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Precursor Signals of Cascading Outages based on Visualization of PMU Data

**NASPI Working Group Meeting
October 16-17, 2008**

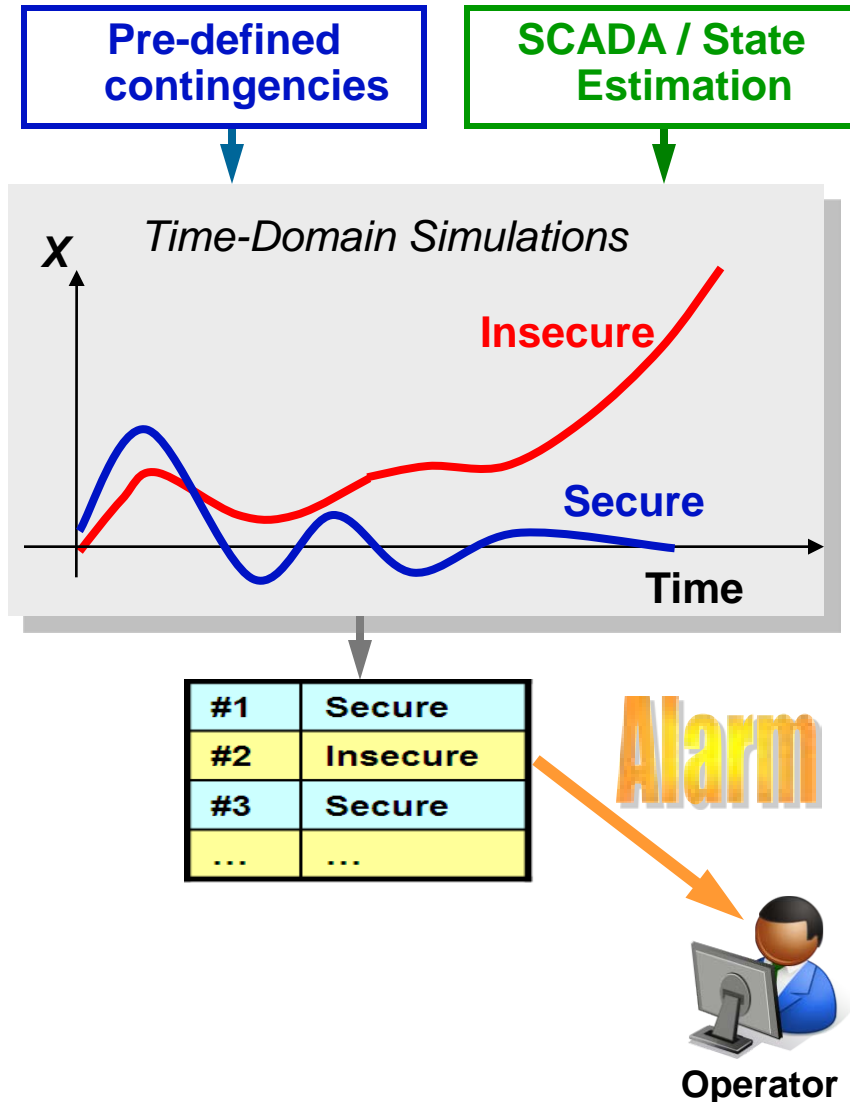
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Senior Technical Executive
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Project Manager



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?



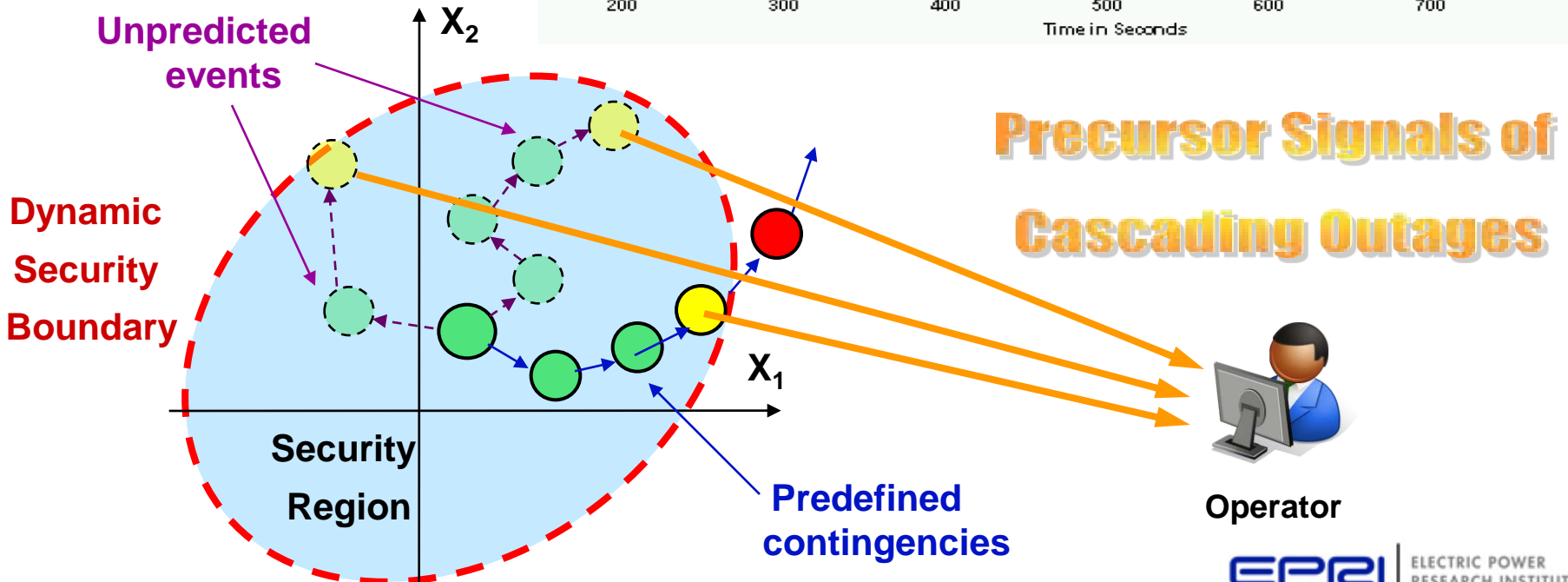
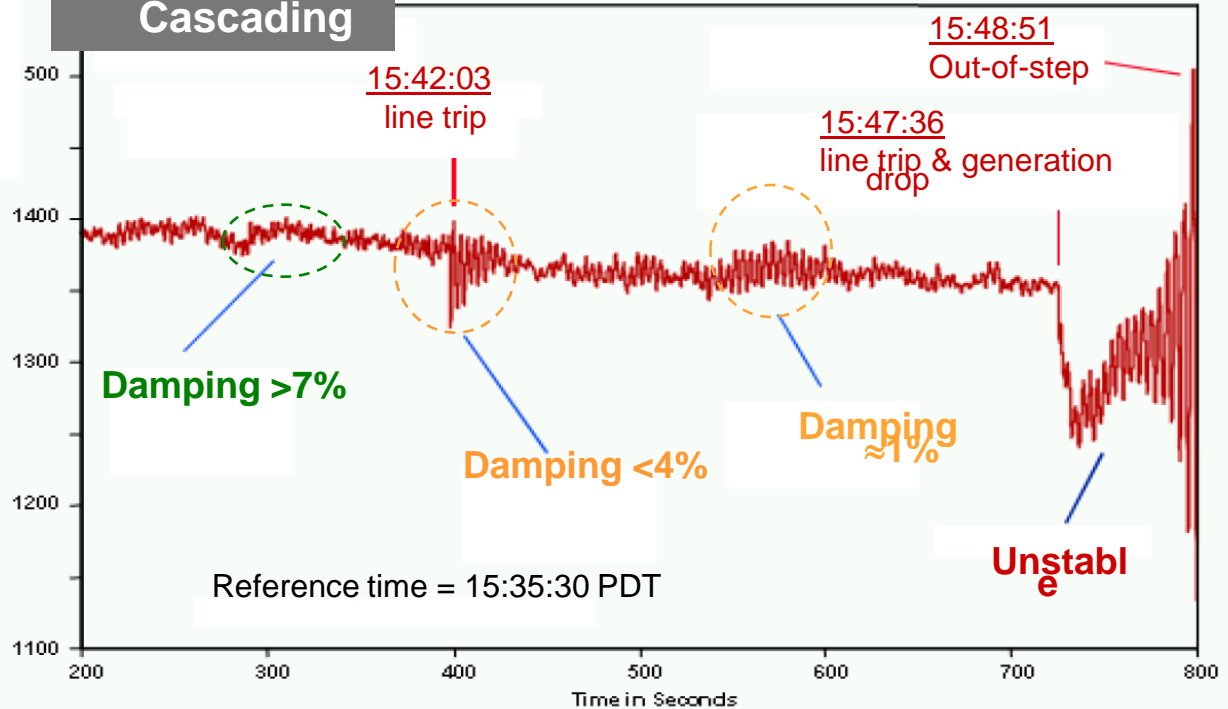
- Shortcomings of simulation-based DSA
 - Limited fault scenarios
 - SCADA systems cannot capture real-time changes of generation or load
 - State estimators may fail to converge
 - High computation burdens of time domain simulations
 - May not work for cascading with successive events

