Wide-Area Energy Storage & Management System to Balance Intermittent Resources in the BPA and CAISO Control Areas

BPA/CAISO/PNNL/Beacon Power Project

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Project Objectives

- Help to cope with intermittent resources by recycling the excess energy, controlling dispatchable load and distributed generation, and exchanging the excess energy between the BPA and CAISO Control Areas
- Develop principles, algorithms, market integration rules, functional design and technical specification for such a system
- Provide a cost-benefit analysis and business model for an investment-based practical deployment of system

Project's Motivation and Main Idea

- BPA expects up to 6,300 MW of wind generation capacity in its service area by 2010
- CAISO expects about 6,700 MW of wind generation and about 1,800 MW of solar generation capacity in its system to meet the CA 20% RPS target
- Currently, each control area balances its load and generation resources independently
- Wide area integration of intermittent resources would help to reduce the relative impact of intermittency on the grid balancing functions
- The existing Control Area structure and business practice does not address this opportunity
- The project will provide a new balancing service for the BPA and CAISO control areas where the ISO system will be helping to balance the BPA system and vice versa
- Energy storage will be used when random deviations of the regulation requirement in these 2 systems are not able to compensate each other
- For the CAISO and BPA Energy Management Systems, the new regulation resource will look as any other existing resource. No changes are required in the EMS systems and markets

Project Budget and Timeline

- First Phase
  - FY 07
  - BPA funding - $130K (goes to PNNL)
  - Cost sharing from CAISO, Beacon Power, and Energy Northwest – 35%
  - Actual beginning of the project – 05/09/07
  - Extended until November 30, 2007
- Second Phase (Physical experiments at San Ramon Test Facility)
  - FY 08
  - Perhaps, starting December 2007
  - Needs co-funding

Phase 1 Stage Gates and Status

- Stage Gate 1 (Completed, currently under revision, $20K):
  - Evaluate and compare different energy storage technologies and participating load / distributed generation control schemes. Identify top three technologies that would meet the needs of this project.
- Stage Gate 2 (Completed, $20K):
  - Design and evaluate different configurations and integration schemes of the energy storage. Identify the most promising configurations and their benefits.
- Stage Gate 3 (90% Completed, $15K)
  - Analyze technical and market compatibility of the proposed integration schemes with the existing regulation and load following systems at BPA and CAISO and identify potential minimum changes if they are required

Stage Gates and Status

- Stage Gate 4 (In Progress, $75K)
  - Develop initial algorithms for the energy storage. Implement them as MATLAB codes
    - Beacon Power flywheel model implemented in MATLAB – 100%.
    - Hydro power plant model – 100%
    - Control algorithm – 70%
    - Integrated MATLAB model – 50%
  - Collect and preprocess data needed for experiments from the BPA and the CAISO – 50%
  - Conduct experiments using the MATLAB model and collected data.
  - Carry out the cost benefit analysis – 90%.
  - Evaluate changes that are needed for the San Ramon prototype SEM (if any) – Beacon Power.
  - Provide a summary and recommendations for BPA on continuation of the project. Write and submit Phase 1 Report – Not Started.

Energy Storage Technology Evaluation

- Evaluation Criteria:
  - Ability to frequently change power output over the regulation range at least several times over a 10-minute interval.
  - Response time (less than one minute, ideally, within several seconds)
  - Resource duration capability (able to provide rated power for 15 - 60 minutes, at least)
  - Scalability to achieve needed energy and capacity
  - Lifetime
  - Maturity of the technology
  - Industrial use experience for regulation/frequency control
  - Cost
  - Environmental impacts
  - Ability to provide other ancillary services
  - Ease of siting

Energy Storage Technology Evaluation

- Selected Technologies:
  - **Flywheel**
  - **Hydro/Pumped Hydro**
  - **Lead Acid Battery (or Ni-Cd Battery) …This part of the study is currently under revision**

