Physical and Operational Margins (POM) Overview

www.vrenegy.com

April 28, 2010

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

VR Energy’s Customers

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

User Testimonials

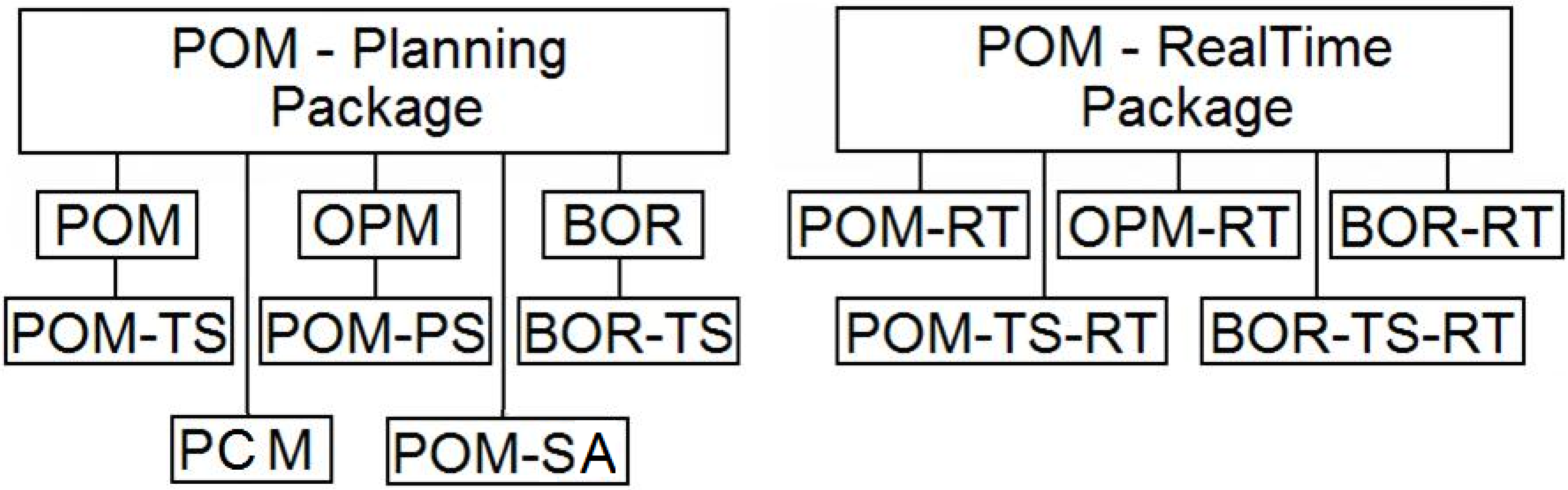
- *I'm convinced you (plural) are the only ones in the industry giving the proper thought and attention to the problems that transmission operators and planners are trying to manage*
  - American Transmission Co.

- *When POM is utilized for planning studies, the person-hours spent could be in the ratio 1:4 compared with the software presently used, which translates to about $50,000 in productivity gains*
  - NYPA

V&R Energy Software Solutions

- Extremely fast:
  - Full AC contingency analysis: 36000 contingencies/hour
  - Time-domain simulation: Execution time for a one second simulation is approximately 6 sec
    - 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 optimum mitigation measures
- Optimally ranks transmission expansion projects and performs cost-benefit analysis