Any precursor signals?

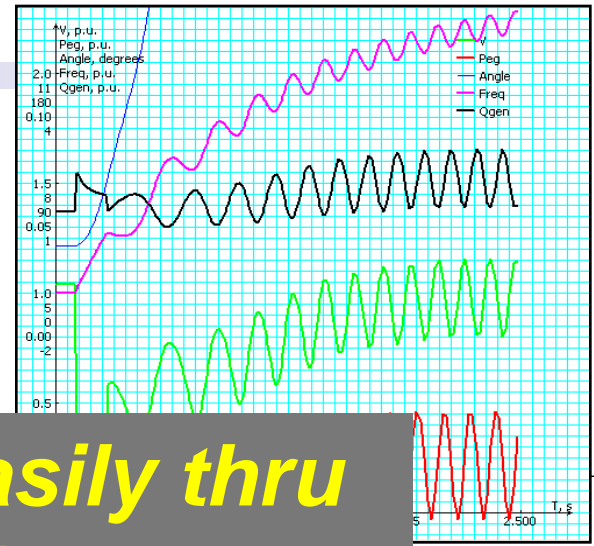
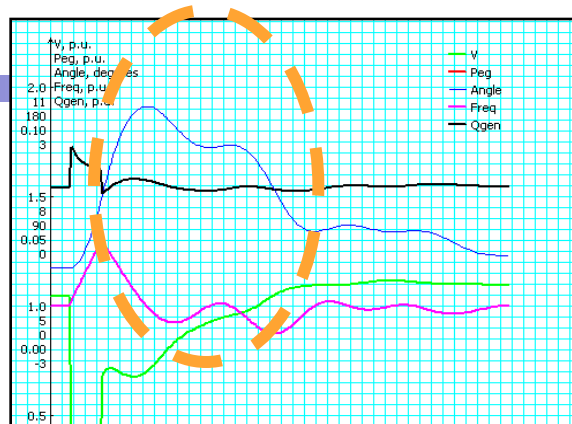
- Abnormal values
- Abnormal behaviors
- PMUs can find them

1996 WSCC Cascading

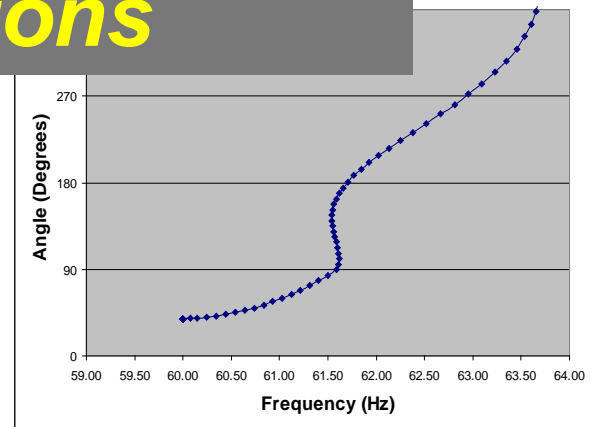
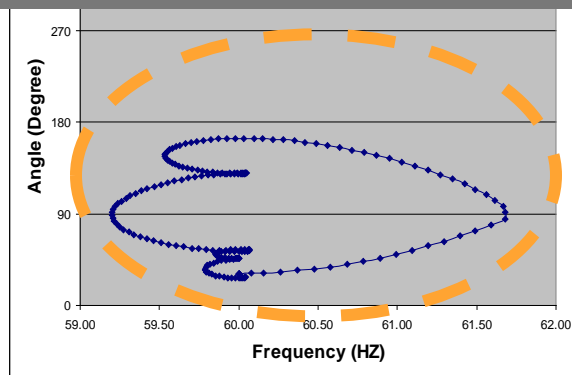
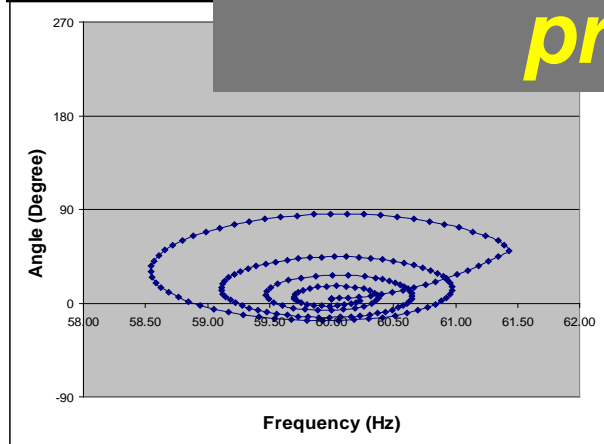
Malin - Round Mountain #1 (MW)



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?

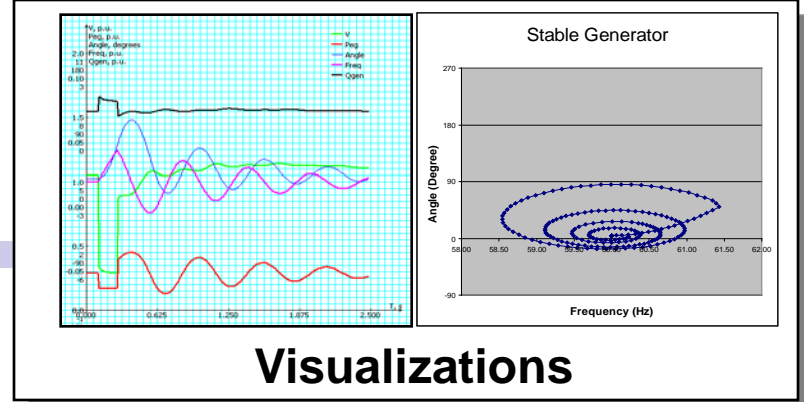
- Define vulnerability indices, computable in real time by PMU data (e.g. V_i , θ_i and P_{ij})
 - **Transient Stability Index:**
 - Approximate inter-area potential energy
 - **Voltage Stability Index:**
 - Weighted average of critical bus voltages
 - **Small-Signal Stability Index:**
 - Damping ratio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

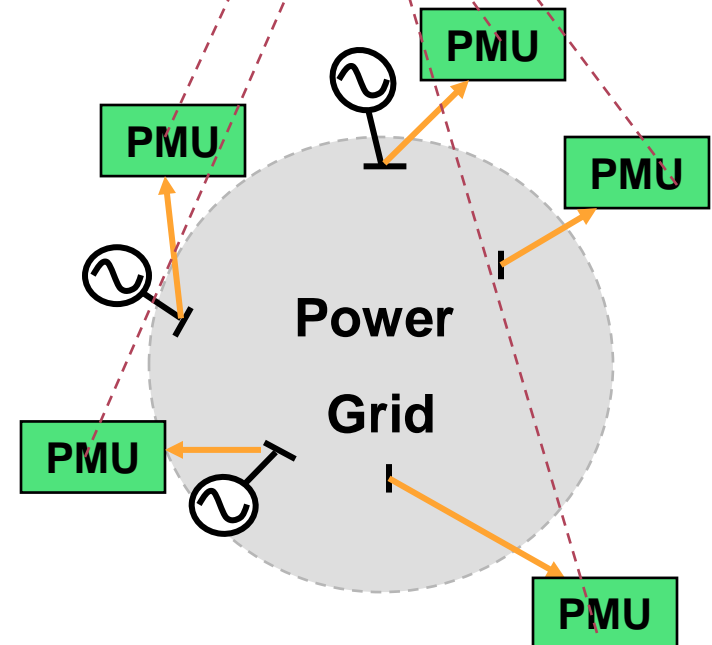
Real-time recognize precursor signals

Tell operators



Vulnerability indices

Real time PMU data
(measurement-based)



