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Synchrophasors Based Voltage Stability Monitoring

Liang Min

Senior Project Manager, EPRI

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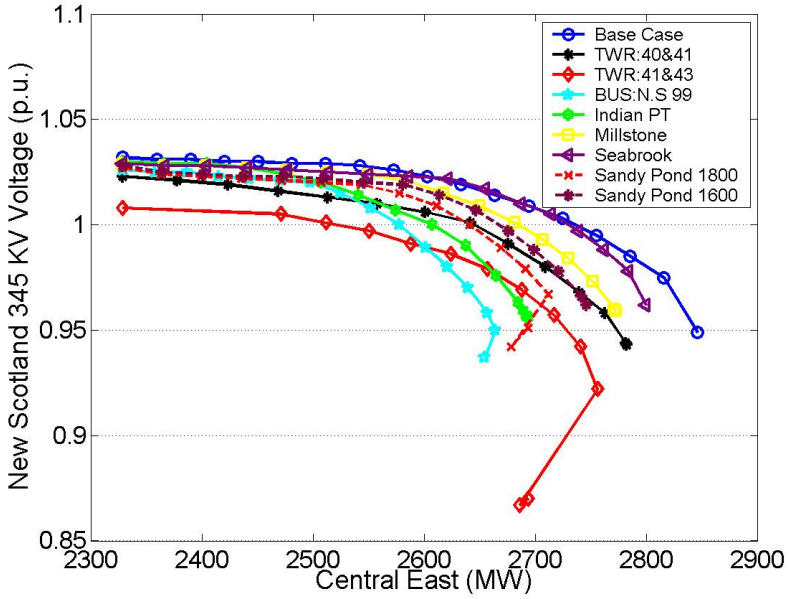
Background



From RTBPTF Report

Background

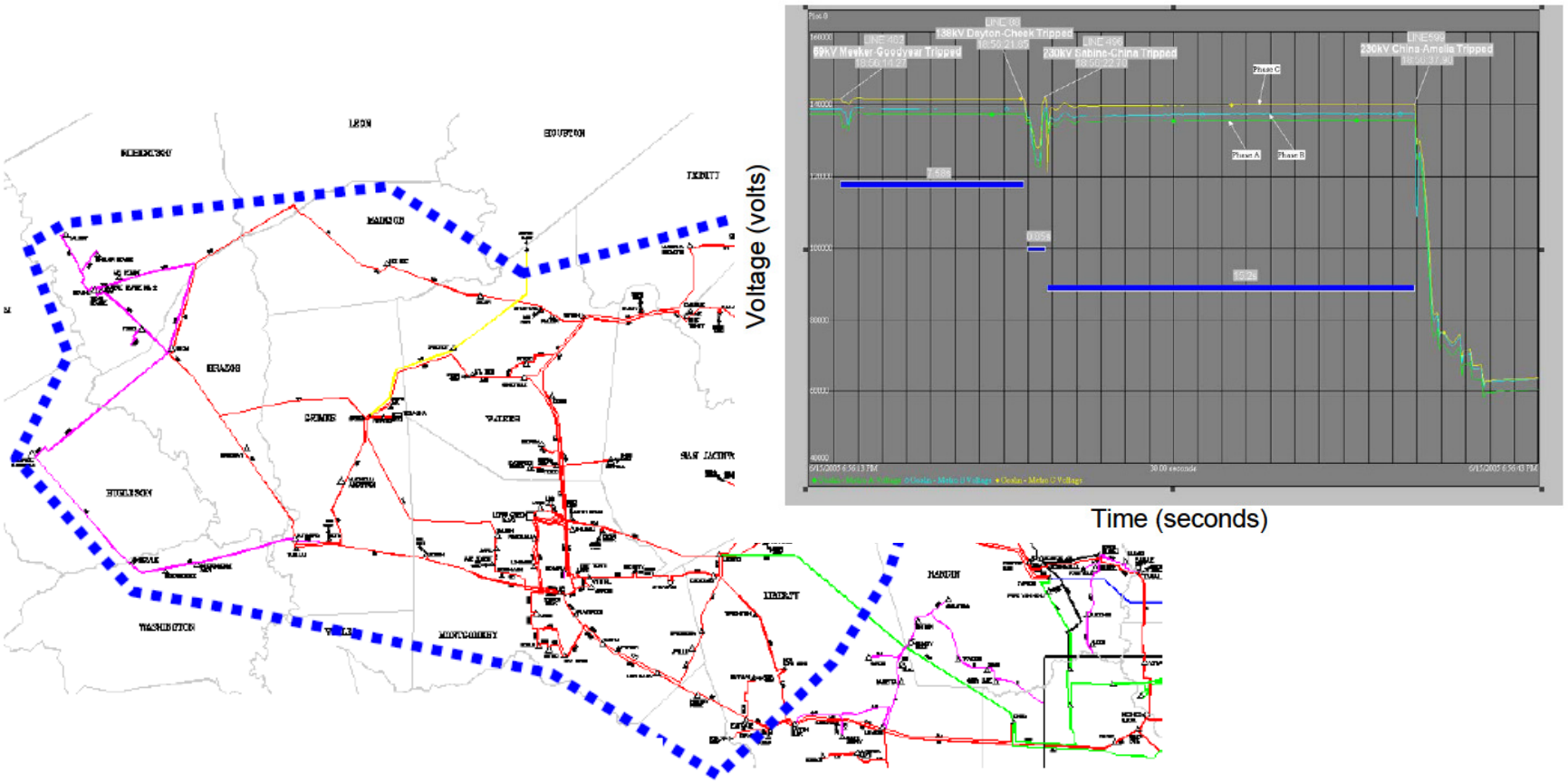
- Voltage Stability Assessment (VSA)
  - A computer simulation tool, to help operators monitor and control system voltage stability

