Voltage Stability Management

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Pacific Gas and Electric Company

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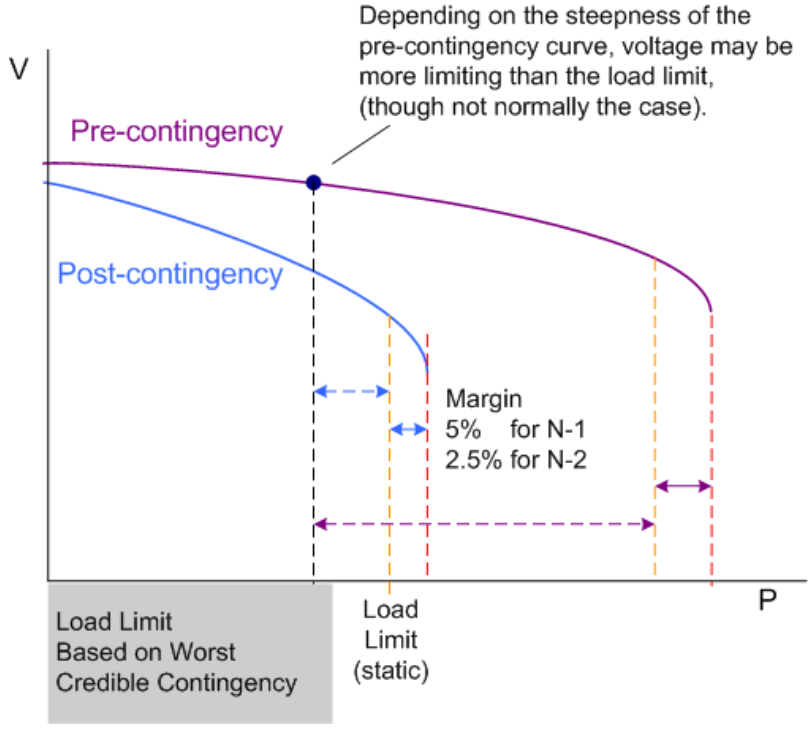
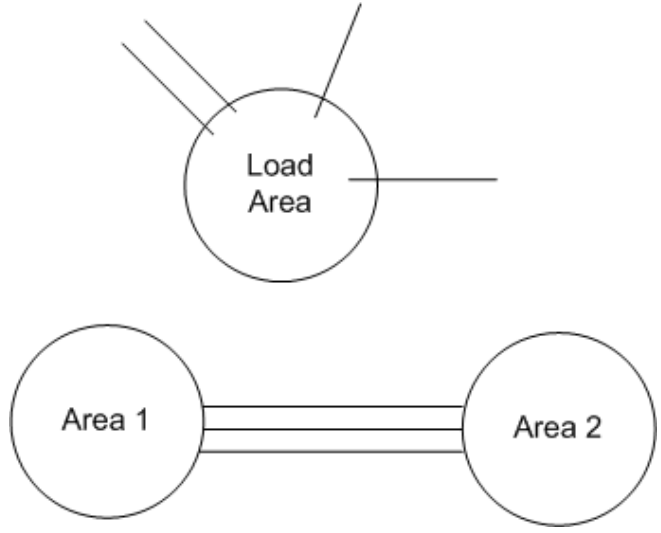
Outline

- Voltage stability management at PG&E
  - What PG&E currently does
  - Features desired in future applications
- Upcoming solutions
  - Model-based Approach
  - Measurement-based Approach
  - Hybrid Approach
- Use of PG&E's Synchrophasor Proof of Concept Facility
  - Development
  - Testing
- Conclusions

Voltage Stability at PG&E – The Present Practice

- Currently voltage stability management at PG&E is based primarily on off-line studies.
  - In most situations PG&E is thermally limited before being voltage stability limited.
  - Where voltage stability limits are an issue, static load limits are established based on PV analysis.



