BESS Overview - Components, Drivers, Applications
Energy Storage Systems
Becoming part of the Smart Grid

- Pilot projects
  - Early pilots demonstrated technical feasibility
  - Later pilots demonstrated local commercial feasibility
  - Future pilots to demonstrate grid-wide benefits
Energy Storage Value Chain
Where to apply and which applications?

- Generation
  - Renewables capacity firming
  - Capacity Firming and ramping
  - Energy & Power applications

- Transmission
  - Ancillary services
  - Frequency regulation
  - High power applications

- Distribution
  - Load management
  - Peak shaving
  - Energy and Power applications

- Residential
  - Time shifting
  - Energy applications
PCS100 ESS

ESS applications

Central Generation

Load leveling for generation utilization
100 MW, 4h

Spinning reserve in case of line loss
10-100 MW, 0.25-1 h

Integration of renewables
1-100 MW, 1-10 h

Load leveling for postponement of grid upgrade
1-10 MW, 6 h

Frequency regulation
1-50 MW, 0.25-1 h

Distributed Generation

20 kV 110 kV

110 kV

20 kV Overhead line

to Load

Heavy Industry

Peak shaving
0.5-10 MW, <1 h

Network ring

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February 8, 2012 | Slide 4
Storage Applications - Power vs Energy

Electricity Storage Spectrum in Utility Grids

High Power  High Energy

Power Quality Applications: “increase of power grid reliability”
seconds or less
- Flicker compensation
- Voltage sag correction
- Reactive power control

minutes
- Spinning reserve (for voltage and frequency regulation)
- Uninterruptible power supply
- Blackstart

Energy Management Applications: “production can be decoupled from demand”
hours
- Load leveling
- Peak shaving
- Energy trading
- Integration of renewables
- Island operation
Volatile generation creates global need for storage
Impact on varies by region and by locality

Need for new storage capacity / technologies

- >80% of new volatile generation will be in US, EU or China
- Proportion of volatile generation will no longer be matched by pumped hydro storage (PHS)
- Local instabilities (e.g. islands) within regions will first create need for distributed energy storage
- Need for additional bulk storage will follow

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th>EU</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total generation capacity (GW); 2015 [2008]</td>
<td>1100 [1050]</td>
<td>1000 [850]</td>
<td>1300 [800]</td>
</tr>
<tr>
<td>Proportion of Wind / Solar PV; 2015 [2008]</td>
<td>7% [2%]</td>
<td>18% [9%]</td>
<td>7% [2%]</td>
</tr>
<tr>
<td>Proportion of Pumped Hydro Storage (PHS); 2015 [2008]</td>
<td>2% [2%]</td>
<td>5% [6%]</td>
<td>2% [3%]</td>
</tr>
<tr>
<td>2010 Smart Grid stimulus funding (BUS$)</td>
<td>7.1 [0.2 for Storage]</td>
<td>1.8</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Source: IEA World Energy Outlook 2010; Zpryme SmartGrid Insights; SBI Storage Report; ABB analysis
Tackling society’s challenges on path to low-carbon era means helping utilities do more using less

Forecast rise in electricity consumption by 2030
Source: IEA, World Energy Outlook 2009

Power and automation solutions are needed for:

- Meeting rising demand for electricity
- Increasing energy efficiency and reducing CO₂ emissions
- Improving productivity to raise competitiveness of businesses and utilities

Meeting the rise in demand will mean adding a 1 GW power plant and all related infrastructure every week for the next 20 years
Energy Storage Drivers – Rollout of EVs

- EV charging will stress out the distribution system
- EV rollout will increase batteries volume and reduce cost
Energy Storage Drivers – Government incentives

- **AB 2514** - California Assembly had just passed the bill AB 2514 that set a deadline by 2012 to set objectives for the utilities to invest in energy storage projects (all technologies).

- **Storage act (1091 – pending)** – the storage act will amend tax code to create incentives for energy storage deployment:
  - **SGIP** (Self generation Incentive program), provides financial incentives (USD 2/watt) for installation of storage (behind the meter) combined with wind turbines and fuel cells.
  - **EISA 2007** – Requires Council to develop a 5 year plan (by Dec 2009) for storage as a tool to manage variability and capacity concerns. Directs DOE to conduct a cost sharing R&D
  - **ACELA (1462)** – Peak demand reduction and load shifting goals with tools like demand response technologies (smart grid technology, dynamic pricing, distributed generation, energy storage)
Energy Storage Drivers – Renewables
Penetration Capacity Variability