- Limitations of Voltage Stability Assessment (VSA)
  - VSA relies on the state estimator to provide steady-state solutions
  - Preventive VSA relies on the selected contingency list (the most critical contingency)
  - The accuracy of results depends on the accuracy of modeling the generation, load, and transmission facilities

Can we use measurement data to calculate voltage stability margins?

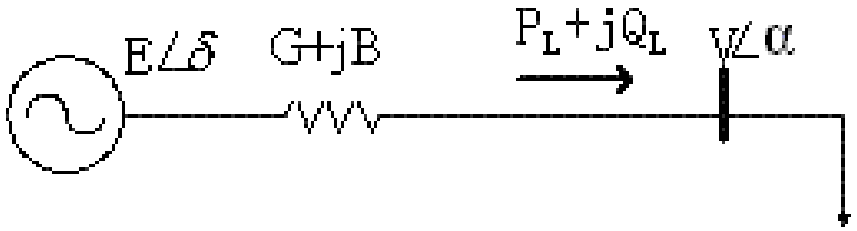
Voltage collapse scenario within the western region

Phasor voltages at Goslin 138 kV station as recorded by the PMU



"Simulation and Analysis of a Major Disturbance in Entergy system that resulted in Voltage Collapse", V.S. Kolluri, etc, IEEE PES General Meeting 2006, Copyright IEEE

EPRI's Measurement Based Voltage Stability Assessment (MB-VSA)



The maximum transfer power and the critical voltage can be used to detect voltage instability:

$$V_{critical} = E \cdot v_{critical} = E \cdot \sqrt{\frac{1}{2[1+\cos(\phi+\beta)]}}$$

$$P_{\max} = E^2 Y \cdot p_{\max} = E^2 Y \cdot \frac{\cos\phi}{2[1+\cos(\phi+\beta)]}$$

$$Q_{\max} = E^2 Y \cdot q_{\max} = E^2 Y \cdot \frac{\sin\phi}{2[1+\cos(\phi+\beta)]}$$

