ROSE - Calculation and Visualization of Power System Stability Margin Based on PMU Measurements

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1. About V&R Energy

V&R Energy

- V&R Energy is a leading provider of Next Generation software solutions for the electric power industry

- V&R Energy's services include:
  - Advanced consulting services
  - Comprehensive software tools for analyzing power system behavior
  - Cutting edge scientific research

- V&R is located in Los Angeles, CA
  - www.vrenergy.com

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V&R Energy's Customers

- AEP
- ATC
- California ISO
- CEATI
- CFE, Mexico
- Con Edison
- East Kentucky Power Coop.
- Entergy
- EPRI
- Exelon
- FirstEnergy
- Idaho Power Co.
- International Transmission Co.
- ISO New England
- Kansas City Power & Light
- KEPCO, South Korea
- KEPRI, South Korea
- KPX, South Korea
- KeySpan/LIPA
- Midwest ISO
- NRECA CRN TRAS
- NYISO
- NYPA
- ONS, Brazil
- PacifiCorp
- Southern Co.
- Southwest Power Pool
- Tri-State G&T
- TNB, Malaysia

2010 V&R Energy's Awards

- **ARRA ISO-NE Synchrophasor Infrastructure and Data Utilization (SIDU) Project, 2010**
  - "Region of Stability Existence" (ROSE) is a part of ISO New England winning bid
- **DOE Award: "20% Wind by 2030: Overcoming the Challenges", 2010**
  - Improving Reliability of Transmission Grid to Facilitate Integration of Wind Energy in Tri-State G&T and AECI
- **NYSERDA Award, 2010**
  - Prevention of Occurrence of Major Catastrophic Events: Demonstration for Con Edison System

2. *The Region Of Stability Existence (ROSE)*

What is ROSE?

- *Region Of Stability Existence - ROSE* defines the range of phasor measurements or other system parameters
  - For which the system may securely operate in terms of the accepted N-k security criteria

- Addresses the problem of utilizing the PMU data to increase the situation awareness of the operators and improve stability and reliability of the electric grid

- Voltage stability, voltage constraint (voltage range and/or pre-to post contingency voltage drop) and thermal overloads may be simultaneously monitored, enforced and visualized on the boundary

Utilizing PMU Data to Make nearly Instantaneous System Operational Decisions

■ *ROSE* uses PMU and State Estimator data for on-line calculation and visualization of the current operating point and its proximity to the stability boundary

 – Additionally, SCADA data may be used to update the boundary

Power flow or Angle

Update Stability Boundary with SCADA data rate

Update Trajectory of Operating Point with PMU data rate

Construct the Stability Boundary with SE data rate

Power flow or Angle

Figure, see http://ewh.ieee.org/reg/1/809/Litvinov.pdf.

■ Relationship between the current operating point and the boundary defines "health" of power system network state:

 – Each point on the boundary corresponds to a "nose" point on the P-V curve, or a thermal or voltage constraint being violated
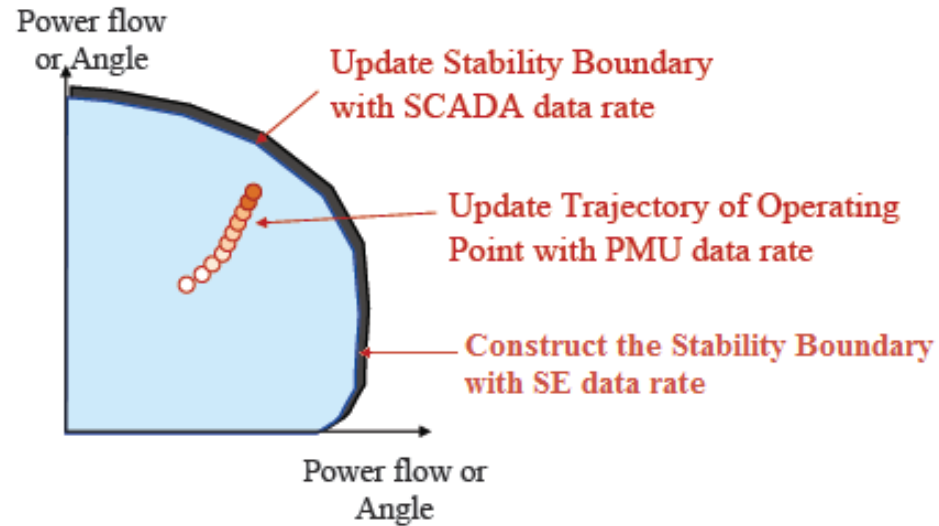
Use of PMU to Identify Steady-State Stability Limit

- *ROSE* provides the framework for utilizing PMU measurements in order to:

  – Improved state estimation;

  – Continuously monitor the electric grid;

  – Identify system stability limits under normal and contingency conditions;

  – Alarm the operator about the impending crisis before a new State Estimator (SE) case arrives;

  – Invoke optimal remedial actions to prevent a blackout.

