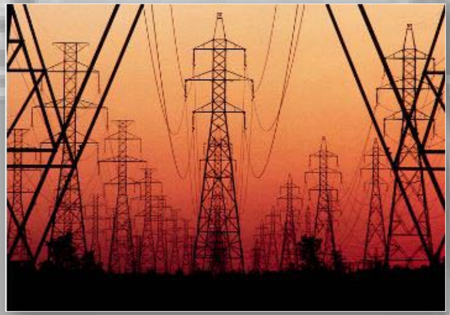

Voltage Stability Management

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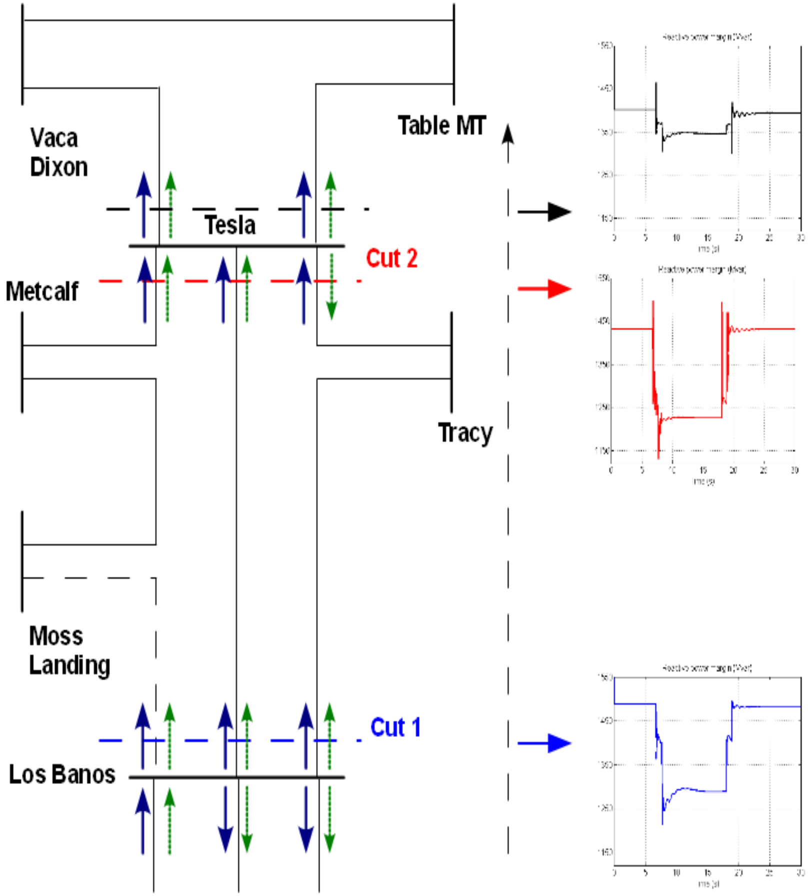
Comprehensive Voltage Management

- Use a combination of selected model-based and model-free methods
  - Each method offers benefits, reflecting a particular aspect of system operation, various manifestations of instability, measurement configurations, etc.
- Real-time, model-free methods: much faster than EMS-based, but less accurate
  - Good for voltage and FIDVR instability detection, trend and status monitoring
  - Could offer predictive capabilities
- Reactive margin means different thing in different contexts
- Criticality of branch in/out Flags
- Contingency Analysis critical to identifying vulnerabilities

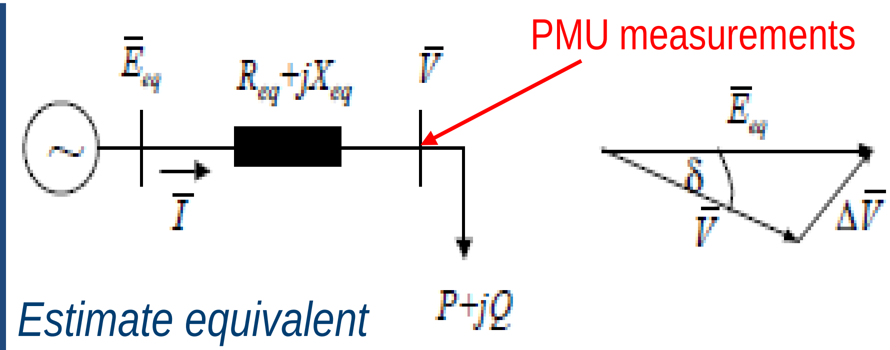
Real-Time Voltage Instability Indicator (RVII):
Bus, Corridor, Load center