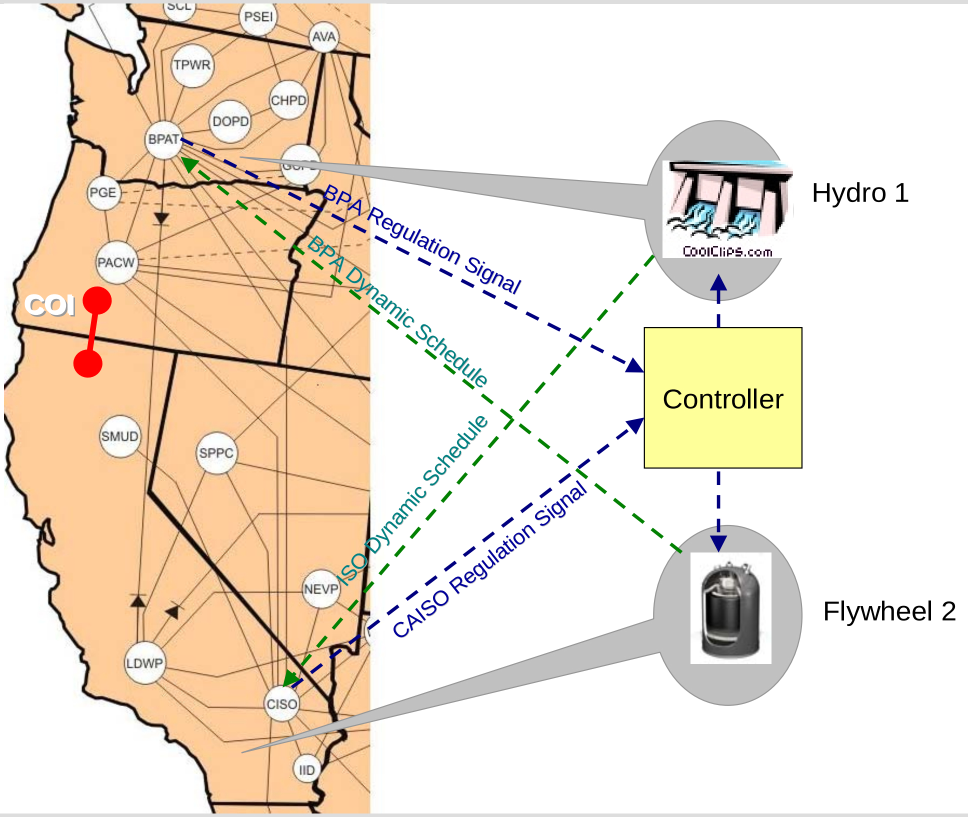
Eliminated Technologies:

- **Superconductive magnetic energy storage SMES**
- **Compressed Air Energy Storage**
- **Super Capacitors … Under revision**
- **Lithium-Ion Batteries**
- **Sodium Sulfur and Flow Batteries …Under revision**
- **Metal-Air Batteries**
- **Demand-side Management**

Main reason: Immaturity of these technologies (except the Compressed Air ES which has slow response disadvantage)

Design and evaluate different wide-area EMS configurations

- Comparison Criteria
  - Ability to provide wide-area regulation service
  - Overall efficiency of the solution (Minimum total regulation capacity required)
  - Compatibility with the existing regulation systems and markets (Minimum changes)
  - Minimum technical difficulty of implementation
  - Minimum cost for BPA and CAISO



Selected Design

- Two ESDs: flywheel +pumped storage (or conventional hydro). Initially, one ESD configuration can be used (first step toward the full configuration)
- Vertical configuration that would integrate the Wide Area EMS with the BPA and CAISO systems.
- BPA's and CAISO ACE and "conventional regulation unit" signals will be used to control the Wide Area EMS
- Dynamic schedules will be used to incorporate the ESD regulation into the corresponding neighboring Control Area AGC system.
- Control algorithms will be designed to mimic behavior of a conventional unit of regulation and to coordinate the control functions of participating ESDs.

