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

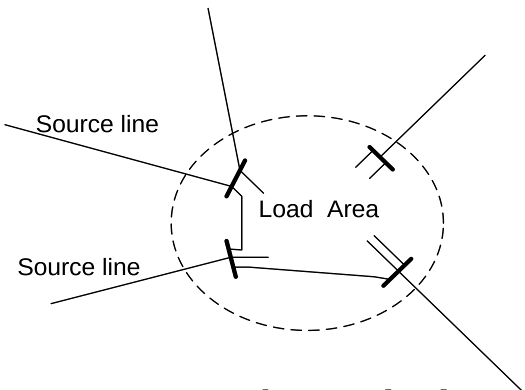
- Strengths
  - Look-ahead capabilities in stability prediction and control for “what-if” scenarios
  - Lots of commercial software tools.

- 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



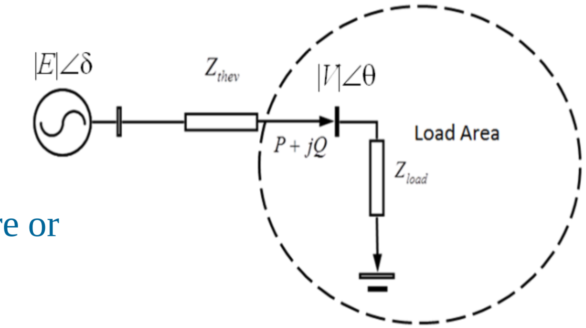
Measuring synchronized voltages V_i and currents I_i at all boundary buses

For a wider load area

Thevenin equivalent (1+1 buses) [1]

1. Merge all lines to be one

$$V = \sum_{i=1}^{N} V_i I_i^* \Big/ \sum_{i=1}^{N} I_i^* \,, \quad S = P + jQ = \sum_{i=1}^{N} V_i I_i^*$$

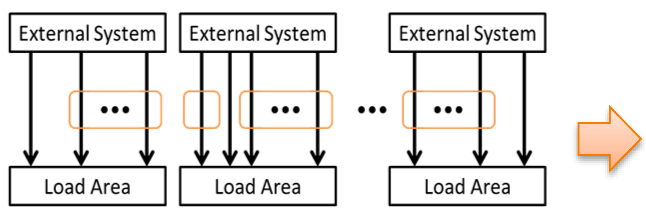


2. Estimate E and Z_{thev} by a least square or Kalman filter method

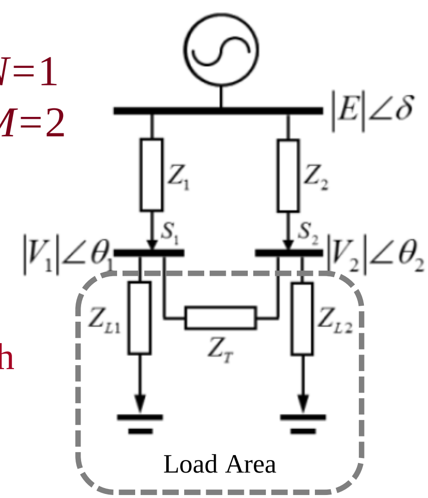
3. Transfer limit P_{max} is met when $|Z_{load}| = |Z_{thev}|$

New multi-terminal network equivalent (N+M buses) [2]

1. Consider equivalents with details on different transfer paths



N=1
M=2

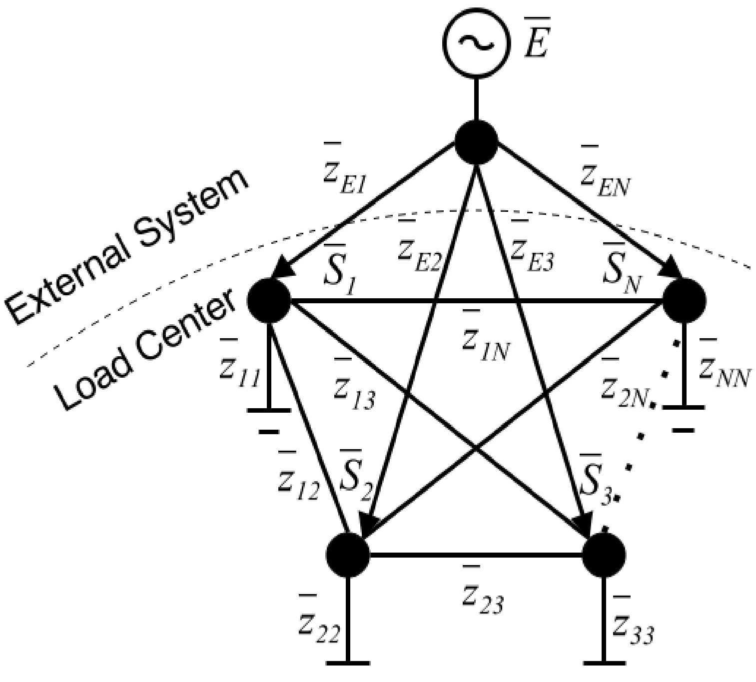


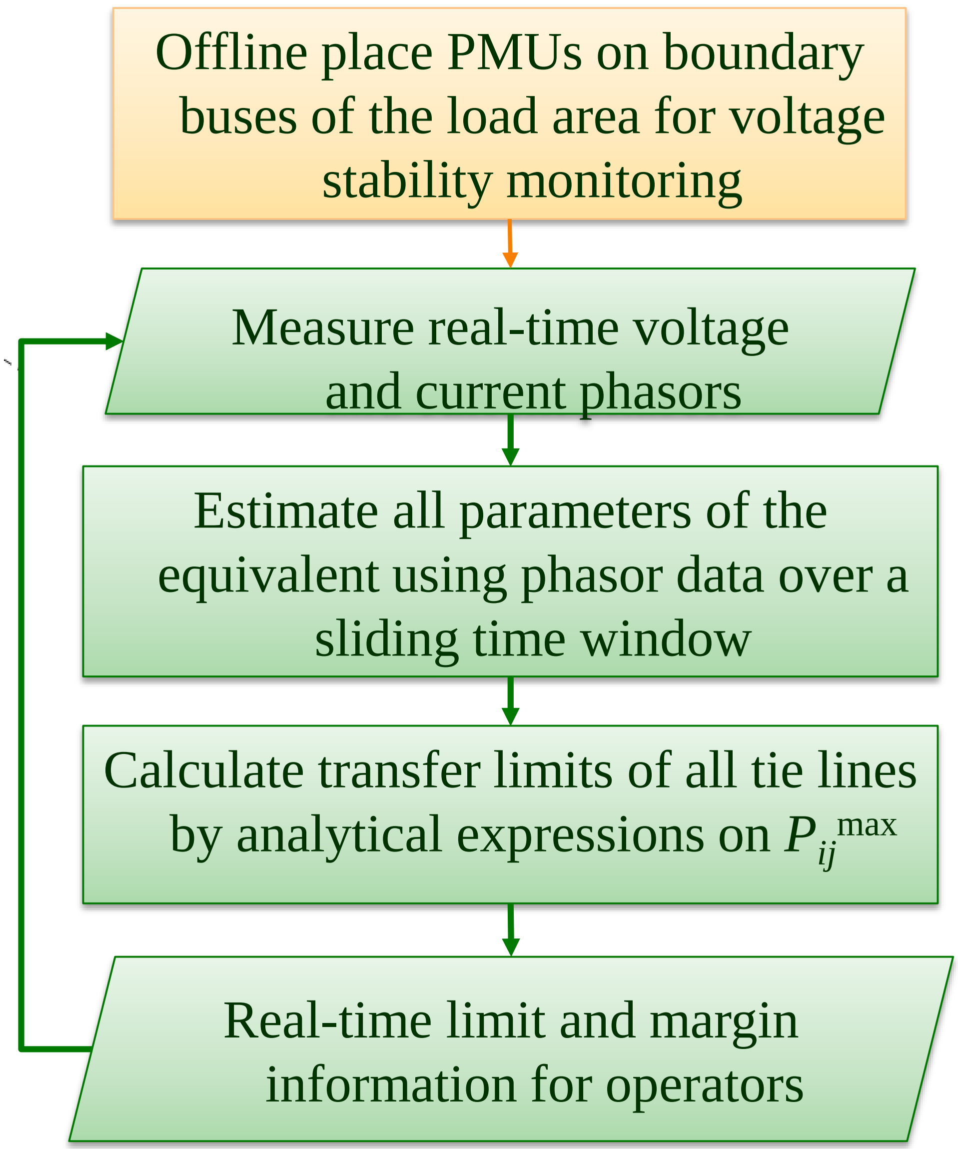
2. Estimate all equivalent E and Z parameters by optimization methods
3. Analytically solve the limit for each transfer path

$$P_{1\max} = f_1(E, Z_1, Z_2, Z_{L1}, Z_{L2}, Z_T)$$
$$P_{2\max} = f_2(E, Z_1, Z_2, Z_{L1}, Z_{L2}, Z_T)$$

