Enhanced Reactive Margin Analysis using Synchrophasors

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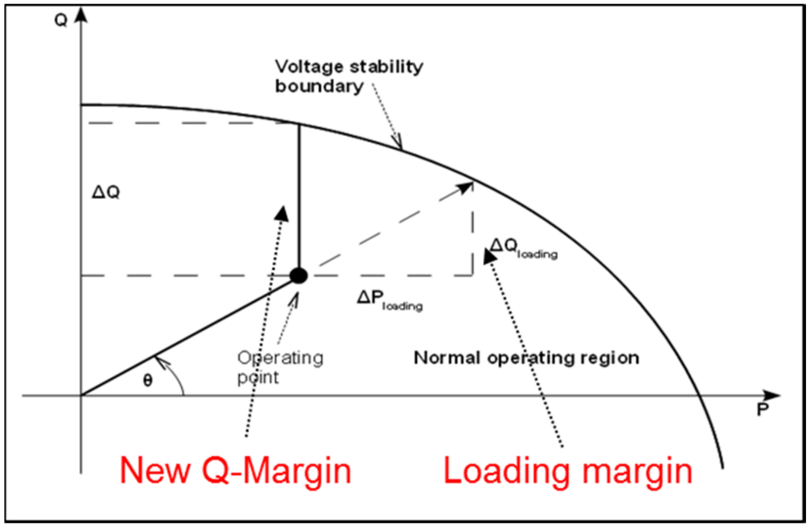
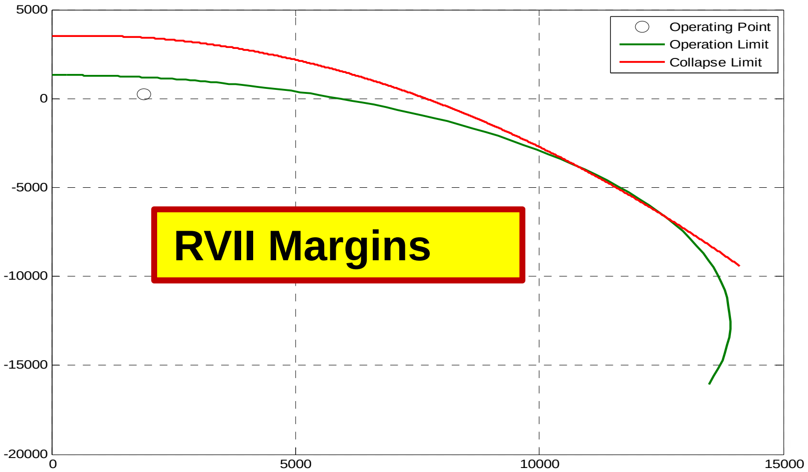
Reactive Power Margins/Reserves

- **Reactive Reserve Monitoring (RRM)**
  - Real-time accounting of reactive margin in each of the zones by adding up unused reactive power capability of generators
  - Summing up potential output of cap/reactor banks (not switched yet)
- **SIL Monitoring** – A single line limit based on the value of a flow for which the reactive power production (due to line capacitance) equals the loss of line reactive power
- **Voltage Stability Assessment**
  - SE-based system dynamic model with relevant contingencies to detect how far the system can be stressed
  - Defines a margin (e.g. corridor MW and MVAR) as difference of the monitored quantity at the collapse and the base case





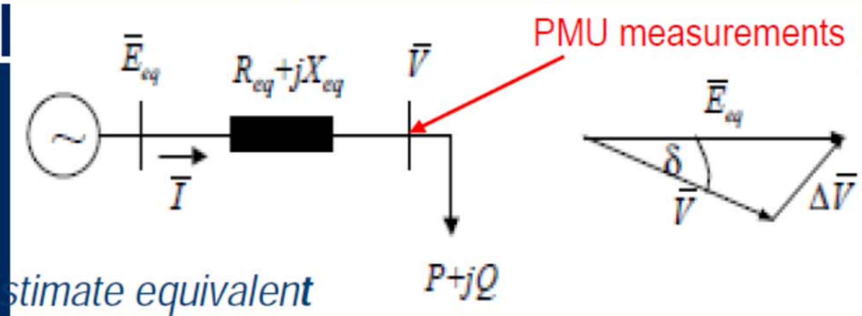
RVII - Real-Time Voltage Instability Indicator

Voltage Stability/Reactive Margin Assessment

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

MEASUREMENT-BASED

Real-Time Voltage Instability Indicator (RVII



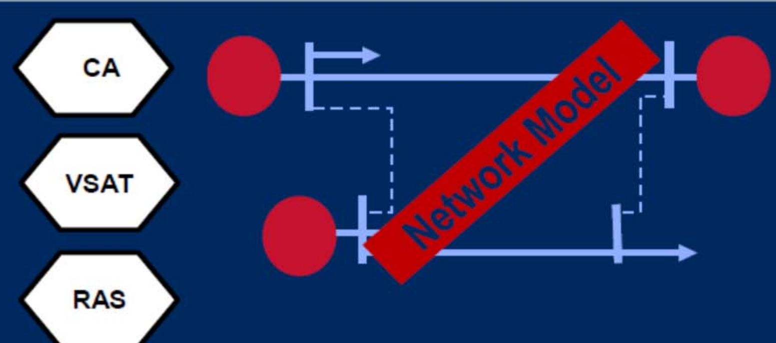
Estimate equivalent parameters in real-time