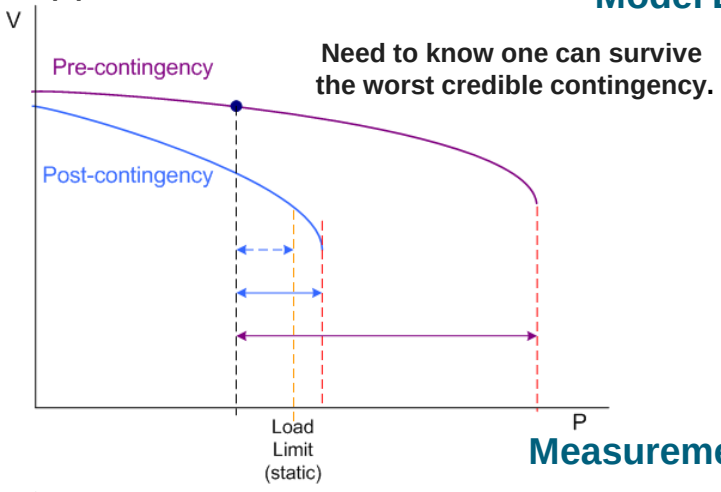


- Load limits and voltage magnitudes are monitored in real time.
- System operated to ensure limits are respected, (generation dispatch / work scheduling).
- Problem: Static Limit…. So would like to compliment off-line studies with real-time analysis.

Voltage Stability at PG&E – Looking Forward

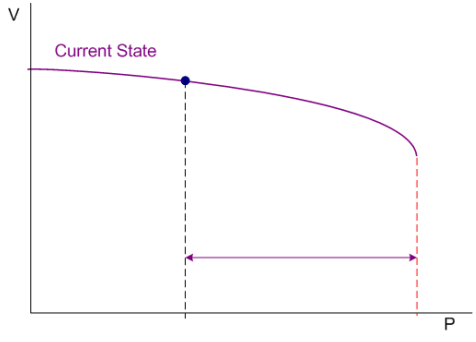
- PG&E is looking forward to supplementing static limits based on studies, with real-time voltage stability assessments. Looking to both Model based and Measurement based applications.

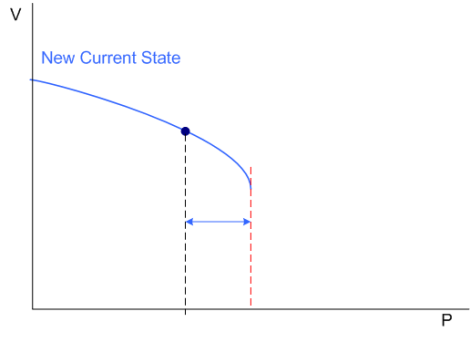
Model Based Application



- Can provide contingency based assessment and current state assessment.
- Ideally provide not just an assessment, but a limit.
- Requires a Model of the Power System (which must be kept up-to-date).
- May be slower than measurement based applications.

Measurement Based Application





- Gives only current state.
- Does not require keeping up a power system model.
- May be faster than model based.
- May be more appropriate for automatic control schemes.

- Each compliment each other and off-line studies.
- PG&E has run PowerTech's VSAT (model based) on its EMS system, to provide a real-time indication of voltage stability, but at this time it is not used on a consistent basis.

Voltage Instability Related Work by Others? A small sample

- Sandro Corsi, and Glauco N. Taranto – IEEE Transaction 2008
- Vijay Vittal, e.t.al - ASU, Sharma Kolluri, et. al – Entergy –- Decision Tree Assisted Online Security Assessment using PMU measurements; PSERC Project 2008
- Venkataramana Ajjarapu - Iowa State Univ - Computational Techniques for Voltage Stability Assessment and Control – 2007 – Publisher, Springer
- IEEE and CIGRE technical committee on Stability Terms and Definitions
- A lot of work within the WECC Dynamic Modeling and Validation and Technical Study Subcommittee
- K. Vu and D. Novosel, “Voltage Instability Predictor (VIP) - Method and System for Performing Adaptive Control to Improve Voltage Stability in Power Systems,” US Patent, April 2001.
- K. Vu, M. M. Begovic, D. Novosel, and M. M. Saha, “Use of Local Measurements to Estimate Voltage-Stability Margin”, IEEE Trans., Aug. 1999
- J. A. Diaz de Leon, C. W. Taylor, “Understanding and Solving Short Term Voltage Stability Problems,” Proc. IEEE PES Summer Meeting 2002, Jul. 2002.
- T. Van Cutsem, C. D. Vournas, “Emergency Voltage Stability Controls: An Overview,” Proc. IEEE PES General Meeting, Tampa, Jun. 2007.
- M. Glavic, D. Novosel, E. Heredia, D. Kosterev, A. Salazar, F. Habibi-Ashrafi, M. Donnelly, “See It Fast to Keep Calm,” IEEE Power and Energy Magazine, July/August 2012.
- M. Glavic, D. Lelic, and D. Novosel, "Real-Time Monitoring of Electric Power System Voltage Stability Margins,” US Patent
- …….
- …….