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

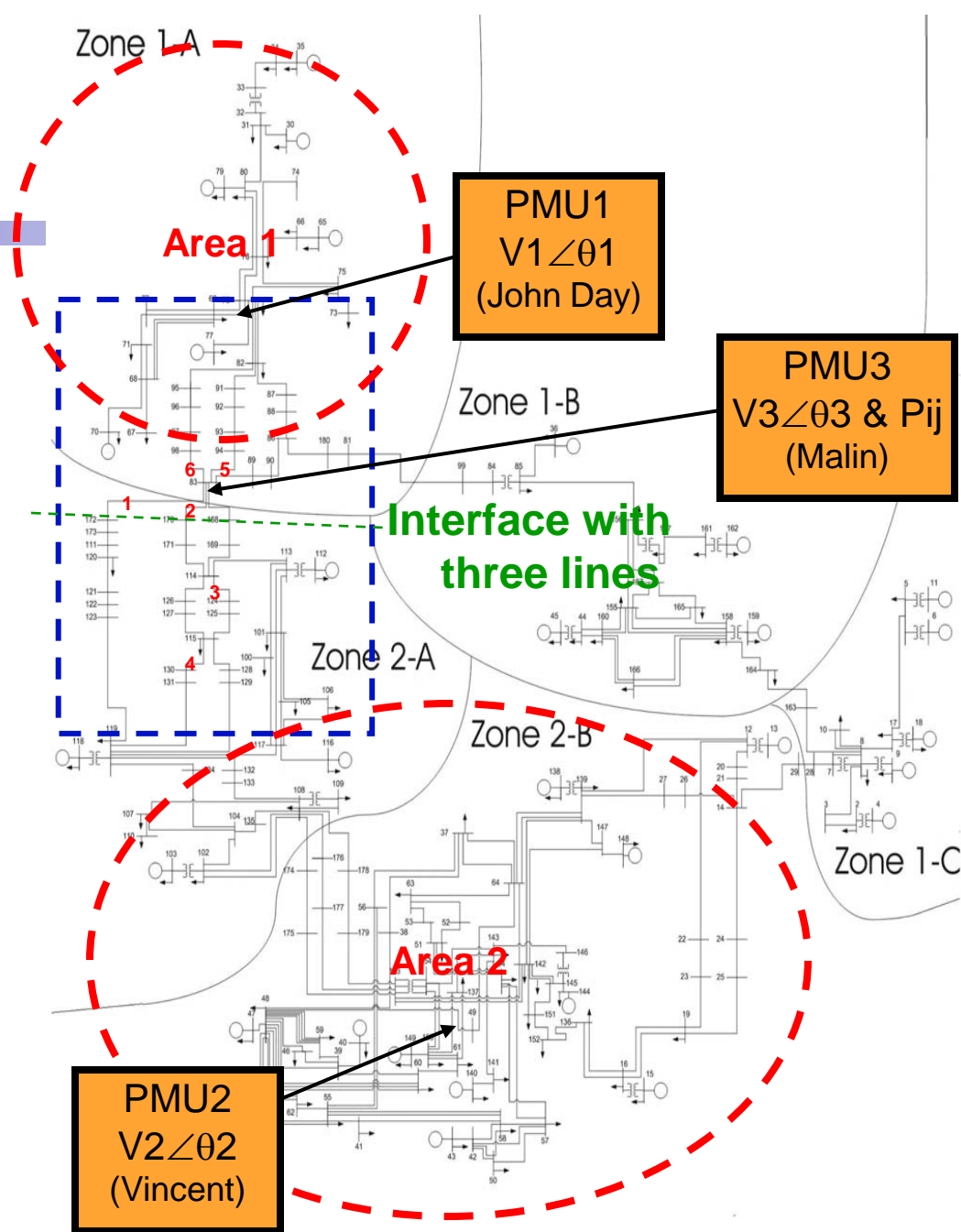
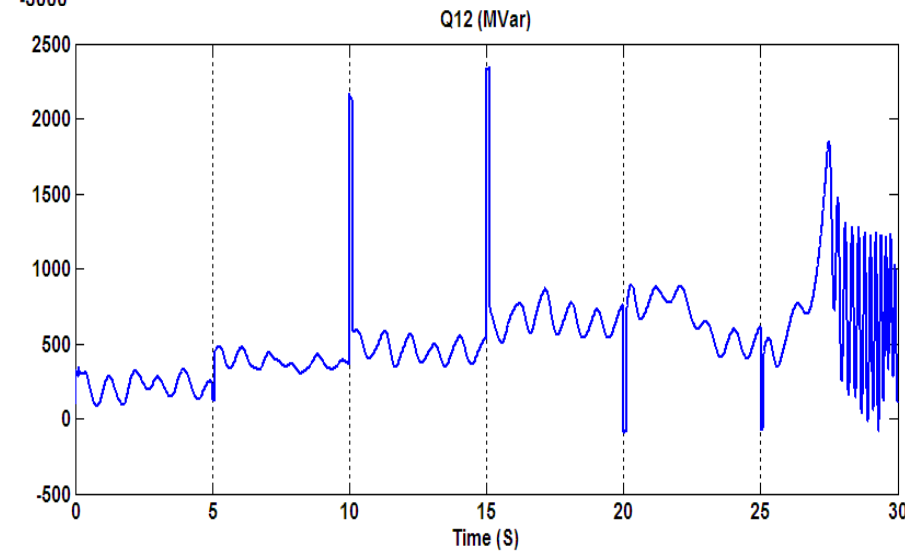