Real-time Alerts

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

MODEL-BASDED

EMS & Online-DSA Applications



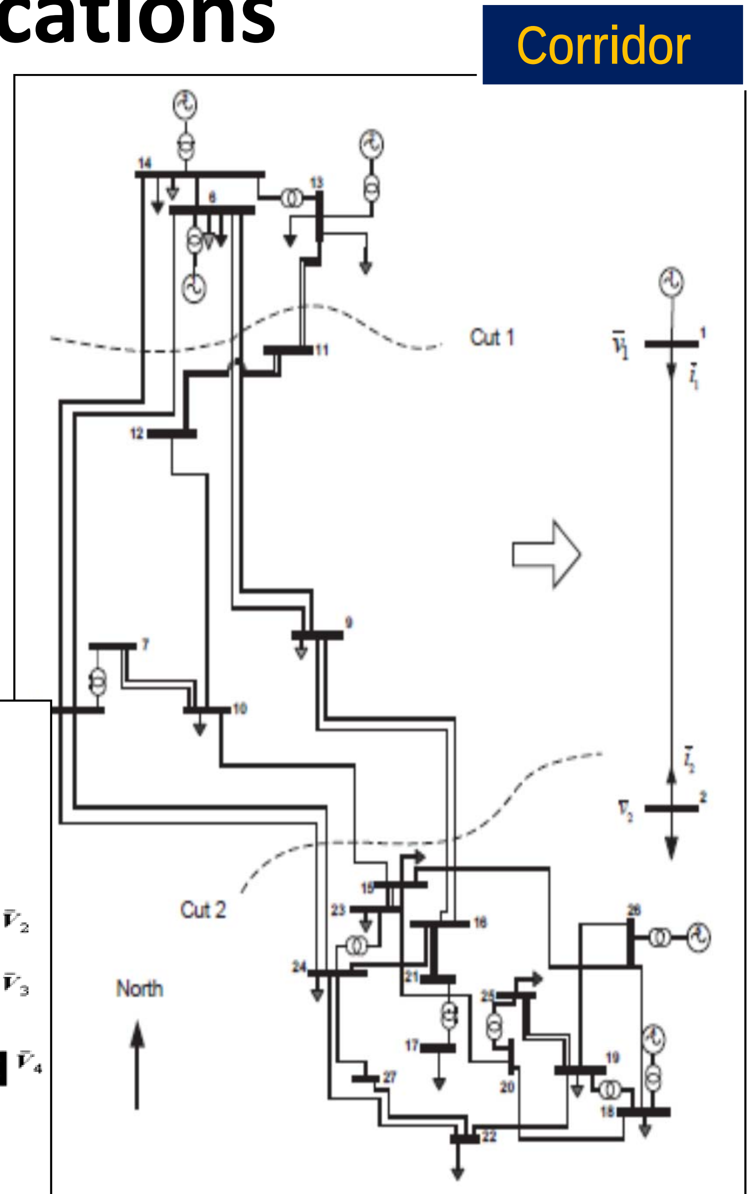
Predict *HOW* to respond / Advance Arming (accurate model).

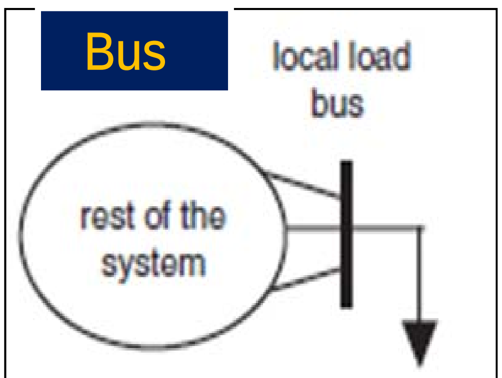
- Predict Q_{margin} *changes* under *"worst case" contingency.*
- Provide recommendations on *corrective actions.*

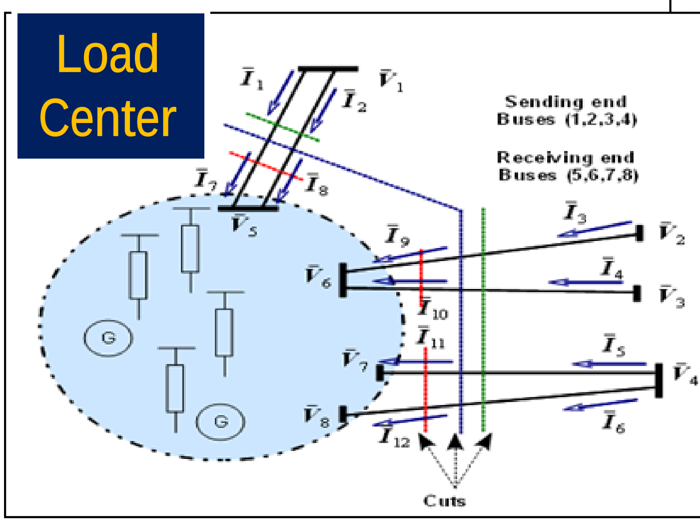
Measurement-Based Applications

RVII configurations:

