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Damping Inter-area Oscillations through Decoupled Modulation

presented by

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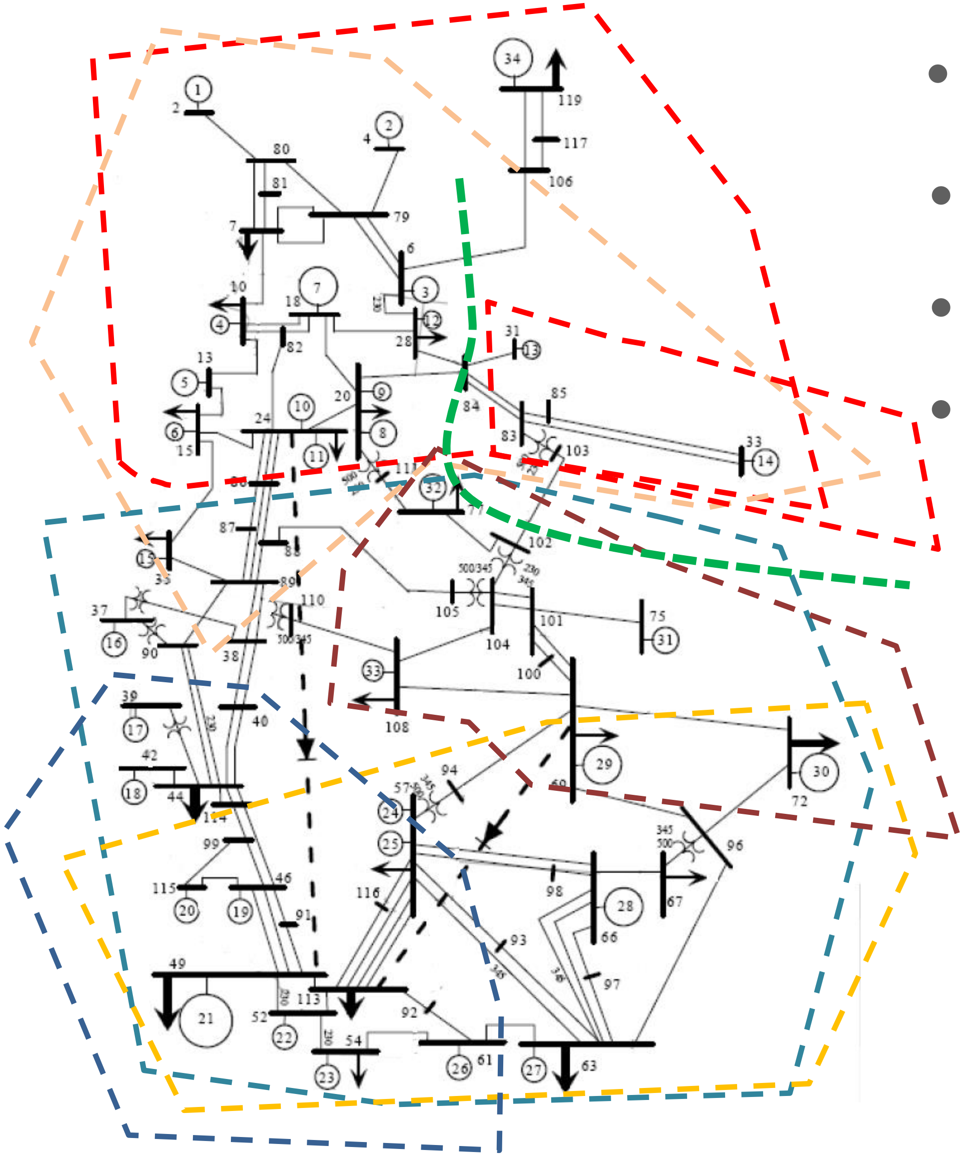
March 24, 2016