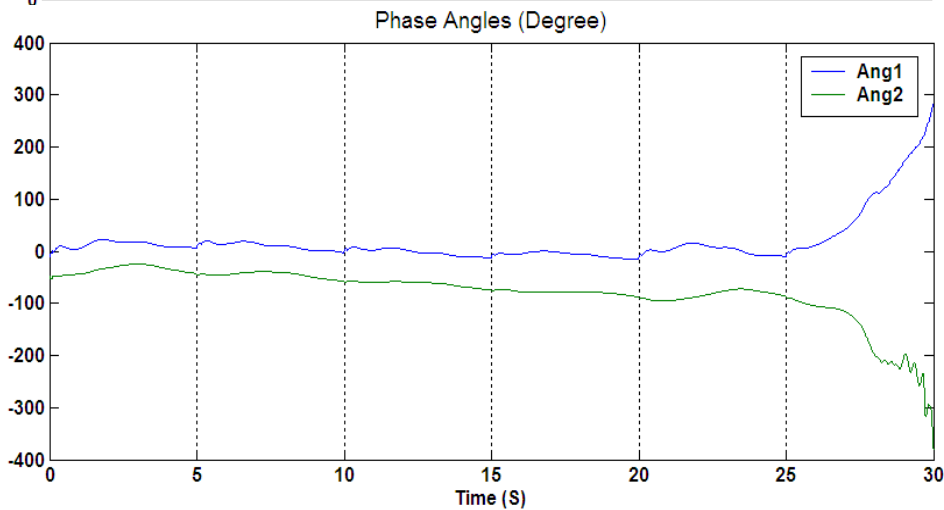
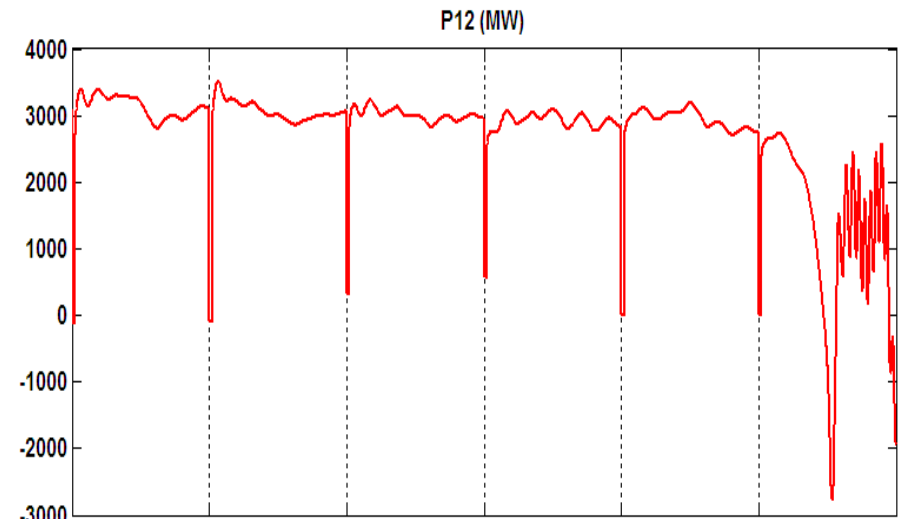
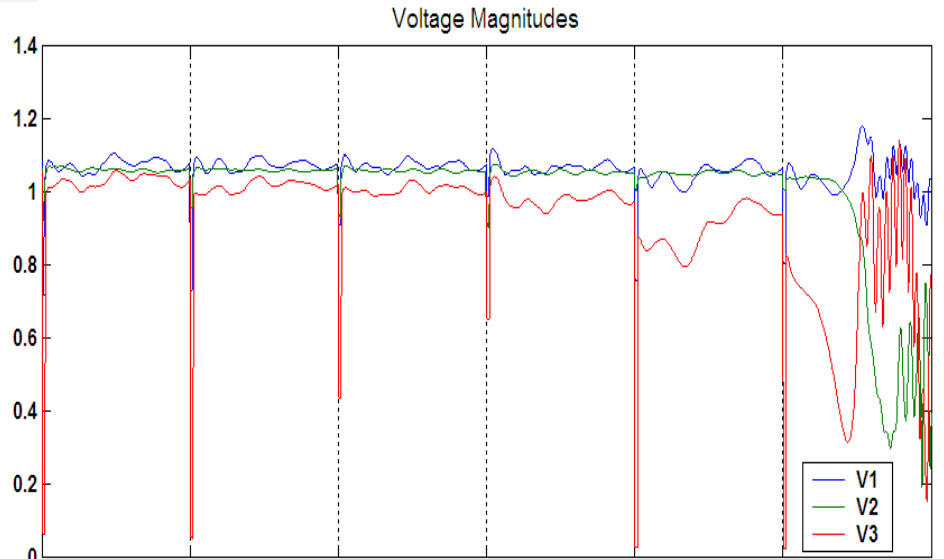
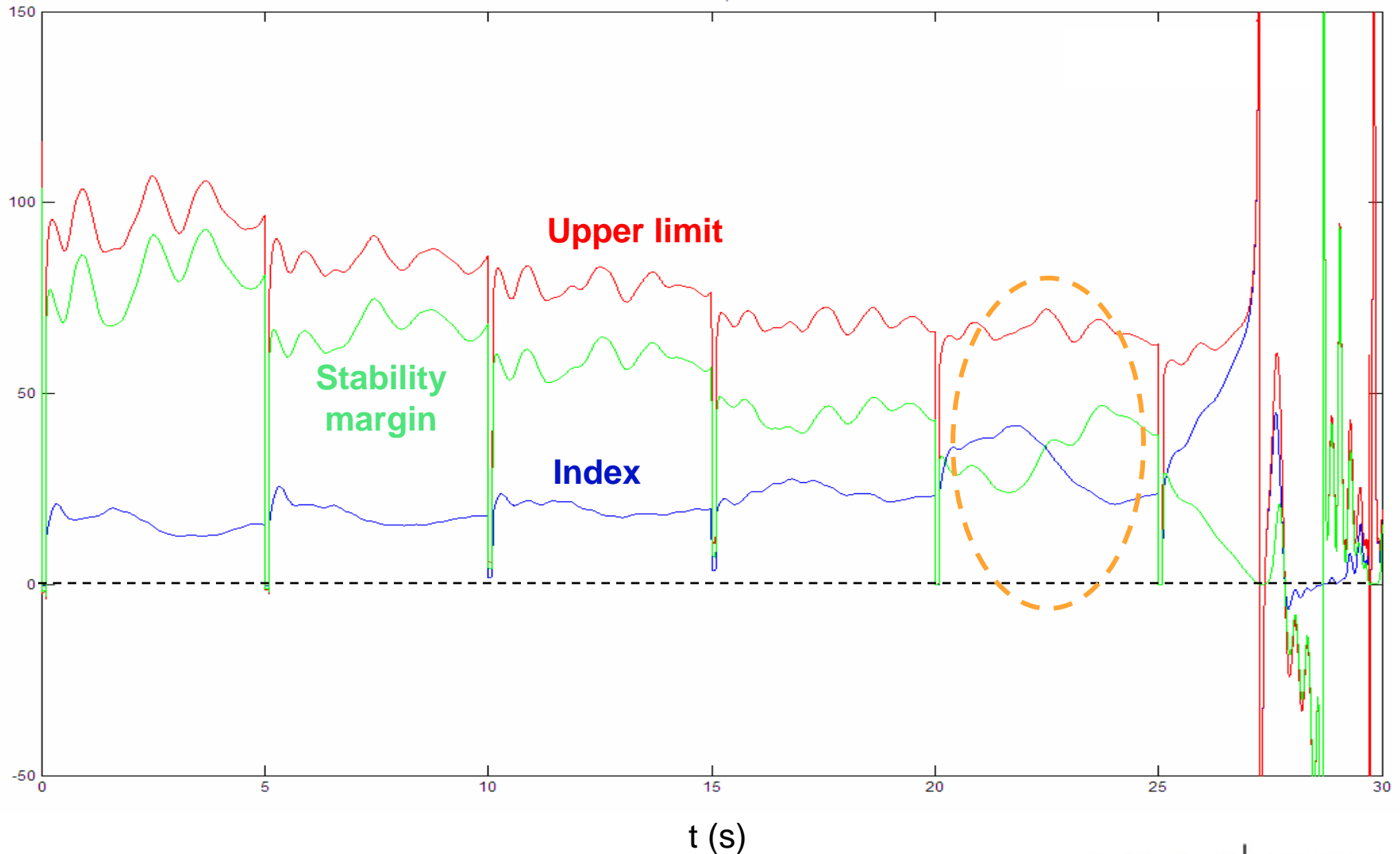