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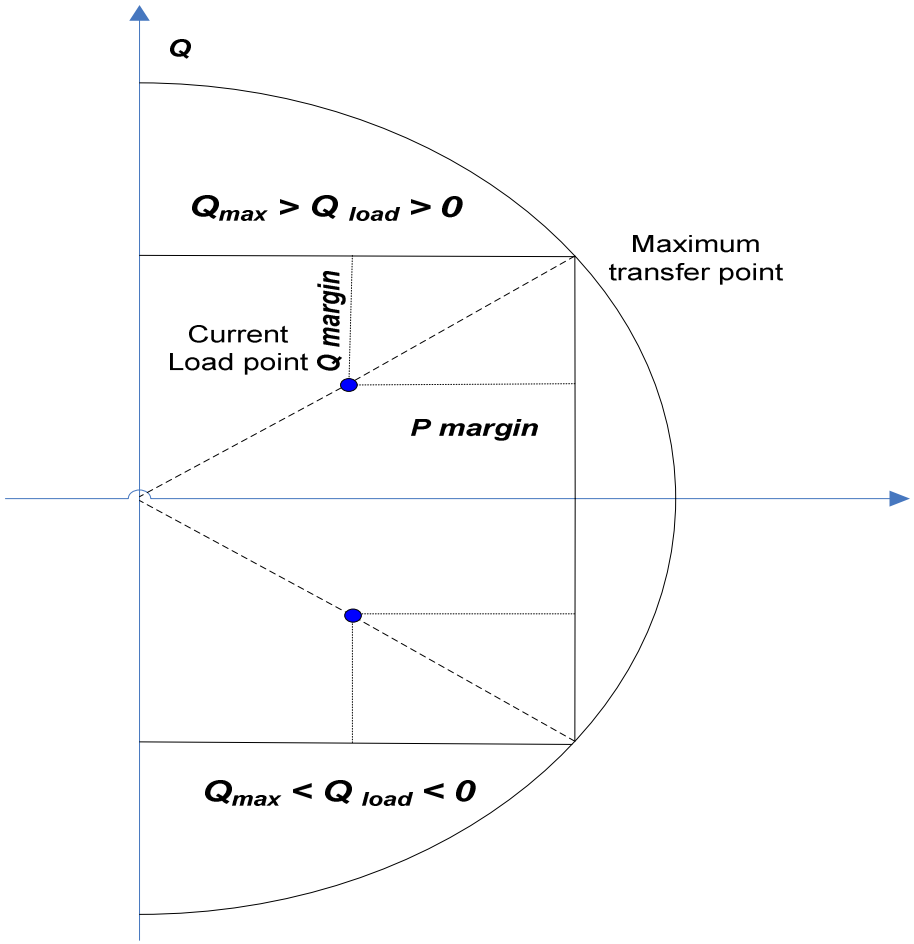

Voltage Stability Margin indexes expressed in P-Q plane

Voltage Stability Margin in terms of active power:

$$P_{\text{margin}} = P_{\text{max}} - P_{\text{L}}$$

Voltage Stability Margin in terms of reactive power:

$$Q_{\text{margin}} = Q_{\text{max}} - Q_{\text{L}}$$

Voltage Stability Margin in terms of apparent power:

$$S_{\text{margin}} = \sqrt{P_{\text{max}}^2 + Q_{\text{max}}^2} - S_{\text{L}}$$