Voltage Stability Management – Model Based

- Reactive Reserve Monitoring (RRM) or Alerts
  - Definition (usually offline) of reactive power zones
  - Real-time accounting of reactive margin in each of the zones by adding up unused reactive power capability of generators, and summing up potential output of cap/reactor banks (those that have not been switched on yet)
  - Contingency reactive power demand, which is the difference of the Reactive Reserve in the base case and after the contingency
- SIL Monitoring – A single line limit based on the value of a flow for which the reactive power production (due to capacitance of the line) equals the loss of reactive power along the line (does not take into account VAR support from the neighbors).
- Voltage Stability Assessment - SE-based system dynamic model with relevant contingencies and stress patterns to detect how far the system can be stressed
  - Defines a margin (e.g. corridor MW and MVAR power) as difference of the monitored quantity at the collapse and the base case

Voltage Instability Tool – Measurement Based

Designed for fast Dynamic Phenomenon

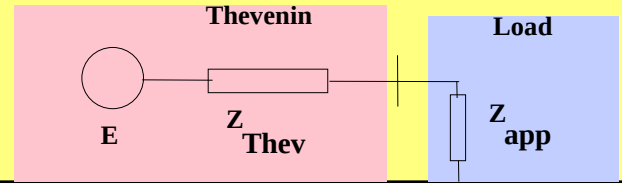
Accuracy compared to model-based methods that requires accurate models

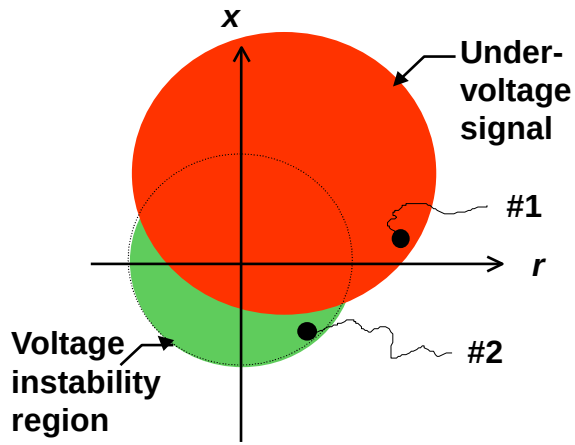
- Distance of the load's apparent impedance to the Thevenin impedance (VIP, REI, RVII)
  - Detecting closeness to instability and local reactive power margins – Can be applied for local UVLS
  - Accuracy improves as closer to instability
  - Could trigger detailed contingency analysis
- Monitor available reactive power levels (capacitor/reactor reserves, tap-changers)
- Singular Value Decomposition & Sensitivity Analysis
- Predictive capability may be beneficial
  - Contingency Analysis comparison

Maximum power transfer

$$\Leftrightarrow |Z_{app}| = |Z_{Thev}|$$

Point of collapse





For accurate calculation of Equivalent Impedance & Reactive Margin important to consider:

1. **Observability – Absence of a PMU**
2. **Multiple iteration computation**
3. **Flags help**
   - **Identify Unloaded and open ended systems**
   - **Incorporate switching or outages, e.g. line or equipment, bypassing capacitors**
   - **Incorporate loss of a PMU data (e.g.: momentary bad network connection)**