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



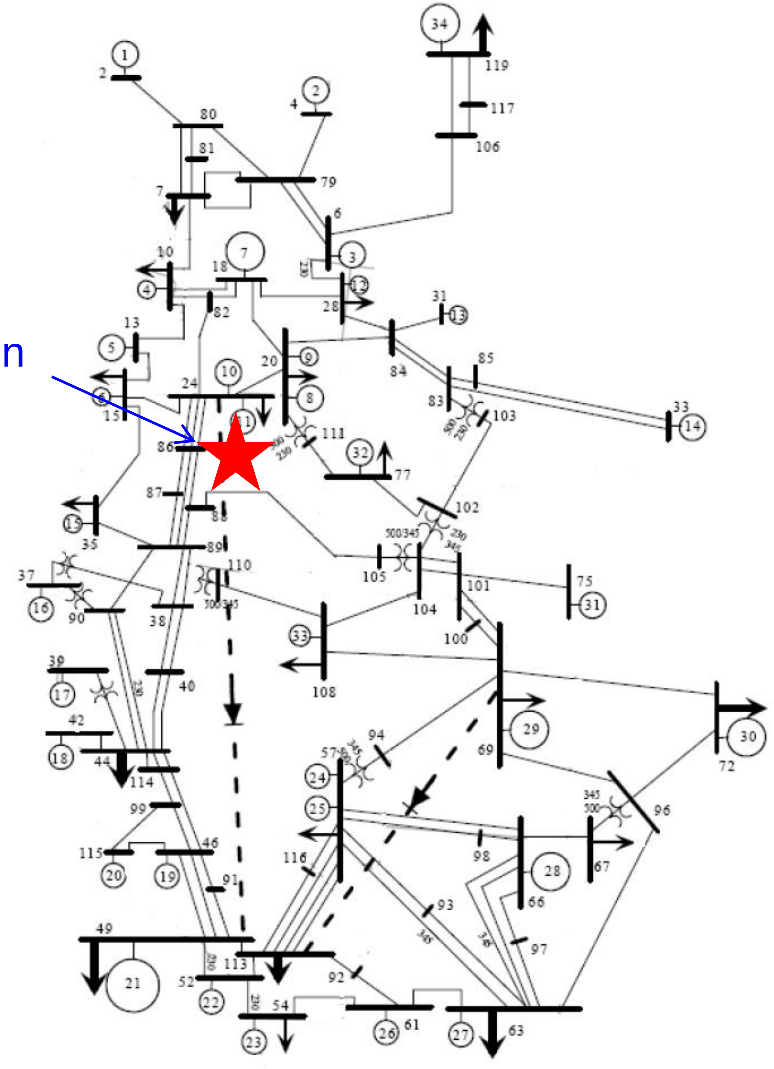
- 0.17 Hz N-S mode
- 0.32 Hz Alberta mode
- 0.5 Hz E-W mode
- 0.55 Hz Montana mode