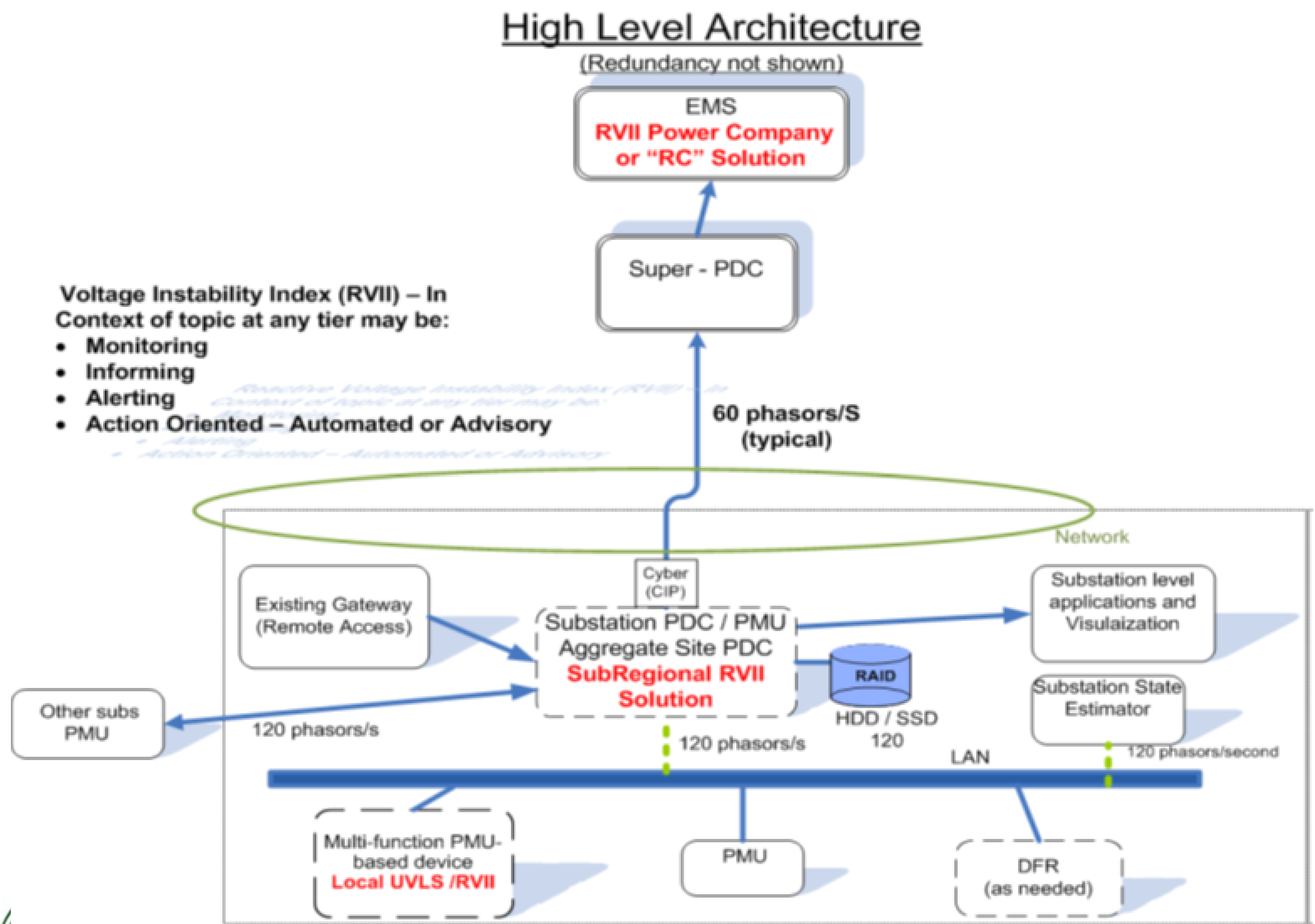
1. ***Bus (measurements at the local station)***
   - ***May also be applied as an Under Voltage Load Shedding tool in a Relay***
2. ***Load Center, including all tie lines***
3. ***Corridor with measurements at both ends***





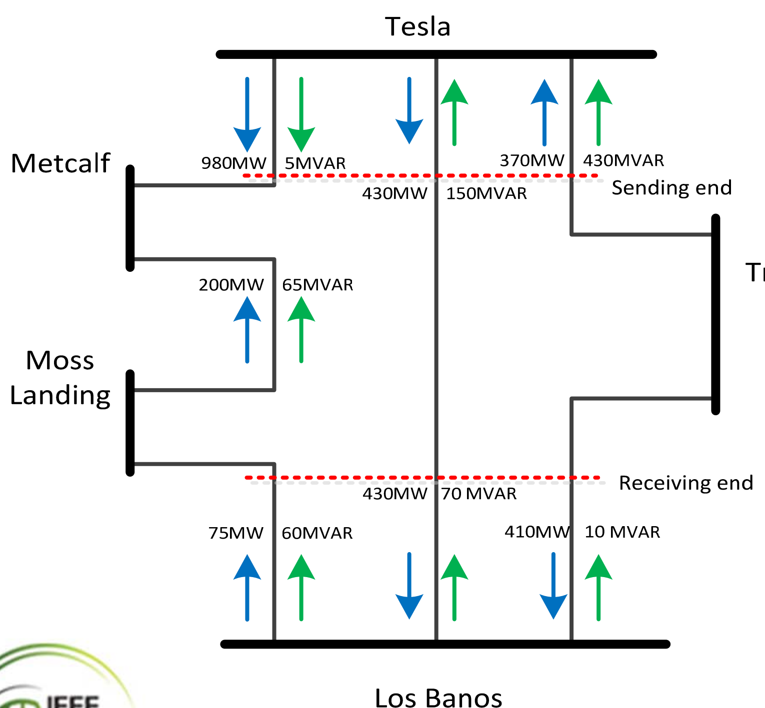


Implementation Options – Measurement Based



Detecting Real-time Reactive Margins

Identify polarity to determine SENDING or RECEIVING ends - Active and Reactive powers (aggregated over the corridor) can flow in different directions