#1: Inaccurate under-voltage detection

#2: Under-voltage fails to detect

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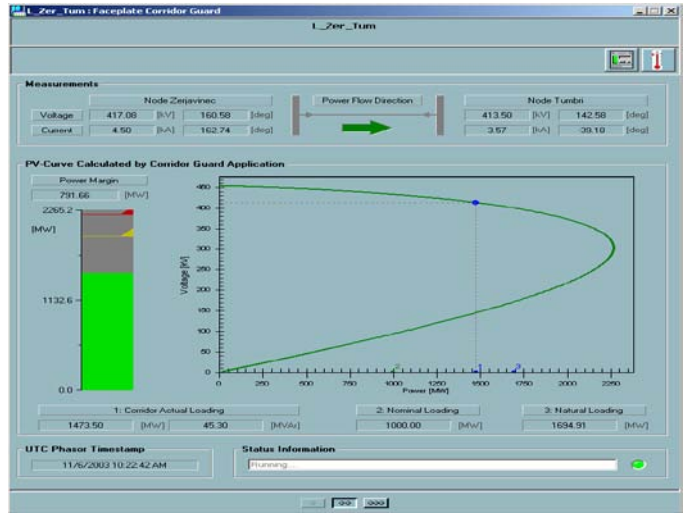
Voltage Instability Monitoring - VSA

- Reactive Reserve Margin (RRM) and VSA margins should get closer as the system moves toward a collapse but are not the same
- Real-time tracking of the relative distance from voltage instability boundary
  - Distance to the PV curve nose
  - State Estimation based stability boundary
- Provide predictive capability
- Important to validate model accuracy



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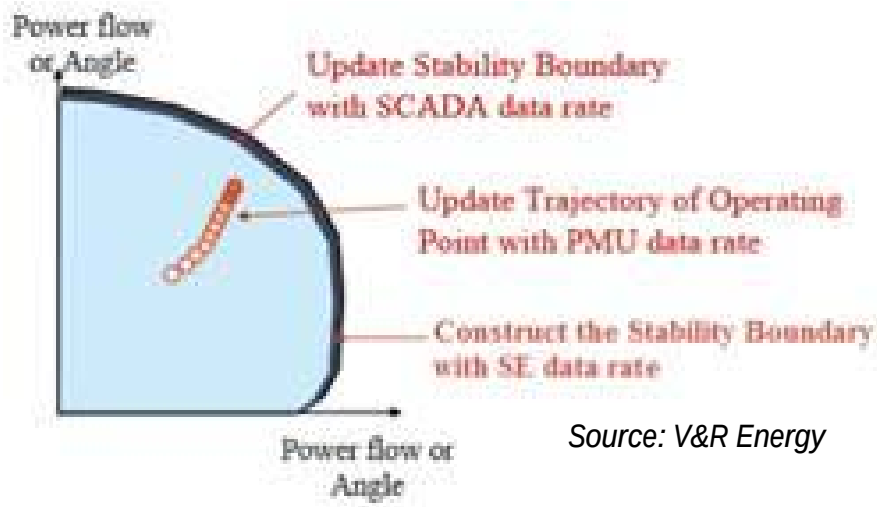

Source: V&R Energy

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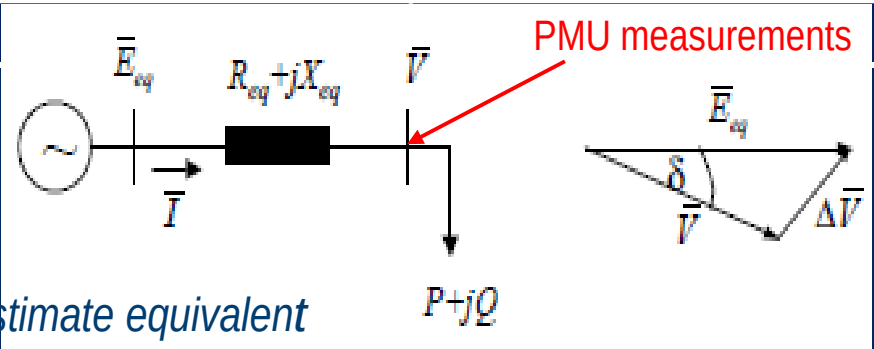
A Hybrid Approach to Voltage Stability Assessment

An integrated "MEASUREMENT-BASED" and "MODEL-BASED" approach

MEASUREMENT-BASED

PMU

Real-Time Voltage Instability Indicator (RVII)