The Region of Stability Existence (*ROSE)* Application

- *ROSE* is a PMU-based software developed by V&R Energy

- A part of Physical and Operational Margins (POM) Suite
  - Extremely fast:
    - Full AC contingency analysis: 36000 contingencies/hour
    - Takes under 10 sec to alleviate post-contingency violations
      - For a load flow case - 50,000 buses, 17000 dynamic models
  - Handles extremely large contingency/fault lists:
    - Millions of N-1-1, N-2 contingencies during one simulation run
    - Hundreds of thousands of faults during one simulation run
  - Provides a reliable and robust solution engine
  - Determines the optimal mitigation measures during massive analysis

Computing System Stability Margins

- System stability margins under N-1, N-2 contingency conditions
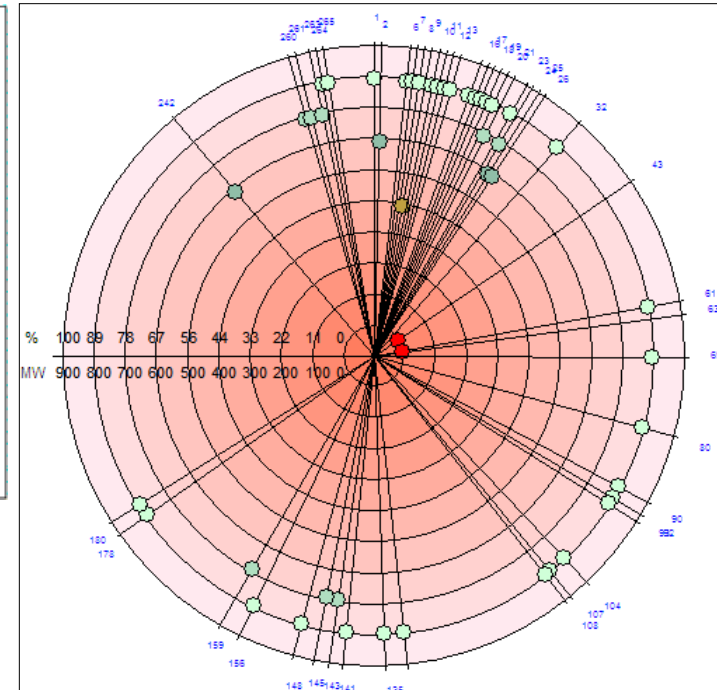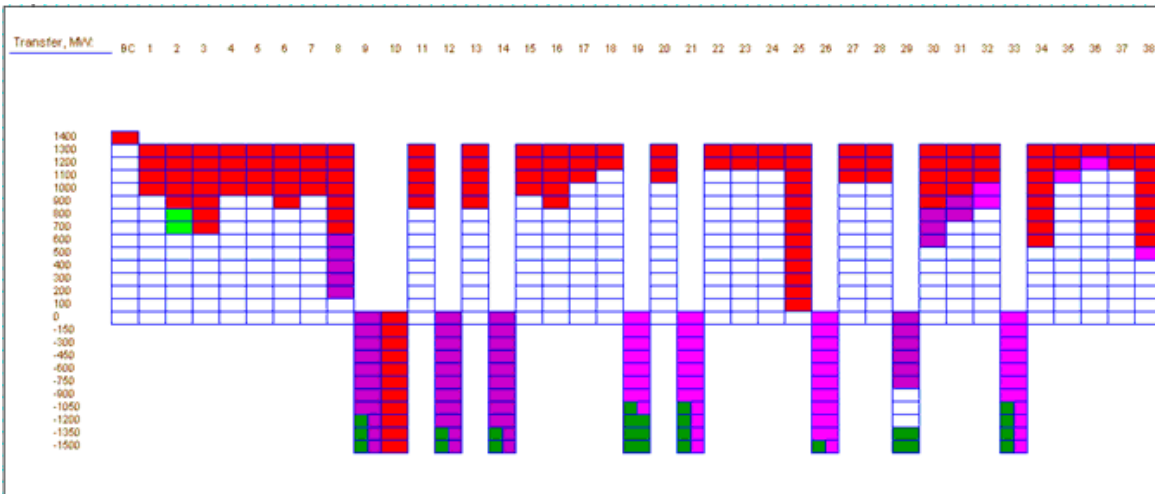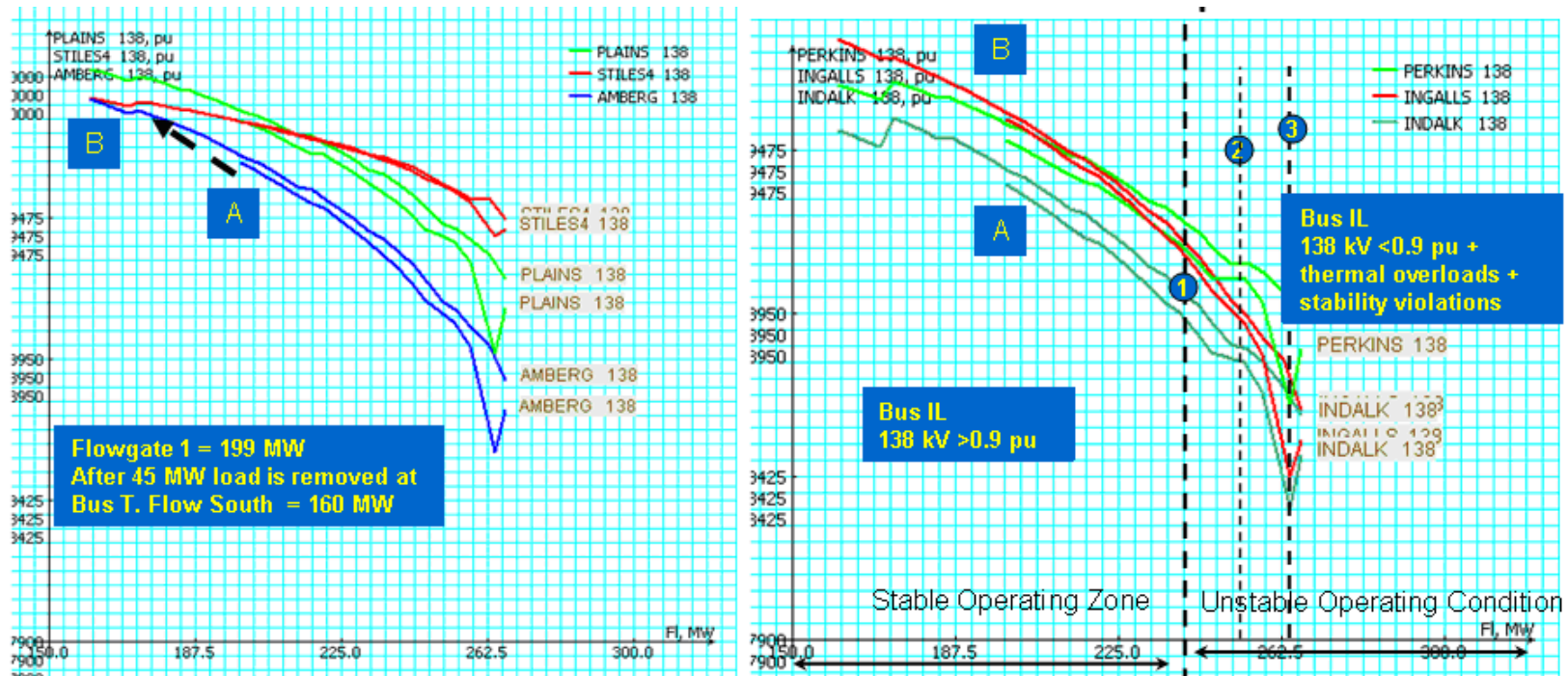
PV- Curve Analysis