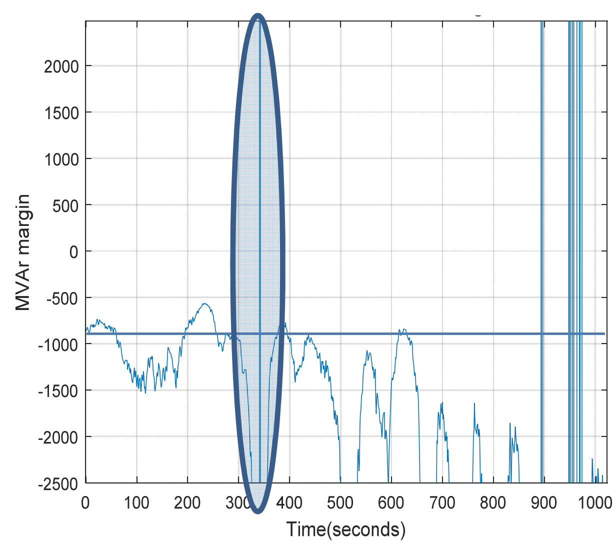


Accurate calculation of Equivalent Impedance & Reactive Margin requires:

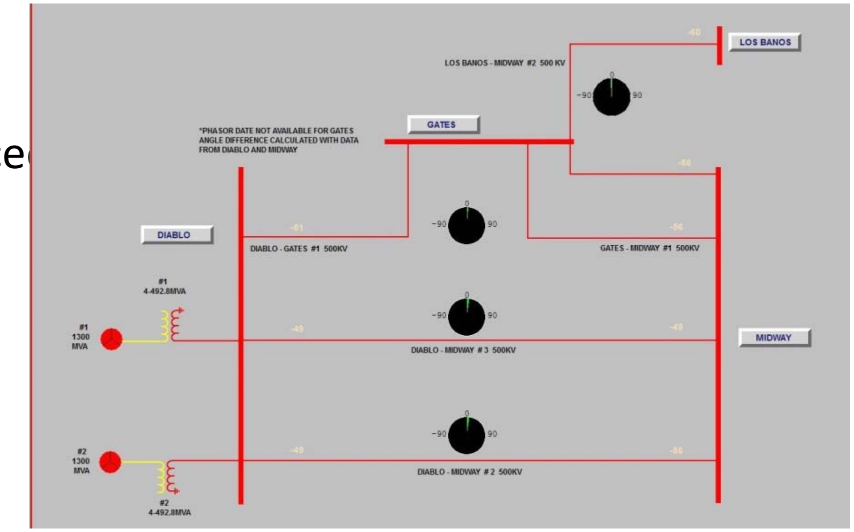
- *Observability – Absence of a PMU*
- *Flags*
  - ✓ *Identify Unloaded and open ended systems*
  - ✓ *Incorporate switching or outages, e.g. line or equipment, bypassing capacitors*
  - ✓ *Incorporate loss of a PMU data (e.g. momentary bad network connection)*

RVII Enhancements

- **Extrapolation**
  - Constant power factor load increase until boundaries reached
  - Unlike other solutions, system equivalent parameters are dynamically computed
- **Prediction Technique -** Integrates real-time measurements and model based parameters
- **RVII accounts for**
  - Corridor Reconfiguration (e.g. planned or unplanned outages, equipment / flags status
  - PMU location - Selection within available corridors based on availability
- **Advanced Detection routines -** Indices range from simple computation of ratio of impedances to dynamic indices
- **Load Shedding Trigger-** Combines functionality of RVII indices and extrapolation margins to trigger (Rule vs Adaptive schemes)
- **Data Quality** - Algorithm needs to be robust for production or sustainability to PMU data flow intermittencies



RVII Validation



- RVII capabilities have been extensively tested
  - PG&E Proof of Concept facility with RTDS reduced network model
  - Load flow and dynamic simulation models
  - Data from Production EMS
- Corridor RVII has been validated on multiple corridors
  - MW and MVAr margins are compared, along with observed equivalent impedances
- Objective: Model validation and baselining
  - Preparation for contingency analysis assessment in real-time
  - Analyze trends in the data
- Case Results Presented
  - Tesla – Tracy – Metcalf – Los Banos (Corridor 1)
  - Los Banos – Diablo – Gates – Midway (Corridor 2)

