DOE/OE Transmission Reliability Program

Voltage Stability

Scott Ghiocel and Joe Chow
Rensselaer Polytechnic Institute
ghiocel@alum.rpi.edu, chowj@rpi.edu
June 3-4, 2013
Washington, DC

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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)

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

Removed *P* equation

Specified bus angle

Reduced Jacobian

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

[1] Ghiocel, S.G.; Chow, J.H., "A Power Flow Method Using a New Bus Type for Computing Steady-State Voltage Stability Margins," *IEEE Transactions on Power Systems*, vol.29, no.2, pp.958-965, March 2014

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Features of the *AQ*-Bus Method

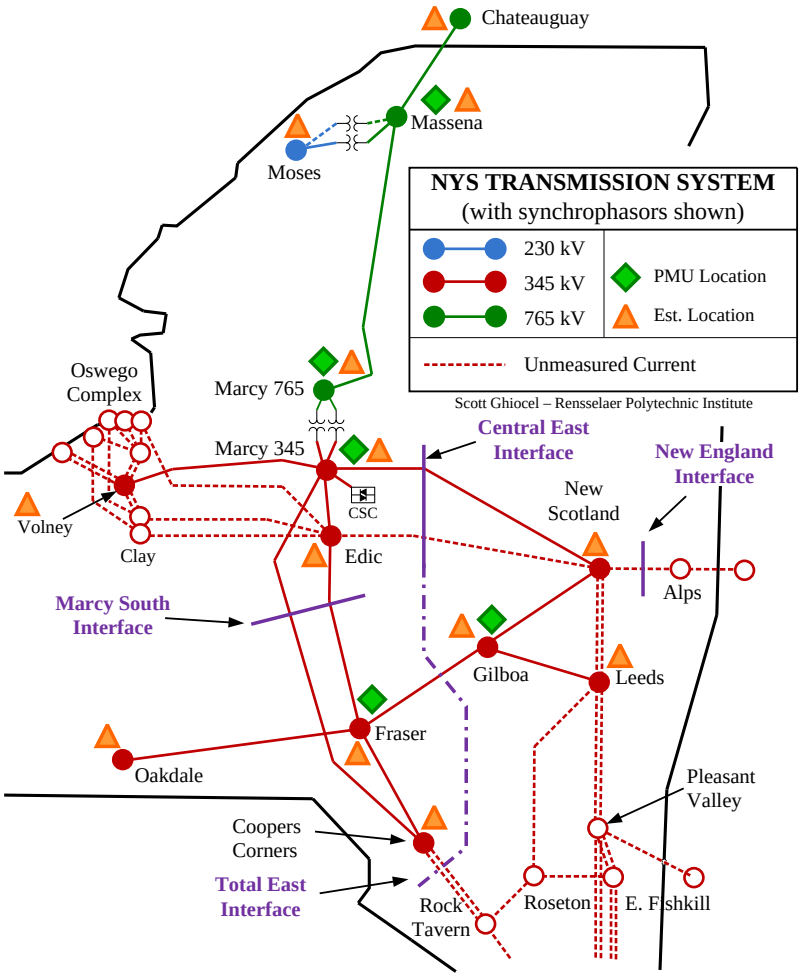
- Includes all features of conventional power flow:
  - Tap-changing transformers
  - Shunt compensation
  - Reactive power limits
- Compute VS margins by adjusting the *AQ* bus voltage angle relative to the swing (*AV*) bus → indirectly increases power transfer
- Accommodates multiple loads and generators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

Bus types	Bus representation	Fixed values
PV	Generator buses	Fixed active power generation and bus voltage
PQ	Load buses	Fixed active and reactive power consumption
AV	Swing bus (generator)	Fixed angle (A) and voltage magnitude
AQ	Load bus	Fixed voltage angle and reactive power consumption

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Hybrid VSA Example: Central NY

