Damping Inter-area Oscillations through Decoupled Modulation

presented by

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Inter-area Oscillation Problem

- At a stressed operating condition, a small disturbance may excite the undesirable oscillation modes
  - Local mode: 0.7 ~ 2.0 Hz
  - Inter-area mode: 0.1 ~ 0.7 Hz
- Undamped or underdamped inter-area oscillations can adversely threaten power system security
- Affected by many factors including improperly tuned dynamic parameters like exciters and PSS, system topology, load models, generation schedules, etc.
- If proper control actions are not taken in time, an initiating event could eventually lead to system separation and/or a large scale blackout
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
Professor at Montana Tech
Controller design facing interference between oscillation modes

Modulation Gain

Damping Ratio

- 0.25 Hz
- 0.31 Hz

Modulation Control
Issues identified in wide-area modulation control

- Traditional PSS uses local measurements
  - providing only a limited view of inter-area oscillations
- Inter-area oscillations involve many generator units
  - PSS installed at one generator is not effective
  - Multiple PSSs installed at several generators raise the issue of coordination
- A large-scale power grid usually has multiple oscillation modes
  Controller designed for one mode may adversely affect other modes
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
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

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

- \( f_0 = \omega_0 / 2\pi \) 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

Tie-line flow

- Applying a filter to eliminate the 0.72 Hz mode

Frequency spectrum

Tie-line flow

Frequency spectrum
Two Inter-area modes have very low damping ratio: Alberta mode and BC mode

Alberta Mode: 0.32Hz, 0.5% Damping
BC Mode: 0.64Hz, 1.7% Damping

Decoupled damping control for only BC mode:
Bandpass Filter (center pass frequency 0.6Hz ) + PSS for Generators: 1, 2, 3, 16, 17, 18, 31, 32, 33
Tie-line Power Flow of minniWECC model

Tie-line Flow (One Line) from LV (Bus 57) to LA (Bus 113)

Frequency Spectrum

- 0.32 Hz Alberta Mode
- 0.64 Hz BC Mode

Original Case

Decoupled Control For BC Mode
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

Pure signal $Z(t)$ → PSS → $V_s$

- Locations of eigenvalues before control:
- Locations of eigenvalues after decoupled control:

Movement of the target eigenvalue
Next steps

- Design of decoupled modulation control based on decoupled signal contents on commercial simulation platforms
- Evaluation of decoupled modulation control with small- to medium-size test systems
- Engage appropriate industry groups (e.g. JSIS) and stakeholders (e.g., BPA)
Questions?

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