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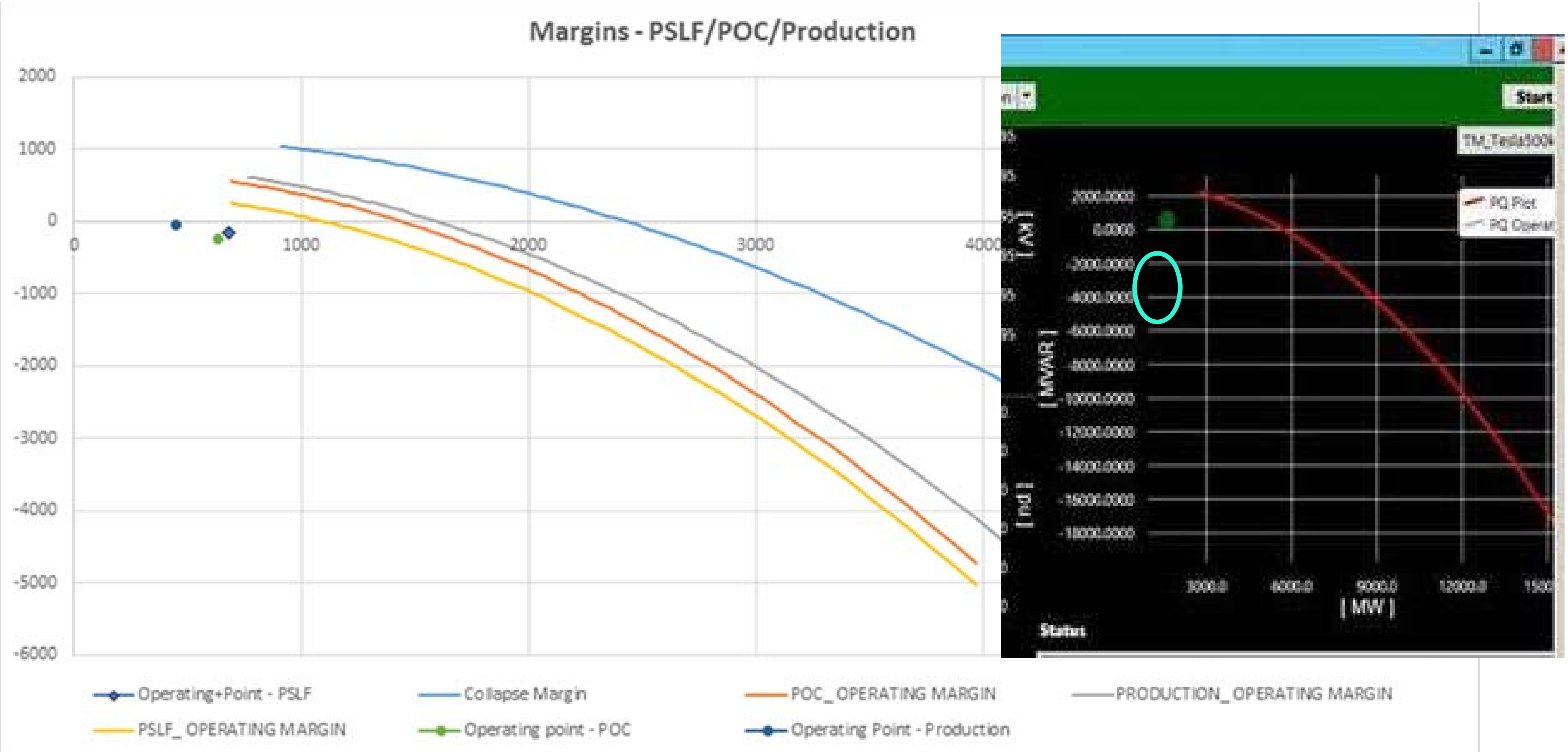
Model Validation: Case fidelity; Corridor 1
(time scales aligned)



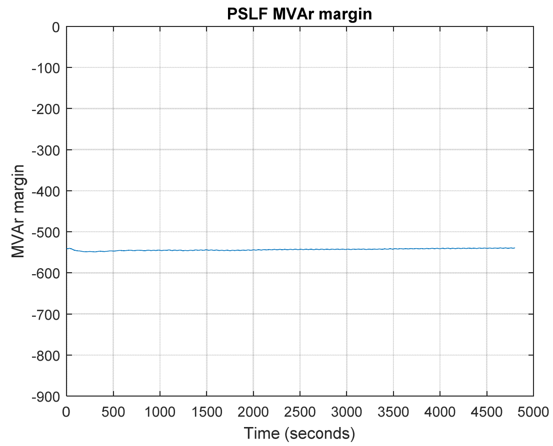
P- Q operating plane

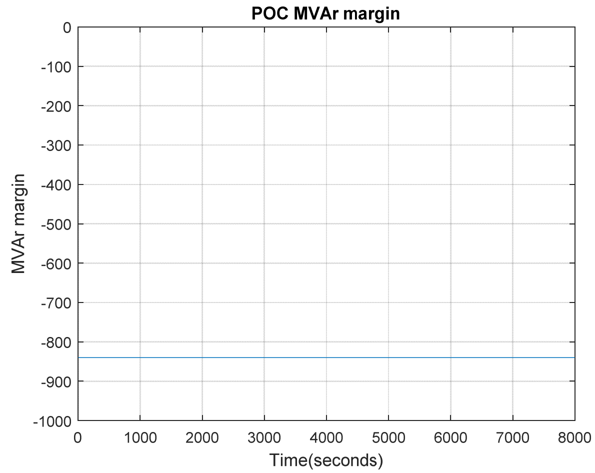
Margin Comparisons: Load flow, POC Facility, Production

Baseline, No Contingency for Corridor 1

	PSLF (Peak Flow)		POC	
	Collapse margin	Operating margin	Collapse margin	Operating margin
Active Power Margin (MW)	**2405**	**2014.22**	**2627**	**1895.34**
Reactive Power Margin(MVAr)	**-550**	**-315**	**-839**	**-612**

- Average margins computed over the period of simulation
- RVII successfully tested using production data, typical operational days (P-Q plots on previous slide)