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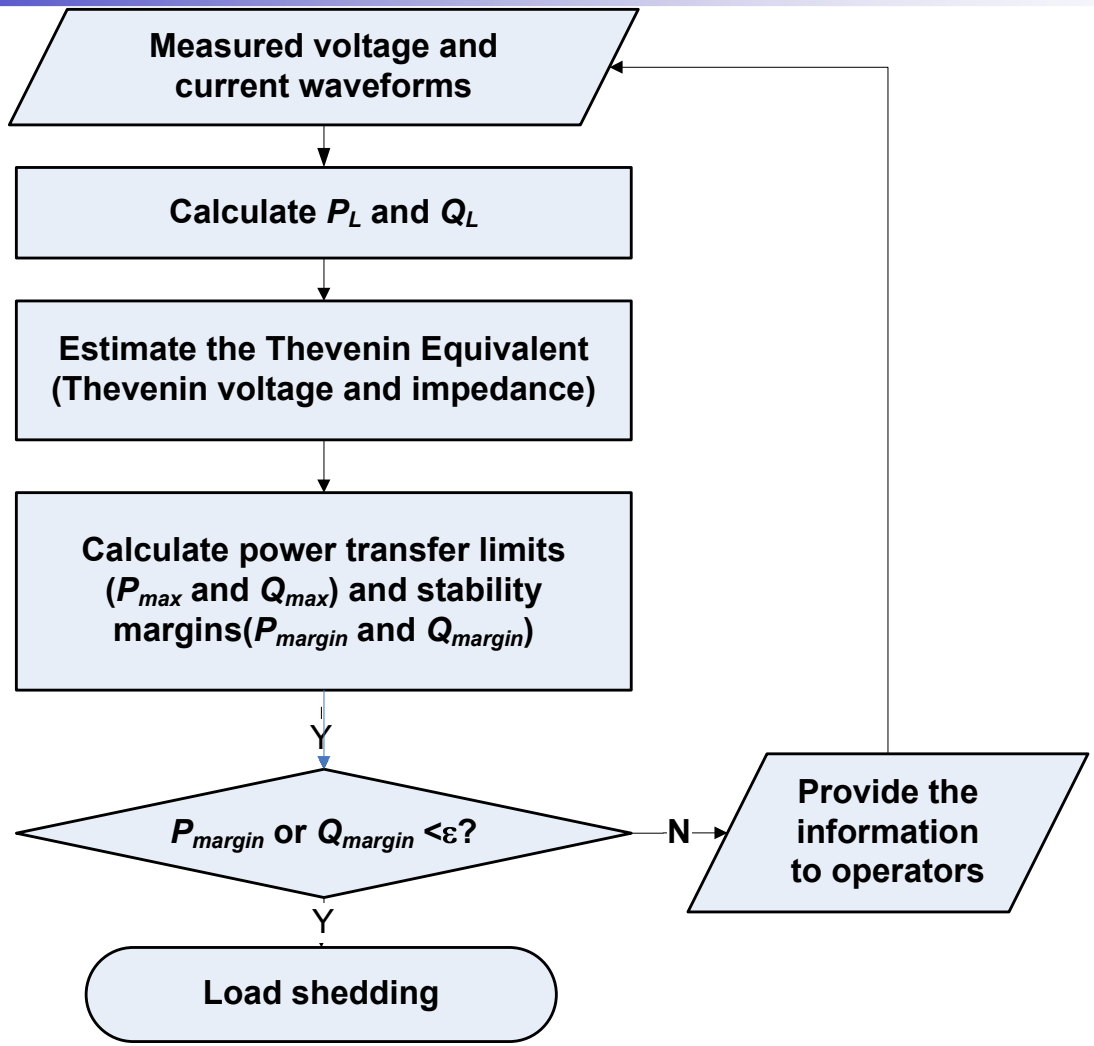
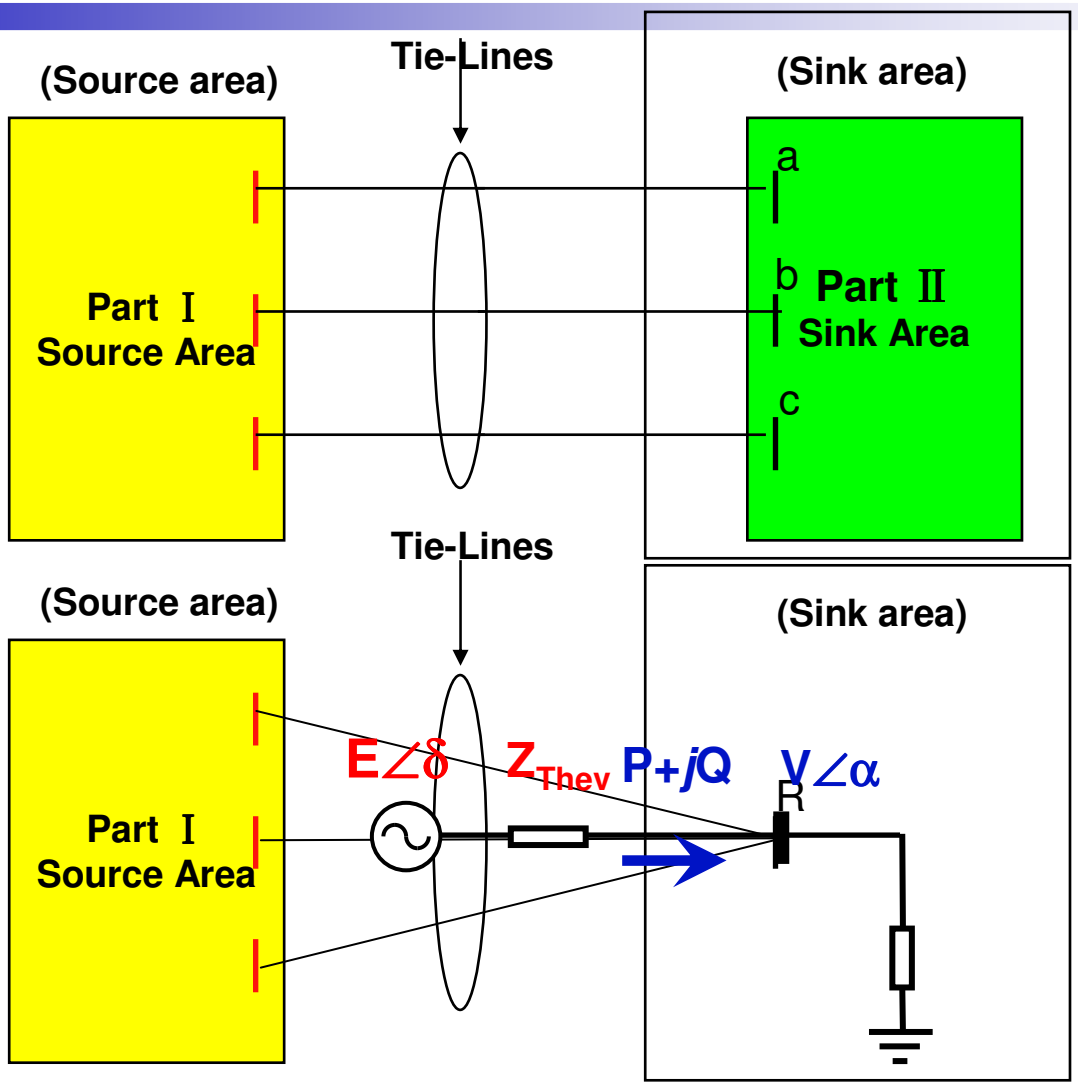