Technical and market compatibility

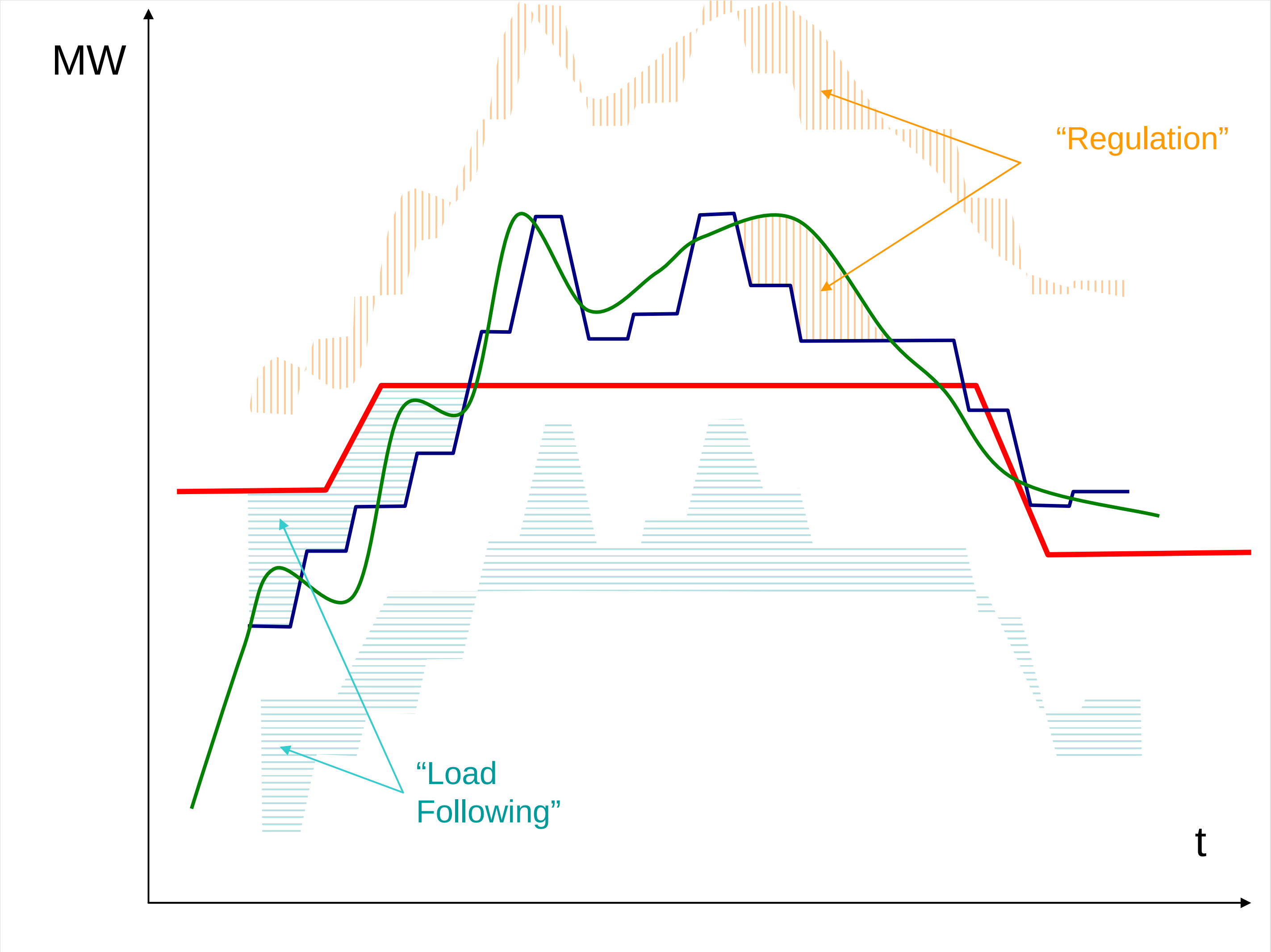
- The proposed wide area EMS is compatible with the BPA and CAISO systems
- Regulation at BPA
  - Hydro units are used for the regulation service
  - Units responding to AGC signal follow load variations through an entire operation hour on the basis of hour ahead schedule
  - No computerized load following process
  - AREVA AGC system is used for regulation: a mechanism with static deadband, dynamic deadband and multiple time constants
  - Feedforward AGC system has been developed by BPA
  - Transmission customer serving load in BPA control area is required to purchase this service
  - $8.85/MWh (BPA's proposed 2008 Transmission and Ancillary Service Rates)

Technical and market compatibility

- Regulation at CAISO
  - A mix of thermal and hydro units is used for regulation
  - Current radial zonal model will be replaced with Full Network Model and Locational Marginal Price model after implementation of MRTU (April 1, 2008)
  - Regulation (Up and Down, respectively) is procured in DA, HA and RT market.
  - Average regulation price in 2006 was about $18/MW-h
  - ABB AGC system