[1] P. Zhang, L. Min, J. Chen, Measurement-based voltage stability monitoring and control, US Patent 8,126,667, 2012
[2] F. Hu, K. Sun, A. Del Rosso, E. Farantatos, N. Bhatt, "Measurement-Based Real-Time Voltage Stability Monitoring for Load Areas," IEEE Trans. Power Systems, 2016 (DOI: 10.1109/TPWRS.2015.2477080)

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

$$\frac{\partial P_i(y_{11},\cdots,y_{NN})}{\partial y_{jj}} = 0 \quad \rightarrow \quad P_{i,j}^{\mathrm{Max}}$$

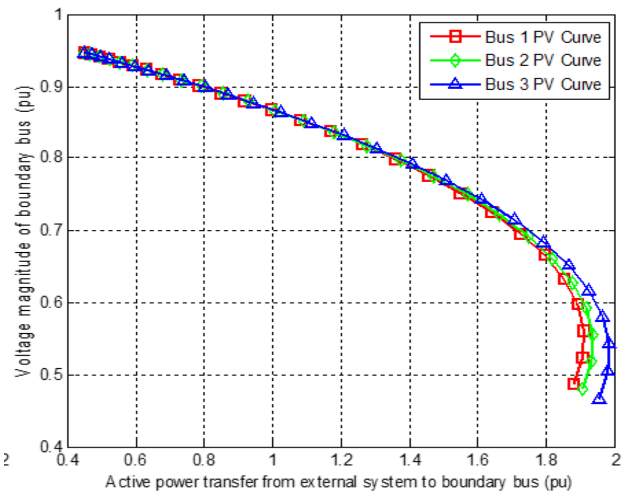
For a load area fed by multiple tie lines

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

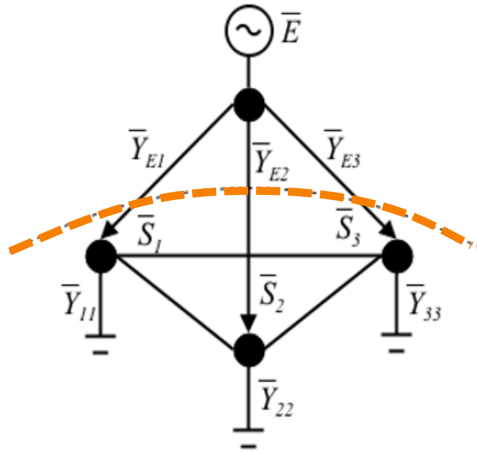
- New MB-VSA method
  - Estimates the transfer limit for each line and can better detect and control voltage instability if any line hits its limit earlier than the others
  - Gives the limits of each line with respect to different scenarios of load changes
  - More accurate in estimating the total transfer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

