Managing Energy Storage and Renewables for California

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### Today’s Power System
- 6 second view of high voltage over limited area, minimal view of distribution / customers
- Limited distributed generation (DG) and storage
- < 2% intermittent generation
- <5% price responsive loads (relatively crude command systems)
- Centralized generation provides significant inertia to help stabilize the grid
- Relatively low asset utilization of large fractions of the system during most hours of the year
- Conservatively rated to avoid blackouts
- End use relatively simple resistance, predictable
- Managed from supply side
- Multiple control centers and regulatory jurisdictions; often not coordinated
- Increasing cyber threat activity

### The Power System of 2020
- Full Smart grid implementation enables 2-way communication to see entire system (G, T, D & EU) in real time (< 1sec) across entire interconnections
- More DG & storage across system
- > 15% renewable (mostly intermittent) generation (net)
- > 15% price responsive demand
- Substantial new high-efficiency loads, hard to predict
- Substantial new demand from electrification of ~25% light duty transportation
- Demand control part of grid management, along with traditional supply side
- Coordinated control and regulatory frameworks
- Inherently resilient to both cyber and infrastructure attack

*Power system (smart grid) includes entire system from centralized generation to transmission (T), and distribution (D), down to consumer loads (EU) and decentralized generation (DG)
Large-scale energy storage is critical for renewable penetration and grid reliability

Drivers for Large Scale Energy Storage

- Renewable Generation
- Grid Reliability Management
- Power quality
- Load leveling, shifting

Size of the challenge – How much storage is needed?

- Over 200GWh of balancing resource (e.g. storage) needed to meet DOE 20% Wind by 2030 goal (20% of wind output)
- 15,000 PHEV batteries required to shift 4 hours of wind from one 100MW project
Renewable Generation Expansion Increasing Importance of Energy Storage

- Growth in renewable generation
  - USDOE targeting 20% renewables by 2020
  - CALISO examining implications of 33% renewables and beyond
    - CA 2020 targets adding 19.2 GW (70.7 GWh) renewables
    - Regulation and load following cost CAISO $300 per year today; expected to double every three years
  - PNW reached 3 GW wind in August 2010; expected to double in next three years. A significant fraction of PNW wind energy reaches the CA market
- California AB 2514 considers targets for energy storage systems
Sizing and placement options of energy storage in electric power systems

With high contributions of intermittent renewable resources, energy storage becomes necessary to smooth out the intermittency and the sharp drop off of solar generation at sunset.

Value of the energy storage depends on size and placement of storage.

Number and size of storage varies as storage equipment is placed closer to the end-user.
Key values for deployment of energy storage

- **Meeting Balancing Requirements**
  - Actual production
  - Generation schedule
- **Real-time operation**
- **Arbitrage**
- **Infrastructure deferment**
  - Located at strategic location in bulk power to reduced congestion
  - In distribution system/home to reduce distribution congestion

Energy storage is one of many grid assets to provide balance services.

**Reliability value**

**Economic value**
CEC and BPA Jointly Exploring Innovative Storage Solutions to Provide Regulation Needed for Renewables Integration

Research Objective: Determine the technical and economic performance of flywheel and sodium sulfur battery energy storage to support California goals for renewable generation integration.

Three-Phase Research Plan

- Phase I: Developed a prototype wide-area energy storage concept (WAEMS) that would integrate CA-based flywheels and PNW-based hydro units to jointly support renewables integration.

- Phase II:
  - Flywheel field tests and results analysis
  - Sodium Sulfur technology evaluation

- Phase III: proposals submitted to BPA and CEC for an investment-based practical deployment of a WAEMs system
A WAEMS is a centralized control system that operates energy storage devices located in different places to provide energy and ancillary services that can be shared among balancing authorities.
Combined Regulation Services between CAISO and BPA

Proposed system configuration

- 2 resources: (flywheel & hydro)
- BPA & CAISO conventional regulation signals
- The hydro unit provides smooth/slow regulation and helps maintain the desired energy level in the flywheel
- The flywheel provides the fast regulation, helps minimize the stress on the hydro unit and keeps its output within the limits
Modeled Benefits of the WAEMs Concept

- Reduce regulation reserve by up to 30%
- Provide fast, cost-effective, and efficient ancillary services
  - Minimize wear-and-tear of conventional regulating units
  - Operate conventional regulating units close to their most efficient operating point.
  - Allow the storage devices to excel in specific applications that fit their characteristics
    - Allow the flywheel to serve biased regulation signals and support the flywheel by maintaining a reasonable state-of-charge (SOC)
- Easy scalable technology
- Compatibility:
  - Fully compatible with the existing BPA and CAISO AGC systems
  - Fully compatible with the other technologies such as ACE Diversity Interchange (ADI)
- Can be used with the other Balancing Authorities
Specific Goals and Objectives of Phase II

► Flywheel Field Test Design and Result Analysis
  ■ Configuration: **Flywheel + Hydro**
  ■ Scenarios: **Now (2009) and future (2013)**
  ■ Performance evaluation: response time, ramping capability, losses, energy limits, and fade time.
  ■ Economic analysis: breakeven prices.