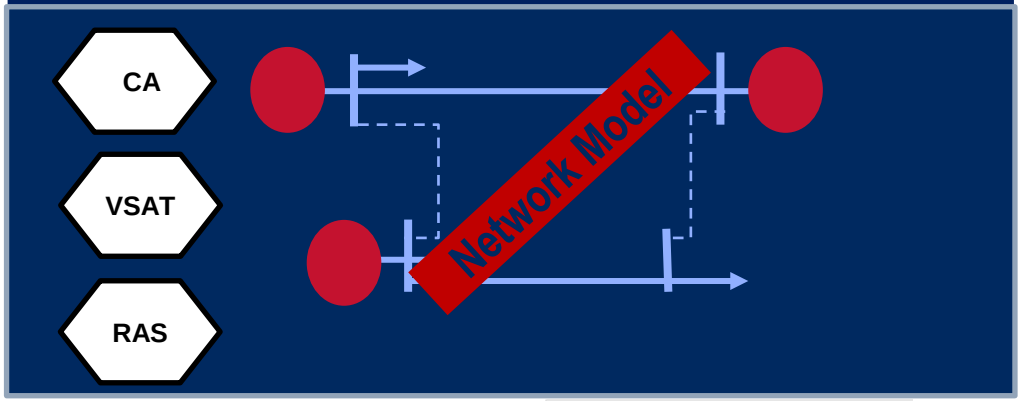
Estimate equivalent parameters in real-time

Real-time Alerts

- Bus Voltage (V)
- Equiv. Imped. (Z_{eq})
- Reactive Margin (Q_{margin})

MODEL-BASED

EMS & Online-DSA Applications



Predict *HOW* to respond / Advance Arming (accurate model).

- Predict Q_{margin} *changes* under *"worst case" contingency*.
- Provide recommendations on *corrective actions.*

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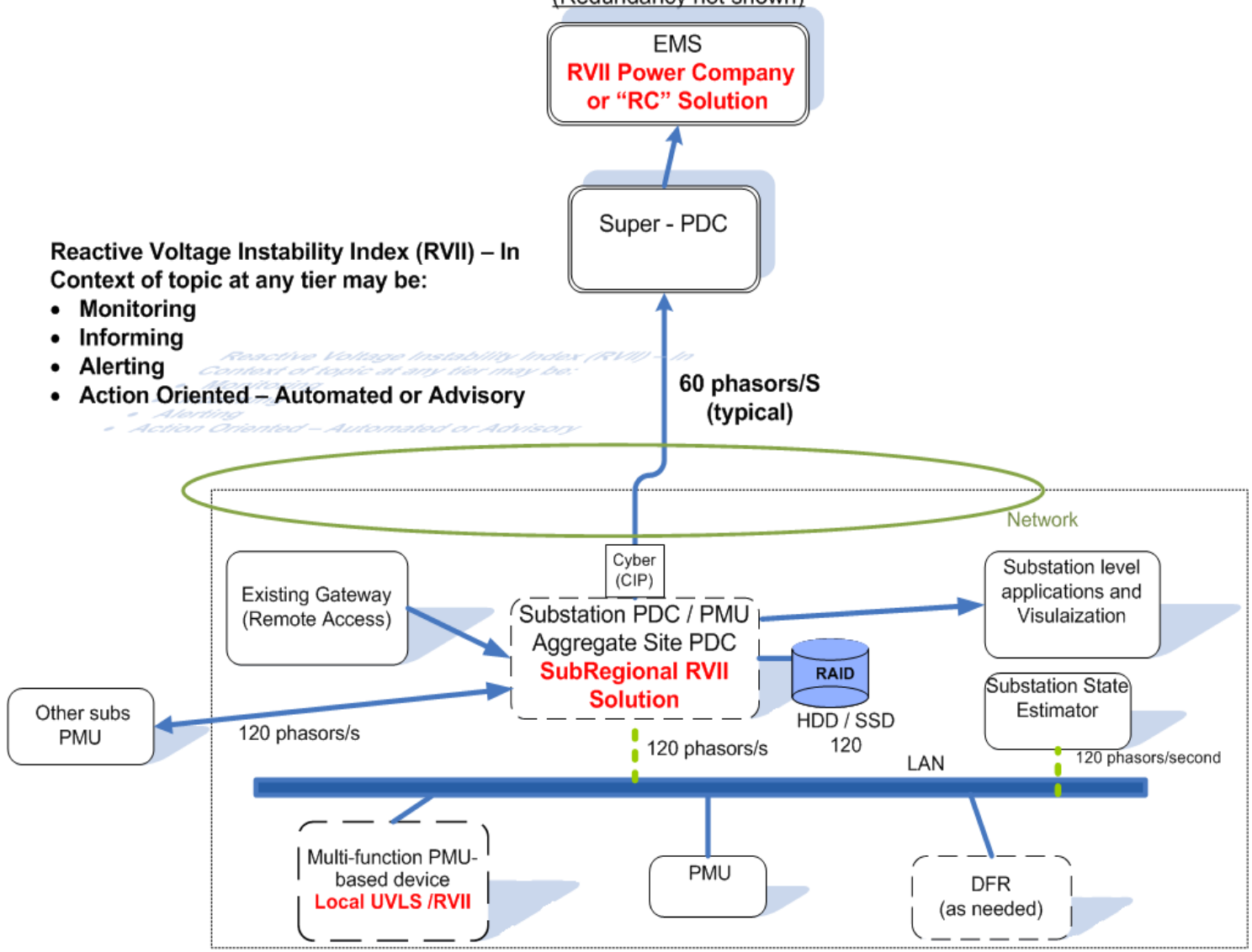
High Level Architecture