Influence from the coupling of boundary buses

Strong

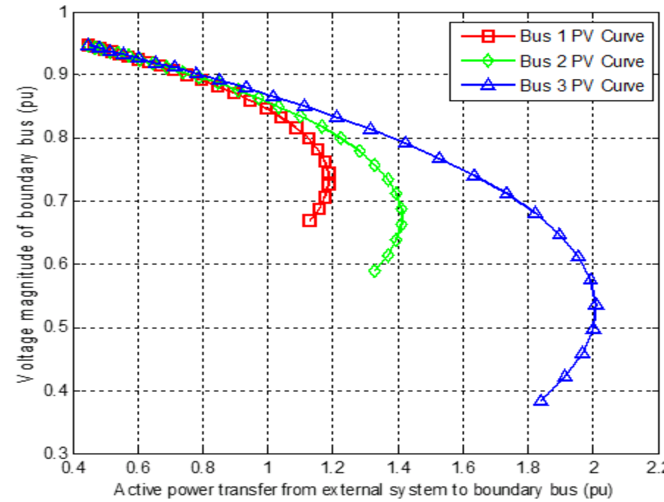


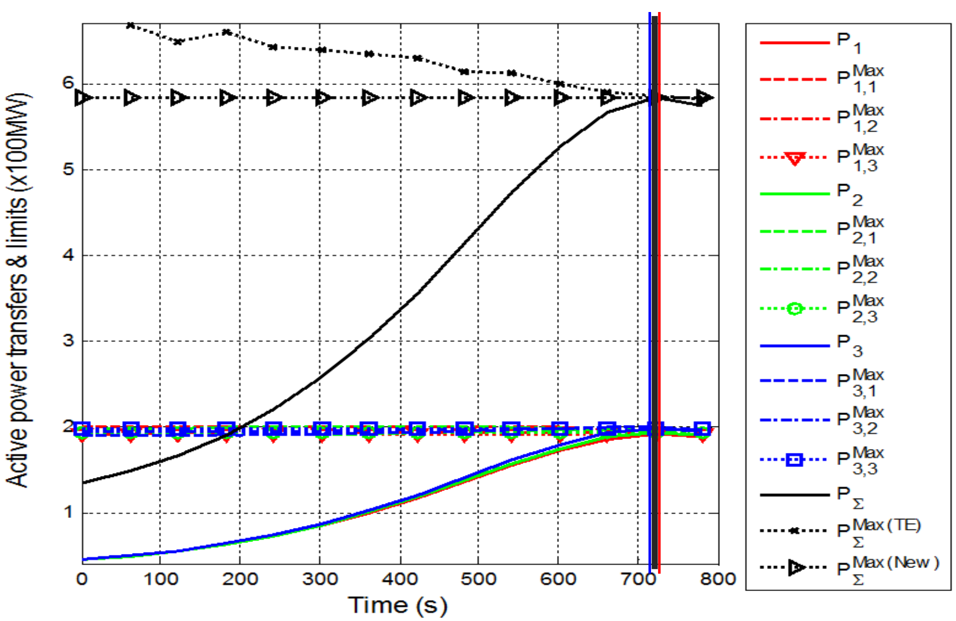
External system

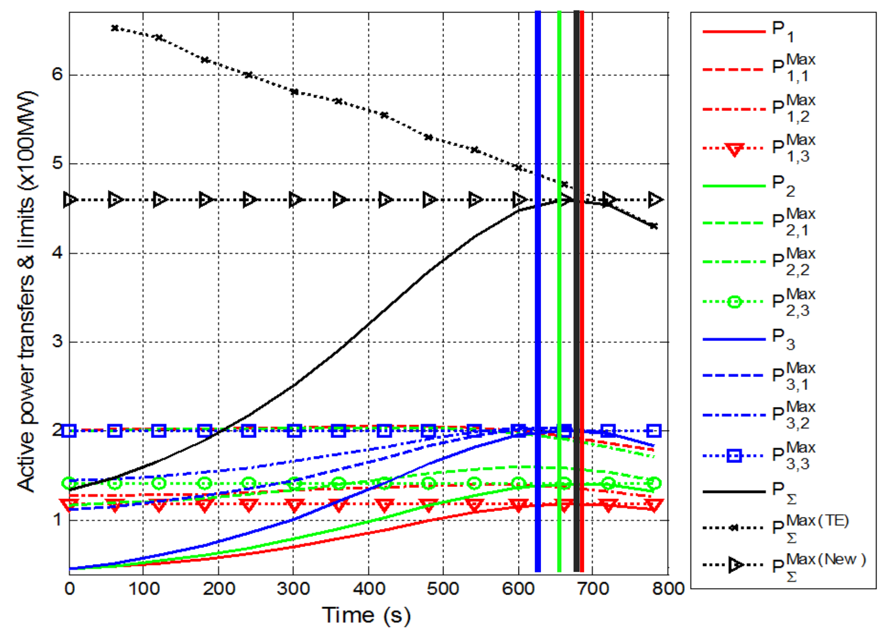


Load Center

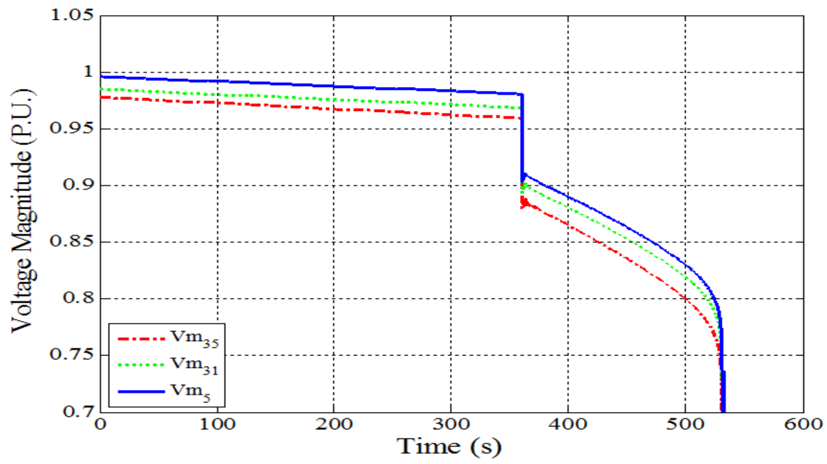
Weak

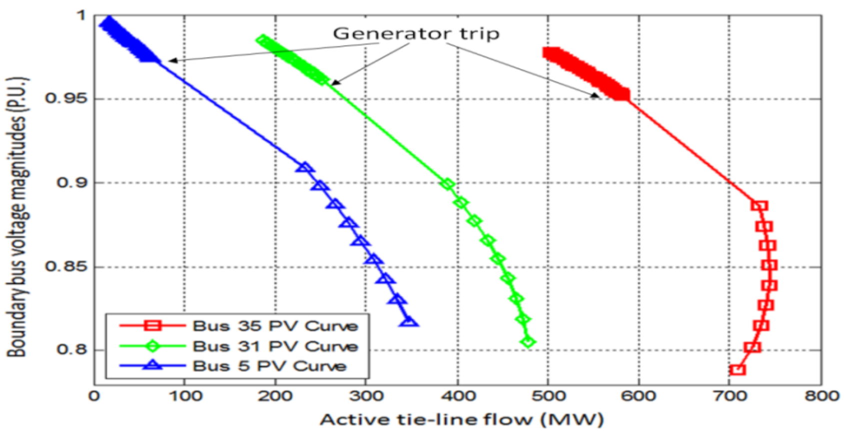


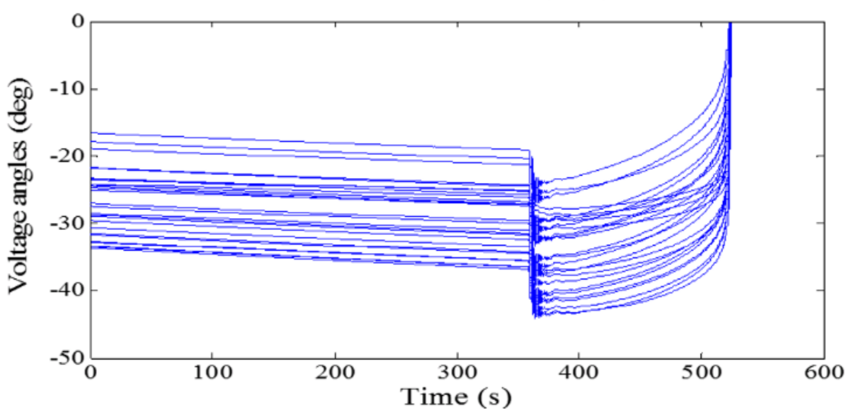


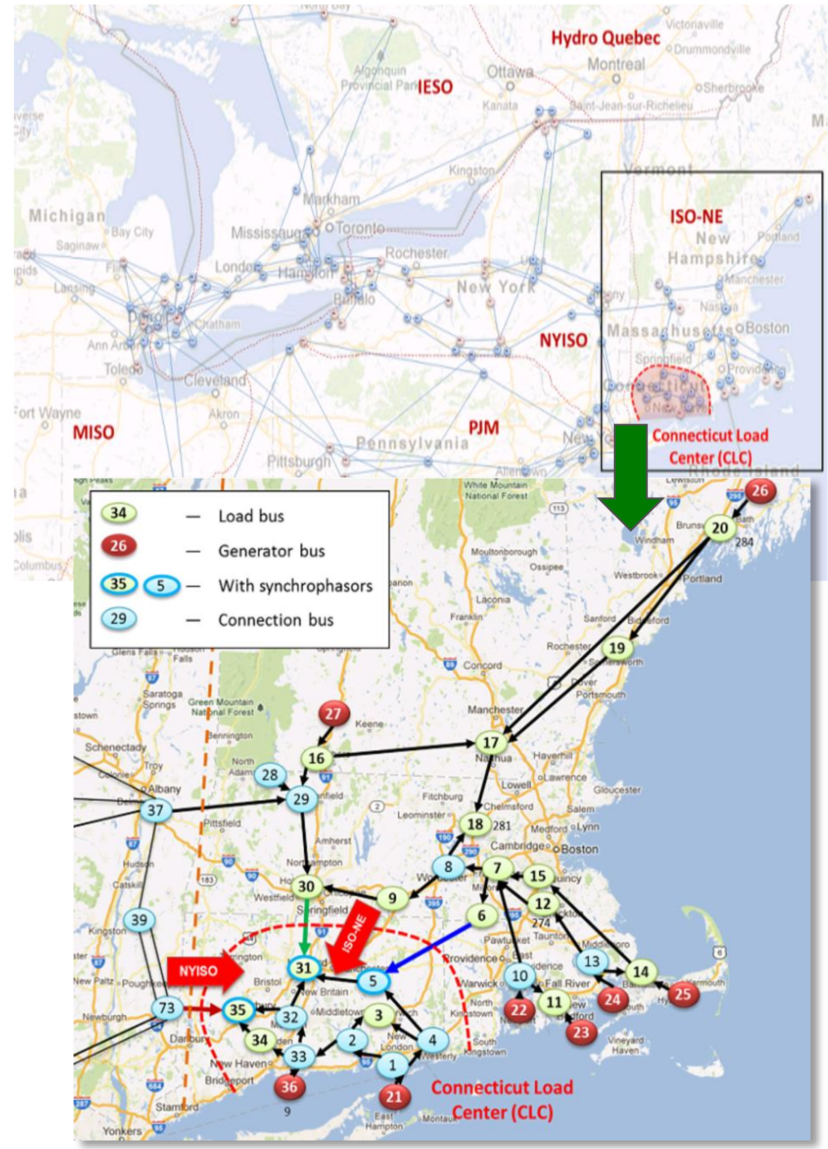


Demonstration on the NPCC 140-bus System





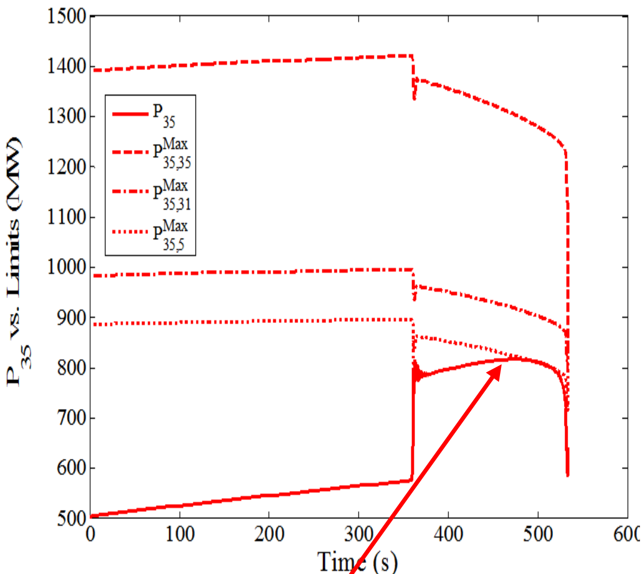


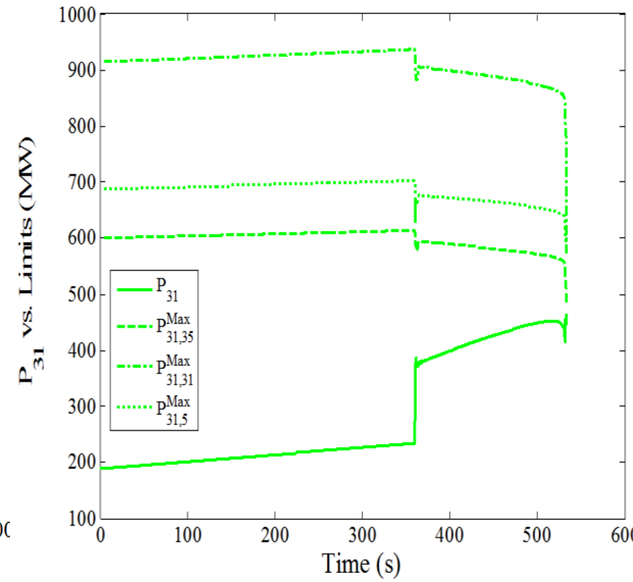


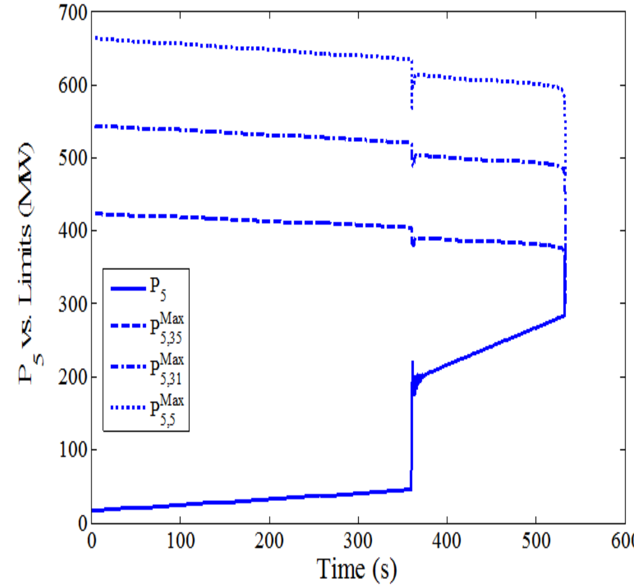
Voltage collapse caused by a generator outage in the load center and load increase