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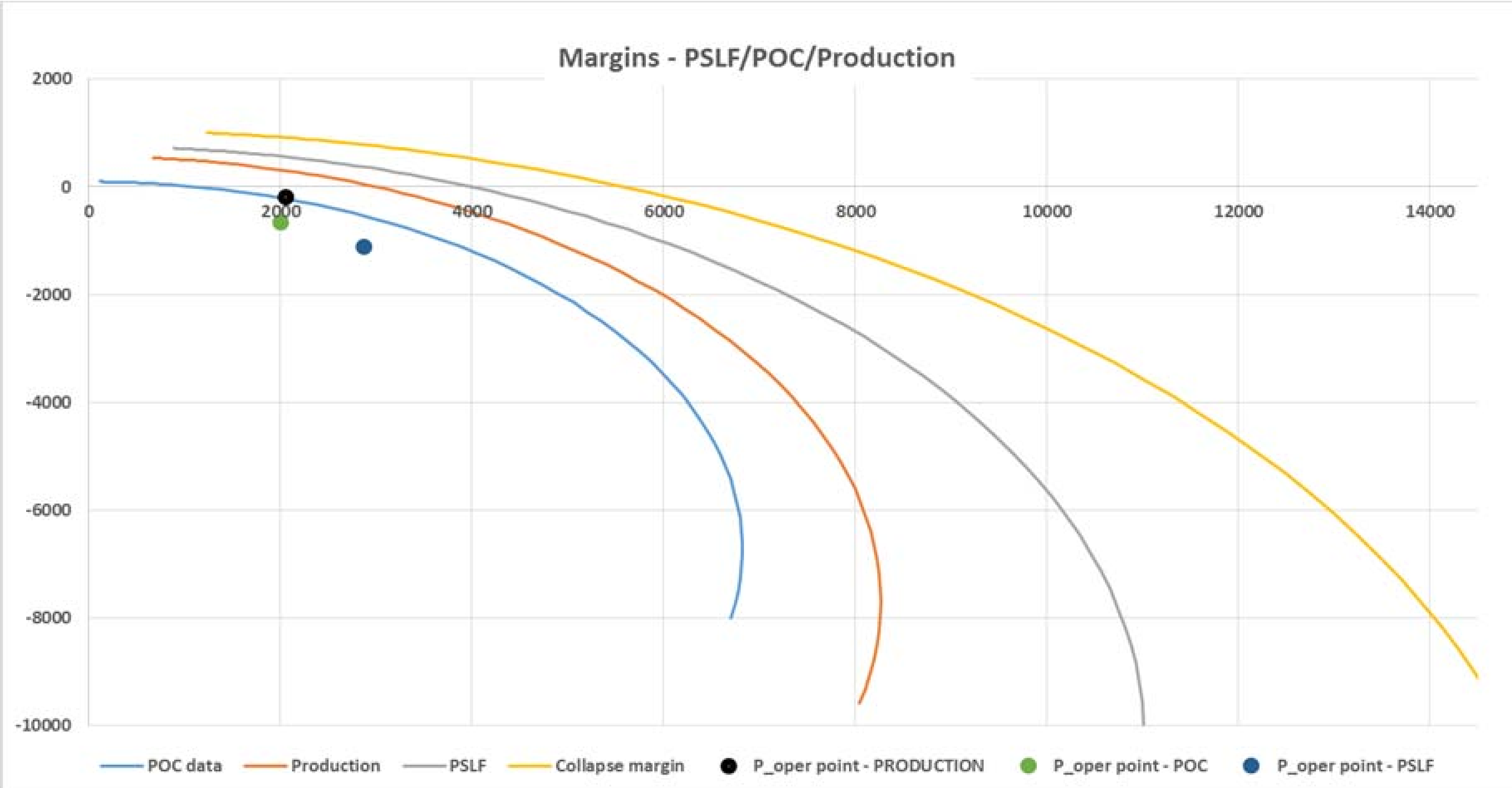
Model Validation: Case fidelity; Corridor 2

(time scales aligned)

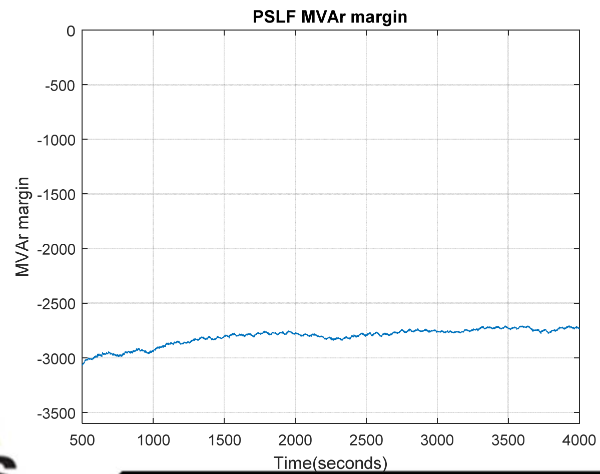


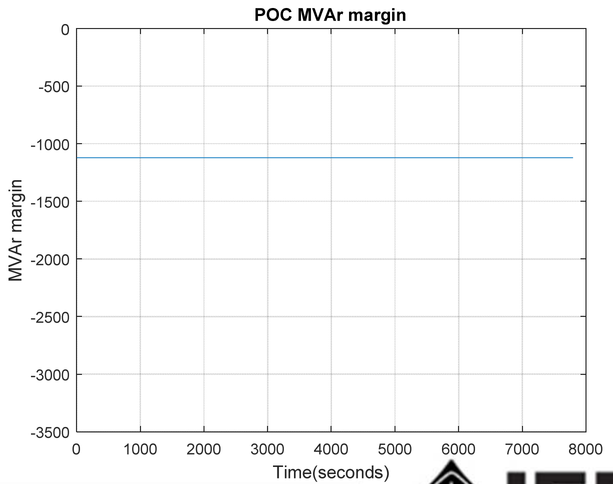
P- Q operating plane

Margin Comparison: *Baseline, No Contingency for Corridor 2*

	PSLF (Peak Flow)		POC	
	Collapse margin	Operating margin	Collapse margin	Operating margin
Active Power Margin (MW)	**3274**	**2881**	**2799**	**2214**
Reactive Power Margin(MVAr)	**-2800**	**-2611**	**-1150**	**-934**

- Average margins computed over the period of simulation
- RVII successfully tested using production data, typical operational days (P-Q plots on previous slide)





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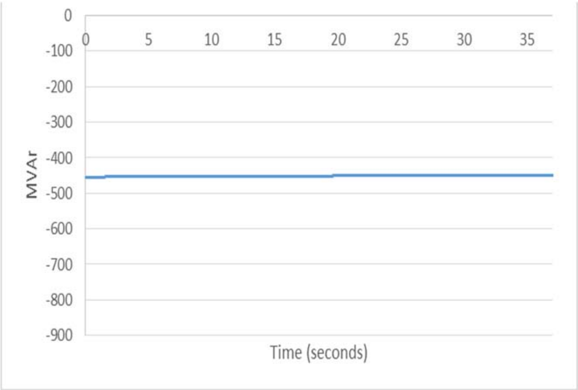
Performance: Real-time Dynamic Condition in the Region