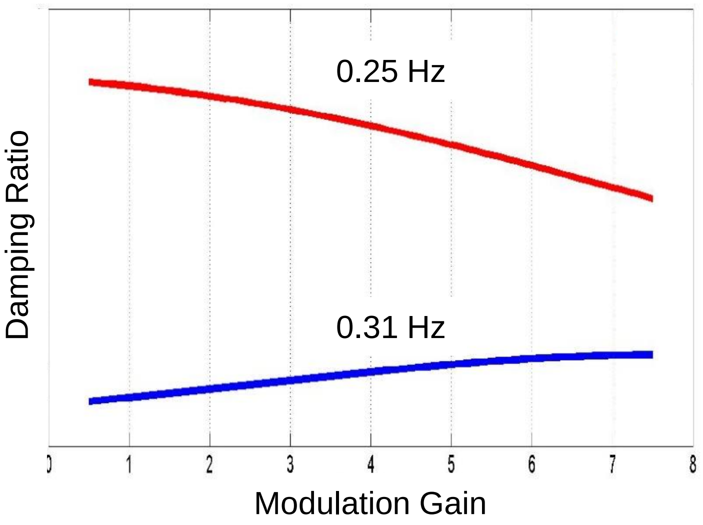
Credit: Dan Trudnowski

Professor at Montana Tech

Controller design facing interference between oscillation modes

Modulation Control





Issues identified in wide-area modulation control

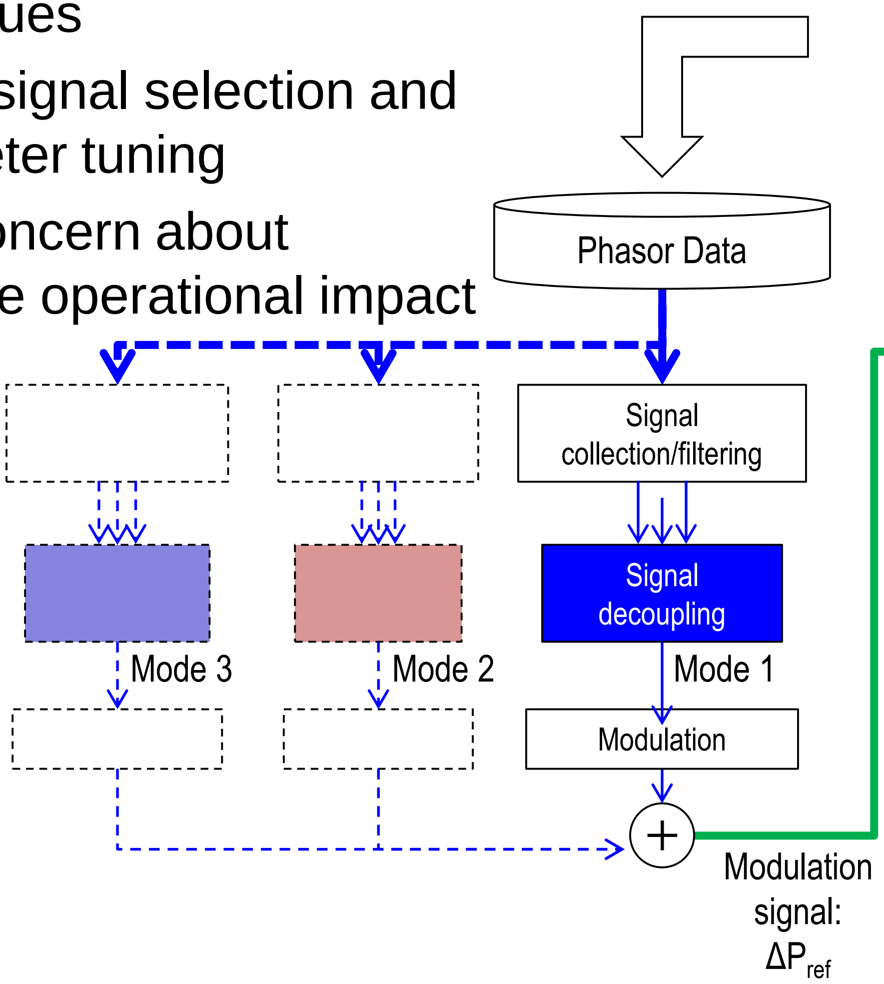
- Traditional PSS uses local measurements
  - providing only a limited view of inter-area oscillations
- Inter-area oscillations involve many generator units
  - PSS installed at one generator is not effective
  - Multiple PSSs installed at several generators raise the issue of coordination
- A large-scale 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