- Used for interfaces in the power system that are sensitive to voltage collapse
  - Then, operating limits are established
- Quickly re-evaluate the limits as system conditions change

Advanced Voltage Stability Analysis: Case of a "Flat" PV-Curve

- Since PV-curve analysis does not always predict the impending collapse, operators do not take any control actions to prevent the collapse until it is too late

- Transmission system starts to exhibit the changes (point P_{lim}) which would eventually lead to voltage collapse (point $P_{collapse}$)
 - V&R Energy's solution identifies P_{lim}
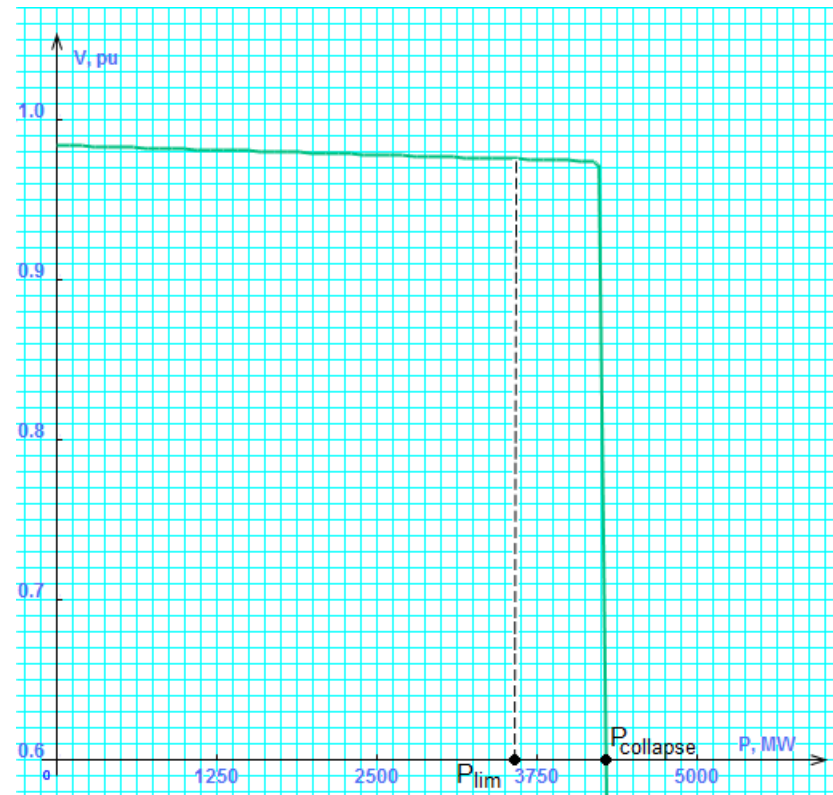
Alarming the Operator

