DOE/OE Transmission Reliability Program

Damping Inter-area Oscillations through Decoupled Modulation

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Complex interactions of multiple inter-area oscillation modes

- 0.17 Hz N-S mode
- 0.32 Hz Alberta mode
- 0.5 Hz E-W mode
- 0.55 Hz Montana mode

Credit: Dan Trudnowski
Controller design facing interference between oscillation modes

Modulation Control

![Graph showing Modulation Gain and Damping Ratio for 0.25 Hz and 0.31 Hz](image)

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Problem formulation and objective

• Problem – interference of modes:
  – *Design Issue*: Signal selection is more complex and constrained by signal availability
  – *Design Issue*: Parameter tuning is more limited due to compromises
  – *Operational Issue*: Possibility of adverse impact on damping of one mode while improving damping of another mode

• Objective – minimize interference in modulation control:
  – Develop a modulation control that decouple the modes
  – Enable multiple modulation controllers, one per mode, at the same location

• Opportunities:
  – Wide-area phasor measurements
  – Available HVDC and FACTS devices, e.g. PDCI
Technical approach: decouple mode interference by decoupling signals

- Supported by linear system theory
- Leveraging filtering techniques
- Easier signal selection and parameter tuning
- Less concern about negative operational impact

![Diagram showing signal decoupling process with modes 1, 2, and 3.]
### Accomplished Deliverables in FY15

<table>
<thead>
<tr>
<th>#</th>
<th>Milestone/Deliverable</th>
<th>Target Date</th>
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<tr>
<td>1</td>
<td>Proof-of-concept studies of decoupled modulation control using simulated data with comparison against traditional modulation control.</td>
<td>11/30/2015</td>
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<tr>
<td>2</td>
<td>Development of real-time signal-decoupling methods to separate frequency contents.</td>
<td>2/29/2016</td>
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<tr>
<td>3</td>
<td>Technical report of the design of decoupled modulation control.</td>
<td>5/31/2016</td>
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A real-time signal decoupling approach via band-pass filter

• Idea: to introduce a band-pass filter to allow certain frequency components of an input signal to pass through, to a traditional PSS
  – Goal: to eliminate other frequency components while keeping a small range

• Filter design

\[ F(s) = \frac{\left( \frac{\omega_0}{Q} \right) s}{s^2 + \left( \frac{\omega_0}{Q} \right) s + \omega_0^2} \]

\[ f_0 = \frac{\omega_0}{2\pi} \] is the center pass frequency

\[ Q \] is the quality factor

Performance test

- 2-area 4-machine system
- Two major oscillation modes
  - 0.72 Hz
  - 1.15 Hz

Applying a filter to eliminate the 0.72 Hz mode
An eigen-analysis based approach

• Goal: to extract pure mode(s) from state trajectories

\[ z(t) = u^{-1} \Delta x(t) \]

Here \( \Delta x(t) \) is the system state variables which can be obtained from state estimation; \( z(t) \) is the decoupled modes signals which are the feedback signals in the decoupled modulation control.

• Currently, we are using power system state variables to extract the desired modes

• In future work, we will use available PMU measurements to extract the target modes for decoupled modulation control
Preliminary testing on the 2-area system

- Decoupled modulation

![Diagram showing the movement of eigenvalues before and after decoupled control.](image-url)
Next steps

- Design of decoupled modulation control for PSS, HVDC, and load, based on decoupled signal contents
- Evaluation of decoupled modulation control with small- to medium-size test systems on commercial simulation platforms
- Engage appropriate industry groups (e.g. JSIS) and stakeholders (e.g., BPA)
- Planned activities and schedule

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<th>Task</th>
<th>Description</th>
<th>Duration</th>
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<tr>
<td>1</td>
<td>Design damping control strategies based on decoupled modulation</td>
<td>12 months</td>
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<tr>
<td>2</td>
<td>Extend decoupled modulation based damping control to HVDC networks</td>
<td>12 months</td>
</tr>
<tr>
<td>3</td>
<td>Develop damping-control strategies based on load modulation</td>
<td>12 months</td>
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<tr>
<td>4</td>
<td>Proof-of-concept testing of different damping-control strategies</td>
<td>12 months</td>
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Thanks!

Questions?