Figure 5.7: WSCC 179-bus model

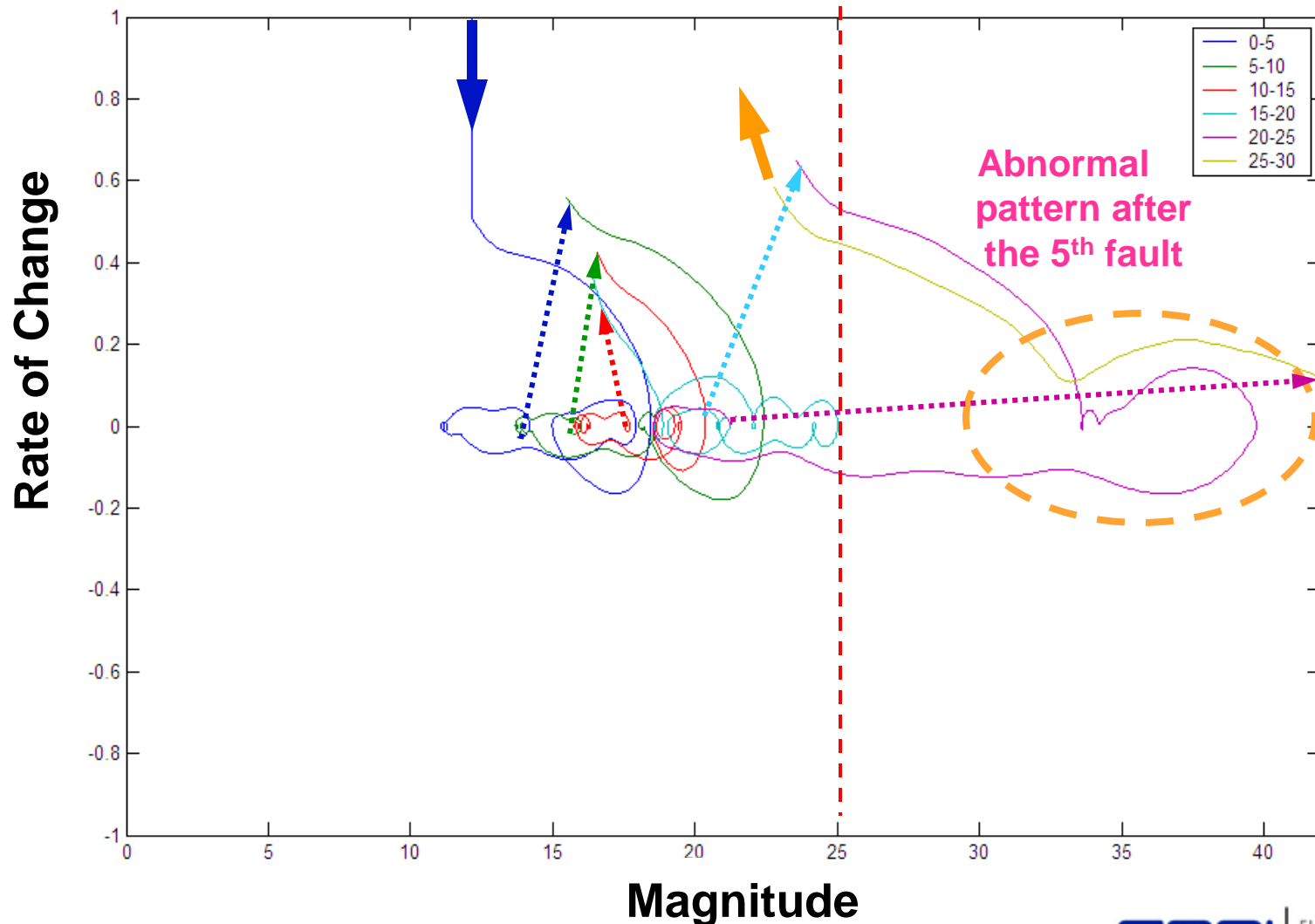
Scenario 1: six three-phase faults



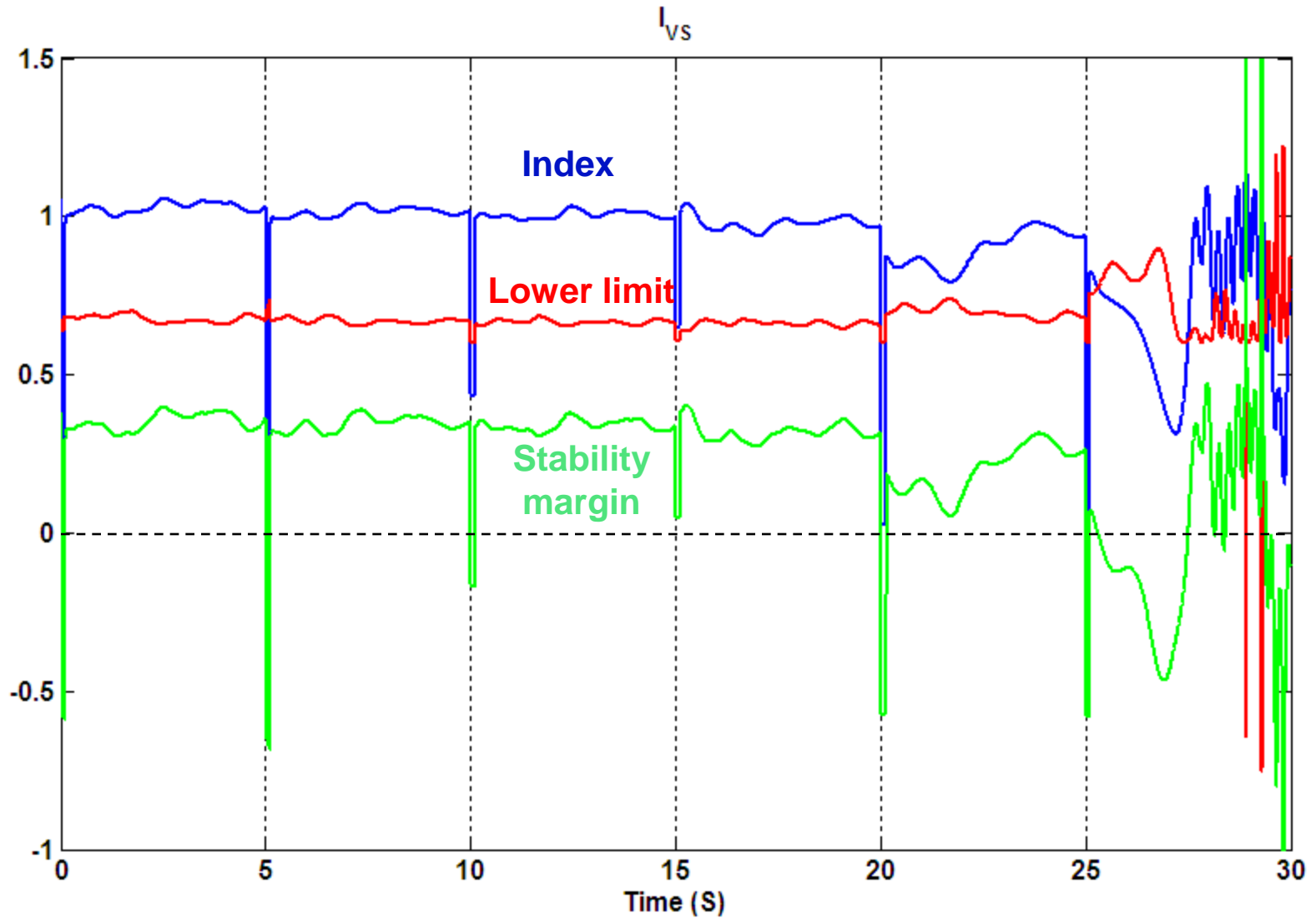
Transient Stability Index



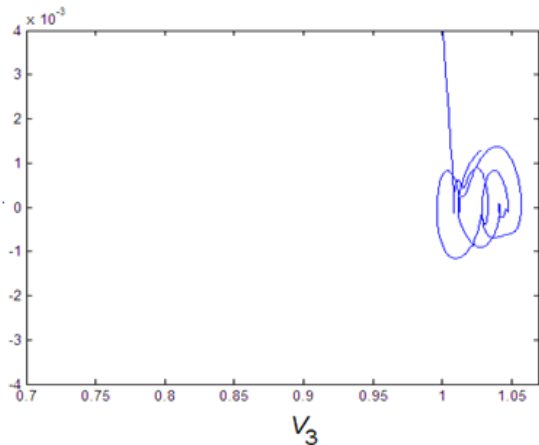
Transient Stability Index in Phase Space