(Redundancy not shown)

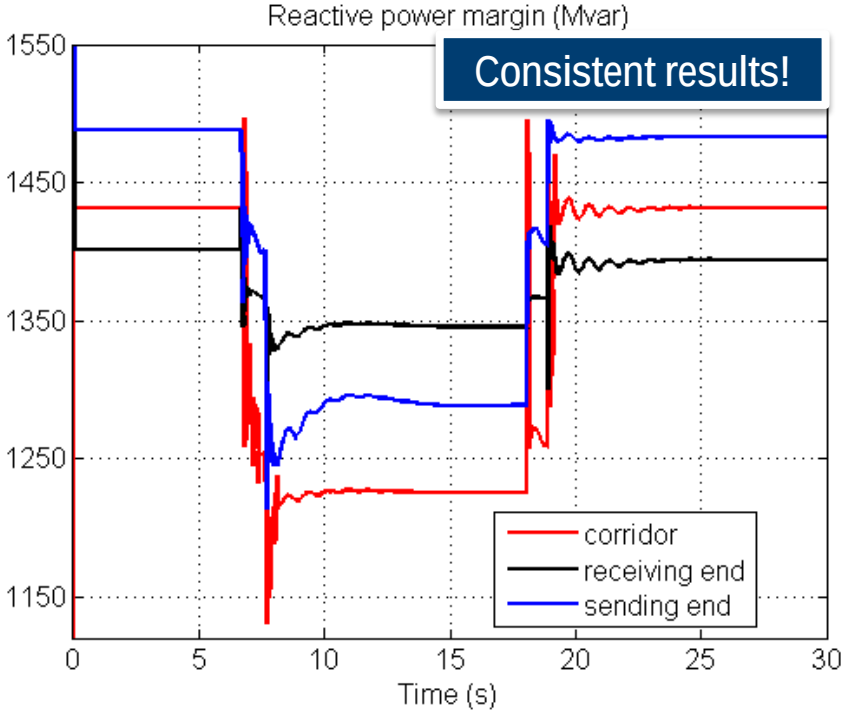


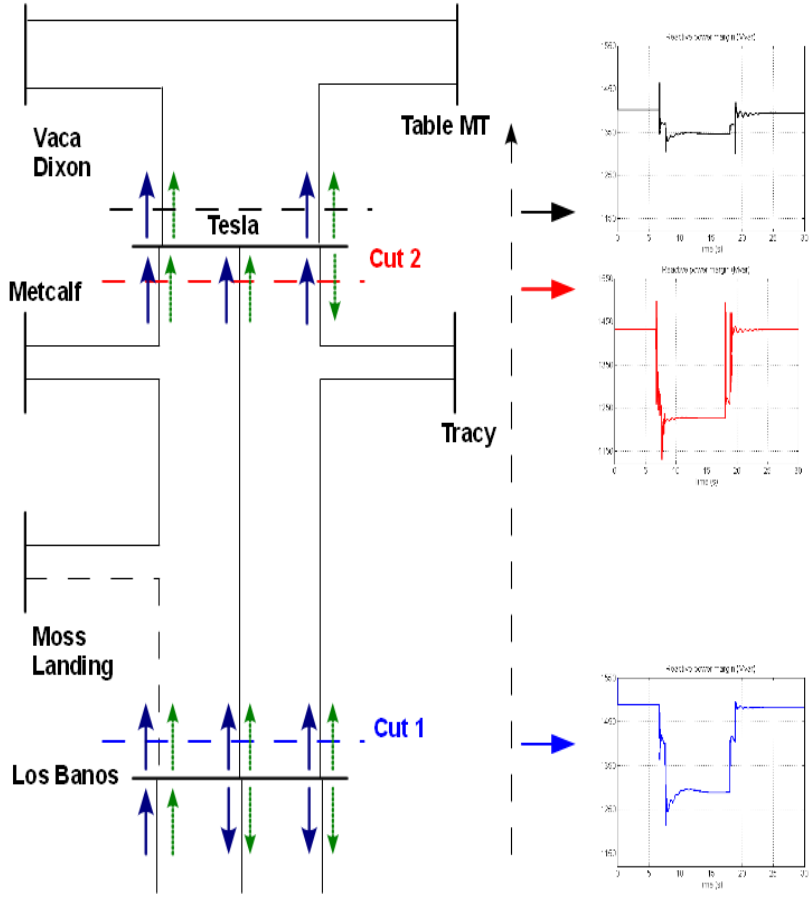
Validating RVII at Proof-of-Concept (PoC)- Results

Increased accuracy with improved observability when tracking Q_{margin}

- **Having additional information provides security provision in computing reactive margin values**