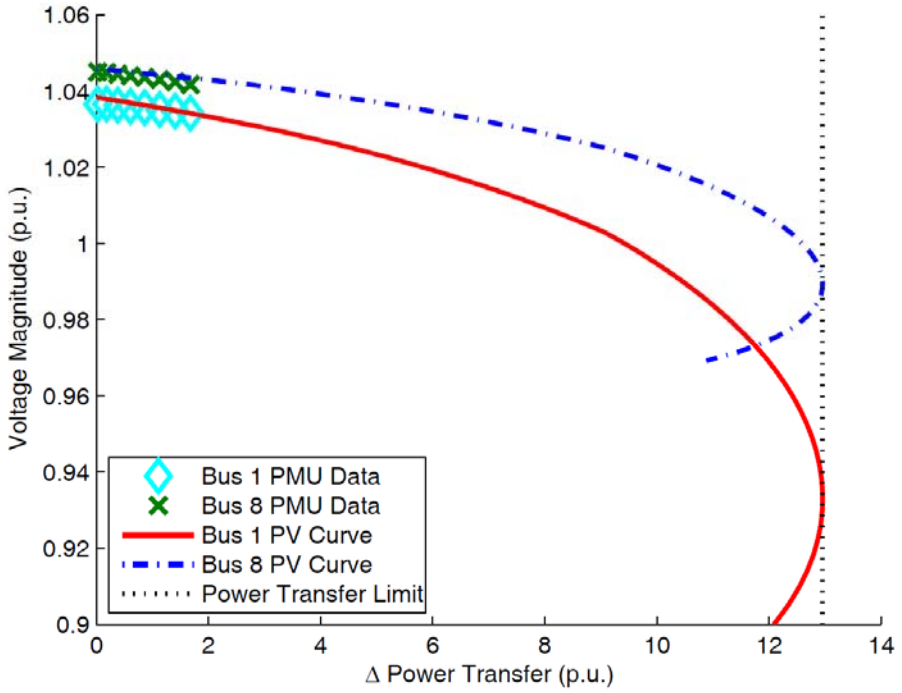
- Phasor data from 6 PMUs provided by New York Power Authority (NYPA)
- 13-bus observable subnetwork
- Pseudo-PMU data calculated on the non-PMU buses using a phasor-only state estimator (PSE)
- Power flows from West and North towards NYC
- Critical power transfer interfaces
- Weaker ties to ISO-New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



CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Computed *PV* Curves for NY System

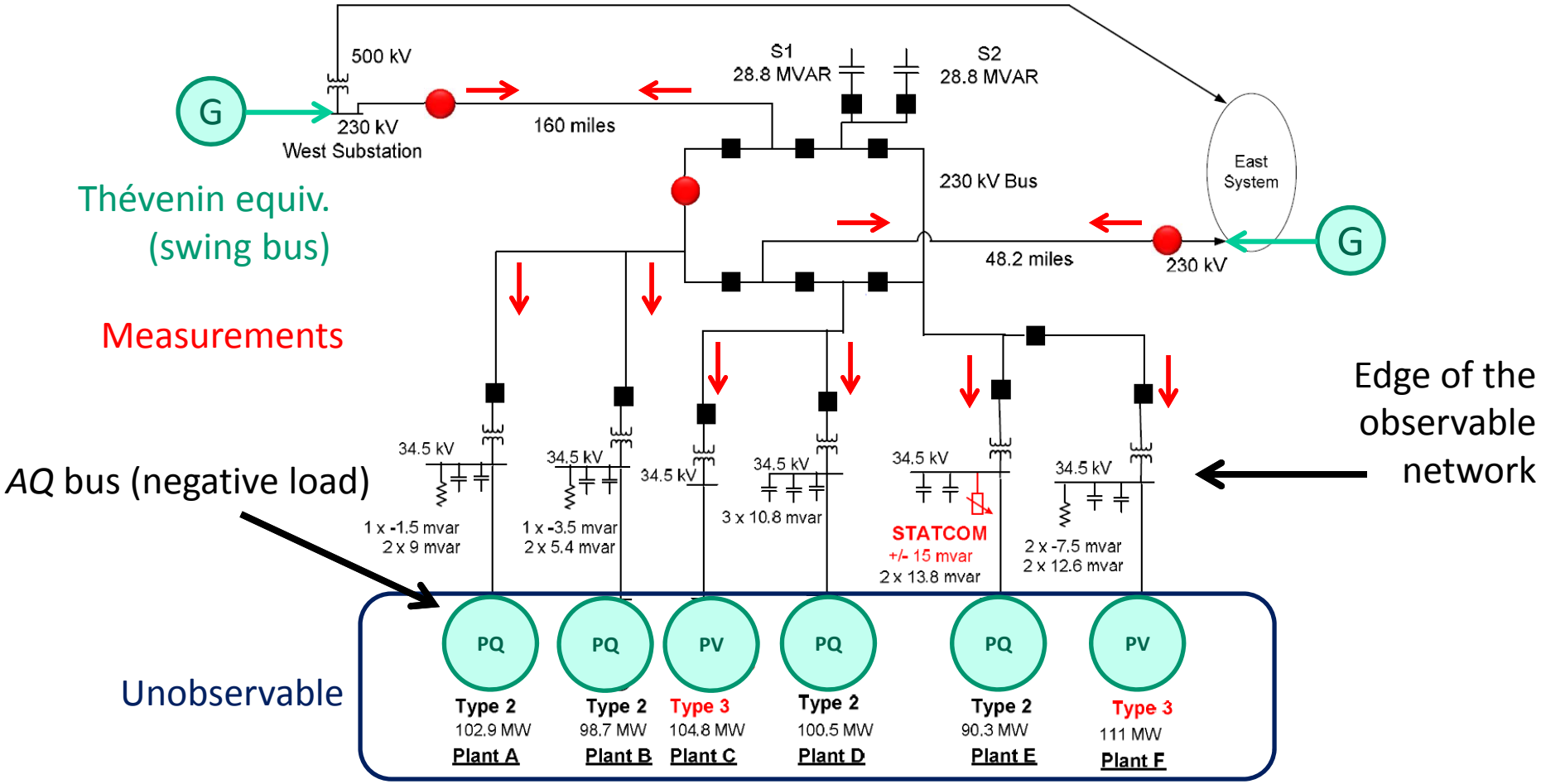
- Calculated *PV* curves based on actual system conditions
- Measurement-adjusted model
- Includes SVC equipment limits
- Multiple generation sources based on information from PMU data