Voltage Stability Assessment

MEASUREMENT-BASED

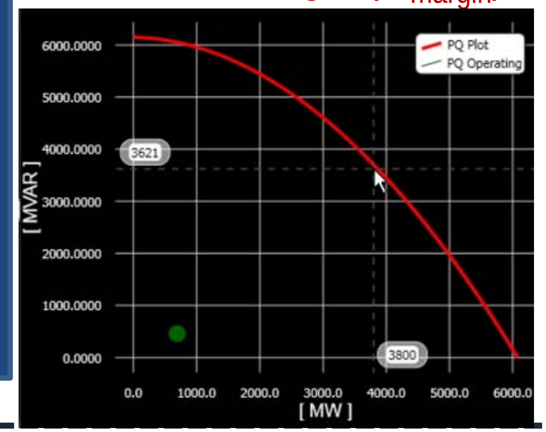
Real-Time Voltage Instability Indicator (RVII)



Estimate equivalent parameters in real-time

RT Alerts (instability & margins)

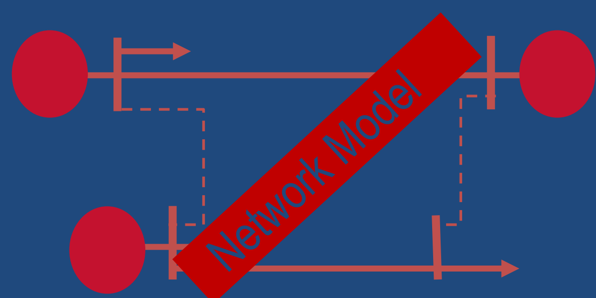
- Equiv. Imped. (Z_{eq})
- Reactive Margin (Q_{margin})