- An operator is alarmed if the operating point and the boundary are moving towards each other in terms of:
  - MW/MVAr/MVA margin across the interface or load pockets

- For multiple PMU installations, *ROSE* identifies two most critical phase angles, and displays the current operating condition and the boundary on the plane of the most critical phase angles and other user-defined parameters
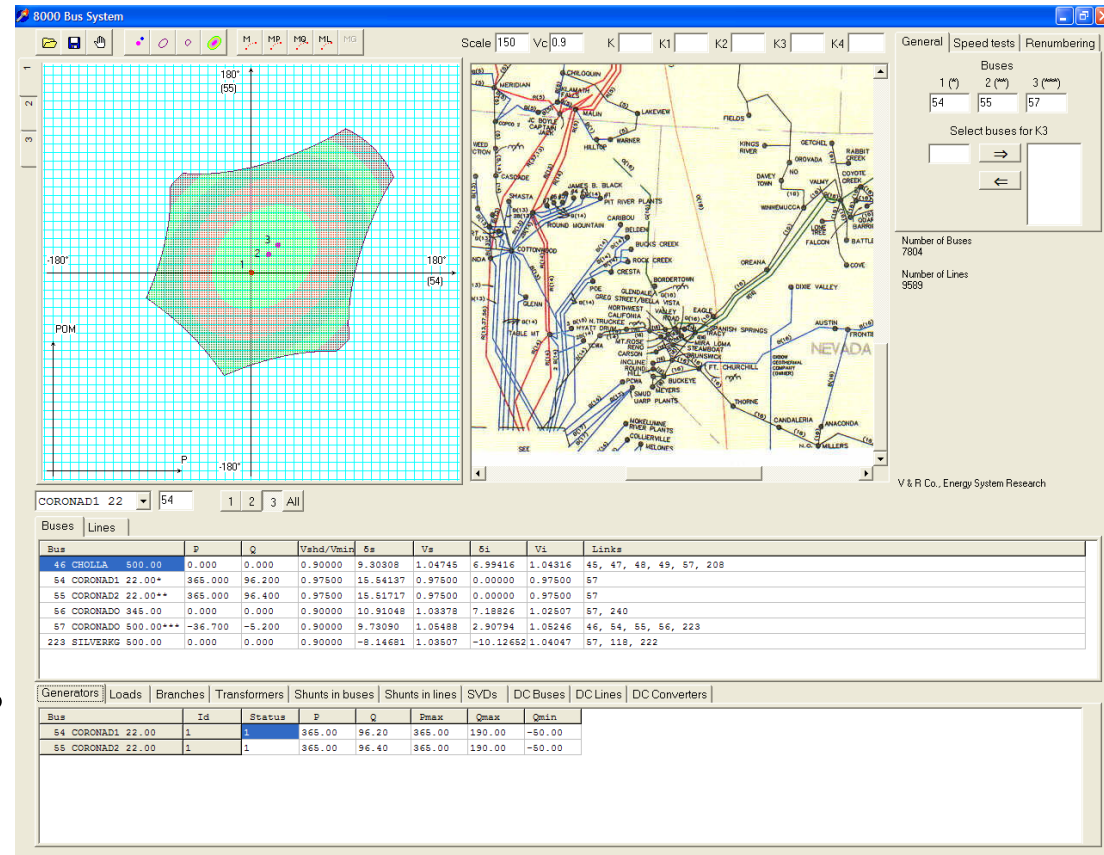
Preventing System Collapse

- If the operating point and the boundary are moving towards each other, **automatically identify (recommend to the operator) minimal optimal preventive actions before the new SE case arrives** and before the system collapse

- Available optimal mitigation measures are MW, MVAR re-dispatch, ULTC settings, phase shifter settings, switching CAP banks, line switching, load curtailment

- Identifies two types of measures:
  - Corrective measures for each contingency
  - Preventive (global) measures for all contingencies

3. *ROSE* Results Using ISO New England System

# ISO NE's SE Data Used for the *ROSE* Analysis

- The *ROSE* works with State Estimator (SE) cases that represent a full model of the network **without combining buses during solution:**
  - Approximately 12000 buses (if combined, 3000 buses)
- These cases are extracted exactly as is after the SE solution
- Include all zero-impedance branches in order to more accurately represent the breakers
  - Before topology processing
- Correspond to SCADA snapshots
- SE cases are provided every 3 minutes