Event	Gen. loss	ΔP_{flow}	Margin
1	800 MW	300 MW	1300 MW
2	700 MW	250 MW	1350 MW

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

BPA Wind Hub Diagram



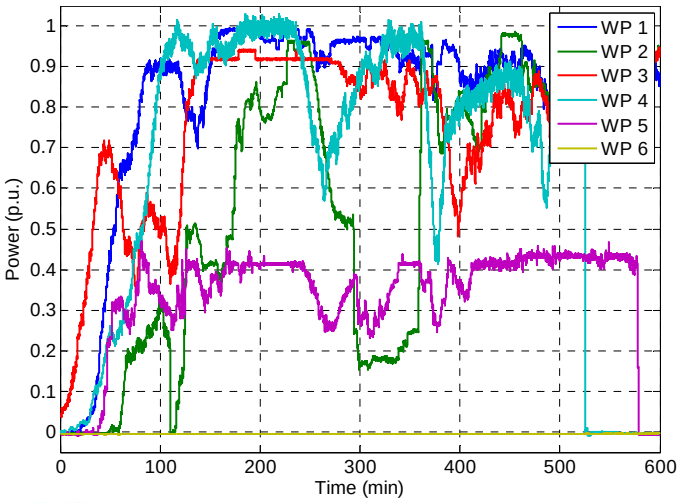
Credit: E. Heredia, D. Kosterev, M. Donnelly, "Wind Hub Reactive Resource Coordination and Voltage Control Study by Sequence Power Flow, *2013 IEEE PES General Meeting*, July 2013.

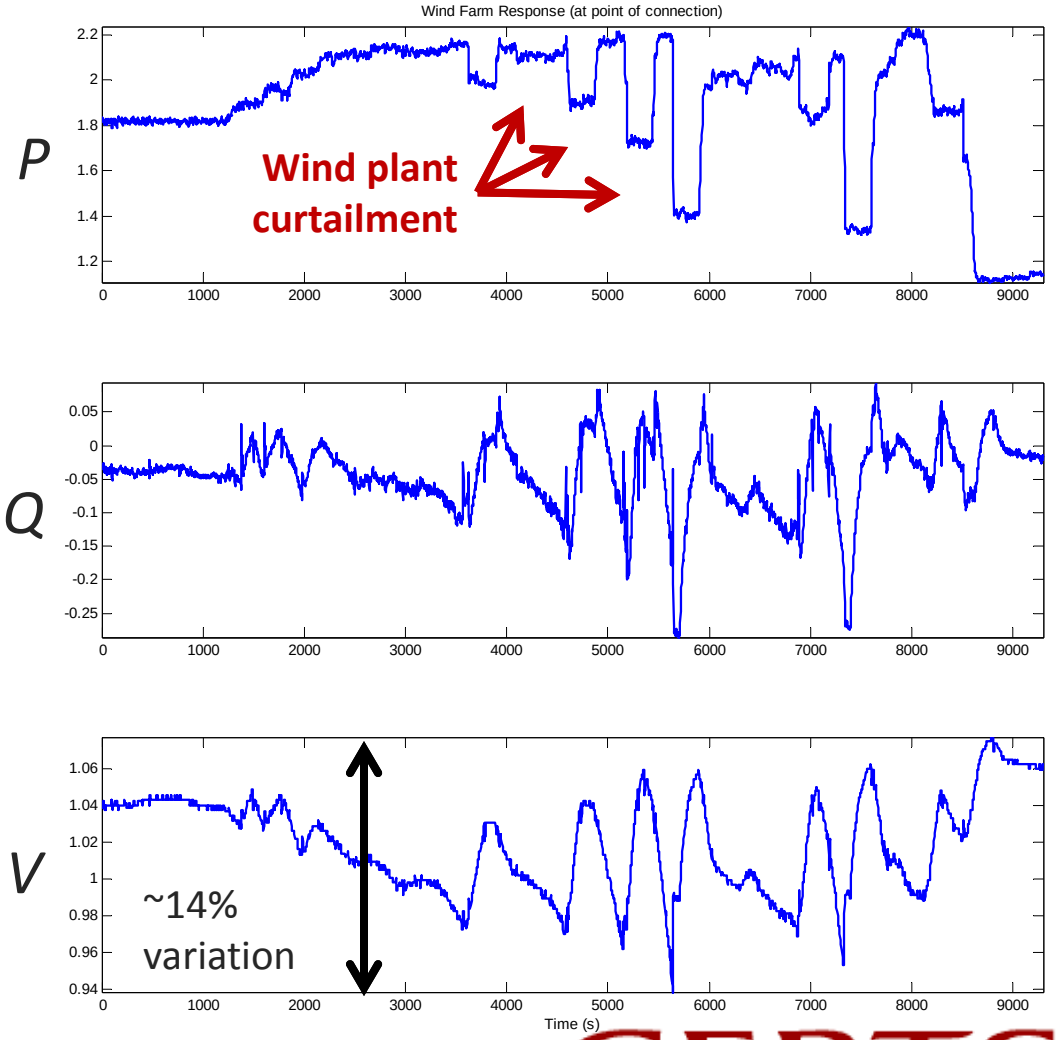
CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Voltage Issues at a BPA Wind Hub