MODEL-BASDED

EMS & Online-DSA Applications

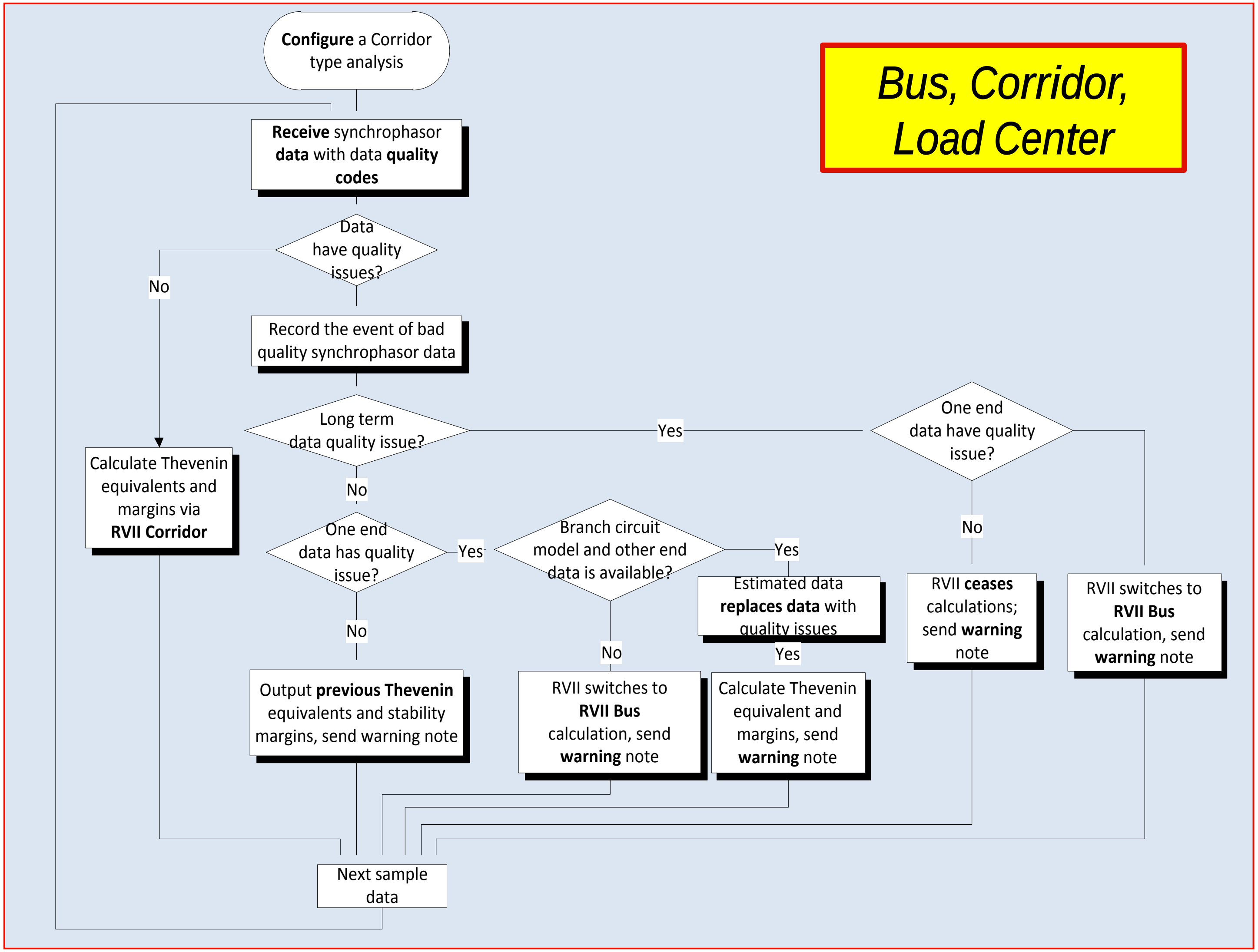
- CA
- VSAT
- RAS



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

- Predict Q_{margin} *changes* under *"worst case" contingency*
- Provide info & initiates *corrective actions*