Phasor Data

Signal collection/filtering

Signal decoupling

Mode 1

Mode 2

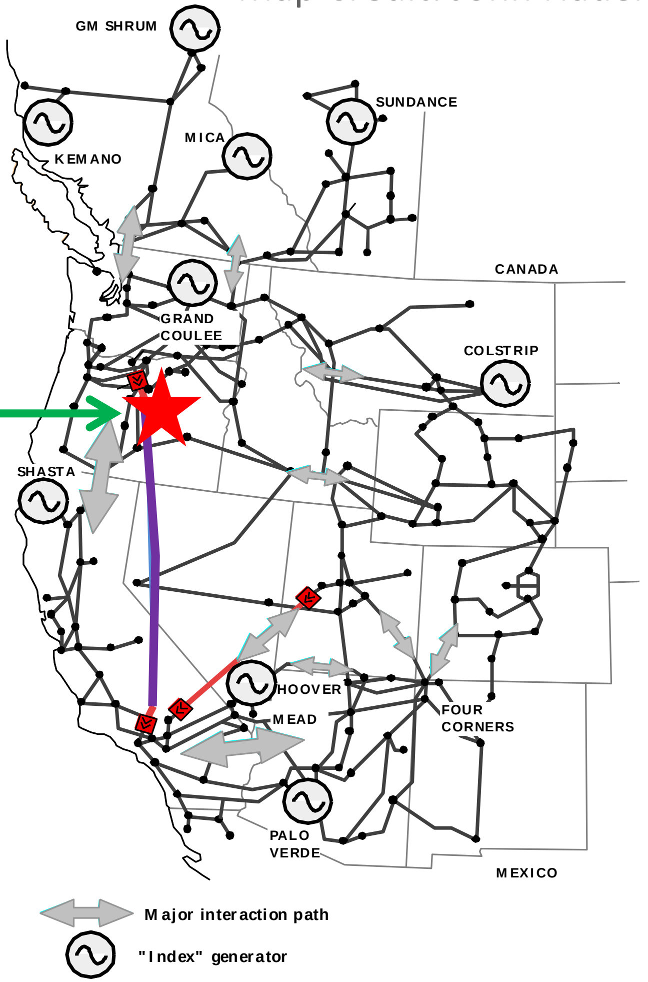
Mode 3

Modulation

+

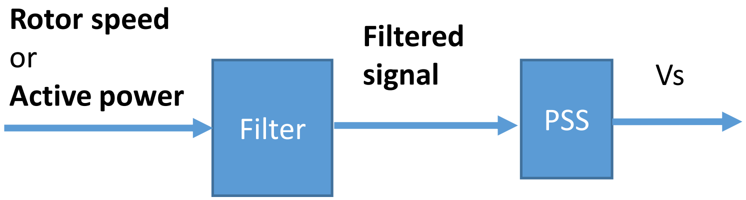
Modulation signal: ΔP_{ref}

Map Credit: John Hauer



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



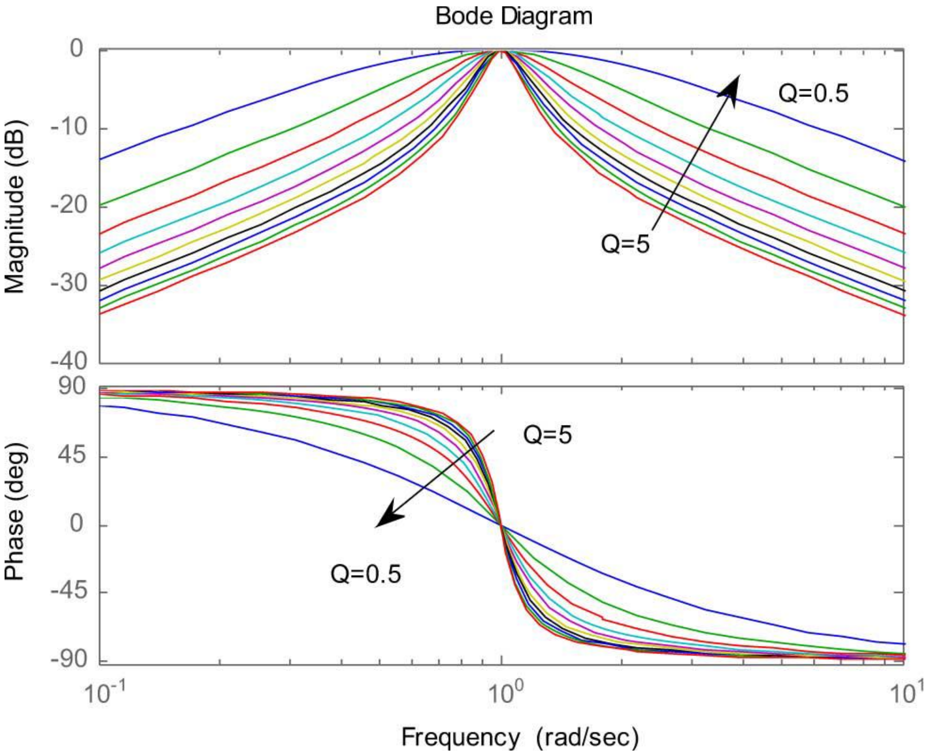
Rotor speed
or
Active power

Filter

Filtered signal

PSS

Vs



- Filter design

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

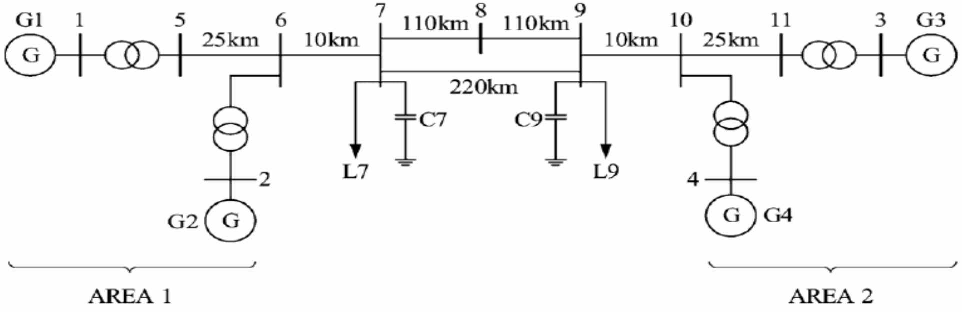
$f_0=\omega_0/2\pi$ is the center pass frequency