"Method for Voltage Instability Load Shedding Using Local Measurement", U.S. Patent 7603203

EPRI's Measurement Based Voltage Stability Assessment (MB-VSA)



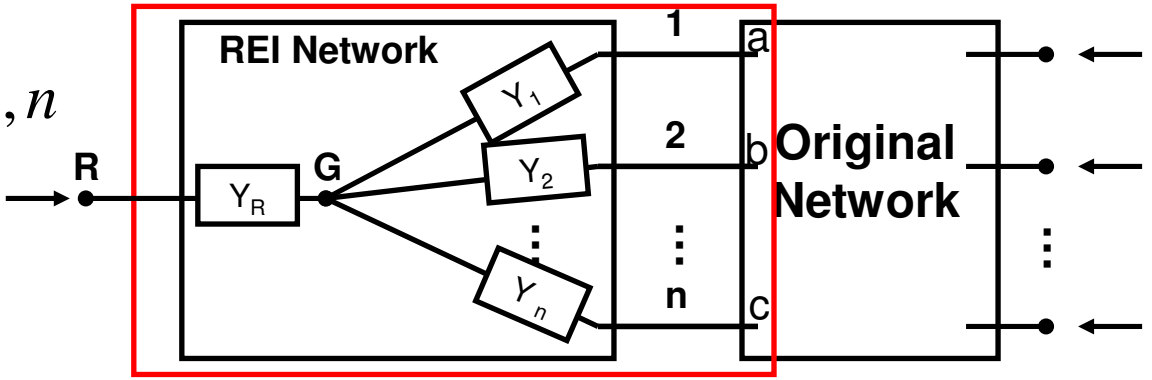
"Measurement-Based Voltage Stability Monitoring for Load Center", U.S. Patent Application Serial No. 12/131,997, filed in May 2008.

EPRI's Measurement Based Voltage Stability Assessment (MB-VSA)

Step1. Construct an REI network from the base case power flow solution and attach it to the buses to be eliminated.

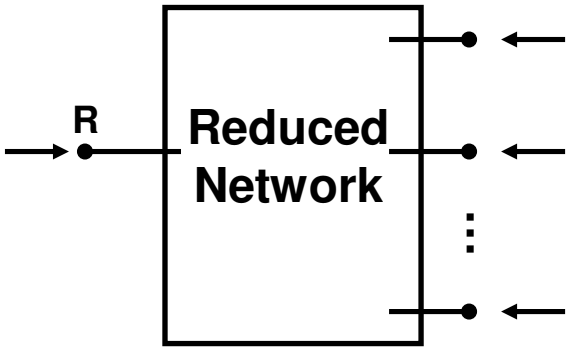
$$Y_i = \frac{-S_i^*}{|V_i|^2} \qquad i = 1, \cdots, n$$