Objective: Model Validation and Baselining

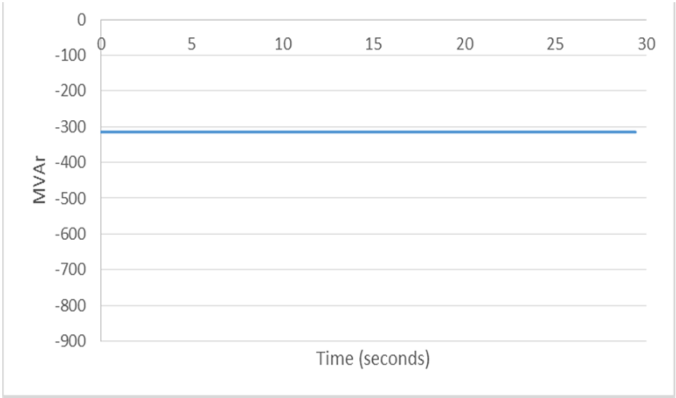
Measurement and Model based margins are compared

- Event 1: Typical Operating day (no outage condition)
- Event 2: Series capacitor insertion in neighboring system 500 kV network due to RAS action
  - ✓Validate load flow against operational events
  - ✓Verify angles across parts of the system
  - ✓RVII to estimate the system margins using dynamic model based simulation
    - Generator dynamic models initialized
    - Round Mt- Table Mt corridor evaluated

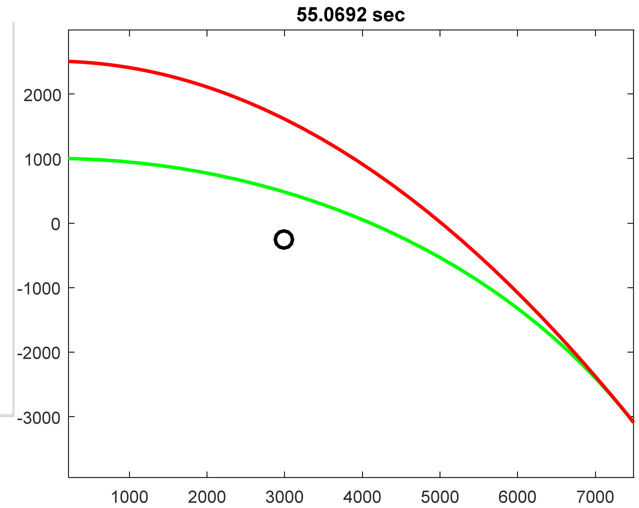
Reactive Power Margins *(Event 1)*



PSLF MVAr margin



POC MVAr margin

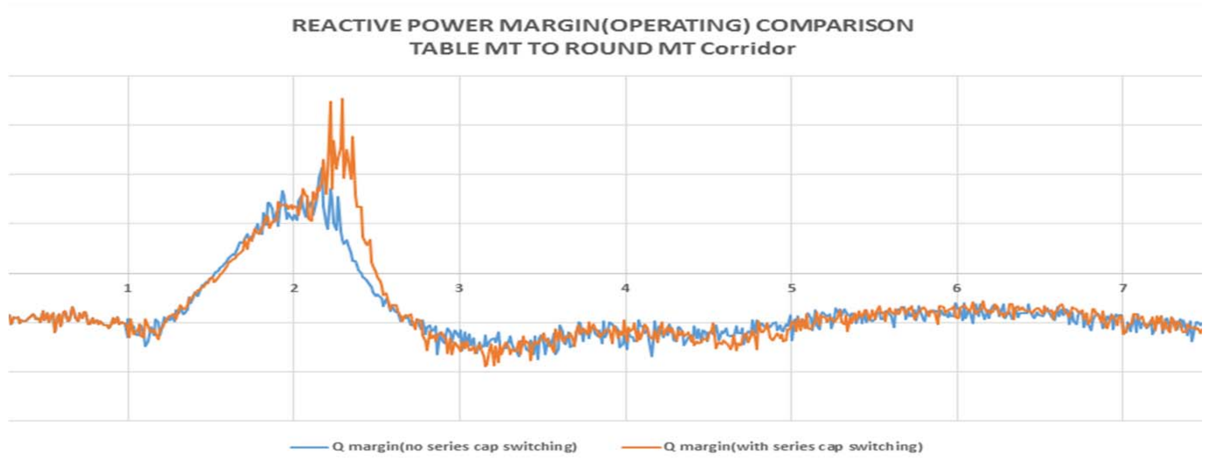


Close correlation in results observed between models.

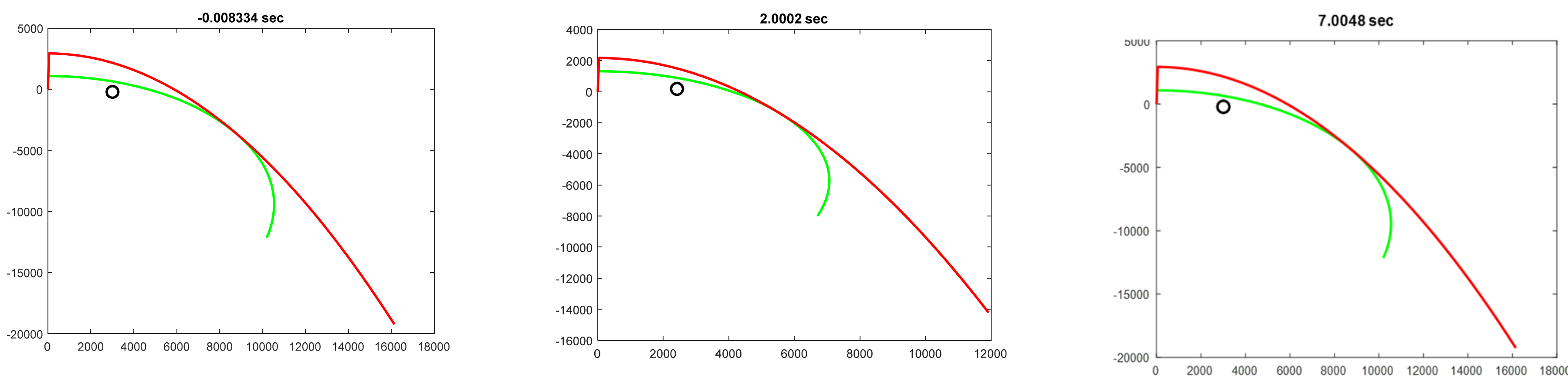
	PSLF (Peak Flow)	POC	Production (Typical)*
Active Power Margin (MW)	2929.14	2542.884	2089.415
Reactive Power Margin(MVAr)	-451	-314	-206