CASE 1: *PMUs at both sending & receiving ends*
CASE 2: *PMU at sending end only*
CASE 3: *PMU at receiving end only*





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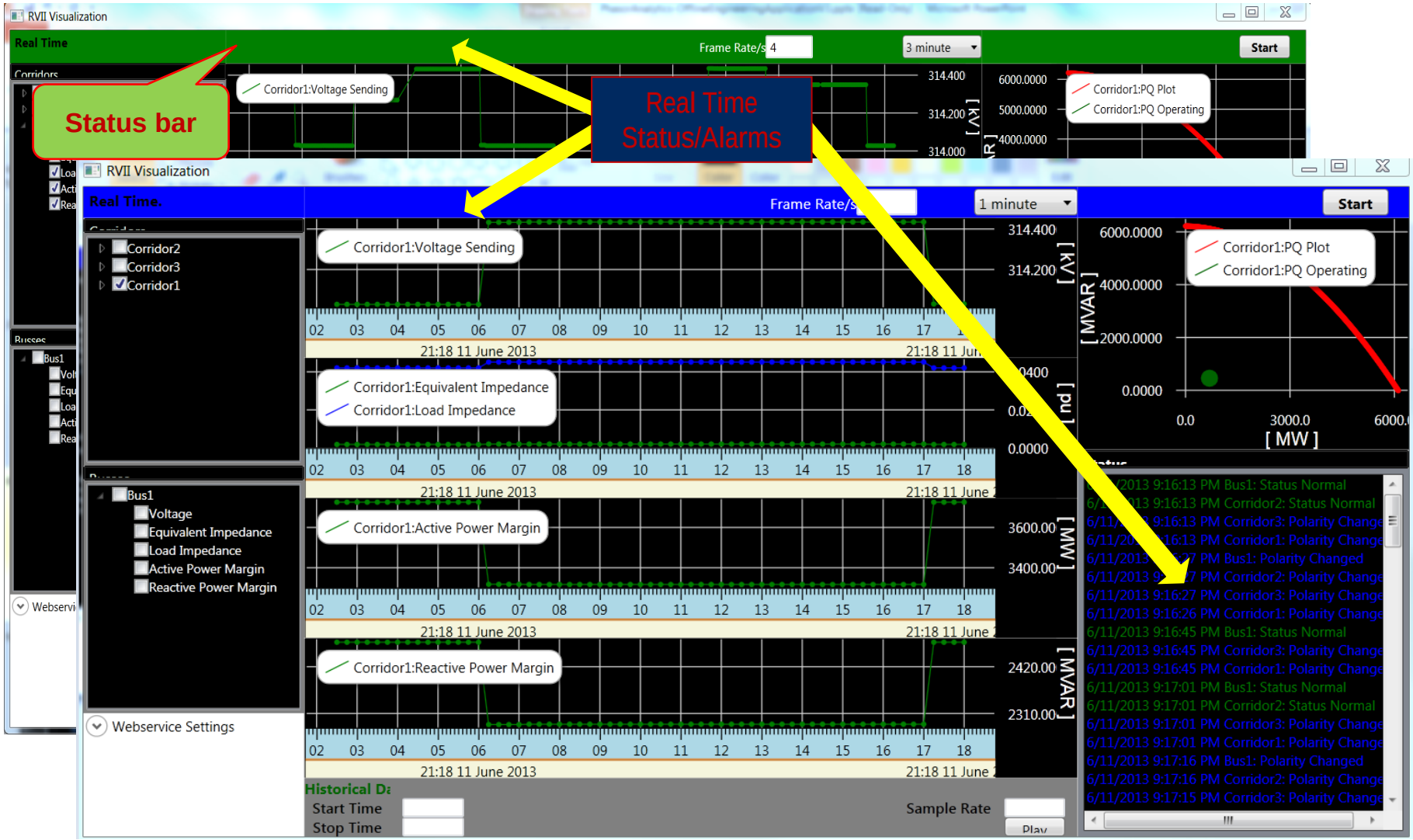
Real Time Bus and Corridor Status Monitor