RVII Robustness Improvements

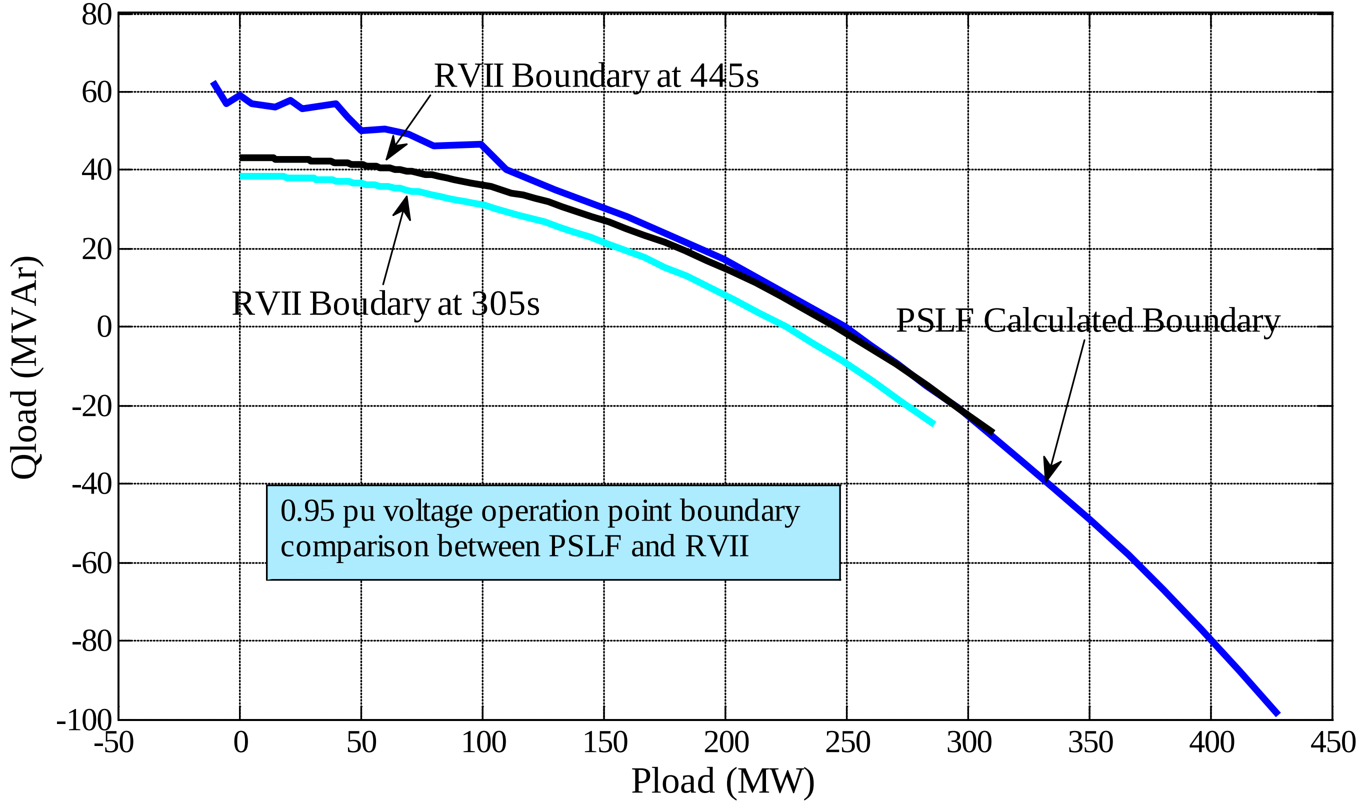


Voltage Stability Under Microscope

- Detection in Real-Time – PRESENT STATE
  - Is the system approaching voltage instability now?
- Prediction in Real-Time – FUTURE STATE
  - Will the system be stable under a given contingency in the future?
  - Will the system be stable under a contingency and a specific flow pattern in the future?
  - How far (in some measure) is the system from instability in the future?
- If we are between two state estimation runs, is NOW as SE defined at last run?
  - No – things can change (some times a lot); we won't know until next SE run
- Model-free approaches fill the gap – Trade off
  - Models of system built only from local measurements
  - These models are very simple, e.g. Thevenin equivalent to represent the whole power system
  - Model updated for each new synchrophasor set