POM Suite



POM - Physical and Operational Margins

OPM - OPtimal Mitigation Measures

BOR - Boundary of Operating Region

PCM - Potential Cascading Modes

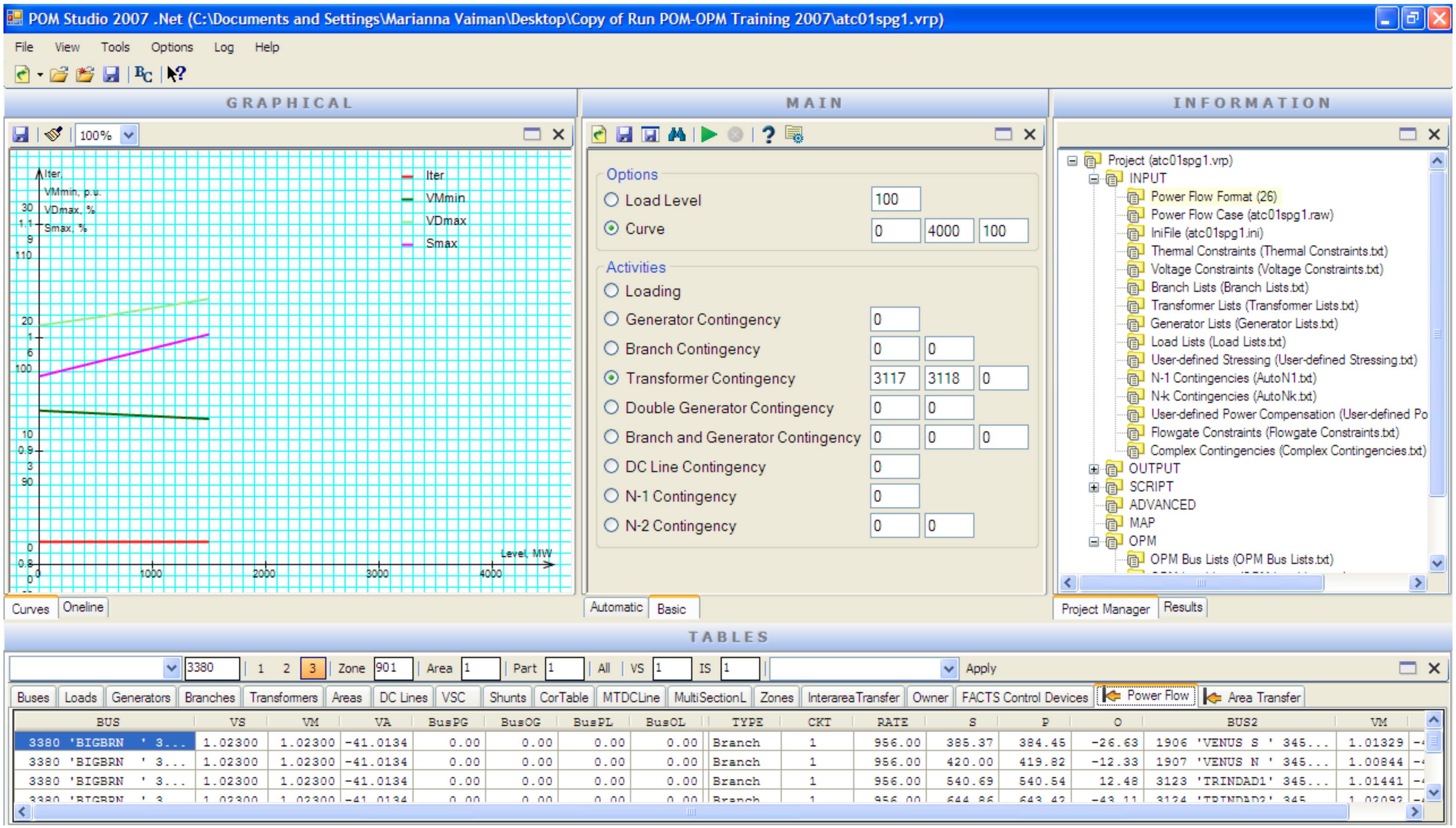
POM-TS - POM-Transient Stability

POM-PS - POM-Project Selection

BOR-TS - BOR-Transient Stability

POM-SA - POM Small-Signal Analysis

POM Suite for an EI case with 50,000 buses



Latest Papers on the Use of V&R Energy's Technology

- Three papers were presented at 2010 PES T&D Conference and Expo, New Orleans, April 19-22, 2010:
  - "Implementation of Optimal Mitigation Measures for Transmission Planning Assessment"
    - by Jason Robison, Makarand "Mak" Nagle, Southwest Power Pool, Marianna Vaiman, V&R Energy
  - "N-1-1 AC Contingency Analysis as a Part of NERC Compliance Studies at Midwest ISO"
    - by D. Chatterjee, J. Webb, Q. Gao, MISO, M. Y. Vaiman, M. M. Vaiman, M. Povolotskiy, V&R Energy
  - "Prevention of Cascading Outages in Con Edison's Network"
    - by M. Koenig, P. Duggan, J. Wong, Con Edison, M. Y. Vaiman, M. M. Vaiman, M. Povolotskiy, V&R Energy

