Measurement-Based Real-Time Voltage Stability Monitoring for Load Areas

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Content

• Background on measurement-based voltage stability assessment

• A new measurement-based VSA method and its comparison with the Thevenin method

• Demonstrations of the new method
Simulation/model based Voltage Stability Assessment

• Strengths
  – Look-ahead capabilities in stability prediction and control for “what-if” scenarios
  – Lots of commercial software tools.

• Limitations in Online Application
  – **Model-dependent**: the accuracy depends on how accurate the power system models is
  – **Contingency-dependent**: only applied to selected critical contingencies
  – **Requiring a steady-state powerflow solution**: the state estimator may fail to converge under stressed operating conditions.
  – **Computationally intensive**: especially for dynamic simulations

• An alternative approach is Measurement-based VSA
Methods for Measurement-based VSA

**For a load pocket area**

Measuring synchronized voltages $V_i$ and currents $I_i$ at all boundary buses

**For a wider load area**

Thevenin equivalent (1+1 buses) \(^{[1]}\)

1. Merge all lines to be one
   \[ V = \frac{\sum_{i=1}^{N} V_i I_i^*}{\sum_{i=1}^{N} I_i^*}, \quad S = P + jQ = \sum_{i=1}^{N} V_i I_i^* \]

2. Estimate $E$ and $Z_{\text{thev}}$ by a least square or Kalman filter method

3. Transfer limit $P_{\text{max}}$ is met when $|Z_{\text{load}}| = |Z_{\text{thev}}|

New multi-terminal network equivalent (N+M buses) \(^{[2]}\)

1. Consider equivalents with details on different transfer paths

2. Estimate all equivalent $E$ and $Z$ parameters by optimization methods

3. Analytically solve the limit for each transfer path
   \[ P_{1\text{max}} = f_1(E, Z_1, Z_2, Z_{L1}, Z_{L2}, Z_T) \]
   \[ P_{2\text{max}} = f_2(E, Z_1, Z_2, Z_{L1}, Z_{L2}, Z_T) \]

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New MB-VSA Method based on an N+1 buses Equivalent

Derive the transfer limit of tie line $i$ with respect to a load change near bus $j$ as a function of all parameters of the equivalent

$$\frac{\partial P_i(y_{11}, \ldots, y_{NN})}{\partial y_{jj}} = 0 \quad \rightarrow \quad P_{i,j}^{\text{Max}}$$
For a load area fed by multiple tie lines

• Traditional Thevenin method
  – Only estimates the total transfer limit of all tie lines

• New MB-VSA method
  – Estimates the transfer limit for each line and can better detect and control voltage instability if any line hits its limit earlier than the others
  – Gives the limits of each line with respect to different scenarios of load changes
  – More accurate in estimating the total transfer limit by considering the coupling among boundary buses
Influence from the coupling of boundary buses

External system

Load Center

Strong

Weak

Active power transfer from external system to boundary bus (pu)

Voltage magnitude of boundary bus (pu)

Active power transfers & limits (x100MW)
Demonstration on the NPCC 140-bus System

Voltage collapse caused by a generator outage in the load center and load increase.
Comparison of two MB-VSA methods

New MB-VSA

Thevenin method

Zero margin at $t=473s$

Positive margin when voltage collapse happens.
Time Performance of the New MB-VSA

Time for estimating external system parameters.

Time for estimating load area parameters.
Application in Closed-loop Control

- Automatically switch in a shunt capacitor in the load area if any tie line margin drops below 5%
- Voltage collapse is postponed
Application of the New MB-VSA Method in System Operations

Voltage collapse following a generator trip at bus 21 without control

Transfer margin on ISO-NE path

Transfer margin on NYISO path

Dispatch more VAR from wind turbines when any line margin<5%

Time (s) | Tie lines ranked by MBVSA
---|---
Before generator trip at Bus 21 | 30-31, 6-5 (most critical)
| 29-30, 8-9, 7-6
| 73-35

After generator trip at Bus 21 | 29-30, 8-9, 7-6 (most critical)
| 30-31, 6-5
| 73-35
Test on a 25k-bus Eastern Interconnection model

From NYISO

Limit for load increase in area 1

Limit for load increase in area 2

Margin > 0

Real-time power

From ISO-NE

Limit for load increase in area 2

Limit for load increase in area 1

Margin < 0

Real-time power
CURENT Hardware Testbed System: power converter-based reconfigurable power grid emulator [3]

Demonstration on CURENT Hardware Test Bed System

Closed-loop control to prevent voltage collapse

**Without control**
Load increases in the load area leading to voltage collapses.

**With control**
Provide $Q$ via MT-HVDC when any tie line margin is below a threshold.
Demonstration on CURENT Hardware Testbed System
Q&A

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