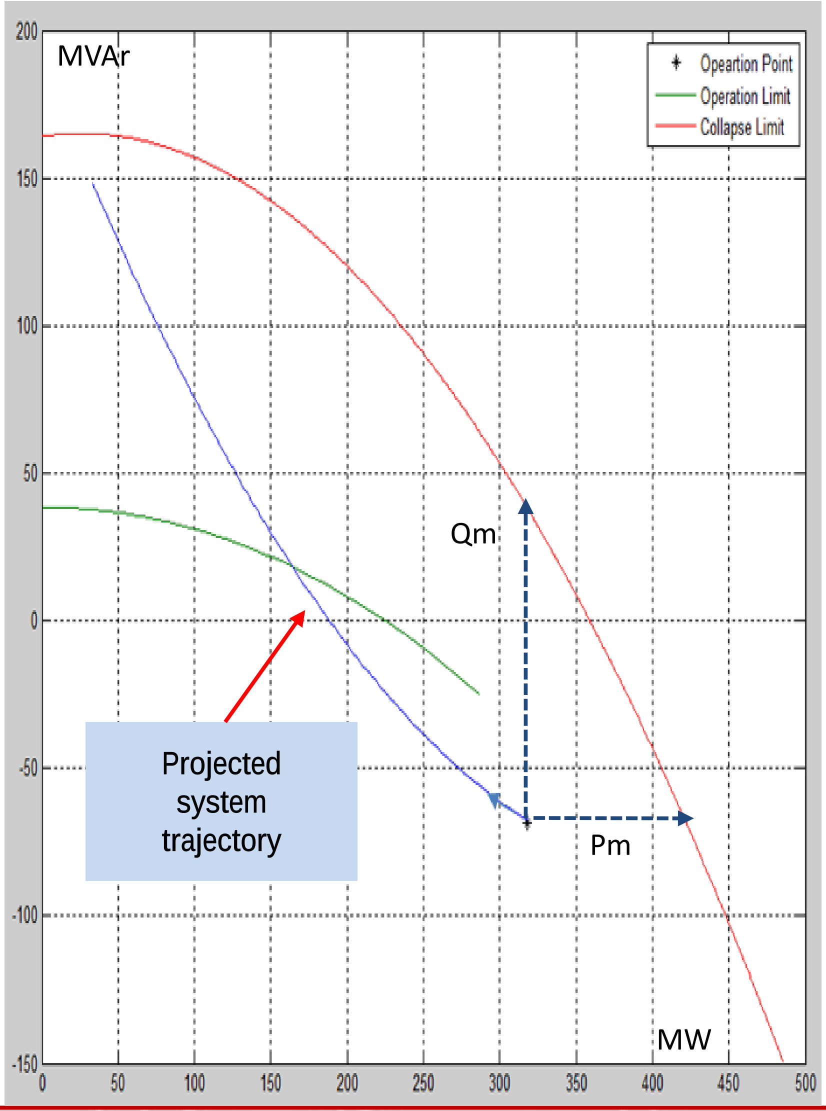
Model-less Instability Detection

Example of comparison between true stability boundary (detailed system model simulations) and RVII calculated stability boundary



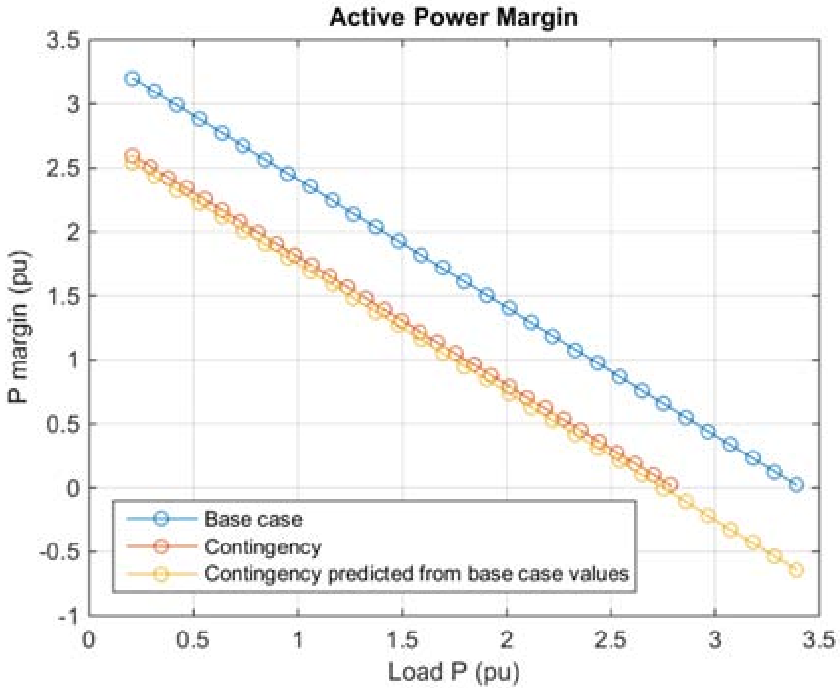
Margin Prediction

- Unlike Detection, which is deterministic, margins always involve hypotheticals:
  - Margins are related to changes of some parameters of interest
  - Requires additional assumptions: e.g., if margin to MW imports, then how exactly is the increased MW generated; and, how exactly is the increased MW inflow distributed to loads; at what power factors?
- All these assumptions define a trajectory of the system from the known point toward the collapse boundary
  - Use of statistical VAr trends or other methods to assess system movement direction