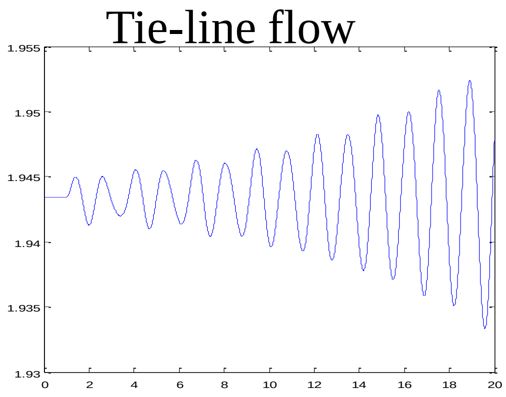
Q is the quality factor

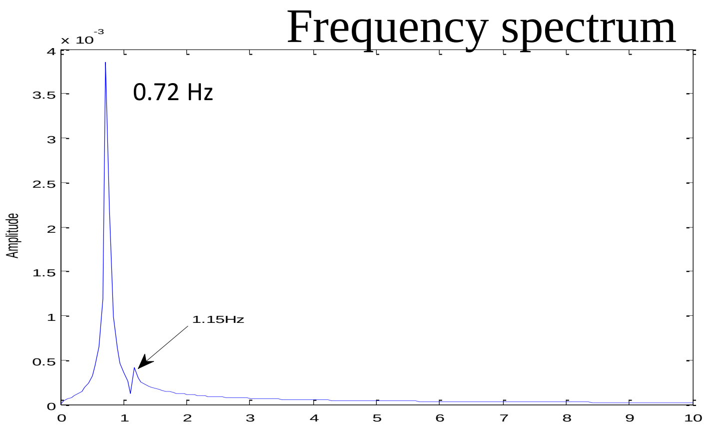
J. Zhang, C. Y. Chung and Y. Han, "N novel modal decomposition control and its application to PSS design for damping interarea oscillation in power system," *IEEE Trans. Power Syst*

Performance test

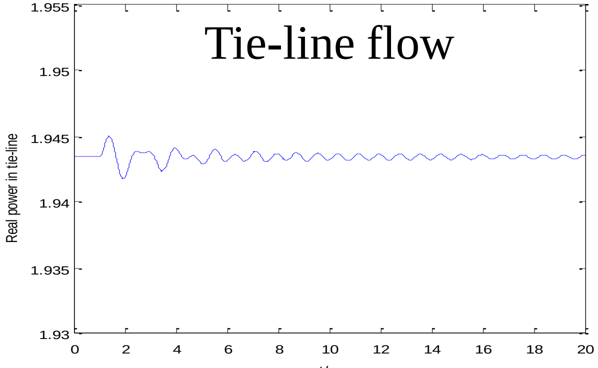
- 2-area 4-machine system
- Two major oscillation modes
  - 0.72 Hz
  - 1.15 Hz