V&R Energy's Awards

- **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
- **ARRA Smart Grid Demonstration Grant, 2010**
  - "Region of Stability Existence" (ROSE) is a part of ISO New England winning bid
- **NYSERDA Award, 2009**
  - Prevention of Occurrence of Major Catastrophic Events: Demonstration for Con Edison System

Current POM-Related Projects

1. Prediction of Power System Instability Based on PMU (with CEATI, www.ceati.com, ISO NE – host utility)
2. Fast Fault Screening for Real-Time Transient Stability Assessment (with NYSERDA, NYISO)
3. Assessing Cascading Outages (with ConEd, Entergy, EPRI, ISO NE, NYPA)
4. Develop methodology and tools for providing settings for safe operation of the Bridger RAS (PacifiCorp)
5. CIM for POM (ConEd, EPRI, NYPA)

POM Use in Planning

- NERC-compliance studies:
  - Massive N-1-1, N-2 AC contingency analysis
  - Automatic remedial actions
  - Database output
  - Fast transient stability analysis with FFS
- AC transfer/load pocket and contingency analyses with visualization
  - Determines available transfer capability for each contingency
  - Determines interface flows
  - Automatically builds PV-curves

POM Use in Planning (cont.)

- Reliability analysis
  - Using results of POM-OPM to compute reliability indices
- Voltage stability analysis:
  - Identifying the causes of voltage collapse
  - Determining **optimal mitigation measurs** to relieve voltage instability
- Phase-shifter settings optimization to relieve post-contingency violations

POM Use in Operations

- N-1 Studies for Outage Coordination
- Voltage Stability – Fast P-V Curve Analysis
- Power Transfer Analysis with Visualization Tool Implemented for N-1, N-2, …, N-K
- Emergency Mitigation Measure Process – Load Shedding

POM Applications in Operations/Real-Time

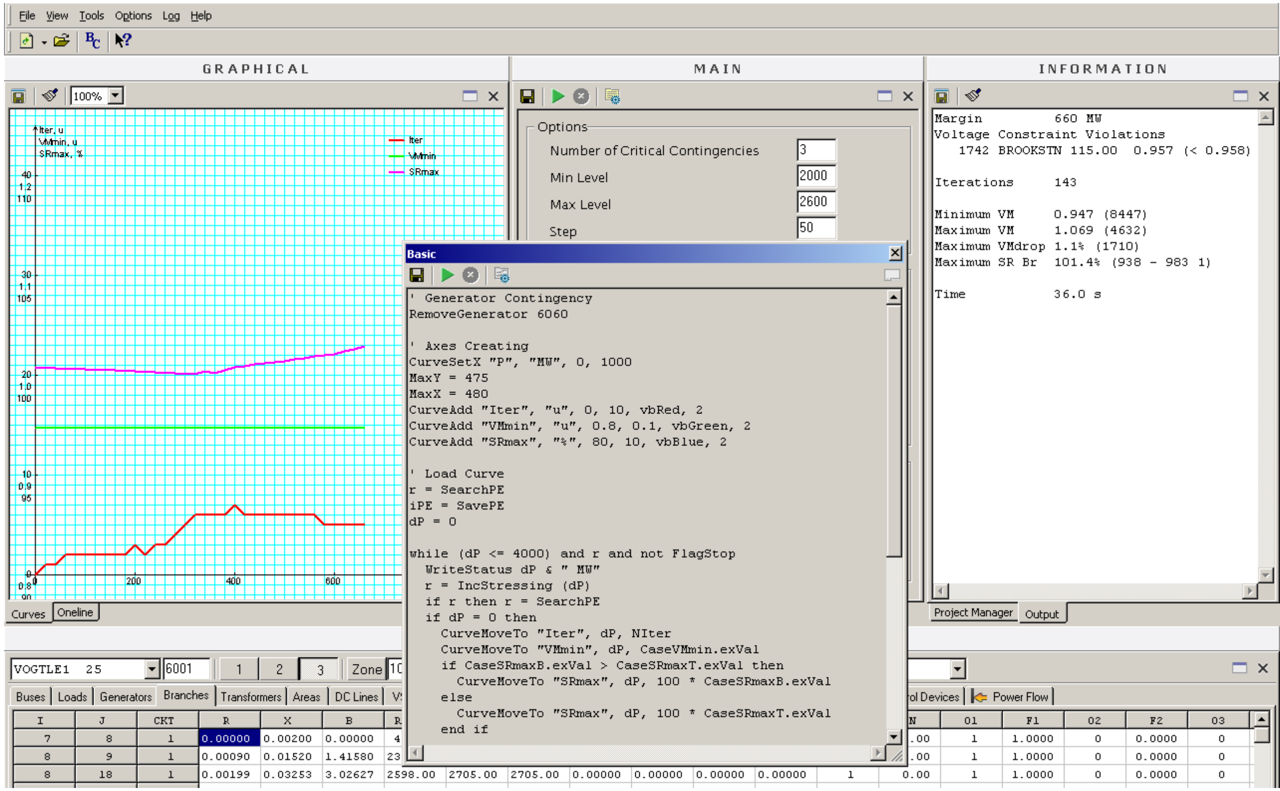
- New applications include:
  - Use of PMU data to predict instability and alarm operators
  - Predicting cascading outages
  - Real-time transient stability analysis