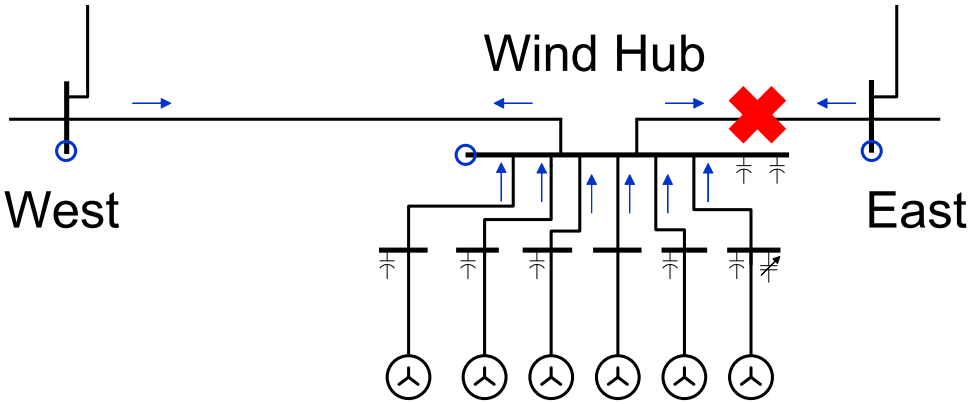
- 600 MW wind interconnection
- Huge voltage variations
- Weak system (line outage)
- Wind plant curtailment
- Shunt capacitor issues