PMU Data Used for the *ROSE* Analysis

- Phasor measurements are provided for voltage angles and magnitudes at each location
- Data consists of 30 sets of phasor measurements per second

ROSE Boundary: Contingency 1

- The *ROSE* boundary is shown on the plane of two phase angles

- The operating point moves in the direction in which the boundary shrinks

- The point lies on the boundary

- This is a limiting contingency

  - It has the smallest margin
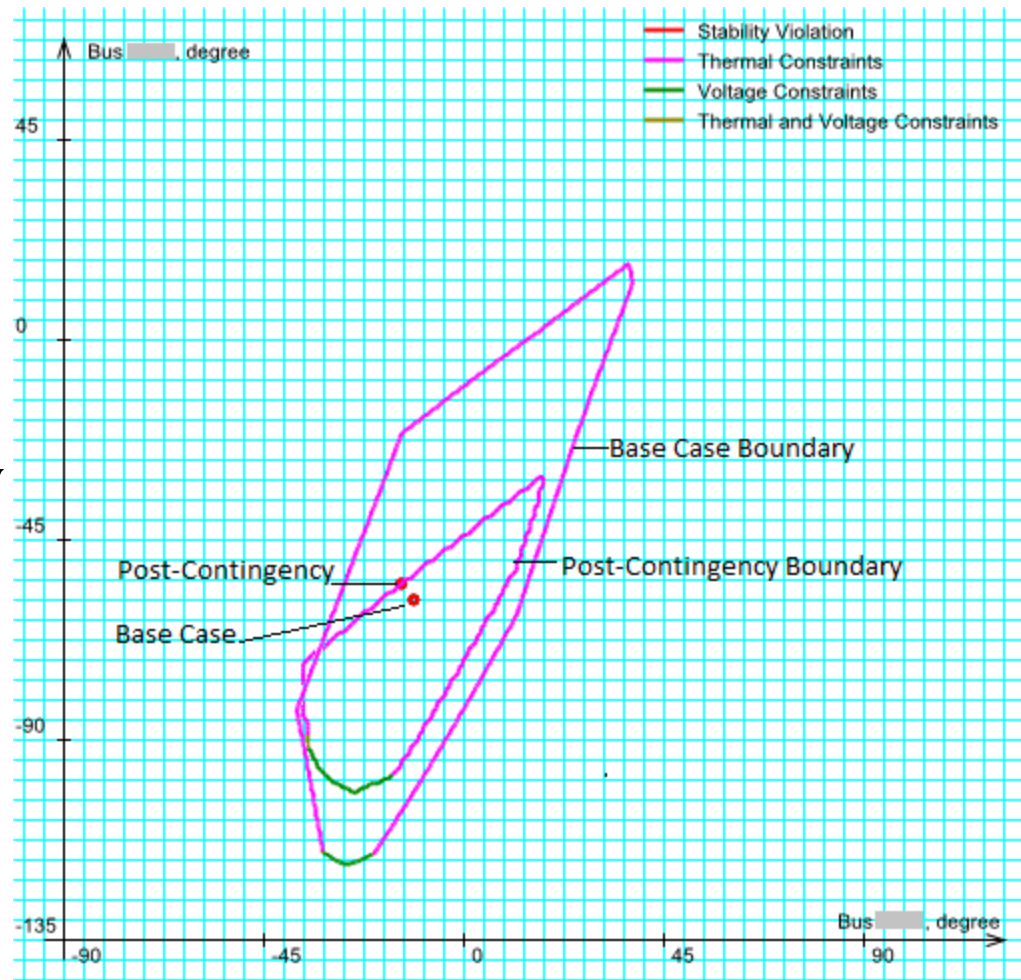
ROSE Boundary: Contingency 2

