Precursor Signals of Cascading Outages based on Visualization of PMU Data

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Outline

• Objective:
  – Prediction of Potential Cascading Outages

• Idea & Methodology:
  – Recognizing Precursor Signals
  – Visualizing PMU-based Vulnerability Indices

• Case Study
  – WECC System

• Conclusions
Can simulation-based DSA predict potential cascading outages?

- Shortcomings of simulation-based DSA
  - Limited fault scenarios
  - SCADA systems cannot capture real-time changes of generation or load
  - State estimators may fail to converge
  - High computation burdens of time domain simulations
  - May not work for cascading with successive events
Any precursor signals?

- Abnormal values
- Abnormal behaviors
- PMUs can find them
Abnormal Behaviors in Phase-Space Visualization

Human can tell them easily thru proper visualizations

Stable generator

Abnormal behavior (marginally stable generator)

Unstable generator
How to use PMUs to find precursor signals?

• Define vulnerability indices, computable in real time by PMU data (e.g. $V_i$, $\theta_i$ and $P_{ij}$)
  – Transient Stability Index:
    • Approximate inter-area potential energy
  – Voltage Stability Index:
    • Weighted average of critical bus voltages
  – Small-Signal Stability Index:
    • Damping ratio

• Visualize the indices:
  – To recognize precursor signals of instability
  – To study different stability issues during cascading
PMU-based DSA Scheme

- Define vulnerability indices
- Offline study precursor signals from visualizations of the indices

Real-time recognize precursor signals

Tell operators
Case Studies: WECC

- **Inter-area behaviors:**
  - 2 PMUs in two areas
  - 1 PMU at the interface

- **Scenario-1: 6 faults**
  - Every 5s, add a 3φ fault and trip the line
  - Instability after the 6th trip

- **Scenario-2: scheduled line outages**
  - Every 30s, remove a line
  - Instability after the 6th line is removed

Figure 5.7: WSCC 179-bus model
Scenario 1: six three-phase faults
Transient Stability Index

Graph showing transients stability index over time (t in seconds). The graph includes:
- Upper limit
- Stability margin
- Index

The graph illustrates the variation of these indices over a period of 30 seconds.
Transient Stability Index in Phase Space

Abnormal pattern after the 5th fault
Voltage Stability Index
Phase-space Snapshots of Voltage Stability Index

After fault 1 \((t=0 \sim 5\text{s})\)

After fault 2 \((t=5 \sim 10\text{s})\)

After fault 3 \((t=10 \sim 15\text{s})\)

After fault 4 \((t=15 \sim 20\text{s})\)

After fault 5 \((t=20 \sim 25\text{s})\)

After fault 6 \((t=25 \sim 30\text{s})\)
Transient Stability vs. Voltage Stability

Transient stability Margin

Voltage stability margin

Abnormal pattern after Fault-5

Security region
Scenario 2: six scheduled line outages
• A security region exists
• Precursor signal: the curve going outside of the region
• The boundary of the region can be studied offline
3D Visualization

Security region

Damping

Transient stability margin

Voltage stability margin
Conclusions

• Precursor signals of cascading do exist
  1. Abnormal dynamic patterns in phase space
  2. Abnormal values (going outside of a security region)
• Vulnerability indices can be used in real-time monitoring
  – Easy to be calculated (by only PMU data)
• Vulnerability indices can be used in offline studies
  – Useful for studying different stability issues in cascading
• A measurement-based monitoring tool
  – A complementary scheme of simulation-based DSA
Q&A

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