Integration with Other Applications

- Reads power flow cases in Siemens PTI PSS/E rev. 23-30 and GE-PSLF versions 16.1 and earlier
- Reads dynamic model data in PSS/E and PSLF formats
- Reads existing contingency lists

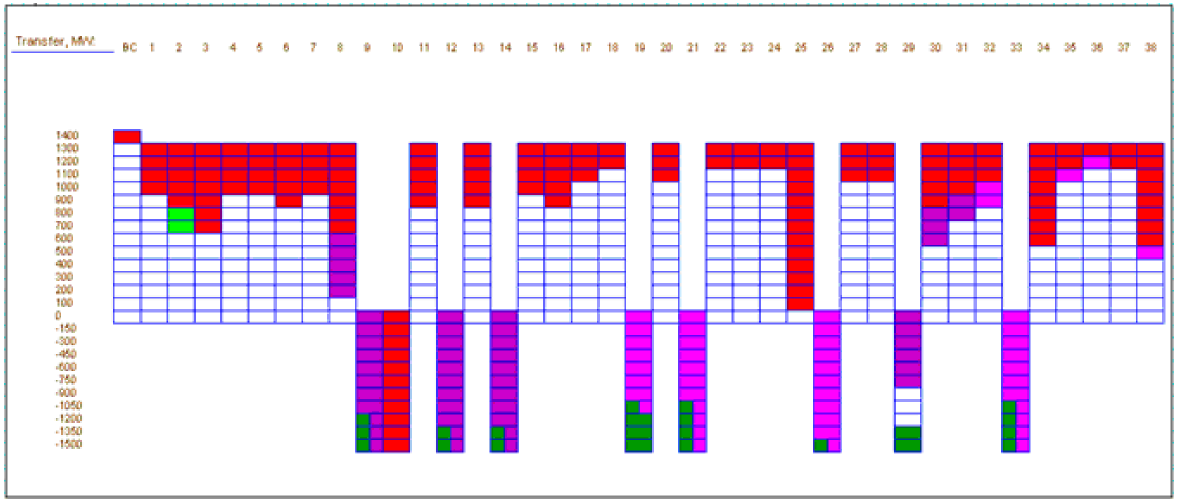
Open Code Program

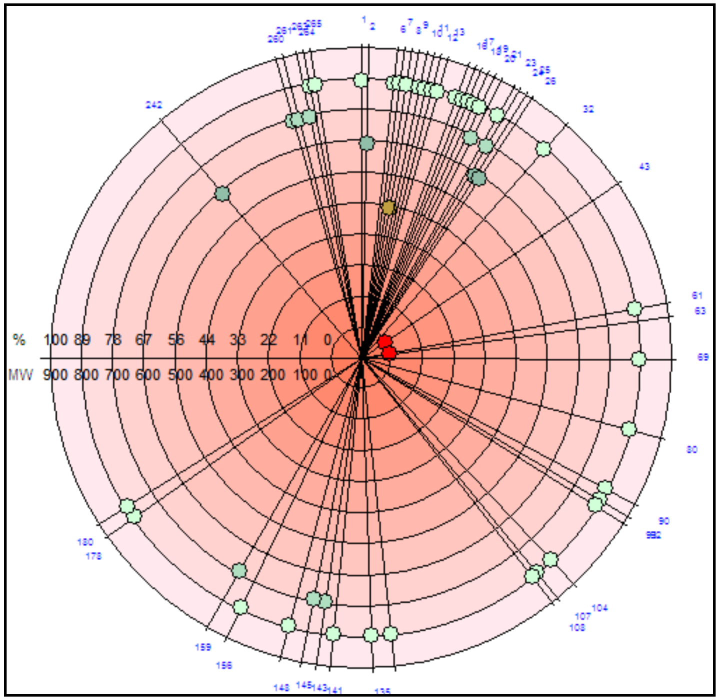
- For each activity executed by POM a corresponding script is generated and displayed
- Scripts can be further modified and re-used