- The boundary is shown on the plane of two phase angles
- The operating point moves in the direction in which the boundary shrinks
- The point is close to the boundary but doesn't lie on the boundary itself
- This is not the most limiting contingency
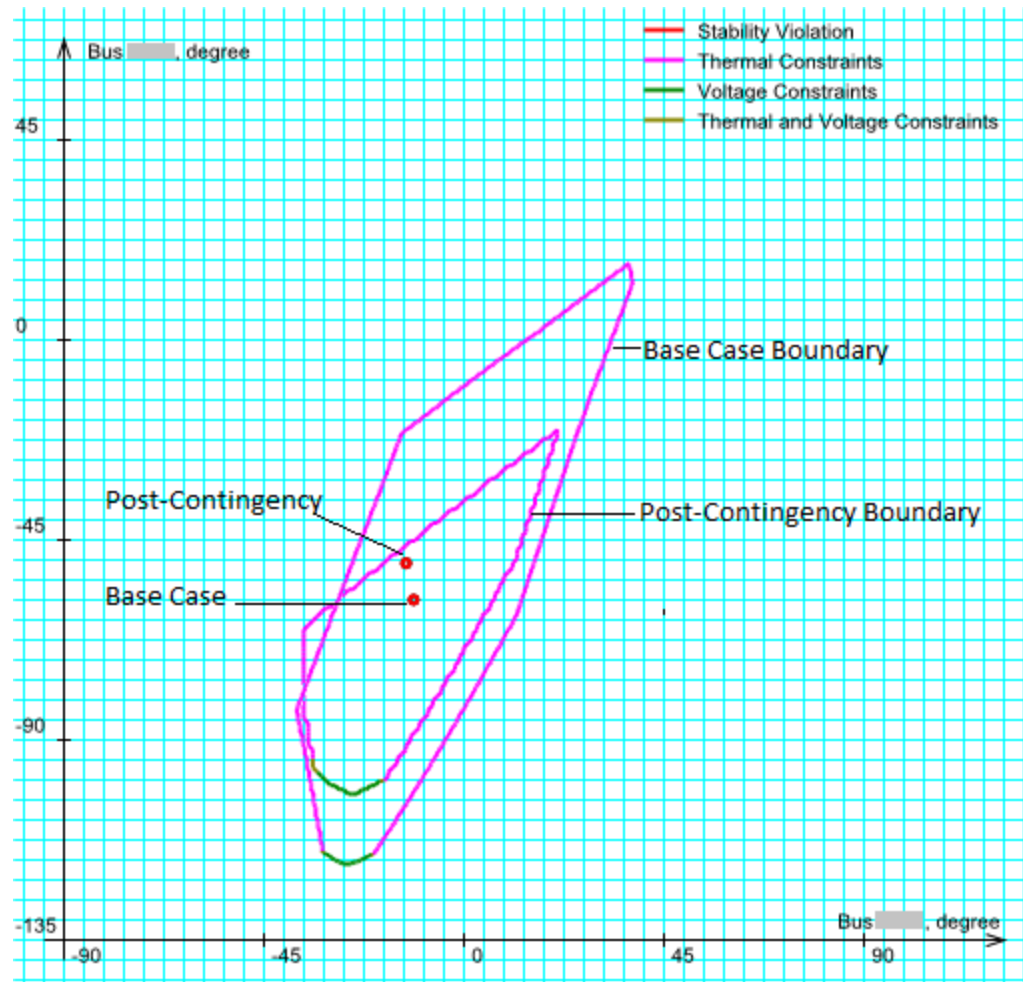
ROSE Boundary for the Base Case and Stressed Conditions

- **Automatically identifies the limit in real-time**

- Shown on the plane of phase angles

- Base case is indicated as "0"