$$S_R = \sum_{i=1}^{n} S_i$$



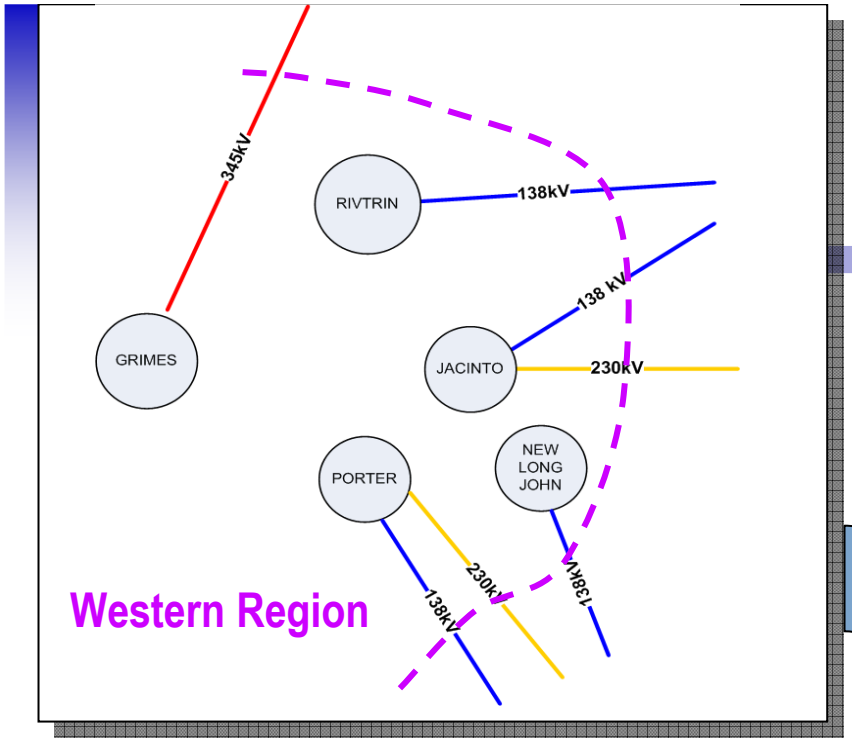
Step2. Eliminate buses 1,2,…,n and bus G by Kron reduction and obtain the equivalent network model.

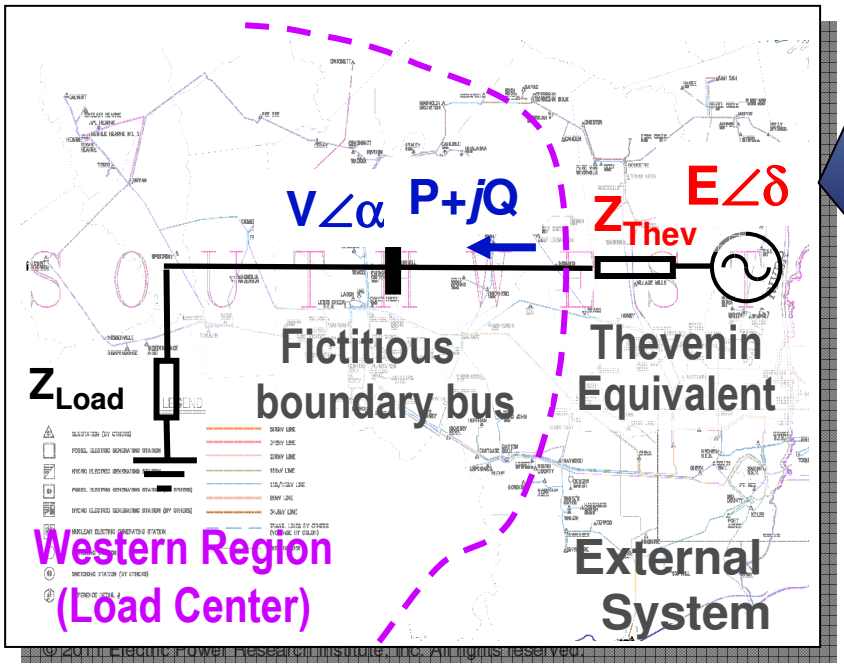
$$Y_R = \frac{S_R^*}{|V_R|^2} \qquad V_R = \frac{S_R}{\sum_{i=1}^{n} (S_i / V_i)}; V_G = 0$$



W. F. Tinney and W. L. Powell, The REI Approach to Power Network Equivalents, Transl.: 1977 PICA Conf. Toronto, ON, Canada, May 1977, pp. 312–320.