Comparison of two MB-VSA methods

New MB-VSA

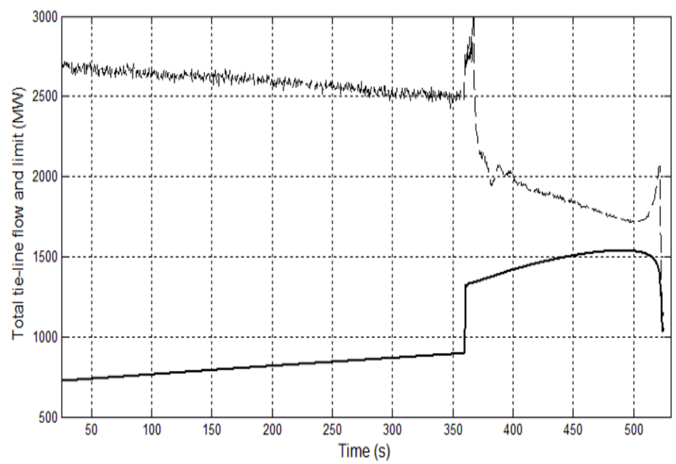






Zero margin at t=473s

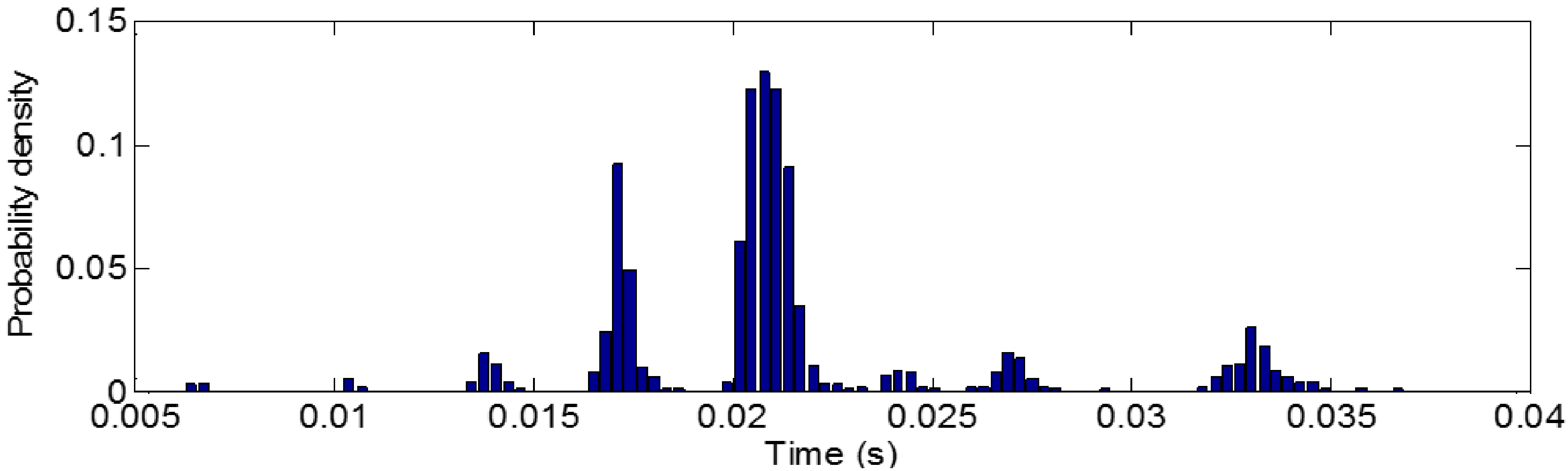
Thevenin method



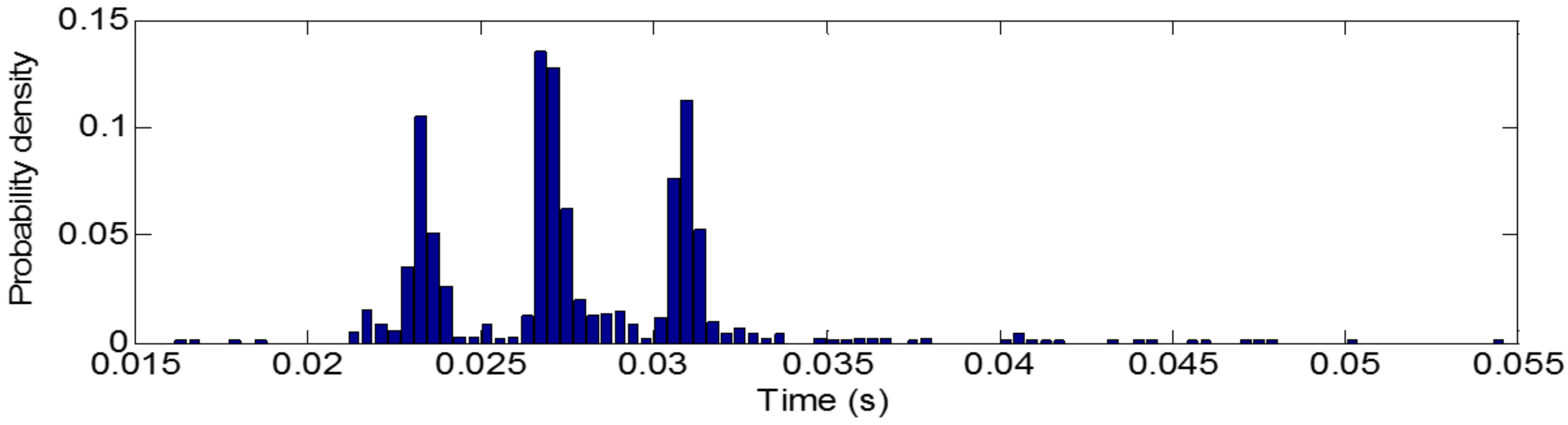
Positive margin when voltage collapse happens.

Time Performance of the New MB-VSA

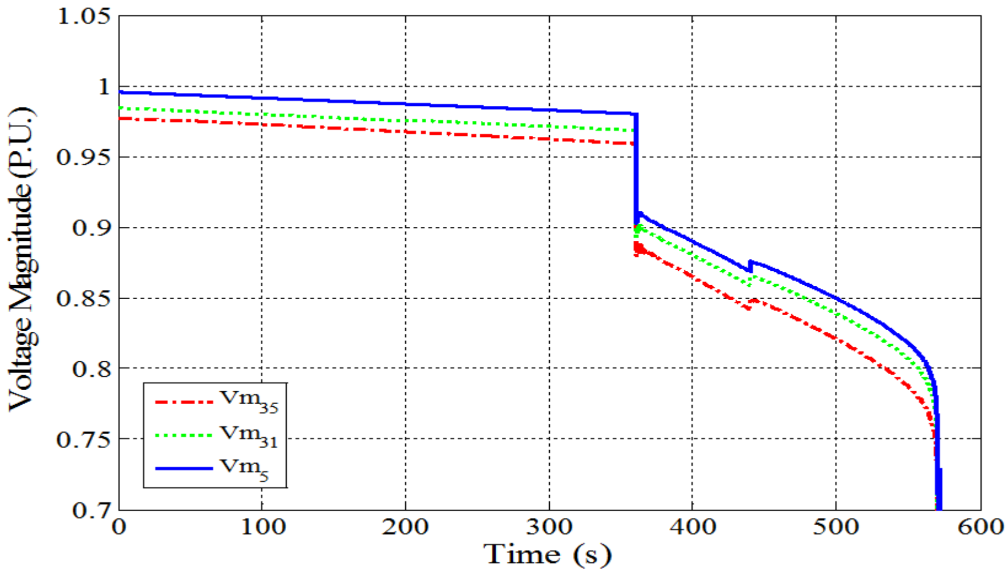
Time for estimating external system parameters.

