Energy Storage Controls for Grid Stability

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Ray Byrne, Ph.D.
Jason Neely, Ph.D.
Cesar Monroy, Ph.D.
David Schoenwald, Ph.D.
*Dan Trudnowski, Ph.D.
*Matt Donnelly, Ph.D.

*Montana Tech University

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Energy Storage Controls for Grid Stability

- Power systems are susceptible to low frequency oscillations caused by generators separated by long transmission lines that oscillate against each other.
- These oscillations are not as well damped as higher frequency “local” oscillations.
- Energy storage-based damping controllers can mitigate these oscillations.

1996 breakup caused by low-frequency oscillations.
Energy Storage Controls for Grid Stability

- There are several low frequency oscillation modes in the Western Electricity Coordinating Council (WECC) region:
  - "North-South" mode nominally near 0.25 Hz;
  - "Alberta-BC" mode nominally near 0.4 Hz;
  - "BC" mode nominally near 0.6 Hz; and,
  - "Montana" mode nominally near 0.8 Hz.

- Researchers at Montana Tech and Bonneville Power Administration (BPA) have investigated damping controls for the WECC.
  - This project builds on their results.

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Damping control basics

\[ \Delta P_1(t) = -K_d(f_1(t) - f_2(t - \delta)) \]
\[ \Delta P_2(t) = -K_d(f_2(t) - f_1(t - \delta)) \]
Project Goals

- Assess storage technologies for the damping control application
  - Develop high fidelity models
  - Perform PSLF simulations to validate performance
- Develop safeguards for the supervisory control system to insure that it can never destabilize the grid
- Develop a pilot project to be deployed in 2013
Damping Control Performance Requirements

- A typical damping control node must meet the following performance requirements:
  - Output power +/- 10MW per device, ~10 total devices
  - Bandwidth to track a $P_{\text{command}}$ signal in the 0.25-1Hz range (real power modulation)
  - Minimal latency

- Previous simulation results from BPA and Montana Tech have shown acceptable performance with a first order system model\(^1\) (bandwidth ~ 3.2 Hz)

\[ \frac{1}{1 + \tau s} \]

\[ \tau = 0.05 \]

Ultra Capacitor System

- High fidelity (12th order) model based on a Maxwell Technologies ultra-capacitor
  - 125V Heavy Transportation Module
  - 1,000,000 charge/discharge cycles
  - 63F, 125V
  - Model accurate to ~10% power dissipated across the ESR
Flywheel System

- High fidelity (14\textsuperscript{th} order) model based on a Beacon flywheel (Smart Energy 25 Flywheel)
  - Parameters were derived from published performance data
Battery System

- High fidelity (14th order) model based on a carbon enhanced valve regulated lead acid battery from East Penn Manufacturing

Performance Validation

- Dynamics are dominated by the control system design (PI of currents in the qd reference frame)
- First order model accurately approximates the higher order system model
- All designs exceed the bandwidth requirements of 3.2 Hz

![Graphs showing gain and phase vs frequency for different models, comparing detailed model and simple models with different time constants.](image-url)
WECC PSLF Simulation Results

\[ k_p = 0.1 \text{ MW/mHz} \]

\[ k_p = 10 \text{ MW/mHz} \]

+/−300MW control nodes at Palo Verde ↔ Coulee
\( f_{\text{dif}} \) measured between Palo Verde ↔ Coulee
2017 Heavy Summer Base Case
Stability Analysis

- Two-area model
- Damping controllers have the form:

\[ P_{D1}(t) = -K_d(\omega_1 - \omega_2(t - T_d)) \]
\[ P_{D2}(t) = -K_d(\omega_2 - \omega_1(t - T_d)) \]

\[ P_{D1}(s) = -K_d(\omega_1(s) - \omega_2(s)e^{-sT_d}) \]
\[ P_{D2}(s) = -K_d(\omega_2(s) - \omega_1(s)e^{-sT_d}) \]
Stability Analysis

- Apply the Nyquist stability criterion to the two-area model
- Specify a relative stability margin
  - Gain margin
  - Phase margin
- ESAC Boundary
- Identify stability regions in (gain, delay) space

Gain Margin = $20 \log_{10} \left( \frac{1}{\alpha} \right)$
Phase Margin = $\Phi_m$ (rad)
Stability Analysis - Results

- ESAC Boundary
  - 3 db gain margin
  - 9 degrees phase margin
- Unstable system (e.g. damping control required)
Accomplishments

- Developed high fidelity models for:
  - Ultra capacitor system
  - Flywheel system
  - Battery system

- Validated damping controller performance in PSLF using a WECC model

- Developed an analytical approach for supervisory control gain scheduling

- A Technology Innovation Proposal to Bonneville Power Administration was accepted for a follow-on demonstration project (co-funded by DOE)
Future Tasks

- Develop battery models for dynamic (e.g. control system) simulations
- Extend supervisory control stability analysis to multi-area systems
- Incorporate additional supervisory control functions
  - Real-time damping monitoring
  - Recommend additional actions in response to contingencies
- Develop methods to apply this technique to the WECC
- Characterize PMU communications latency
- Recommend PMU design standards for control applications
- Proof-of-concept demonstration with BPA
Contact Information

- Ray Byrne, Ph.D.
  email: rhbyrne@sandia.gov
  phone: 505 844-8716