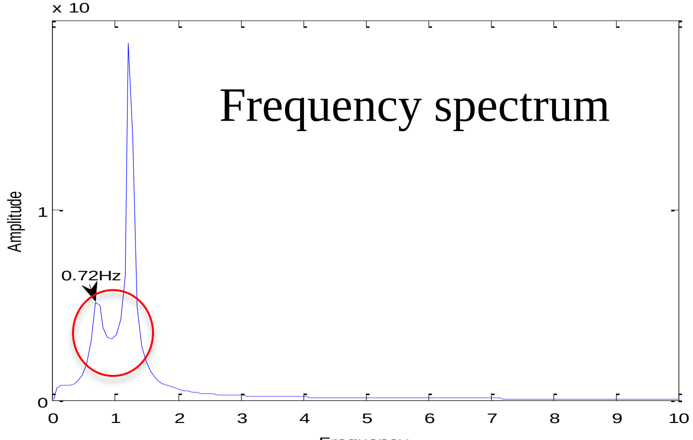






- Applying a filter to eliminate the 0.72 Hz mode

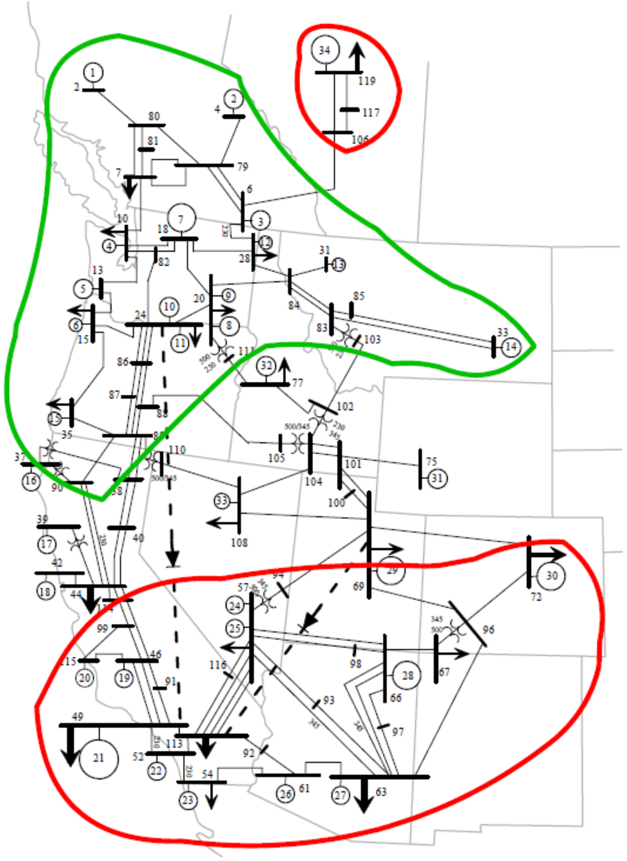




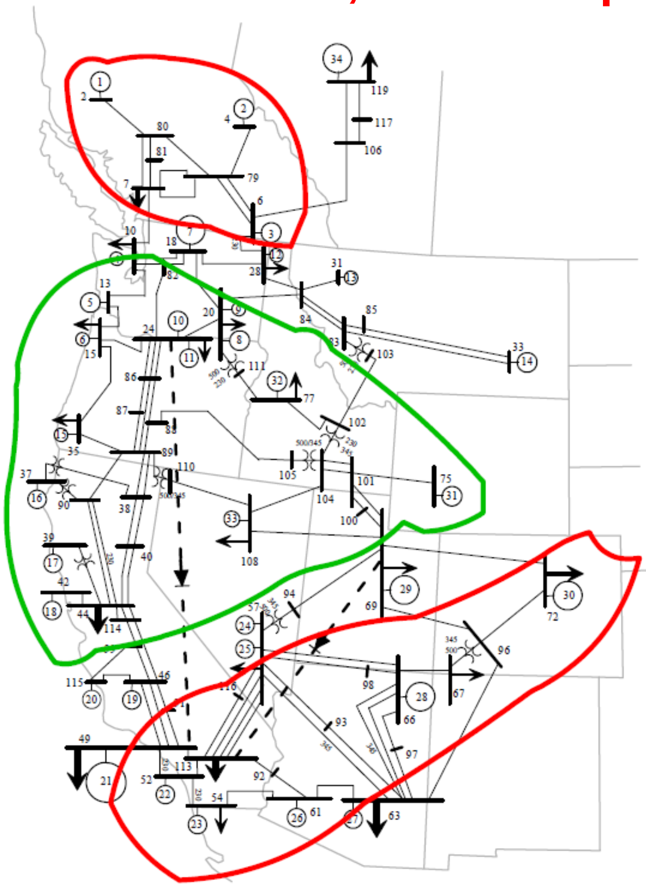
MinniWECC model Test Results