Overview of this application





Measure **voltage and current waveforms** at the boundary buses (key substations) of the load center

Calculate **V∠α**, **P** and **Q** at the fictitious bus using **voltage and current waveforms**

Calculate the external system's Thevenin Equivalent parameters:
V∠α, **P**, and **Q** → **E∠δ** and Z_{Thev}

Calculate power transfer limits:
E∠δ and Z_{Thev} → P_{max} and Q_{max}

Calculate voltage stability margin:
$P_{margin} = P_{max} - P$ and $Q_{margin} = | Q_{max} - Q |$

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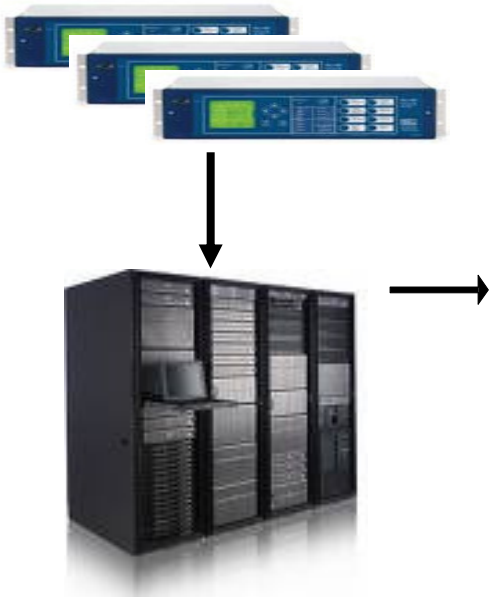
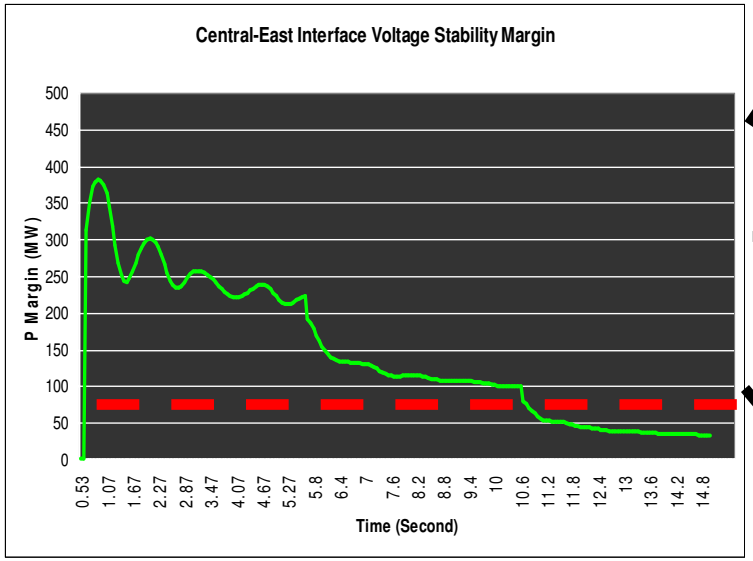
How to turn the PMU data into control actions?