New Contingency RVII

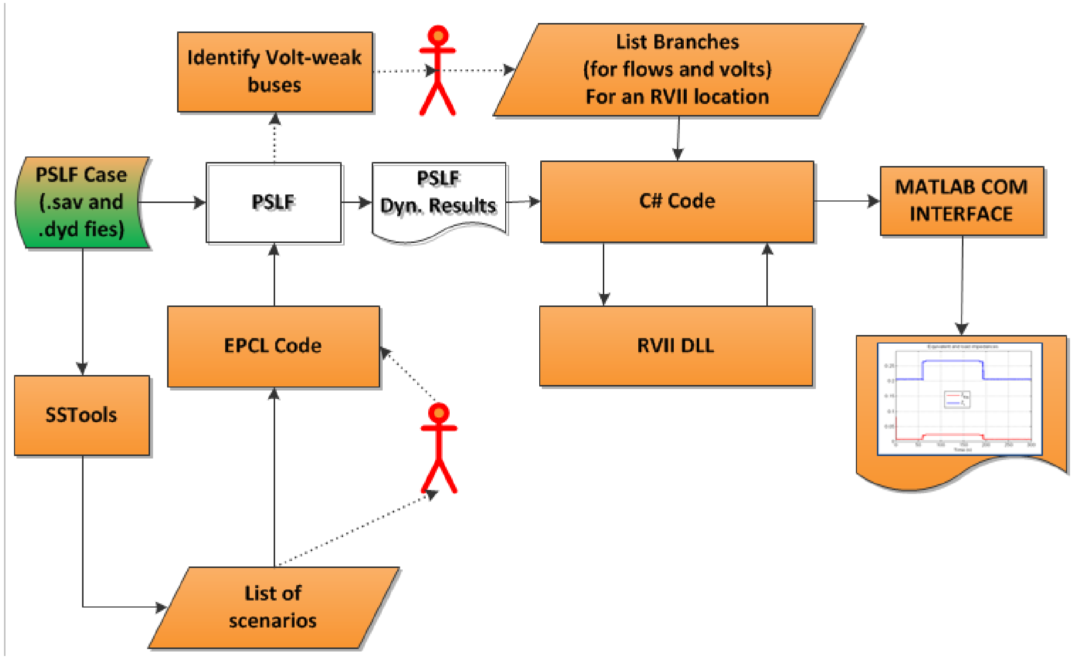
- Predict margins for contingencies while the system is still operating in normal conditions
  - Detect contingencies that could create instability conditions
  - Bulk of model computation at the Control Center; small amount of info transferred to RVII deployment location
- Preliminary results from 140 bus
  - Blue: true margin for Base Case
  - Brown: true margin for contingency
  - Light brown: RVII contingency margin



Testing, testing, and more testing…

At PG&E

- Virtual RVII Deployment
  - Extensive, WECC model
  - PSLF – based
  - Establish RVII locations, inputs and accuracy
- Proof of Concept Lab
  - RTDS models:
    PG&E 500 kV system,
    most lower voltage and
    PG&E-external as equivalents
  - Physical and virtual PMUs
  - RVII deployed on a physical PDC



Input PSLF case; output plots of Thevenin and "Load" impedance at RVII location

Concluding Remarks

- Use a combination of selected model-based and model-free methods, including a hybrid approach
- Contingency-based RVII shows promising results
- Hybrid approach
  - Most of the network model processing needs to take place at the control center, where it is done on a minutes time scale
  - Minimal amount of information to be transferred to the RVII deployment location
    - For margin computation: Direction of system trajectory from the current operating point
    - For contingency RVII: A few data items per contingency to assist with mapping from updated Thevenin equivalent to an estimate of the same equivalent post-contingency
- A test-bed, like the one developed for PG&E testing, is crucial to validate results

Thank You!