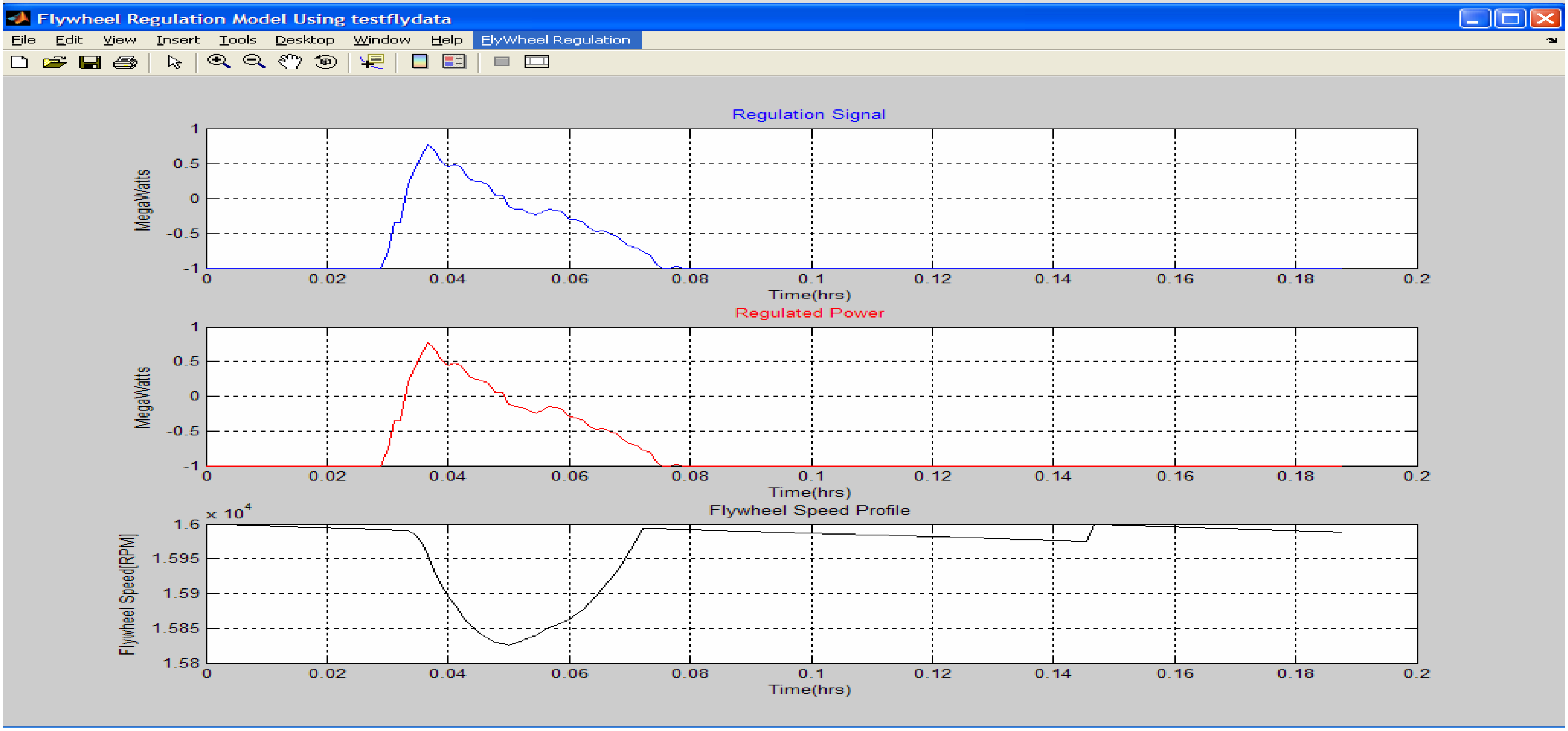
Technical and market compatibility

- Regulation and Load Following at CAISO



Beacon Power Flywheel Model

- Developed by Beacon Power
- Originally was an Excel application
- Implemented in MATLAB by PNNL
- Verified against the original Excel model



Control Algorithm

- Goals and main principles
  - Deliver MW output request to flywheel and hydro unit after obtained control signals from CAISO and BPA
    - Total MW output of flywheel and hydro unit should equal total MW request from both control areas
    - Flywheel is providing regulation down (or regulation up) service
    - Hydro unit is providing regulation up (or regulation down) service
    - Hydro unit is used to maintain the lowest (or the highest) possible SoC on the flywheel
    - The hydro power plant output will be kept as close as practical to the most efficient operating point
    - Dynamic schedules are used to “distribute” the flywheel’s and hydro’s outputs among the control areas

Benefit/Cost Summary of Energy Storage Options for Wind Power Integration

Draft

Performance Parameter	Flywheel*	Hydro
Storage Capacity	20 MW x0.5 hr =10MWh	20 MW x0.5 hr =10MWh
Service Life (yr)	25	40
Capital Cost ($/kWh)	300	10
Annual Benefit ($k)	669	585
Annual Cost ($k)	478	14
Benefit/Cost Ratio	1.40	41.8
Net Present Value ($M)	1.89	6.20