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

Alberta Mode: 0.32Hz, 0.5% Damping



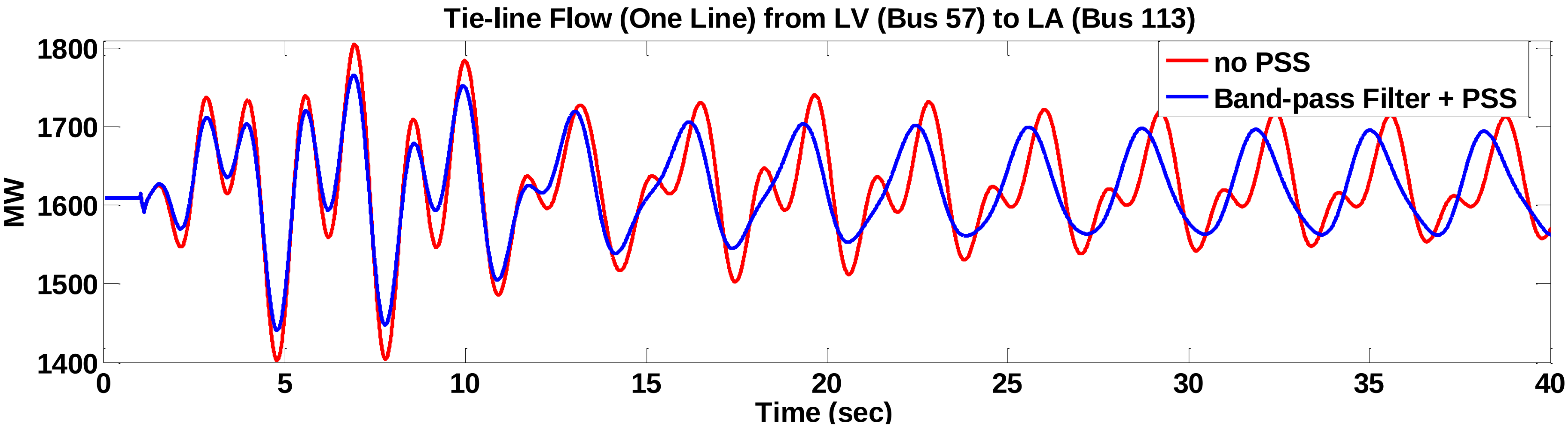
BC Mode: 0.64Hz, 1.7% Damping

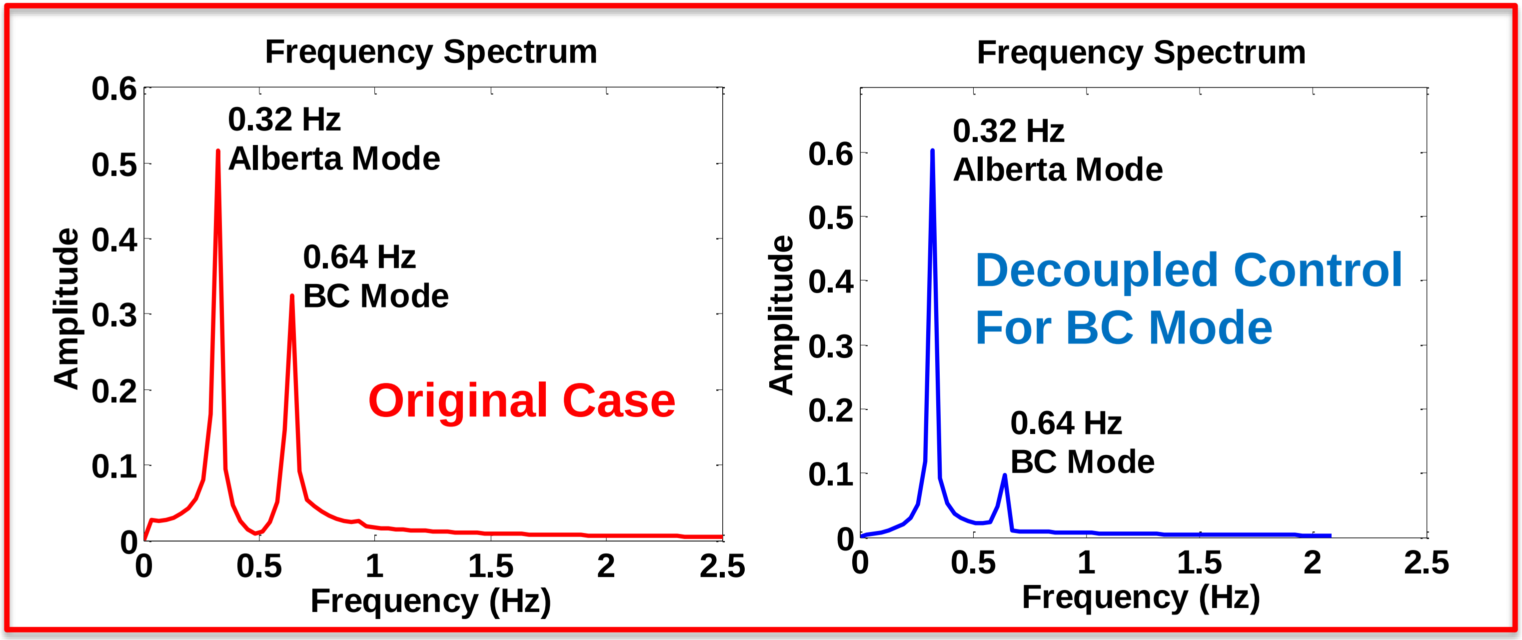


- Decoupled damping control for only BC mode:

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)



Original Case

Decoupled Control For BC Mode

An eigen-analysis based approach

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

$$\mathbf{z}(t) = \boldsymbol{u}^{-1}\Delta\boldsymbol{x}(t)$$

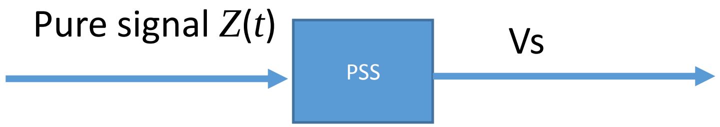
Here $\Delta\boldsymbol{x}(t)$ is the system state variables which can be obtained from state estimation; $\mathbf{z}(t)$ is the decoupled modes signals which are the feedback signals in the decoupled modulation control.

- 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

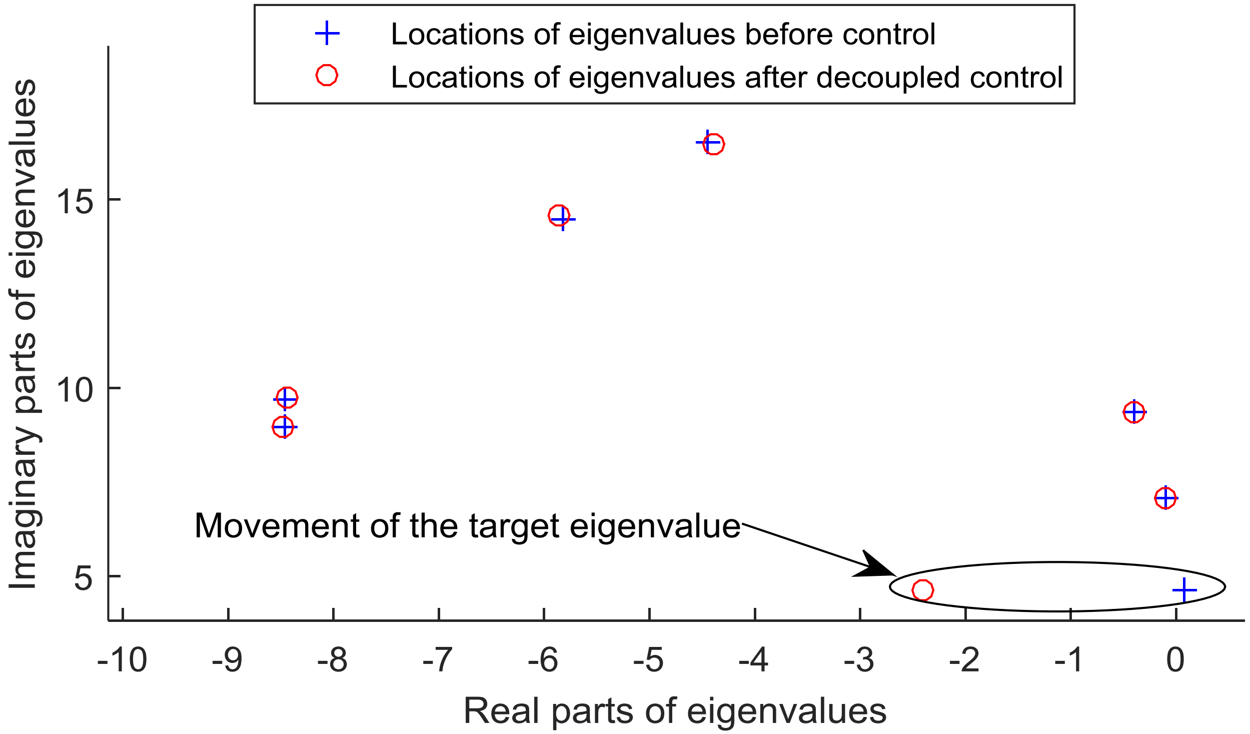
- Decoupled modulation



Pure signal $Z(t)$

PSS

Vs



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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