Data -> Information -> Action





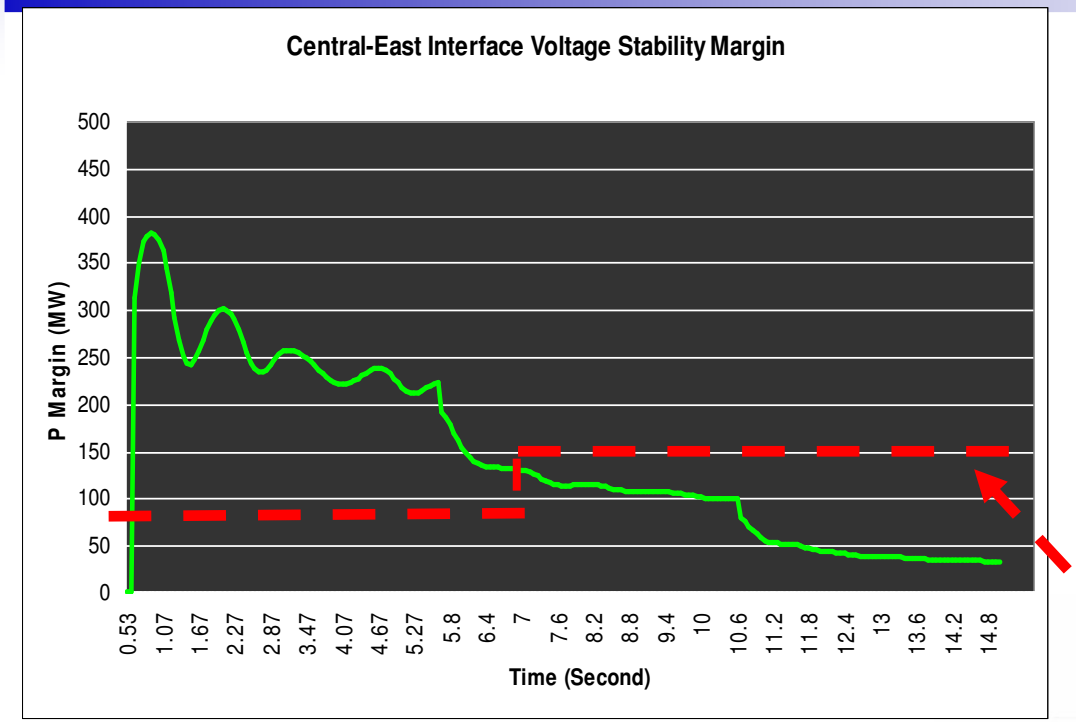

Generator

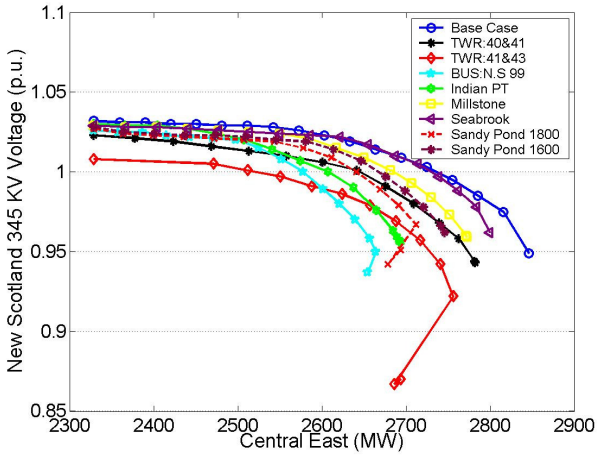

FACTS

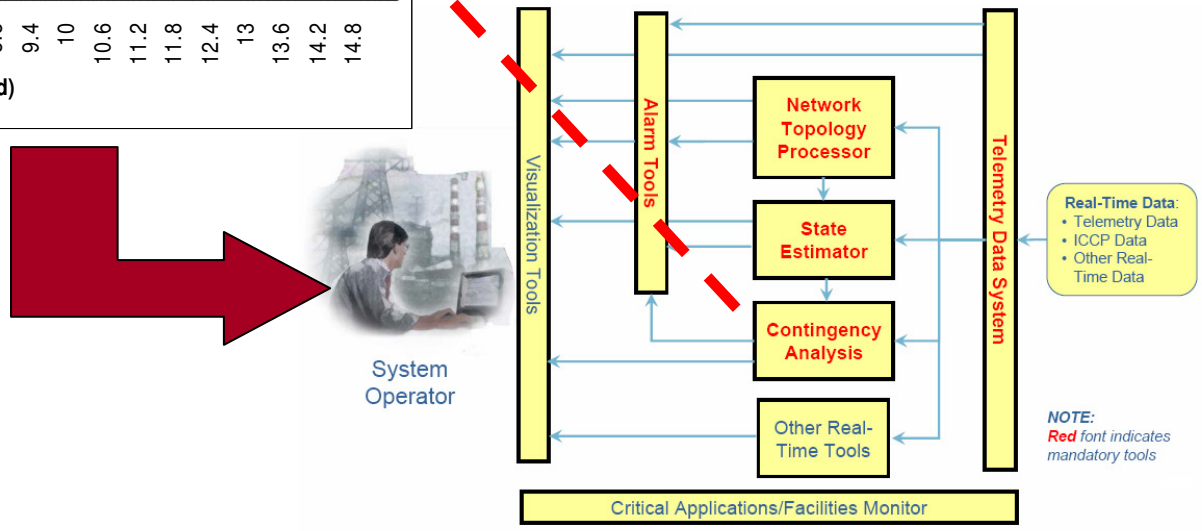

Relay

When the margin below certain threshold, we trigger the control actions.

Complimentary to Model Based Approach







Summary

- Only needs measurements at key substations within the load center or at the receiving ends of the transmission corridor;
- Calculates and displays the proximity to voltage instability in real-time;
- Can be used as decision support for operator to take actions to improve voltage stability;
- Can be integrated to automatic control schemes;
- Can coordinate multiple load centers to provide wide-area voltage stability monitoring and control.

Questions

Liang Min
Phone: 650-855-8705
E-Mail: lmin@epri.com