Voltage Stability

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Project Objective

• Synchrophasor-based voltage stability (VS) analysis
• Real-time monitoring of VS margins considering:
  – Actual system conditions (adjusting the model using online measurements)
  – Complex power transfer paths (instead of radial)
  – Contingencies
  – Computational efficiency
• Project Status – near completion
  – Started January 2013
  – Scheduled completion by end of July 2014
New Idea: The AQ-Bus Type

- Eliminates the Jacobian singularity at the maximum power transfer point
- Specify the voltage angle for the load bus (remove 1 unknown)
- Remove load $P$ equation (load power not enforced)

\[ J = -\frac{1}{X} \begin{bmatrix} V_L E \cos \theta_s & E \sin \theta_s \\ V_L E \sin \theta_s & 2V_L - E \cos \theta_s \end{bmatrix} \]

- No load parameter required
- This reduced Jacobian matrix is nonsingular at the maximum loading point [1]

Features of the AQ-Bus Method

• Includes all features of conventional power flow:
  – Tap-changing transformers
  – Shunt compensation
  – Reactive power limits
• Compute VS margins by adjusting the AQ bus voltage angle relative to the swing (AV) bus → indirectly increases power transfer
• Accommodates multiple loads and generators
• Useful for fast contingency-based voltage stability analysis
• Can be generalized to large power systems:

<table>
<thead>
<tr>
<th>Bus types</th>
<th>Bus representation</th>
<th>Fixed values</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>Generator buses</td>
<td>Fixed active power generation and bus voltage</td>
</tr>
<tr>
<td>PQ</td>
<td>Load buses</td>
<td>Fixed active and reactive power consumption</td>
</tr>
<tr>
<td>AV</td>
<td>Swing bus (generator)</td>
<td>Fixed angle (A) and voltage magnitude</td>
</tr>
<tr>
<td>AQ</td>
<td>Load bus</td>
<td>Fixed voltage angle and reactive power consumption</td>
</tr>
</tbody>
</table>
Hybrid VSA Example: Central NY

- Phasor data from 6 PMUs provided by New York Power Authority (NYPA)
- 13-bus observable subnetwork
- Pseudo-PMU data calculated on the non-PMU buses using a phasor-only state estimator (PSE)
- Power flows from West and North towards NYC
- Critical power transfer interfaces
- Weaker ties to ISO-New England and other neighboring control areas
Computed PV Curves for NY System

- Calculated PV curves based on actual system conditions
- Measurement-adjusted model
- Includes SVC equipment limits
- Multiple generation sources based on information from PMU data

<table>
<thead>
<tr>
<th>Event</th>
<th>Gen. loss</th>
<th>$\Delta P_{flow}$</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>800 MW</td>
<td>300 MW</td>
<td>1300 MW</td>
</tr>
<tr>
<td>2</td>
<td>700 MW</td>
<td>250 MW</td>
<td>1350 MW</td>
</tr>
</tbody>
</table>
Voltage Issues at a BPA Wind Hub

- 600 MW wind interconnection
- Huge voltage variations
- Weak system (line outage)
- Wind plant curtailment
- Shunt capacitor issues

Wind Farm Response (at point of connection)

Wind turbine output over 10 hrs

~14% variation

CERTS
Consortium for Electric Reliability Technology Solutions
PV Curves with East-WH Line Outage Contingency

[Diagram showing wind hub and voltage magnitudes for West and East buses, with measured and calculated values for different wind hub power levels.]
Local voltage issues on 230 kV system

Some stiff buses (Big Creek generators) and weak buses (particularly Bus 11)

Reactive power support and series compensation on high-voltage lines

Some wind generation around Bus 17

PMU data – one data point per minute
Accomplishments

• Development of AQ-bus method for VS analysis:
  – Publications
  – Patent application filed (May 2014)
    • Interest from a commercial software vendor
• Measurement-based VS analysis development and demonstration:
  – Central NY power transfer interfaces
  – BPA wind hub
Project Status

• Deliverables for FY14:
  – Application installation and testing at BPA
    • Installation – June 2014
    • Testing – June-July 2014
    • Report – July 2014
  – SCE voltage stability analysis report – June 2014
  – Final report – July 2014
  – Demonstrate the online application at NASPI VSA Workshop (tentative) – October 2014

• Risk Factors:
  – Data availability
  – Data accuracy
Follow-on Work

• New PMU data
  – Increased BPA PMU availability for wide-area VS assessment
  – New wind and solar plant PMU data from Southern California
  – Wind turbine PMU data from NY North Country from NYPA

• Multiple voltage collapse scenarios and cascading failures
  – Considering multiple load areas
  – Sensitivity of the maximum loadability to outages, wind turbine type, etc.

• Extend to system-wide voltage stability analysis
  – Implementation in commercial power system software
  – Implementation in EMS for real-time contingency analysis

• Moving from stability assessment to decision support
  – Evaluating and recommending preventative/remedial actions using online PMU data