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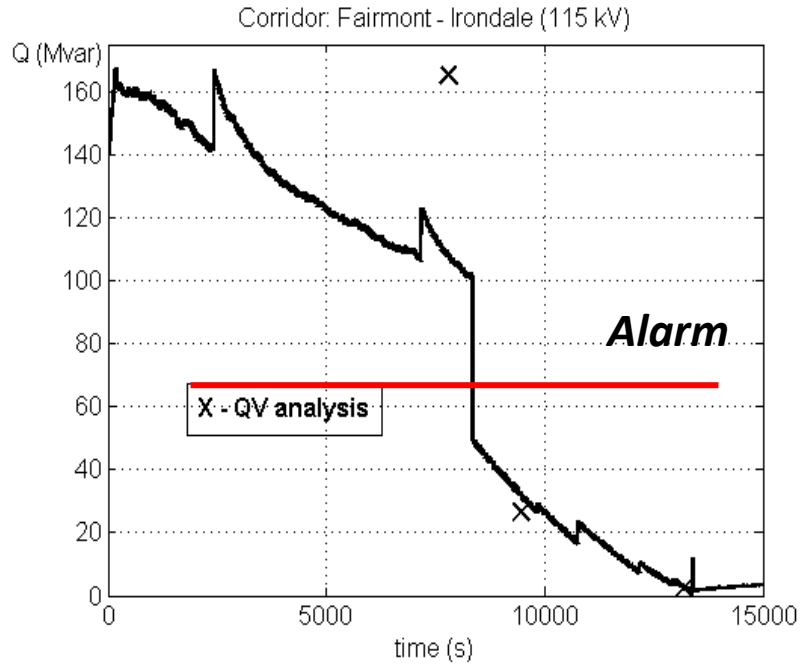
Voltage Management Conclusions

- Comprehensive solution for voltage management is to use a combination of selected methods
  - Each method offers some benefits, as they reflect a particular aspect of system operation, various manifestations of instability, measurement configurations, etc.
- Real-time, model-free methods are faster compared to EMS based Systems
  - Good for trend and status monitoring
  - Should offer predictive capabilities - e.g. wind hub prediction for reactive power support needs
- Reactive margin means different thing in different contexts
- Recognizing the Criticality & Importance of Flags
- Contingency Analysis critical to identifying vulnerabilities
- Invaluable - Importance of observability in reactive margin computation



Source: BPA

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Questions and Contacts