Inter-area Oscillations in Power Systems

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Introduction

- The power system is operated in a conservative way
- Inter-area oscillations are difficult to detect
- Inter-area oscillations can cause blackouts (e.g., WECC 1996)
- Operation of the system closer to its stability limit saves money (e.g., transmission deferral).
- Loading of transmission paths follow several stability “limits” (e.g., thermal, voltage)
- Inter-area oscillations limits loading of transmission paths (e.g., COI)
What are Inter-area Oscillations?

- Oscillations (modes) in power systems can be divided into:
  - Local modes
    - Oscillations associated with electrically “close” groups of generators.
    - Generally observed at frequencies >1 Hz.
    - Sometimes caused by inadequate tuning of control systems (exciters, HVDC converters, SVCs).
  - Inter-area modes
    - Oscillations associated with the flow of power between “electrically far” areas.
    - Generally observed at frequencies between 0.1-1 Hz.
    - Groups of generators in one area swinging against another group of generators in another area.
    - Occur across weak or heavily loaded transmission paths.

- Local and inter-area modes are small-signal stability issues.
Example of Inter-area Oscillations

- Small 2-area, 4-generators, 6-bus system
- Impedance of lines connecting areas 1 and 2 are approximately 10X higher than intra-area lines.
- PSLF simulation
- Fault at bus 5 (0.1 sec)
Thermal Generation

- **Area 1**
  - Load: 1,000 MW
  - Gen1: 900 MW (1,200 MVA), Gen2: 400 MW (600 MVA), total: 1,300 MW (1,800 MVA)

- **Area 2**
  - Load: 1,500 MW
  - Gen 3: 582.8 MW (1,050 MVA), Gen 4: 650 MW (1,050 MVA), Total: 1,233 MW (2,100 MVA)
Thermal + Wind Generation

- Replace Gen 3 (Area 2) with a type 4 wind farm
- Asynchronous generator connected through power electronics
- No inertia contribution
Simulation Results - Thermal

Generator Speeds - Thermal Generation

- Gen 1
- Gen 2
- Gen 4
- Gen 3

Speed (pu)

t (sec)
Simulation Results – Thermal + Wind

Generator Speeds - Thermal + Wind Generation

- Gen 1
- Gen 2
- Gen 4

Speed (pu)

`t` (sec)
Prony Analysis - Thermal

- Speed Gen 2 – Gen 4

Prony Fit
Case: Thermal system-exp1-G2-G4
Damping = 4.65, f (Hz): 1.03, E/E_{max} = 1.00

Graph showing speed (p.u.) over time (s).
Prony Analysis – Thermal + Wind

- Speeds Gen2 – Gen 4

Prony Fit
Case: Thermal system-exp2-G2-G4
Damping = 6.12, f (Hz): 1.24, E/E_{max} = 1.00

![Graph showing Prony Fit results for Speeds Gen2 – Gen 4 with damping, frequency, and ratio values.]
Prony Analysis - Thermal

- Speed Gen 1 – Gen 4

Prony Fit
Case: Thermal system-exp1-G1-G4
Damping = 4.67, f (Hz): 1.03, \( \frac{E}{E_{\text{max}}} = 1.00 \)
Prony Analysis – Thermal + Wind

- Speeds Gen 1 – Gen 4

Prony Fit
Case: Thermal system-exp2-G1-G4
Damping = 5.97, f (Hz): 1.24, E/E_{max} = 1.00
Inter-area Oscillations in the WECC

- PSLF models of the WECC for several cases were employed
- Small signal disturbance: 1.4GW breaker insertion (Chief Joe) at different buses in the system
- Generator speeds were tracked
- Mode shape was determined using Prony analysis
  - Damping
  - Frequency
  - Phase
- North – South Mode (N – S)
- Alberta – BC Mode (AB – BC)
- Other modes: BC Mode (0.6Hz) and Montana Mode (0.8Hz)
Light Summer 2012

- N – S Mode
- 0.24 Hz
Light Summer 2022

- N – S Mode
- 0.29 Hz
Heavy Winter 2012

- N – S Mode
- 0.24 Hz
Heavy Winter 2022

- N – S Mode
- 0.24 Hz
2012 Light Summer

- AB – BC Mode
- 0.40 Hz
2022 Light Summer

- AB – BC Mode
- 0.47 Hz
2012 Heavy Winter

- AB – BC Mode
- 0.35 Hz
2022 Heavy Winter

- AB – BC Mode
- 0.39 Hz
Mitigation Strategies

- Control of real power injection into the grid at strategic locations
  - Generators
  - Energy storage
  - HVDC converters
- Control of real power flow at strategic branches in the grid
  - FACTS
  - Transmission switching
- Control of reactive power injection into the grid at strategic locations
  - Power electronics based resources (e.g., wind and solar generation)
  - FACTS (e.g., SVCs)
Simulation Results – Thermal + Wind

Generator Speeds - Thermal + Wind Generation

- Gen 1
- Gen 2
- Gen 4

speed (pu)

8 10 12 14 16 18 20 22 24 26 28 30

t (sec)
Thermal + Wind with Droop Ctrl

Generator Speeds - Thermal + Wind Generation

- Gen 1
- Gen 2
- Gen 4

(speed in pu vs. t (sec))
Thermal + Wind with Droop Ctrl and Synthetic Inertia

Generator Speeds - Thermal + Wind Generation

- Gen 1
- Gen 2
- Gen 4

speed (pu) vs. t (sec)
Future Work

- Testing wind controls in the WECC
- Determine adequate levels of droop control and synthetic inertia (tuning of control schemes)
- Determine curtailment level or energy storage size that would allow for implementation of controls
Conclusions

- Results are only as good as the models
- Test on small system indicate that wind has almost no effect on inter-area oscillations
- Increases in renewable generation penetration will change mode shapes in the WECC
- Modes seem to remain well damped, but it could change depending on the location of new renewable plants
- Active power control, using either curtailed wind plants or in combination with energy storage helps reduce inter-area oscillations
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Want to read more...

- *Power System Oscillations* by G. Rogers
- *Power System Stability and Control* by P. Kundur
QUESTIONS

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