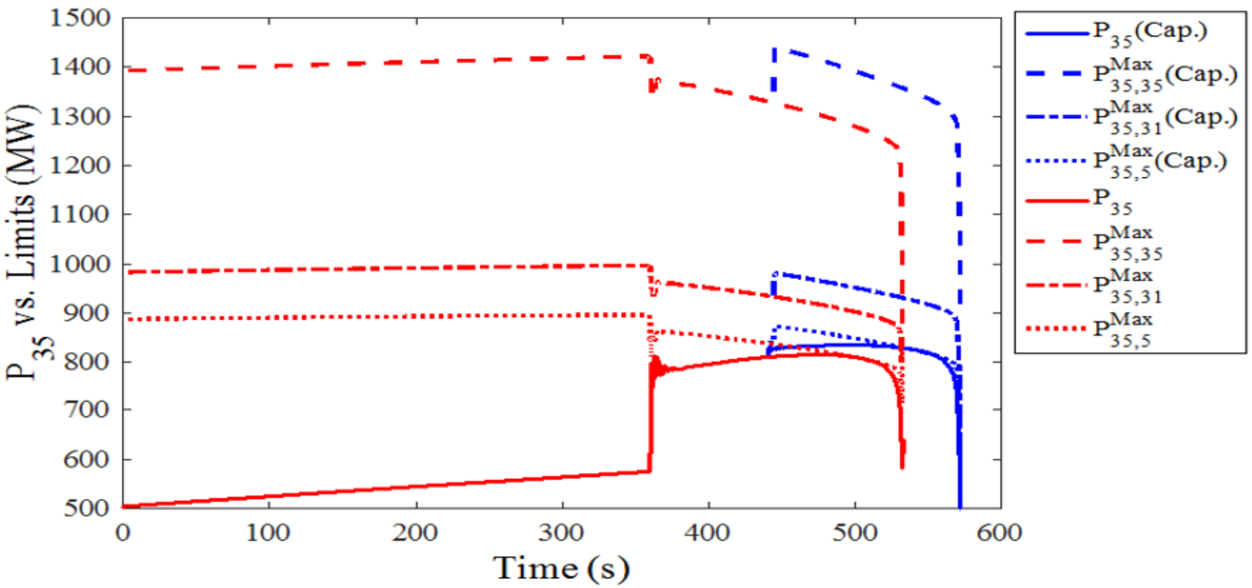


Time for estimating load area parameters.



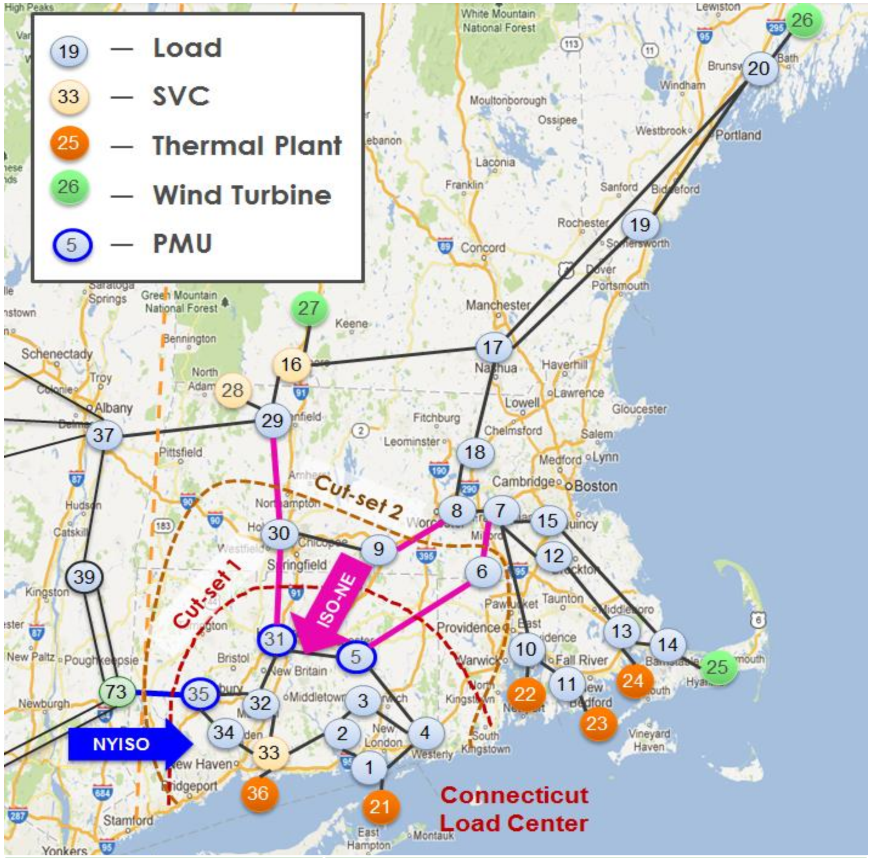
Application in Closed-loop Control



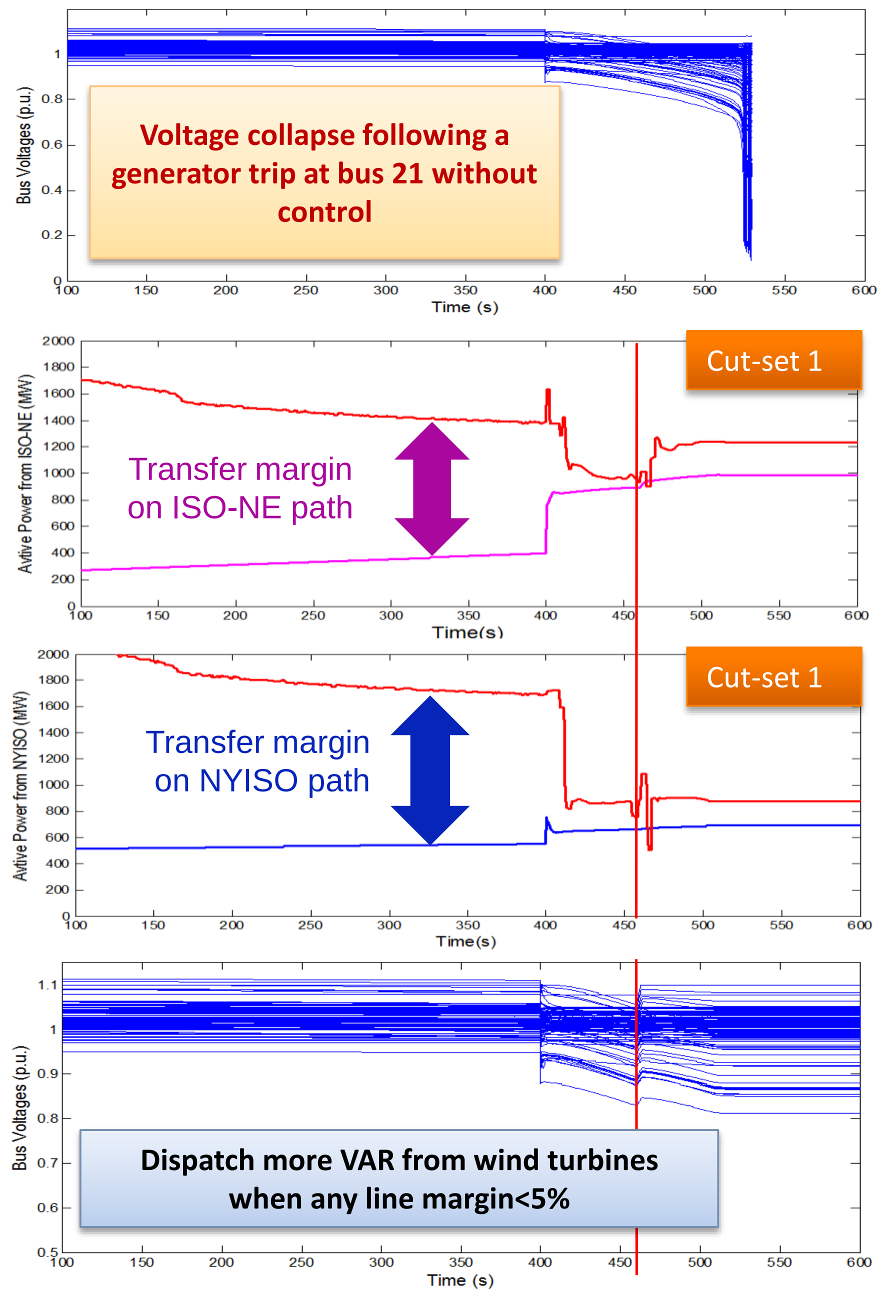


- Automatically switch in a shunt capacitor in the load area if any tie line margin drops below 5%
- Voltage collapse is postponed

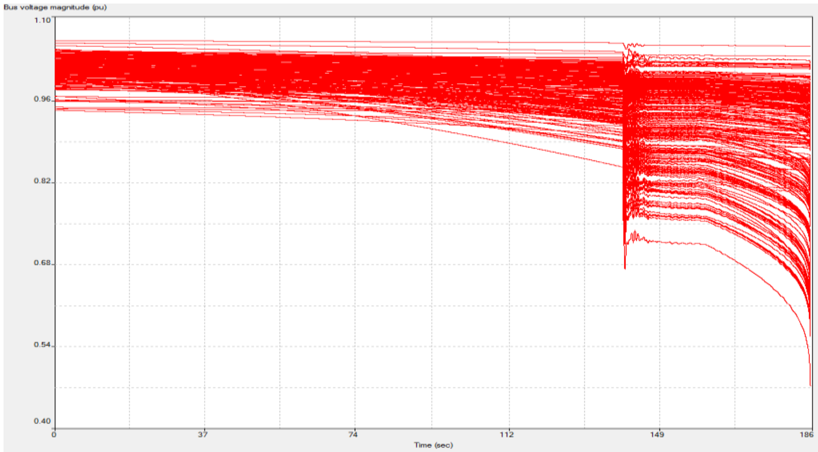
Application of the New MB-VSA Method in System Operations