- US government targets of 20% (renewable generation) by 2020
- Variability generates stress on the fossil generation assets and jeopardize system stability
- Generation > Demand + reserve
Wide applications of Energy Storage System (ESS)

Power Quality Improvement

- Load shifting
  - ESS shift wind energy from night to peak hour

- Frequency regulation
  - ESS regulate frequency when wind is connected to grid

Energy Storage System (ESS)

- Intermittency Mitigation
  - ESS supply minimize the voltage sags
  - @Source: SANDIA
  - # Source: ABB

- Frequency regulation
  - ESS regulate frequency when wind is connected to grid

- Peak power shaving
  - ESS supply the power during peak output
  - Source: SANDIA

- Uninterrupted Power Supply
  - ESS supply power when source fails

- Source: ABB
Energy Storage Drivers – Renewables penetration – Wind /solar Generation’s capacity peak

- US government targets of 20% (renewable generation) by 2020
- Wind and solar generation peaks are not aligned with demand peak
### Applications - Load Shifting / Peak Shaving Benefits

**Load Shifting.** Defined as the practice of altering the pattern of energy use so that on-peak energy use is shifted to off-peak periods. – **energy arbitrage** – **cost savings**

**Peak Shaving.** Peak shaving uses store energy to eliminate the peaks in the energy consumption pattern. – **load factor increase, reduction of power charges, increased return on investment of utility assets, cost savings due to reduction in peak generation**

- **Time shift benefit ($)** = ($/kwh\text{\_peak} \times \text{Sthr} -$/kwh\text{\_off} \times \text{Sthr/eff}) \times \text{Power}
- **Peak shaving benefit ($)** = Power (kw) \times \text{Power fee} ($/kw)

- $/kwh\text{\_peak}$: onpeak energy price ($/kwh)
- $/kwh\text{\_off}$: off peak energy price ($/kwh)
- Sthr: hours of storage (hr)
- Eff: efficiency system (%)
Energy Storage Drivers – Demand management

- Generation, Distribution and Transmission assets need to be sized for peak demand.
- Peak shaving allows to increase the Load factor of the assets, increasing the return on the investments.
PCS100 ESS

ESS applications

Central Generation

- Load leveling for generation utilization
  100 MW, 4h

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Distributed Generation

- Integration of renewables
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- Peak shaving
  0.5-10 MW, <1 h

Network ring

- 20 kV
- 110 kV

220 kV Overhead line

to

Load
Renewables Capacity Firming

Wind and solar generation intermittency

- Short duration intermittency from variations in wind speed and/or shading of the sun occur through the day
- Objective is to use BESS to “fill in” so that the combined output from the renewable generation plus storage is close to constant
- Maintain higher forecasted levels of generation => higher revenue
- Increased amount of CO2 free generation to allow renewable integration
Ramping
Need for dispatchable generation

- Sudden changes in wind – heavy wind conditions could lead to that an entire wind park is disconnected to the grid, which could have severe impact on the power system
- Need for dispatchable power sources whose output can change rapidly => ESS to play a role
- Use ESS to bridge the time needed to start up other generation
Wide applications of Energy Storage System (ESS)

**Power Quality Improvement**

- Load shifting
  - ESS shift wind energy from night to peak hour

- Intermittency Mitigation
  - ESS supply minimize the voltage sags

- Frequency regulation
  - ESS regulate frequency when wind is connected to grid

**Peak power shaving**

- ESS supply the power during peak output

**Uninterrupted Power Supply**

- ESS supply power when source fails

**Source:** SANDIA, ABB

- ESS smooth the power output from PV

- ESS supply power during peak output

- ESS shift wind energy from night to peak hour
Primary Frequency Regulation

- Frequency control (50 or 60 Hz)
- Fast reserve for emergencies
Wide applications of Energy Storage System (ESS)

- **Power Quality Improvement**
  - ESS shift wind energy from night to peak hour
  - ESS supply minimize the voltage sags

- **Load shifting**
  - ESS smooth the power output from PV
  - @Source: SANDIA
  - # Source: ABB

- **Frequency regulation**
  - ESS regulate frequency when wind is connected to grid

- **Peek power shaving**
  - ESS supply the power during peak output

- **Uninterrupted Power Supply**
  - ESS supply power when source fails

- **Intermittency Mitigation**
  - ESS supply power when source fails
Additional Applications

Power Quality.

- Power quality applications involve using ESS to protect loads downstream against short-duration events that affect the quality of power delivered to the load.