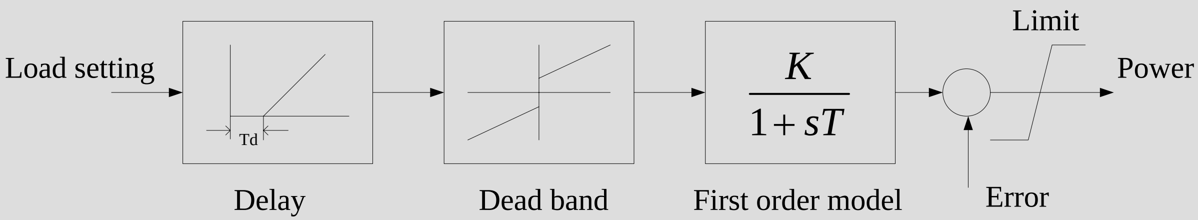
*Based on $8.85/MWh (BPA)

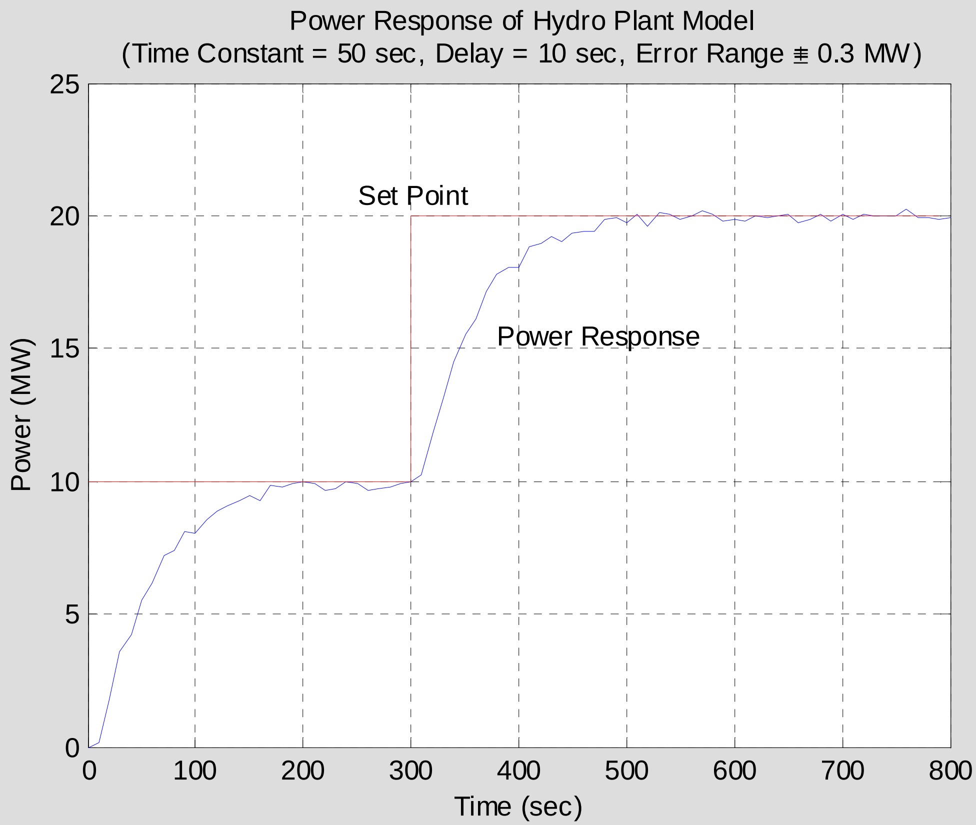
Conclusions

- Wide Area EMS is a feasible and efficient inter-area regulation service
- Stage Gates 1 and 2 of this project are accomplished successfully; some revisions are currently being made to the battery storage analysis
- Stage Gate 2 and 3 are under development; significant progress has been made
- Phase II of the project can be recommended for the next FY
- CEC financial support will be essential for Phase 2

Hydro Power Plant Model

- Developed by PNNL
- Implemented in MATLAB





Formula for Calculating Net Present Value of Energy Storage Options

PV = (AB - AC){[((1 + I)^n - 1)/(1 + I)^n]}

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Where:

PV is net present value ($)
AB is annual benefit ($)
AC is annual cost ($)
I is discount rate
n is life of plant in years

- Annual benefit derives from energy exchanges with the grid valued at BPA ancillary service rates (ACS-08)
- Annual cost consists of levelized cost of capital and O&M (estimated as a percentage of original investment)
- Account taken of technology-specific factors including round-trip charge/discharge efficiency, capital cost, maintenance, repair and life characteristics