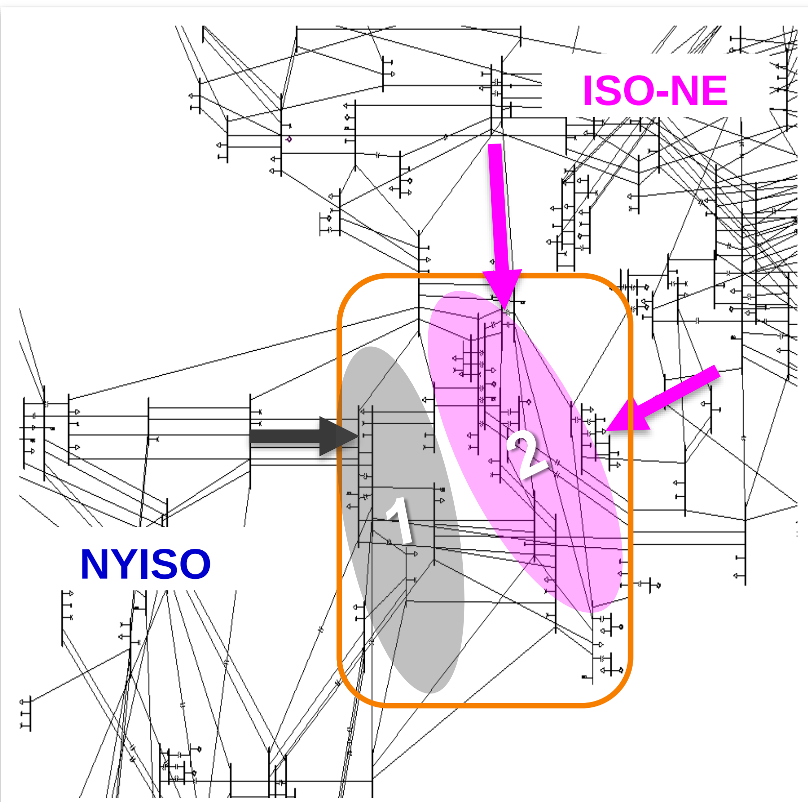


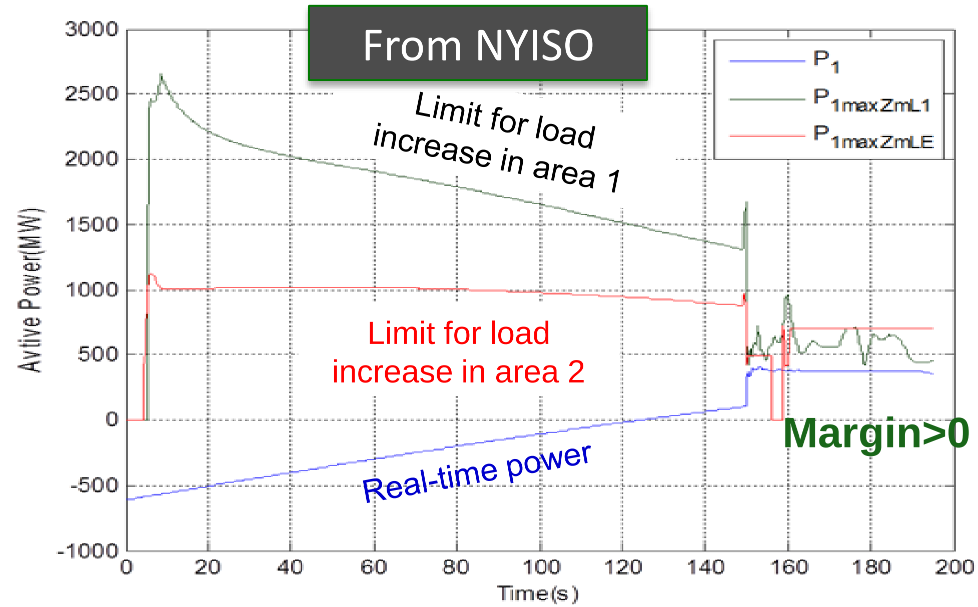
Time (s)	Tie lines ranked by MBVSA
Before generator trip at Bus 21	30-31, 6-5 (most critical)
	29-30, 8-9, 7-6
	73-35
After generator trip at Bus 21	29-30, 8-9, 7-6 (most critical)
	30-31, 6-5
	73-35