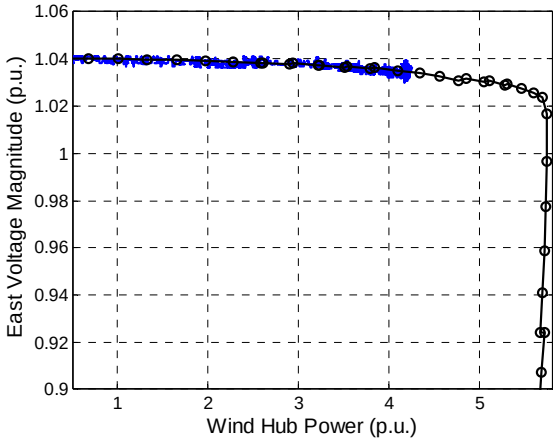
Wind turbine output over 10 hrs



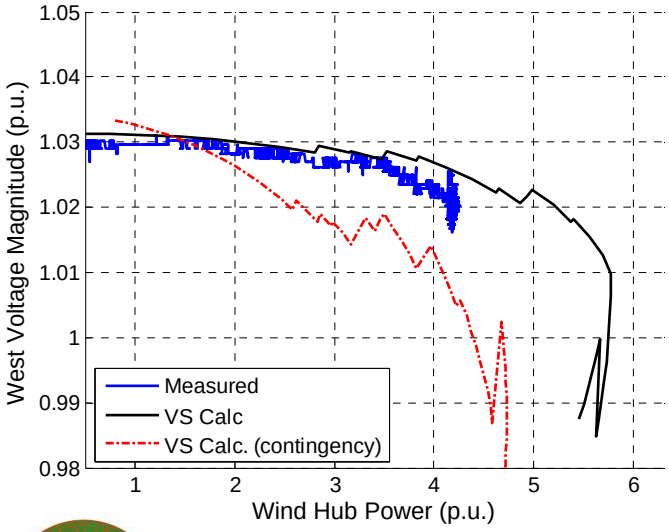


PV Curves with East-WH Line Outage Contingency

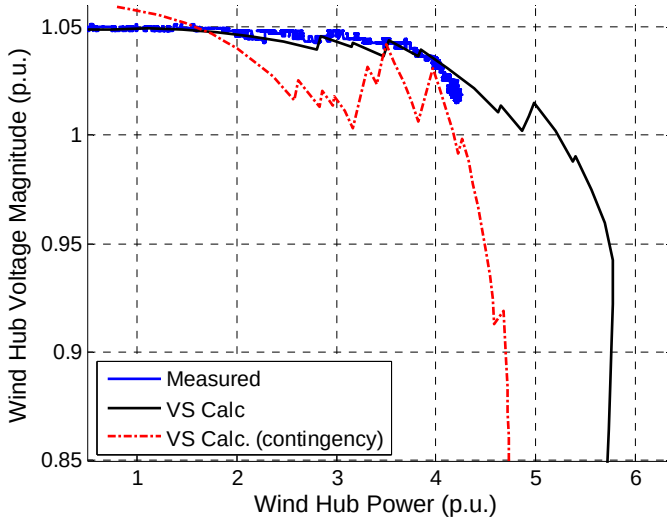




East bus



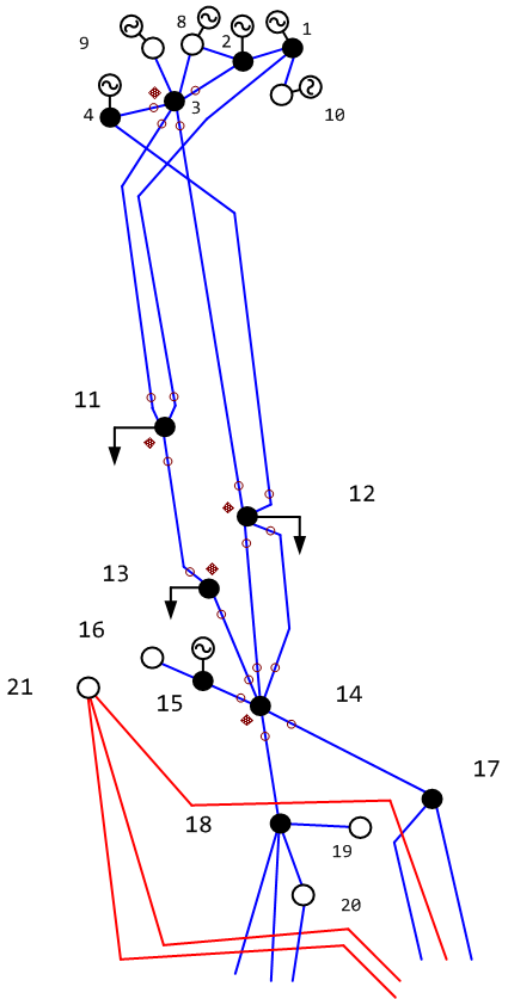
West bus



Wind Hub bus

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Ongoing Analysis: Southern California



- 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

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Accomplishments

- Development of AQ-bus method for VS analysis:
  - Publications
    - S.G. Ghiocel, J.H. Chow, "A Power Flow Method Using a New Bus Type for Computing Steady-State Voltage Stability Margins," *IEEE Transactions on Power Systems*, vol.29, no.2, pp.958-965, March 2014
    - S.G. Ghiocel, J.H. Chow, R. Quint, D. Kosterev, D.J. Sobajic, "Computing measurement-based voltage stability margins for a wind power hub using the *AQ*-bus method," *Power and Energy Conference at Illinois (PECI),* March 2014
    - S.G. Ghiocel, J.H. Chow, G. Stefopoulos, B. Fardanesh, D. Maragal, D.B. Bertagnolli, M. Swider, M. Razanousky, D.J. Sobajic, "Phasor-measurement-based Voltage Stability Margin Calculation for a Power Transfer Interface with Multiple Injections and Transfer Paths," *Power Systems Computation Conference*, August 2014 (accepted)
  - 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