- At the limit value of stressing
  - The boundary degenerates
  - The operating point lies on the boundary
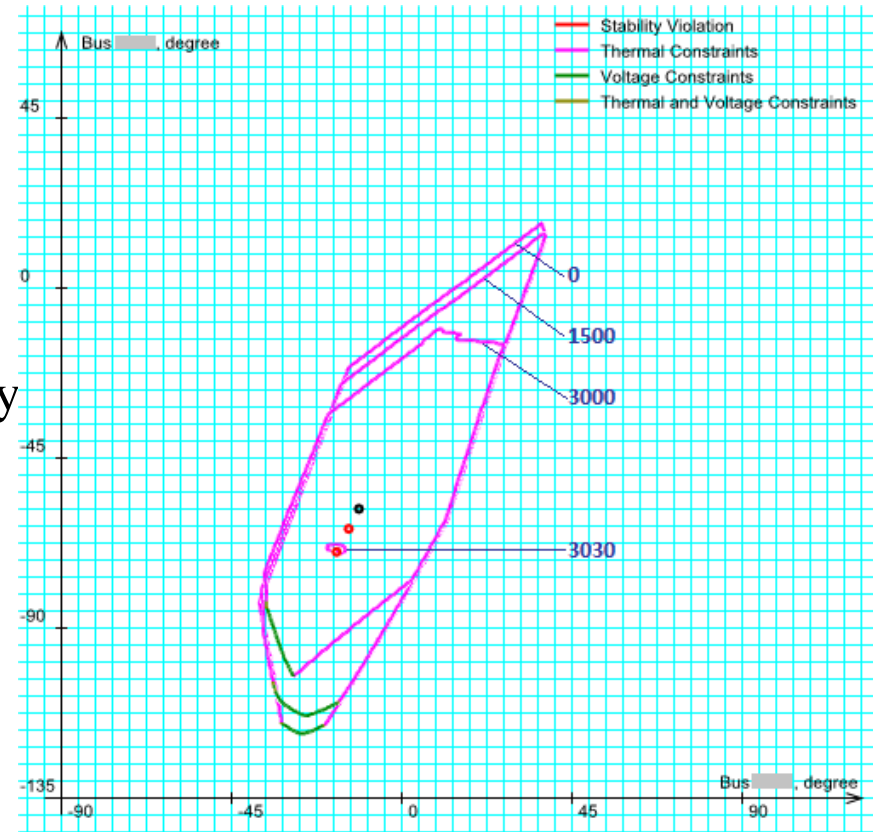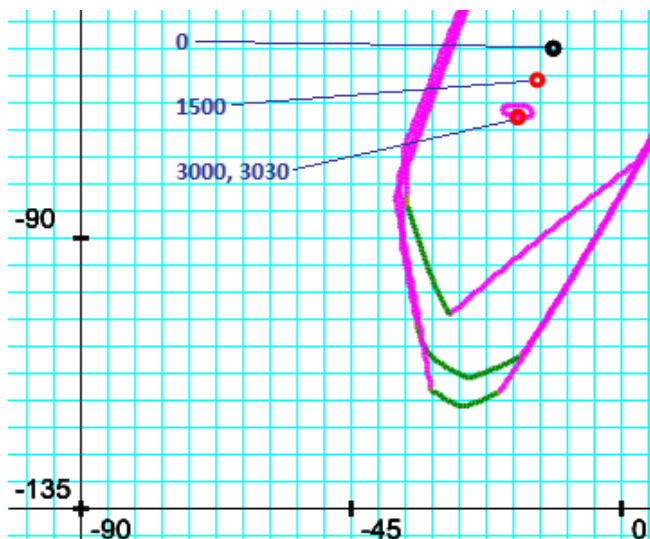
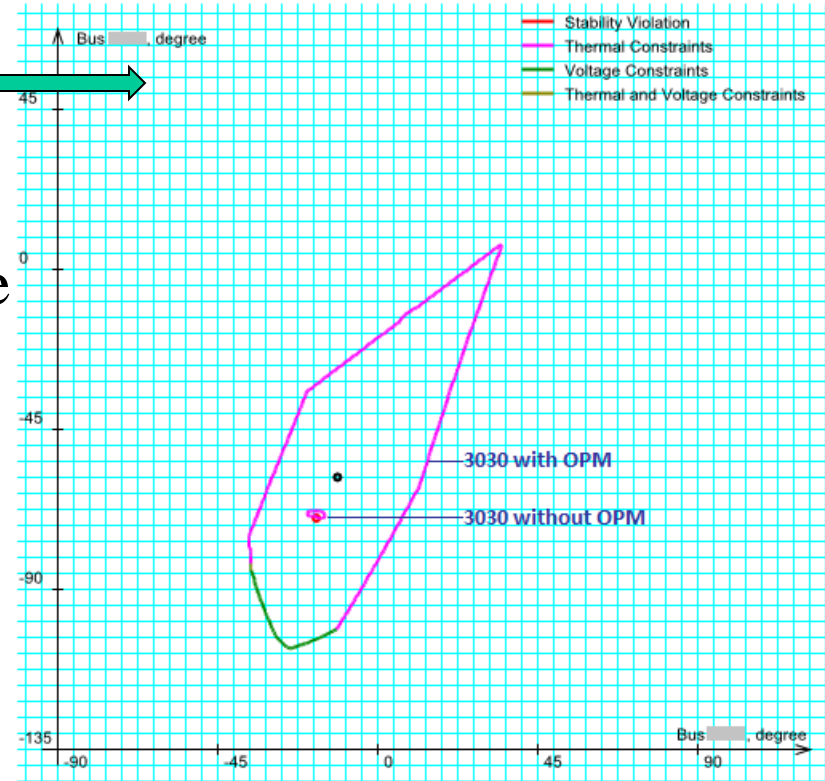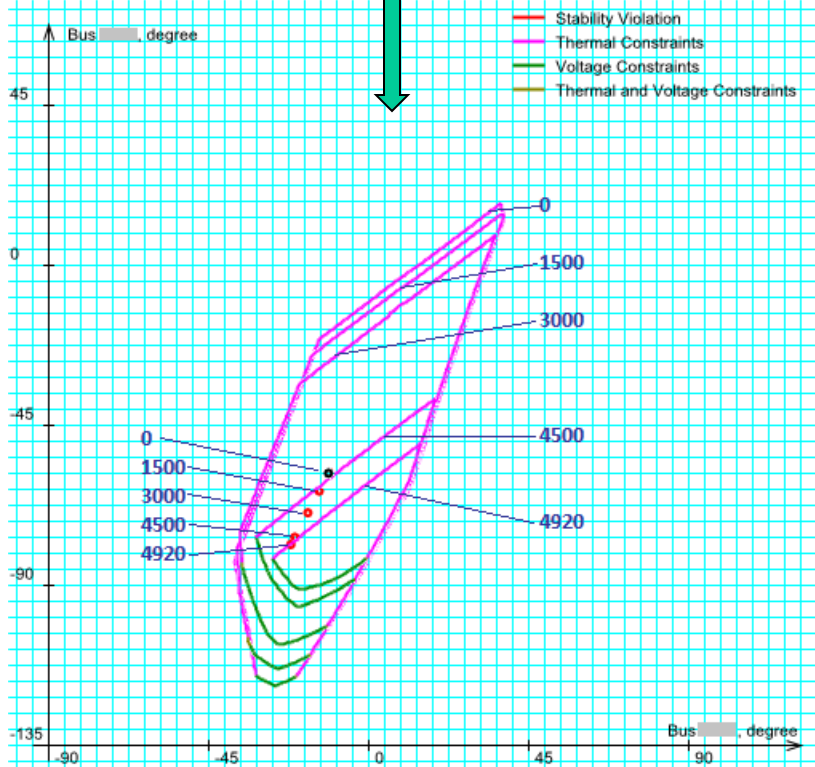# *ROSE* Boundary for the Base Case and Stressed Conditions