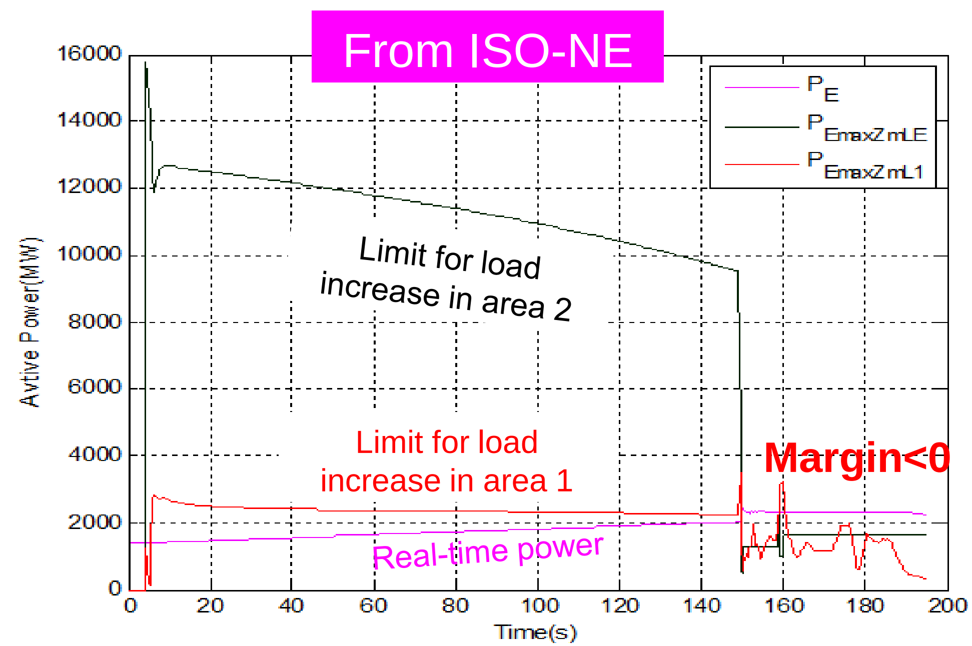


Test on a 25k-bus Eastern Interconnection model

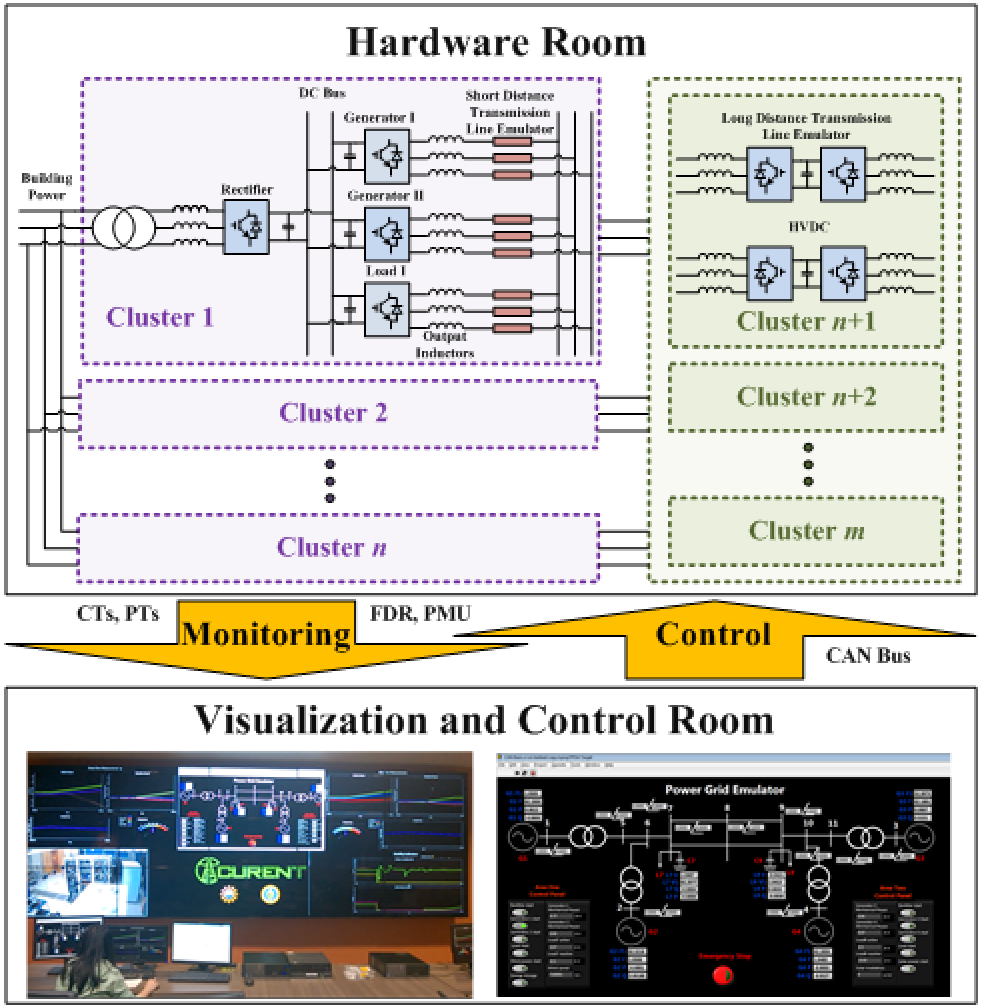






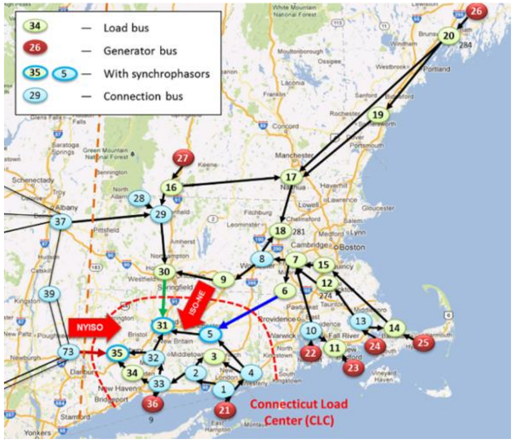


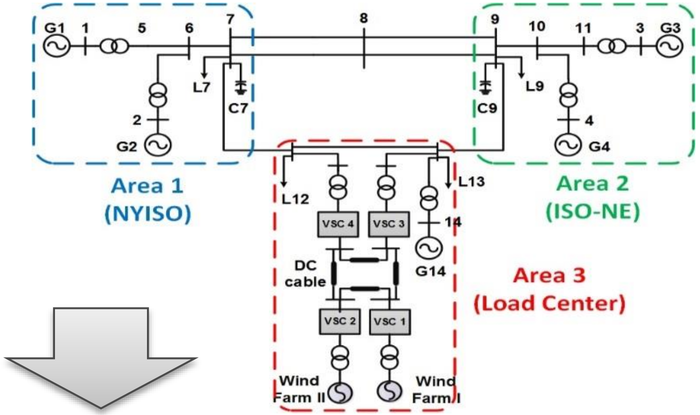
CURENT Hardware Testbed System: power converter-based reconfigurable power grid emulator [3]

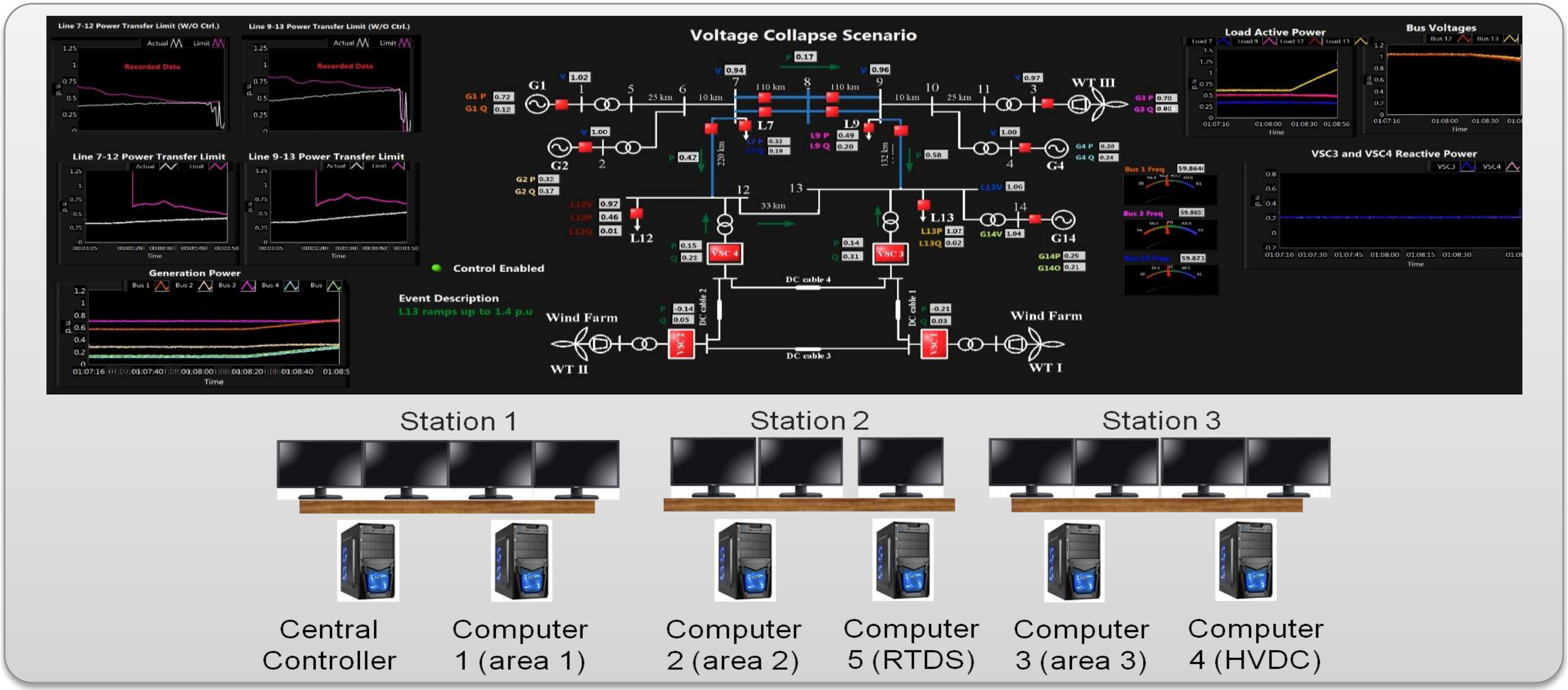


[3] L. Yang, et al, "Development of converter based reconfigurable power grid emulator," 2014 IEEE ECCE in Pittsburgh, PA

Demonstration on CURENT Hardware Test Bed System [4]







[4] F. Hu et al, "Measurement-based Voltage Stability Assessment and Control on CURENT Hardware Test Bed System," 2016 IEEE PES General Meeting in Boston, MA

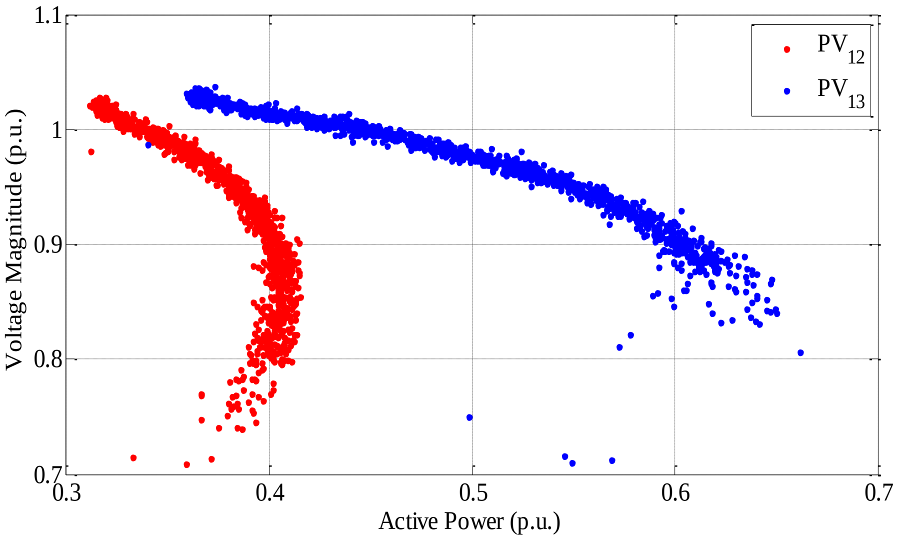
Closed-loop control to prevent voltage collapse