- **Voltage Support** / Energy storage with reactive power capability can provide voltage support and respond quickly to voltage control signals.
BESS Design Components

- AC Grid Voltage
- Battery DC Voltage & Application
  - Battery Type
- PCS SYSTEM

[Diagram showing components: Grid Connection, PCS System, Step-up Transformer (XFMR), Sine Filter, Inverter, DC Breaker, Battery Supply]
Various types of energy storage

* Holger Hannemann, “Innovative Solutions for grid stabilization and support”, ABB Power Electronics Napier, 30 March 2010
How to select the ‘right’ storage technology
Define what it must do, not what it must be

1. Functional specification
2. Storage specification
3. Evaluation and selection
4. Functional guarantee

Diagram:
- Useable capacity
- Service life (years)
- Energy (MWh)
- Nominal energy rating
- Max State of Charge
- Min State of Charge
Battery Power Module Construction

+ 6V 10Ah
- 3V 10Ah
  3V 10Ah

+ 6V 10Ah
- 6V 10Ah
  6V 20Ah

+ 6V
-
Hierarchy of the battery solution - <1200Vdc

Cell -> Modules -> Battery Container
Battery System Definitions

- **C-rate** - Discharge or Charge rate. Capacity of cell (or battery) divided by 1 hour.
  - 1MWh battery will deliver 1MW for 1 hour (1C)
  - 1MWh battery will deliver 2MW for 30 min (2C)
  - 1MWh battery will deliver 500kW for 2 hours (C/2)

- **Efficiency**
  - Defined through charge/discharge cycle

- **Depth of Discharge (DoD) and Cycle Life**
Power Electronics based Energy Storage Systems core range:

- Supercaps: 5 to 15 seconds ~500,000 cycles
- Flywheels: 1-30 min no cycle limitation
- Batteries: NiCd 30-120 min ~2500 cycles @ 80% depth of discharge
  - Li-Ion: 15-60 min ~3,000-6,000 @ 80% DoD
  - Flow: 3-6 hours expected 10,000 cycles @ 80% DoD
- NaS: 6-8 hours ~ 4500 @ 80% DoD
BESS – ABB PCS Design Capabilities

Packaging
- Indoor or Outdoor
- Transformer internal/external to PCS container

Environmental Conditions
- Temperature
- Altitude
- Wind, dust, harshest environments

AC Grid and DC Battery voltages

Control and Operations
- BESS function, Statcom
- BMS interface
- EMS/SCADA interface
- Remote Diagnostics

Operation and Maintenance Support
PCS100 Platform
The Concept

- Traditional high power converters are constructed as a single unit
- Topology is not as flexible
- Service is complex

- The PCS100 converter platform is a modular structure
- Flexible sizing of converters by adding power modules
- Service is simple
- Highly reliable with redundancy
Inverter Technology

- IGBT Technology
- DC Voltage Range
- Forced Air, HVAC or Liquid Cooled
- Module kVA rating
- LCL Filter integrated or external
- Sized for temperature, altitude, overload and kVA ratings.
Inverter Waveforms
Sinusoidal PWM Modulation

PWM Waveform generated by the IGBT’s

Red Waveform

Blue Waveform
PCS100 Statcom & ESS
Advanced redundancy feature

Traditional Statcom / ESS
- Filter
- Inverter
- Available power: 0 kVA / 0 %
- MTTR: many hours

Modular Statcom / ESS without Redundancy
- Available power: 0 kVA / 0 % (fault with one module stops the whole system)
- MTTR: 30min

PCS100 Statcom / ESS Advanced Redundancy
- Available power: 1900 kVA / 95 %
- MTTR: 30min or continue operation until scheduled maintenance
BESS – PCS Containerized Solution

• Fully Containerized solutions for ratings up to 4MW.
• Transformer contained for <2.5MW units and <20kV.
  • External transformer for ratings above that.
• Testing for complete PCS prior to shipment to site.
• Mobile solution
• Minimize install & commissioning time
• Reduce transportation costs
• Non-walk-in enclosure for added safety.