- Shown on the plane of real powers
- The same scenarios
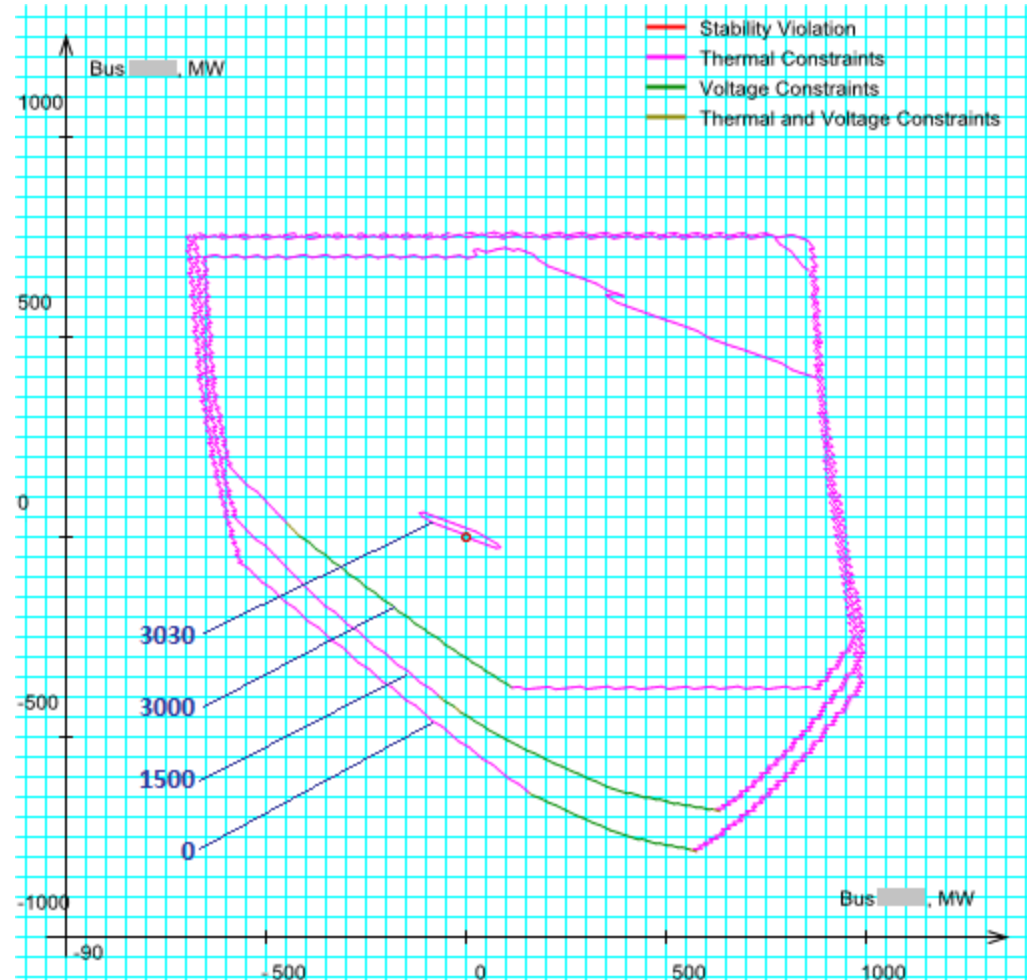
Use of Remedial Actions

- The effect of remedial actions on increasing the boundary for the limit case

- Using remedial actions to increase the region beyond the limit case

Execution Time

- Depending on the computer used, takes approx. 3 - 6 sec to construct a boundary
  - For about 350 iterations of the Newton method (~ 0.015 sec per iteration)

Conclusion

- *ROSE* increases situational awareness of the operators by allowing them to accurately and timely predict steady-state instability and compute system stability limits in real-time environment by using phasor quantities collected by PMUs

- *ROSE* offers continuous monitoring of the system conditions under normal and contingency conditions

- Operator is alarmed before a new State Estimator case arrives

- Automatically identifies optimal mitigation measures for the use by the operators in order to prevent collapse

- *ROSE* uses phasor measurements in its model