*** RVII was run with data gaps in the simulation (no data quality filtering). Hence averaged over several smaller periods.**

Reactive Power Margins *(Event 2)*

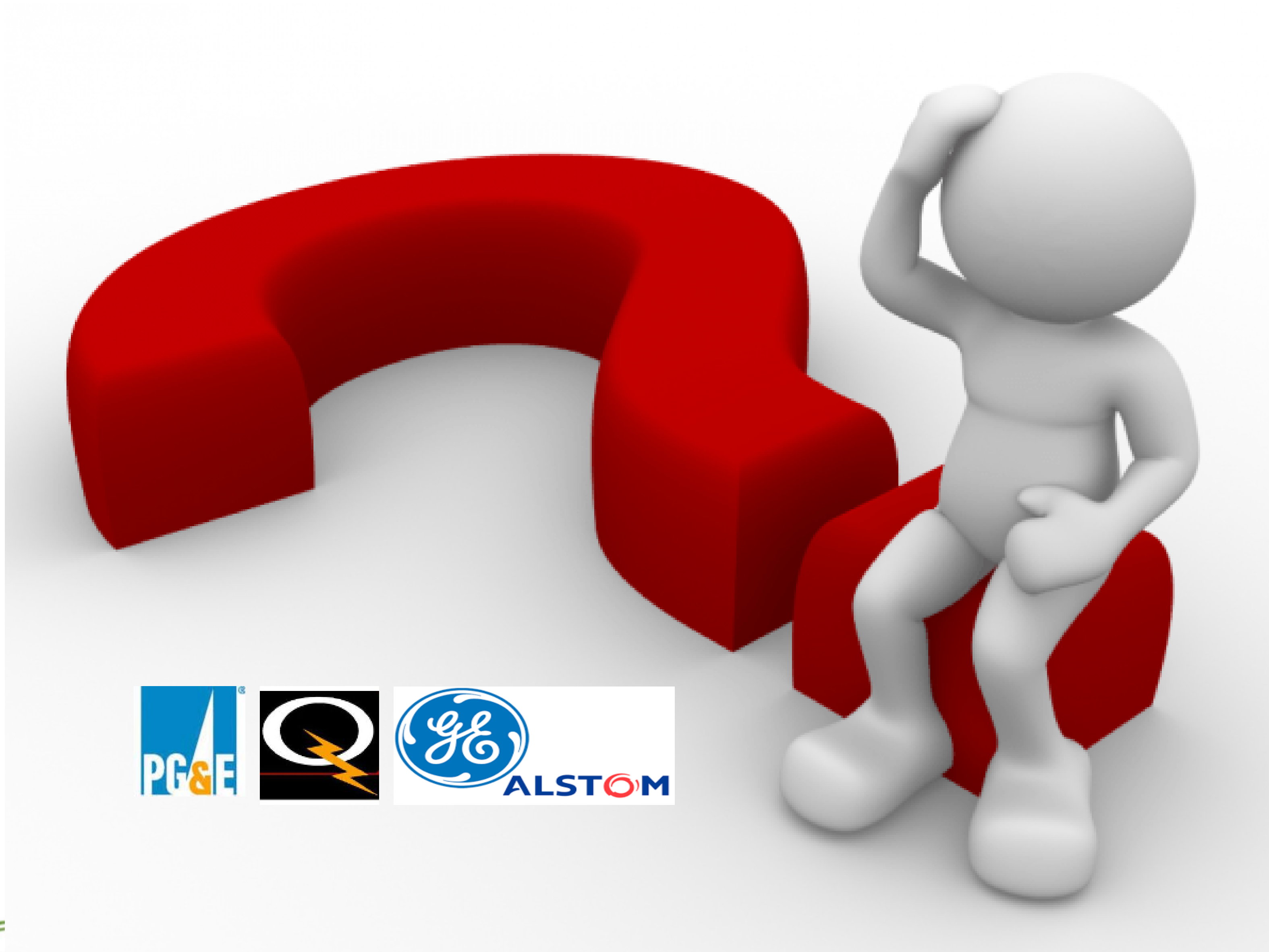


Evolution of margins throughout the event represented in P-Q plane



CONCLUSIONS

- Knowledge of reactive margin is critical to system operation
- Tools performance validation before placing to operation
  - Importance of flags
  - Data quality and tool tolerance to imperfect data
  - Proper corridor identification (Incoming and outgoing sources)
  - Angle measurement
- Impact of observability
  - Optimizing use of available measurements
  - Importance of redundancy of measurements
- RVII has been validated to perform well under dynamic condition and disturbances in the WECC system
  - Continue with additional validations of future system disturbances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Supplemental Information

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
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