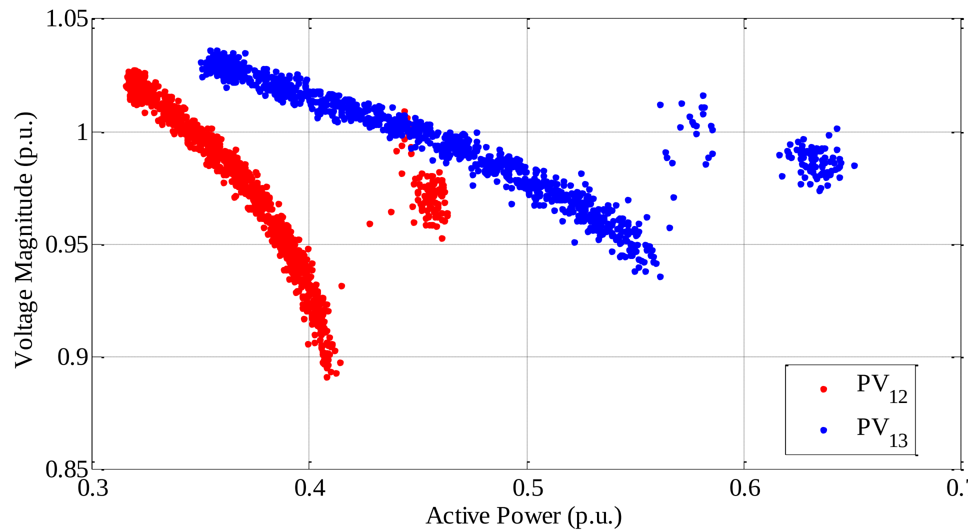
Without control

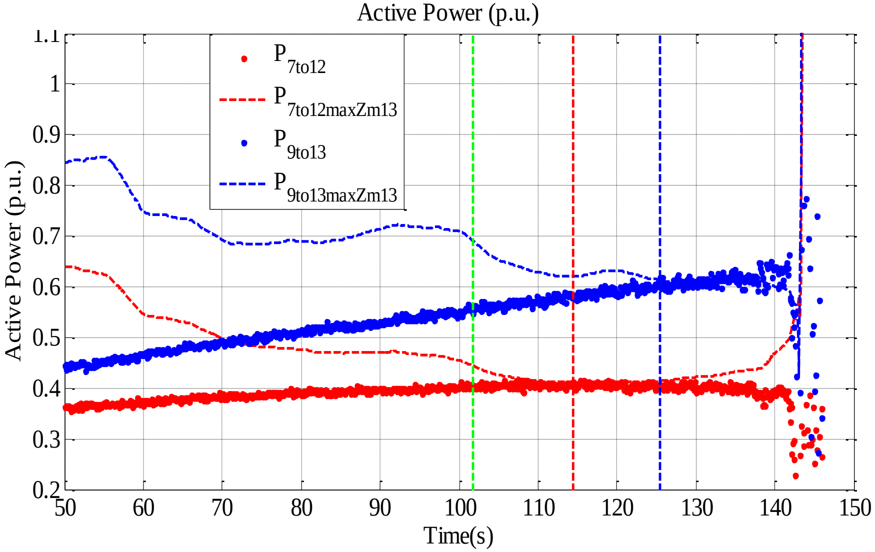
Load increases in the load area leading to voltage collapses.

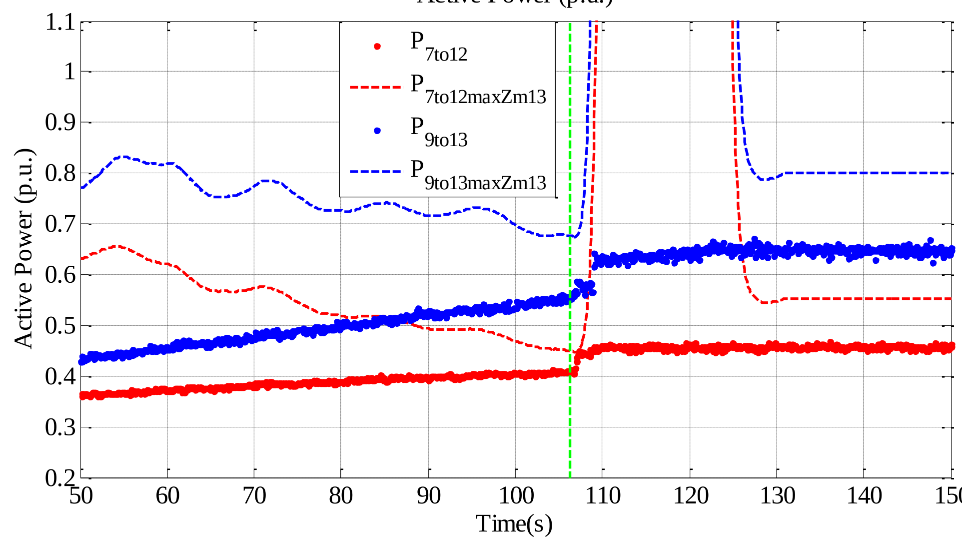
With control

Provide Q via MT-HVDC when any tie line margin is below a threshold

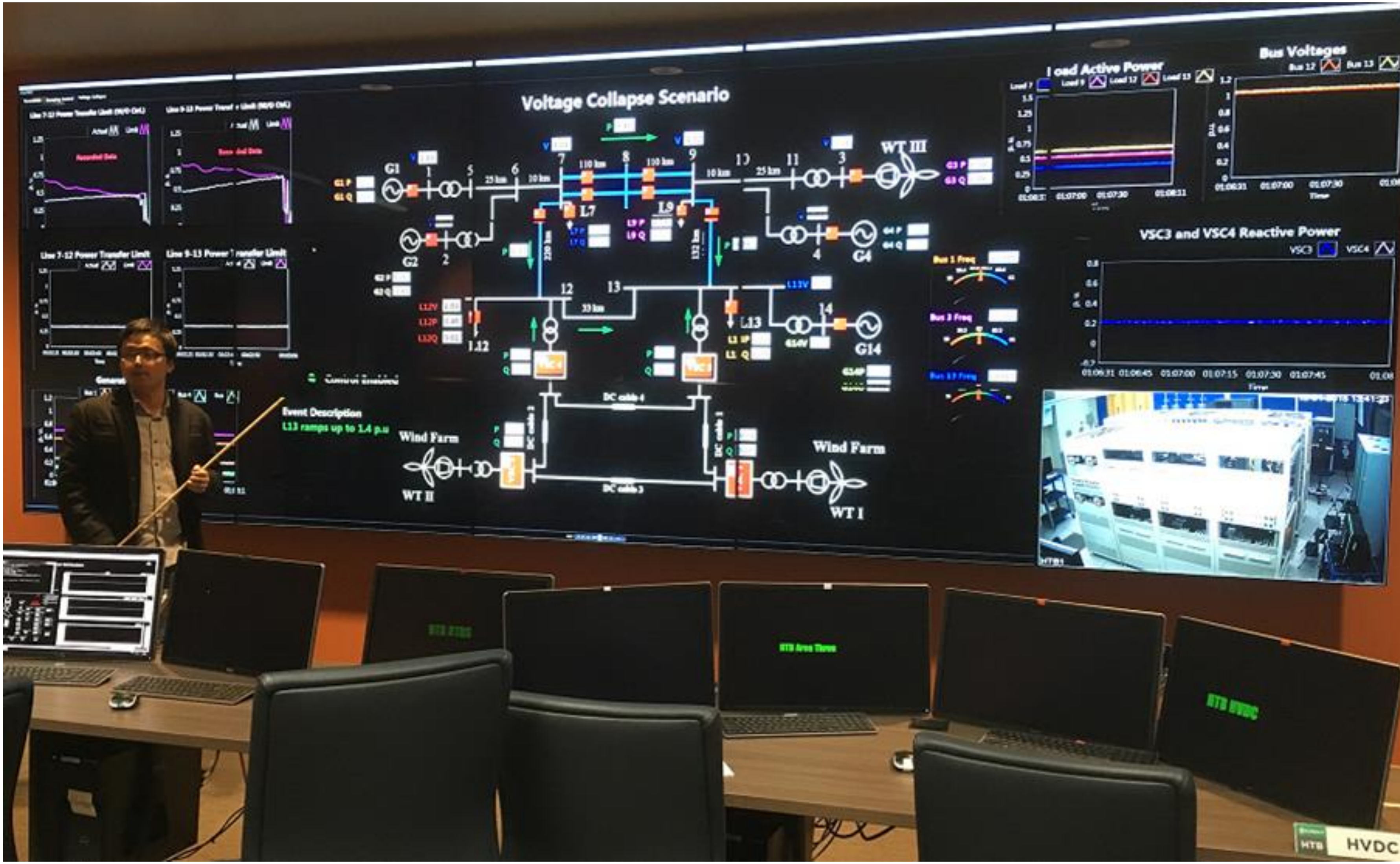








Demonstration on CURENT Hardware Testbed System



Q&A

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