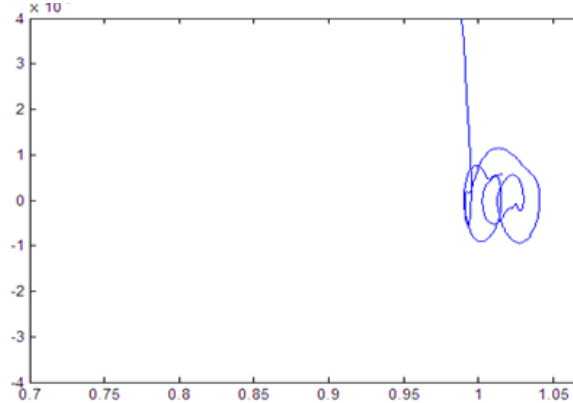
Voltage Stability Index



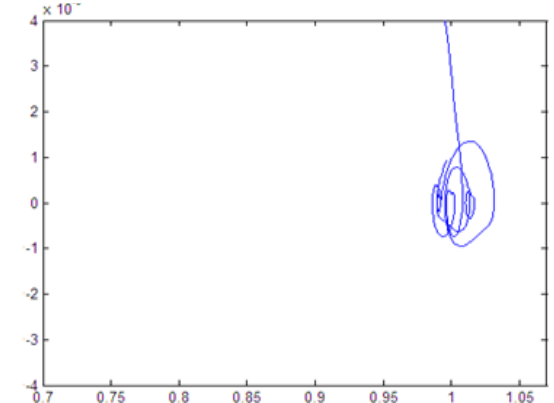
Phase-space Snapshots of Voltage Stability Index



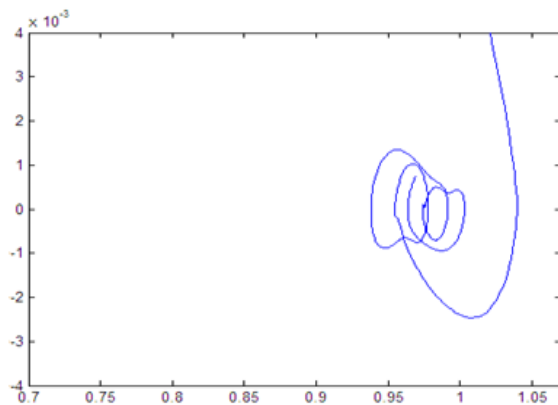
After fault 1 ($t=0\sim 5s$)



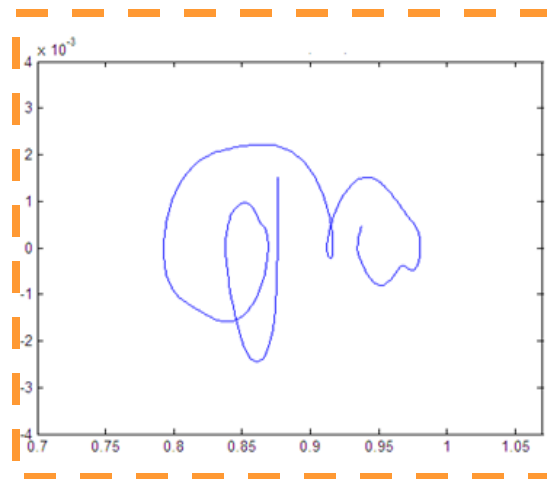
After fault 2 ($t=5\sim 10s$)



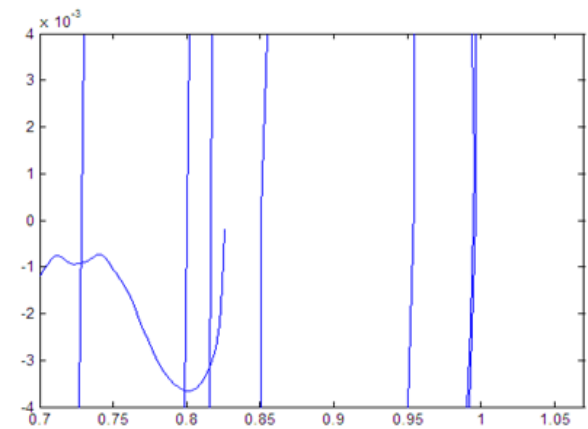
After fault 3 ($t=10\sim 15s$)



After fault 4 ($t=15\sim 20s$)

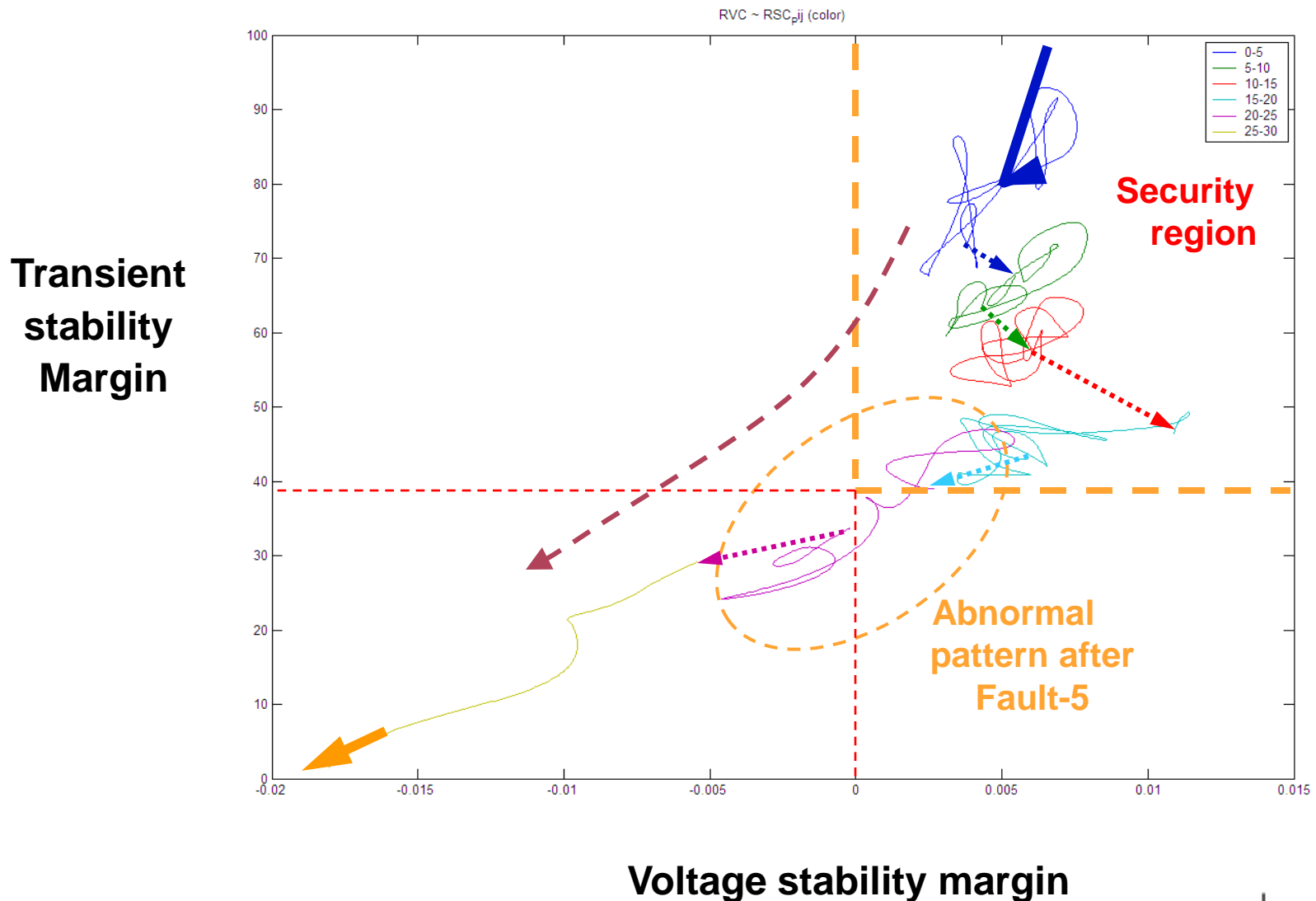


After fault 5 ($t=20\sim 25s$)

