Grid Oscillations

Limiting Your Power

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The Grid of The Future
A fundamental transformation

Today’s *Power System
- 6 second view of high voltage over limited area, minimal view of distribution / customers
- Limited distributed generation (DG) and storage
- < 2% intermittent generation
- <5% price responsive loads (relatively crude command systems)
- Centralized generation provides significant inertia to help stabilize the grid
- Relatively low asset utilization of large fractions of the system during most hours of the year
- Conservatively rated to avoid blackouts
- End use relatively simple resistance, predictable
- Managed from supply side
- Multiple control centers and regulatory jurisdictions; often not coordinated
- Increasing cyber threat activity

The Power System of 2020
- Full Smart grid implementation enables 2-way communication to see entire system (G, T, D & EU) in real time (< 1sec) across entire interconnections
- More DG & storage across system
- > 15% renewable (mostly intermittent) generation (net)
- > 15% price responsive demand
- Substantial new high-efficiency loads, hard to predict
- Substantial new demand from electrification of ~25% light duty transportation
- Demand control part of grid management, along with traditional supply side
- Coordinated control and regulatory frameworks
- Inherently resilient to both cyber and infrastructure attack

*Power system (smart grid) includes entire system from centralized generation to transmission(T), and distribution (D), down to consumer loads (EU) and decentralized generation (DG)
CEC Research Develops New Tools to Detect and Mitigate Oscillations

- Build upon prior DOE and BPA research to enable operators to quickly detect dangerous oscillations
  - Extend the mode meter tools developed by DOE and BPA to quickly detect oscillations and alert operators while there is time to respond.
- Provide decision support tools to guide operator actions to mitigate dangerous oscillatory situations
  - Demonstrate DOE research for operator decision support on the California system to test the performance of real-time response decision aids.
Basic Reliability Approach

“*The interconnected power system shall be operated at all times so that general system instability, uncontrolled separation, cascading outages, or voltage collapse will not occur as a result of any single contingency or multiple contingencies of sufficiently high likelihood.*”

WECC Minimum Operating Reliability Criteria

- Otherwise known as “N-1”
- Steady state and transient response
- Achieved by:
  - Generation having sufficient operating reserve, spinning reserve
  - Strict adherence to transfer capacity limits on the transmission grid
    - Determined through comprehensive planning studies
  - Operations discipline, detailed procedures, coordination
  - When all else fails, rely on emergency controls to limit cascading failure (e.g., under-frequency load shedding)
  - If blackout occurs, implement restoration plans (e.g., “Black Start”)
Grid Oscillations -- Types

- **Spontaneous oscillations**
  - weakened or overstressed transmission
  - maltuned controller(s)
  - defective sensor or other hardware

- **Forced oscillations**
  - incomplete separation of asynchronous areas
  - defective sensor or other hardware
  - system test in progress

- **Transient oscillations**
  - tripping of major line or facility
  - discrete controller action
  - system test in progress

Map showing:
- Alberta: 0.45 Hz
- North – South: 0.25-0.3 Hz
- East-West: 0.6-0.7 Hz
- California – Desert Southwest: 0.5 Hz

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Understanding Oscillation “Damping”

1. Damping Ratio = 10%
2. Damping Ratio = 3%
3. Damping Ratio = 0%
4. Damping Ratio = -1%

Each graph shows the oscillation behavior at different damping ratios. The graphs illustrate how the amplitude decreases over time as the damping ratio increases, with a more pronounced decay at higher damping ratios.
Example of Dynamic Stability

- Marginally-Damped Loading
- 50 MW Additional Import

Bus Voltage Magnitude (pu) vs. Seconds
Example of Spontaneous Oscillation

Spontaneous Oscillations on the Pacific AC Intertie, August 2, 1974
Example of Forced Oscillation

Produced by feedback controller on IPP HVDC line, March 6, 1987
Lessons Learned from August 10, 1996

Data captured from Wide Area Measurement System (WAMS) was essential to support the blackout investigation.

The need for better model validation was demonstrated.

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“Ringdown” Graphical User Interface

Tool for advanced dynamic analysis

Extracting a linear model from measured data

• Dynamic analysis
• Model validation
• Control design
Stability Assessment and Blackout Prevention

- **Today:** no real-time monitoring of oscillatory stability
- **Tomorrow:** real-time monitoring of oscillatory signatures – frequency and damping ratio – using advanced signal processing techniques
- **Future:** real-time wide-area decision support to prevent oscillations using eigenvalue sensitivity analysis

- Damping Ratio: 1% → 7%

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Time Domain

- Power (MW)
- California-Oregon Intertie
- August 10, 1996 Western Power System Breakup
- Early Warning ~6 minutes
- Damping Ratio
  - ~ 8.4%
  - < ~3.5%
  - ~3.1%

Freq Domain

- ~ -3.1%
- < ~3.5%
- ~8.4%

- Generation
  - ~320 MW
  - +300 MW
  - +320 MW
  - -480 MW
  - -430 MW

- Load
  - +300 MW
  - -480 MW
Prior Work: Real Time Mode Identification

Application of oscillation “mode meter” on historical measurements taken from the August 10, 1996 blackout. Also available as an on-line tool to characterize the damping in near real time.

Credit: U.S. Department of Energy and the Bonneville Power Administration
CEC Research for Rapid Oscillation Detection

- Use multiple indices signal-noise ratio, oscillation energy, and prediction error for fast and robustness oscillation detection.
- Provide operators with rapid detection of dangerous oscillations

Mode estimation by R3LS mode meter algorithm, off-line study, oscillation detection and analysis.

Recorded real power flow from Malin to Round Mountain (Reference time: Aug 10th, 1996, 15:35:30 Pacific Daylight Time)
Modal Analysis for Grid Operations (MANGO)

Stage 1: Manual (Operator-in-the-loop)
- Generation re-dispatch
- Load shedding
- Capacitor switching

Stage 2: Automatic (beyond scope)

Operation Procedures

MANGO Model

Target Modes (damping)

Real-Time Phasor and SCADA Measurements

Parameter Selector

Power Grid

Mode Meter
- Mode Estimation
- Mode Shape Estimation

Modes and Mode Shapes

MANGO

Recommended Actions

Operation Parameters

Feasibility Test

Power Flow and Dynamic Models

Key Operation Parameters

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Damping Control through Tie-line Flow Adjustment Using Generator Pairs

Damping improves from 1.3% to 4.1%

DC offset removed for clarity

Relative Modal Sensitivity

MW Line flow from bus 106 to 6 (3 pu)

Dampening improves from 1.3% to 4.1%
Conclusions

- Oscillations limit the flow of electricity in the western power system.
- Measurement-based oscillation detection methods can detect lightly damped conditions.
- Studies have shown that oscillation damping can be effectively controlled by making changes to generation dispatch settings.
- CEC investments have leveraged U.S. Department of Energy and Bonneville Power Administration investment.
- When implemented by power system operators, oscillation detection and mitigation should help to maximize asset utilization and improve power transfer capability in the western power system.
Future Work (proposed)

- Pilot testing of the oscillation detection tool on the California ISO system
- Understand topology change impact on oscillation modes
- Study interaction among multiple modes
- Further exploration of smart grid technologies (e.g., intelligent demand response, smart chargers for plug-in electric vehicles, etc.)