► Battery Storage Evaluation
  ■ Analyze the existing opportunities for **NaS battery storage** in California (market opportunities, possible technical services, advantages and disadvantages, etc.)
  ■ What helps or harms the project (markets, regulations, etc.)
  ■ Provide recommendations
Flywheel Field Tests

Objective: To validate the ability of flywheels to meet the performance demands of the wide area energy management concept to support renewables integration

Evaluated a 25-kWh, 100-kW flywheel
Field Test Design

2009 April ACE and regulation data from BPA and CAISO

Implemented on Beacon Flywheel Controller

Field tests conducted at the Beacon Power facility

Evaluation:
- Economic Analysis
- Performance Metrics
The Flywheel Field Test Results

- The flywheel followed regulation signal with Mil-second response delay.
- The WAEMS algorithm successfully allocated the fast regulating signal to the flywheel and the slow one to the hydro.
- The flywheel state-of-charge was maintained within its capacity limit by the support from the hydro unit.
An Example Result: Flywheels + Hydro plants

Calculated Breakeven Prices:
Pay-by-capacity
Flywheel-hydro: $12.19/ MW
Flywheel alone: $20.37/ MW

CAISO:
$11.95/ MW for regulation

BPA:
$9.38/ MW for regulation

If the same service was provided by the flywheel alone, because the regulation signal is biased, the flywheel will be out of energy in some hours and will not comply with the regulation requirement. This might double or triple the cost for the flywheel to provide the regulation service.
Conclusions – Flywheel Field Test

- Flywheel response delays are within millisecond range and state-of-charge is well maintained.
- The WAEMS control algorithm successfully allocated the fast regulating signal to the flywheel and the slow one to the hydro.
- The WAEMS combined service has:
  - Millisecond fast response characteristic
  - No strict energy storage limitation
  - Better performance and more economical than flywheel-only service.
- MW regulation service provided by a MW flywheel and MW hydro (assuming its cost is $4/MW) system will then cost $12.19/MW as compared to the average CAISO ($11.95/MW) and BPA ($9.38/MW).
- The WAEMS controller helped the hydro unit to reduce the wear and tear and allow it to operate close to the most preferred operating point.
Objective: Analyze the existing opportunities for **NaS battery storage** in California (market opportunities, possible technical services, advantages and disadvantages)
**Input Data:** Provided by CAISO

- Wind and Load Forecast Statistics
- Actual Wind Data (2006)
- Actual Load Data (2006)
- 20% Renewable (2012)

**Battery Performance Modeling**

- Regulation Signals
  - Case 1: 2012 20% Renewable
  - Case 2: 2006 No wind
- Real-time Dispatch Signals
  - Case 1: 2012 20% Renewable
  - Case 2: 2006 No wind

- Sodium Sulfur (NaS) Battery Model
  (Life Cycles versus Depth of Discharge)

- Regulation Services
- Real-time Dispatch Services

**Benefit Study**

- Conduct Cost Benefit Study: Breakeven Cost Calculation
Conclusions – Sodium Sulfur (Na-S) Battery Performance Evaluation

- **Improved lifecycles**: If manufacturers can improve the NaS battery’s number of lifecycles at high DODs, the breakeven prices will drop significantly for high DOD cases.

- Under the *pay-by-energy* scheme for regulation and real-time dispatch services, for a 4 MW, 28 MWh NaS battery to provide regulation and real-time dispatch services, breakeven prices are above $100/MWh, making the operation not economical.

- Under the *pay-by-capacity* scheme for regulation and real-time dispatch services, the high-end cost will be $26/MW and the low-end cost will be $16/MW. In the California market, this means the NaS battery may become marginally profitable.

- If the *power-to-capacity ratio* (now 1:7) increases, the NaS regulation service will become more economical when providing regulation or load following services.

- For the battery storage to become economical, providing *multiple energy and ancillary services* to collect revenue from multiple markets are necessary.
Summary Conclusions

- Wide-area energy storage control concepts appear technically feasible and offer significant cost savings to provide regulation services for renewables integration.

- Flywheel field tests demonstrated good technical performance in meeting regulation requirements, and appear to offer competitive cost performance when integrated with hydro resources in the framework of the WAEMS.

- Coordination of energy storage devices such as flywheels with conventional generators does improve generators’ efficiency and performance, reduce generators’ wear-and-tear, and provide compatible services that do not require much modification of the existing operating system.

- Na-S battery systems are currently an expensive option for providing just regulation services; leveraging them for multiple services significantly improves economic performance.
Questions?