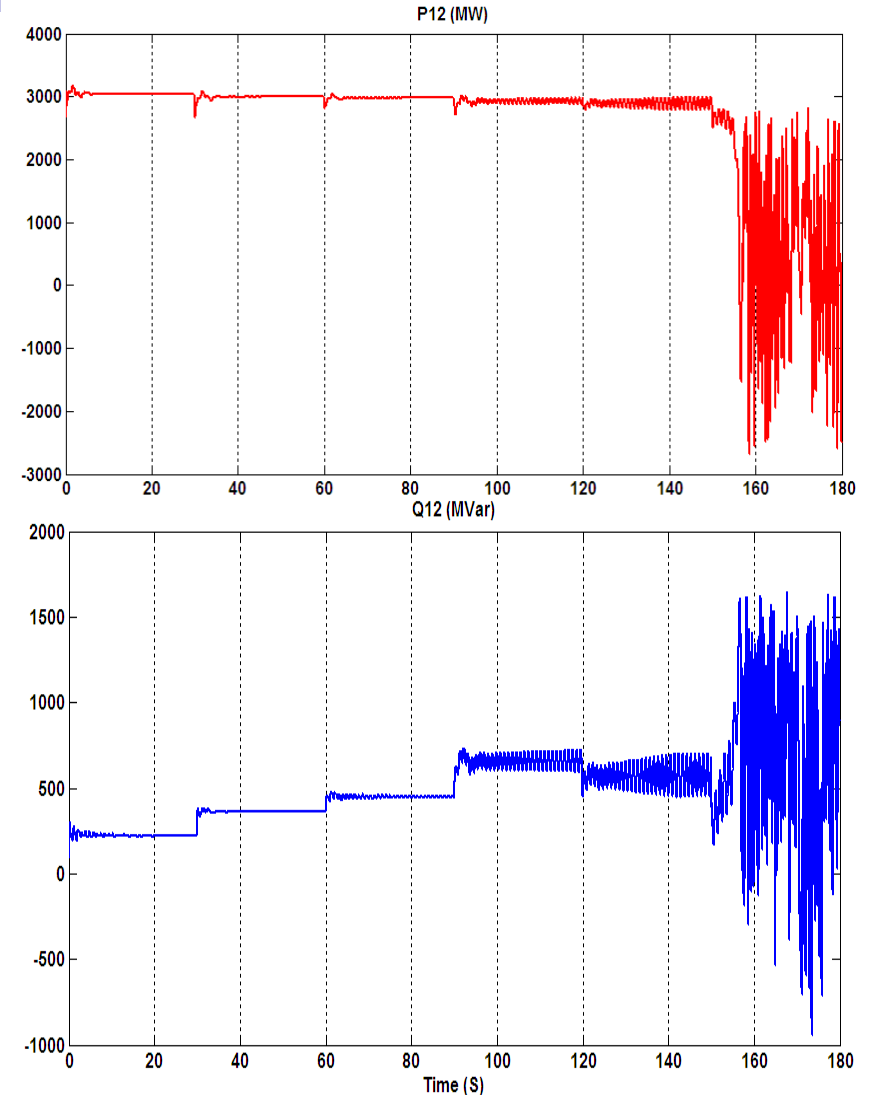
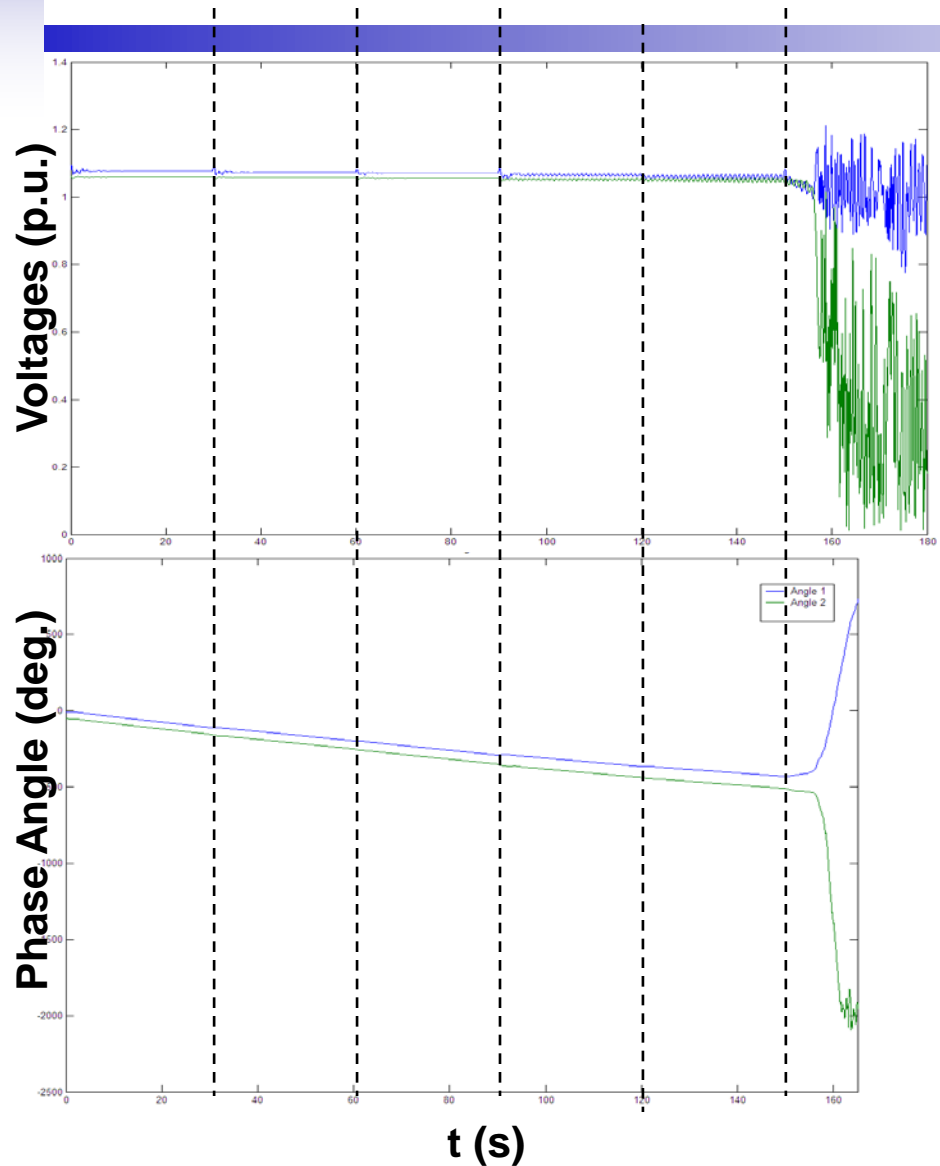


After fault 6 ($t=25\sim 30s$)

