renewable energy production.</td>
<td>• Allow utility control for targeted reliability enhancement.</td>
</tr>
<tr>
<td></td>
<td>• Support islanding system operation and/or serve loads in isolated areas.</td>
<td>• Provide renewable generation and load demand response management.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Provide load specific voltage support.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Provide emergency power.</td>
</tr>
</tbody>
</table>
Schematic Diagram of a Typical BESS

Power Conversion System

UTILITY SYSTEM

AC FILTER

INVERTER

DC BUS

CHOPPER

NaS ENERGY STORAGE
S&C Delivered BESS Projects

- 2 x 1-MW System – Canada
- 4-MW System – California
- 2-MW System – Indiana
- 1-MW System – Minnesota
- 1-MW System – Missouri
- 1-MW System – New Mexico
- 4-MW System – Texas
- 2-MW System – West Virginia
- 2-MW System – Ohio
- 2 x 1-MW System – North Carolina
- 1-MW System – West Virginia
- 1-MW System – Scotland
- 1-MW System – Australia
- 1-MW System – New Mexico

Chemical Technologies:
- NaS
- Li-Ion
- Advanced Lead Acid
- NaNiCl
BESS with Renewable Energy Application

October 2013
Case Study Results

For example, when the WTG production is such that the BESS operates with 100% Depth of Discharge (DOD) per day, the revenue from the BESS would be:

\[
\text{Revenue from BESS} = 6 \text{ MWh} \times 300 \times 365 \text{ (days)} = 657,000 \text{/year}
\]

When operating with 90% DOD per day, the revenue from the BESS would be:

\[
\text{Revenue from BESS} = 90\% \times 6 \text{ MWh} \times 300 \times 365 \text{ (days)} = 591,300 \text{/year}
\]
System Modeling (Peak-Shaving, Islanding Operation, etc)

- Load MVA without ES
- Load MVA with ES
- Peak Shaved
- ES Charging
- ES Discharging
- Valley Filled

Active Power Command, pu
Active Power Command Limiter

Power Rate of Change Limiter

Pactual, pu

Active Power Command Limiter

Vactual (low bus), pu

P
-P
S
+ -
S
+
+
÷ 
Id

Power Rate of Change Limiter

PI Controller

P

\( \frac{\text{P}_{\text{batt} \%}}{\text{P}} \)

Id

Idr

Vactual (low bus), pu
System Modeling (Peak-Shaving, Islanding Operation, etc) (Cont’d)
Case Study – Peaking-Saving
Case Study – Islanding Operation
Conclusions

• Typical applications of the BESS include output smoothing and time shifting for intermittent renewable (wind and solar) energy sources, and peak shaving and valley filling for the power grid, and islanding system operations. This paper presented case studies to discuss these types of applications. The paper also included modeling and simulation of the BESS with the widely-used Power System Simulator PSS®E. Simulation results show that the BESS dynamic model responds properly and correctly as expected when operating in peak shaving/valley filling mode and in islanding operation mode in a simplified system. This model can be used for power system studies involving those typical BESS applications.