2MW Containerized PCS
PCS Designs - Indoor and Outdoor
ABB FACTS: Dynamic Energy Storage

- Energy storage connected on DC-side of converter (SVC Light)
- Size depends on power level and duration
- Charge energy equal to load energy
- Focus on “dynamic”, manages:
  - High number charge and discharge cycles
  - High Power at medium duration
- Chosen high performance battery as energy storage
Energy Storage Platform #2
DynaPeaQ / SVC Light with Energy Storage

Typical layout for 20 MW during 15 min +/-30 MVAr continuously
Energy Storage Platforms >1200V DC
Hierarchy of the battery solution for both Platforms
Battery Energy Storage System
Topology & Functions

Functions:
1. Voltage Control Operation: Reactive Power $Q_{inj}$
2. Frequency Control Operation: Real Power $P_{inj}$
3. Load Leveling / Peak Shaving Operation: Active Power
4. Black Start / Stand-alone Capability: Voltage and Frequency
Grid Connect Interfaces

STATCOM: The concept

- Voltage source with variable voltage amplitude
- Transformer acts as inductance
- Shunt connected to the distribution (or transmission) grid
Low Voltage Ride Through – Grid Codes
PCS100-ESS Low Voltage Ride Through capability

No UPS

With UPS
PCS100-ESS Operating Range

PCS100 Inverter System pu

pu MW

pu MVar

PCS 100 Operation Area
Grid Connect Interfaces
ESS inverter control modes

- **Generator Emulator Voltage Source Control**
  A unique feature of the PCS100 is its ability to provide power to the grid in the same manner as a regulator generator. This has many benefits for the grid;
  - Ability to source negative sequence current to correct grid unbalance
  - Stabilization of small grids through ‘synthetic’ inertia

- **High Speed Current Source Control**
  The PCS100 can also control power flow by controlling the current from the inverter. Direct current control provides a faster response to a power command.
  - Sinusoidal current regardless of grid voltage distortion
  - Minimizes DC ripple current
  - Fast response

---

Operating Modes

- Dynamic Power
- Voltage & Frequency Regulation
- Island
- Dynamic Power
PCS100 Graphic Display Module (GDM) Interfaces

- Touch PC
- Easy access to information
- Visual representation of the system
- Event log, date and time stamped
- Fault log, date and time stamped
- Factory tags and location data
- Ethernet (SCADA)
- USB (service)
**PCS100 Graphic Display Module (GDM) Interfaces**

### Power Quality

**Status:** GENERATOR MODE

### Event Log

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Time</th>
<th>Event</th>
<th>Origin</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2010-04-29</td>
<td>16:22:48.94</td>
<td>Warning</td>
<td>System</td>
<td>67</td>
<td>VCAN Warning</td>
</tr>
<tr>
<td>2</td>
<td>2010-04-29</td>
<td>16:17:57.65</td>
<td>Info</td>
<td>System</td>
<td>165</td>
<td>Run</td>
</tr>
<tr>
<td>3</td>
<td>2010-04-29</td>
<td>16:17:57.65</td>
<td>Info</td>
<td>System</td>
<td>159</td>
<td>Sync’d, output enabled</td>
</tr>
<tr>
<td>4</td>
<td>2010-04-29</td>
<td>16:17:57.65</td>
<td>Info</td>
<td>System</td>
<td>158</td>
<td>Sync’d, No output</td>
</tr>
<tr>
<td>5</td>
<td>2010-04-29</td>
<td>16:17:56.36</td>
<td>Info</td>
<td>System</td>
<td>156</td>
<td>Syncing Phase, No Output</td>
</tr>
<tr>
<td>6</td>
<td>2010-04-29</td>
<td>16:17:55.43</td>
<td>Info</td>
<td>System</td>
<td>155</td>
<td>Syncing Volt/Freq, No Output</td>
</tr>
<tr>
<td>7</td>
<td>2010-04-29</td>
<td>16:17:55.23</td>
<td>Info</td>
<td>System</td>
<td>154</td>
<td>Wait; Sync Good, No Output</td>
</tr>
<tr>
<td>8</td>
<td>2010-04-29</td>
<td>16:17:55.01</td>
<td>Start</td>
<td>System</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2010-04-29</td>
<td>16:17:47.57</td>
<td>Stop</td>
<td>System</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2010-04-29</td>
<td>16:17:47.35</td>
<td>Reset</td>
<td>System</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The event log as comma separated file (csv): Last 100, 1000, 5000 or All events. Long ones can take 10 minutes to download.
Factory and Site Acceptance Testing

ABB in-house test capability to test systems up to a primary voltage of 26 kV and power up to 4 MVA.

- Functional testing
- Full power testing
- Heat Run testing

ABB New Berlin FAT

BESS/PCS FAT
Delivering a distributed energy storage system

Resources needed

- Power System modeling
- Research & development
- Quality & OpEx
- Supply management
- Sustainability
- Service

Power Electronics
Modular Systems

FACTS
Substations
Conclusions

- Energy Storage Systems
  - …are approaching maturity
  - …are one more tool for the Power System engineer
  - …must integrate seamlessly into the grid
ABB Power Electronics

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