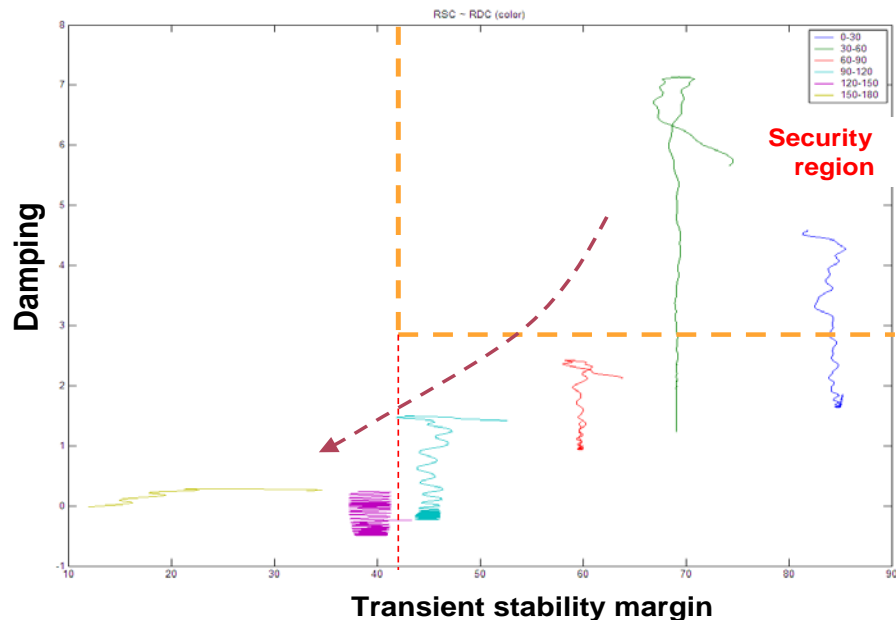
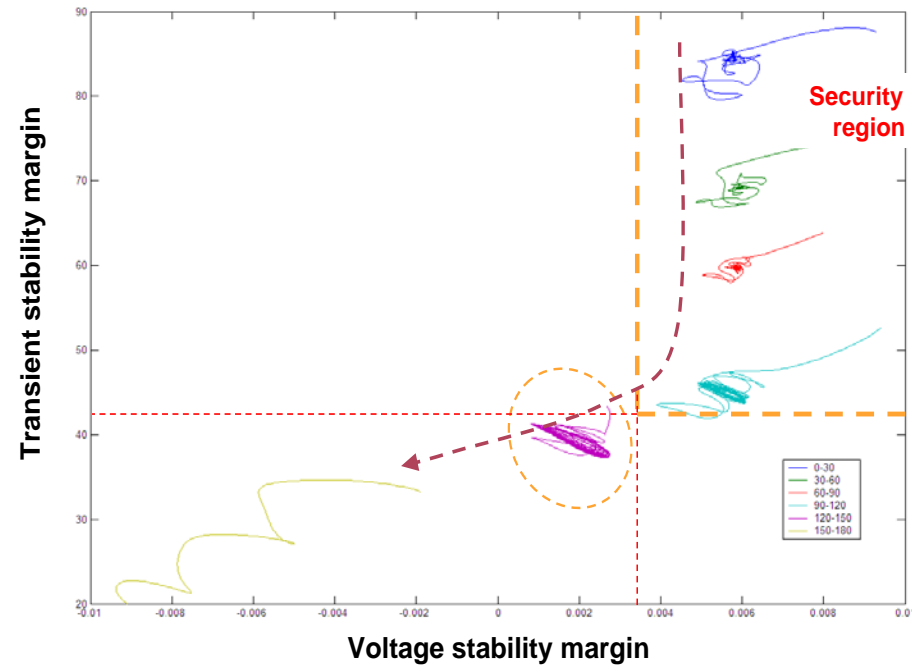
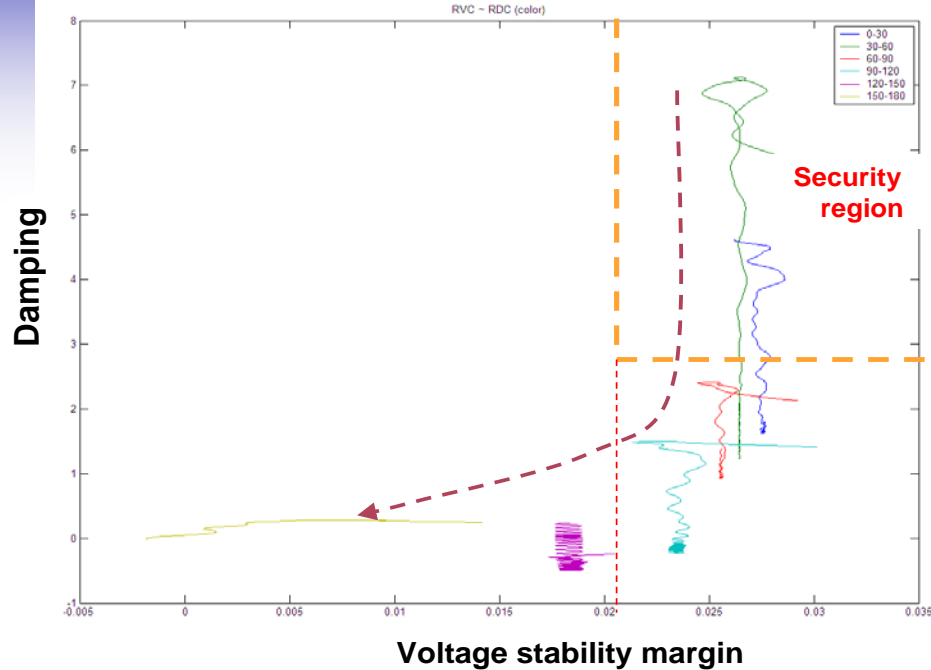
Transient Stability vs. Voltage Stability



Scenario 2: six scheduled line outages

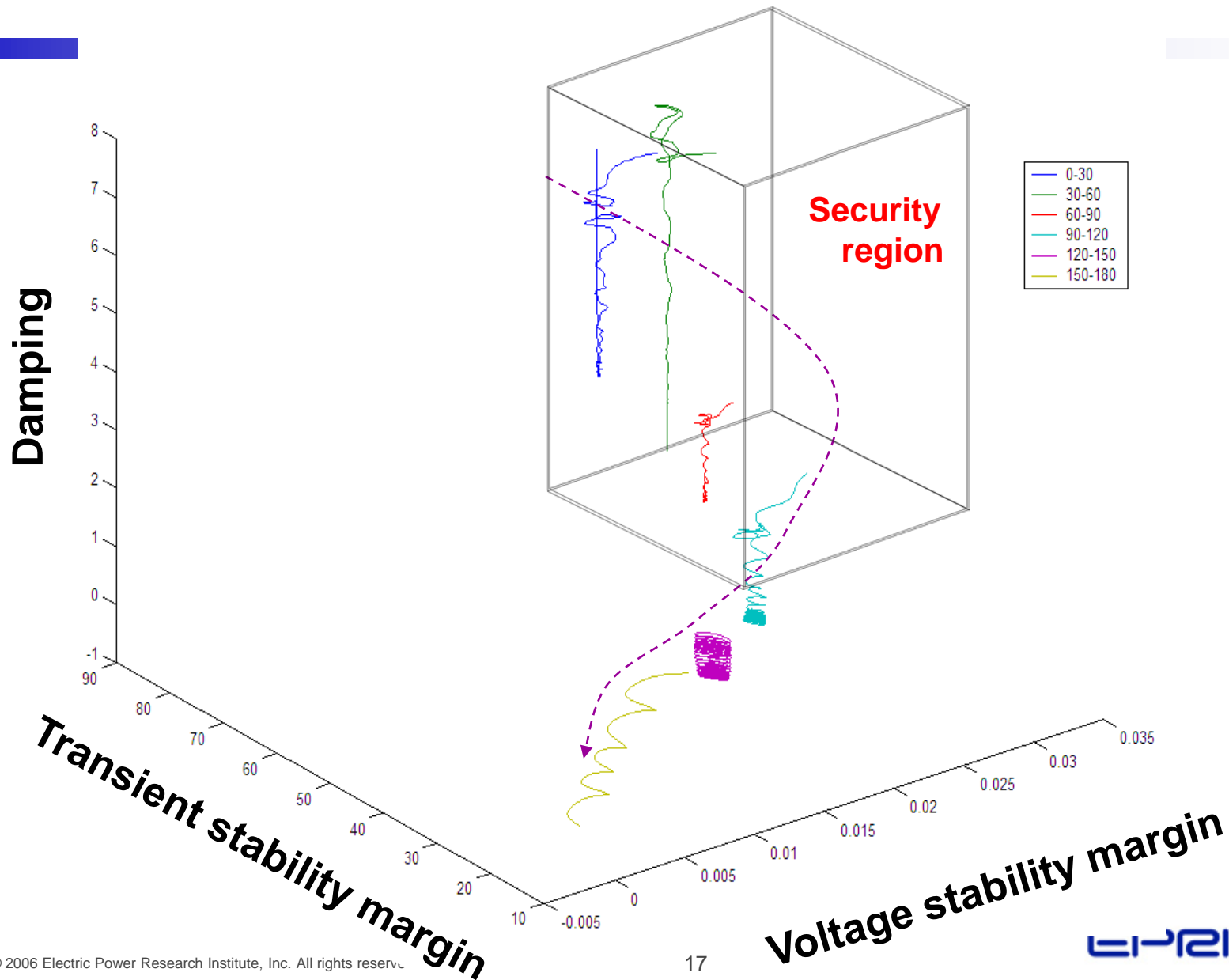


Visualizations of stability margins



- A security region exists
- Precursor signal: the curve going outside of the region
- The boundary of the region can be studied offline

3D Visualization



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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