Visualizing Contingency Analysis

- User-specified graphical and tabular output





Complying with the New NERC TPL Standard

- Automatic AC contingency analysis and visualization to assess system performance following Planning Events:
  - N-1 Contingencies – Categories P1, P2
  - N-1-1 Contingencies – Categories P3, P6
    - Loss of one element followed by system adjustments, and then loss of the second element
  - N-2 Contingencies – Categories P4, P5, P7
    - Loss of multiple elements simultaneously
  - Fast fault screening for three-phase and unbalanced faults
- System Performance Following Extreme Events

Ability to Perform Massive Contingency Analysis

- Ability to handle very large contingency lists:
  - MISO analyzed approx. **one million N-1-1 contingencies** in the end of 2009
  - SPP runs seven cases each year (~ 60,000-bus model)
    - 5 different cases for Near-Term assessment
    - 2 different cases for Long-Term assessment
    - N-2 contingency list range from **550,000 to over 760,000 contingencies** per run plus identification of corrective actions for each contingency causing violations
  - Con Edison and Entergy run multiple cases each year for Long-Term assessment
    - Each case approx. 100,000 contingencies

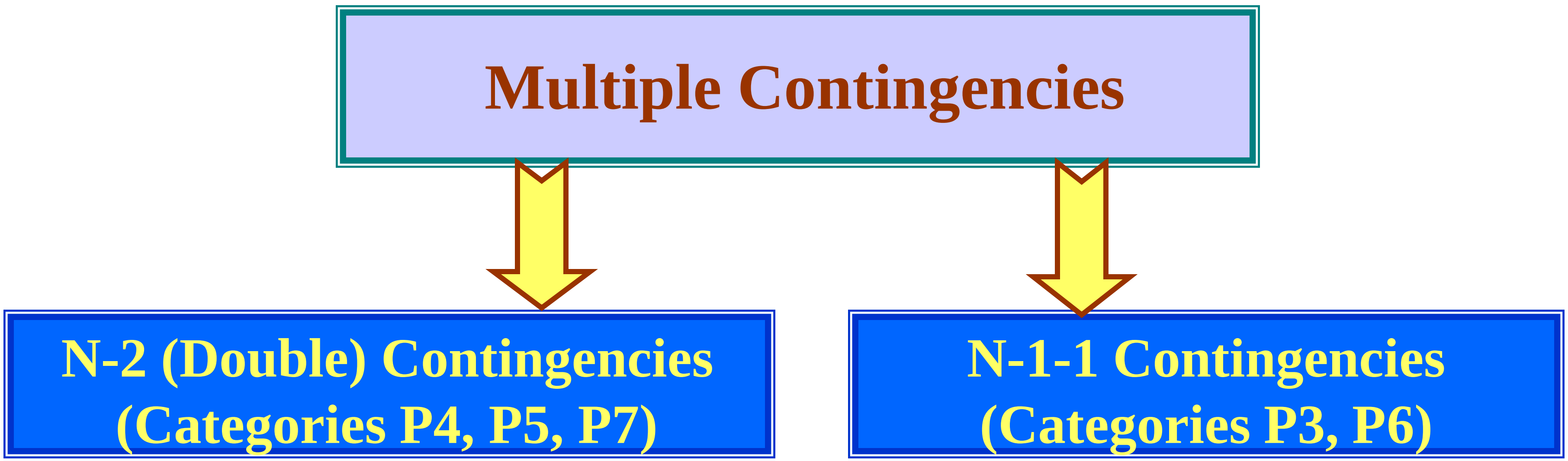
Reading/Creating Contingency Lists

- N-1 contingency lists:
  - Reads existing contingency files
  - Creates generic files based on specified criteria
  - Combines existing files with generic files
- N-2 (N-k) contingency lists
  - Combines all contingencies from N-1 list
  - Combines contingencies based on generic rules
  - Combines contingencies based on user-defined rules
  - Combines two N-1 contingency lists

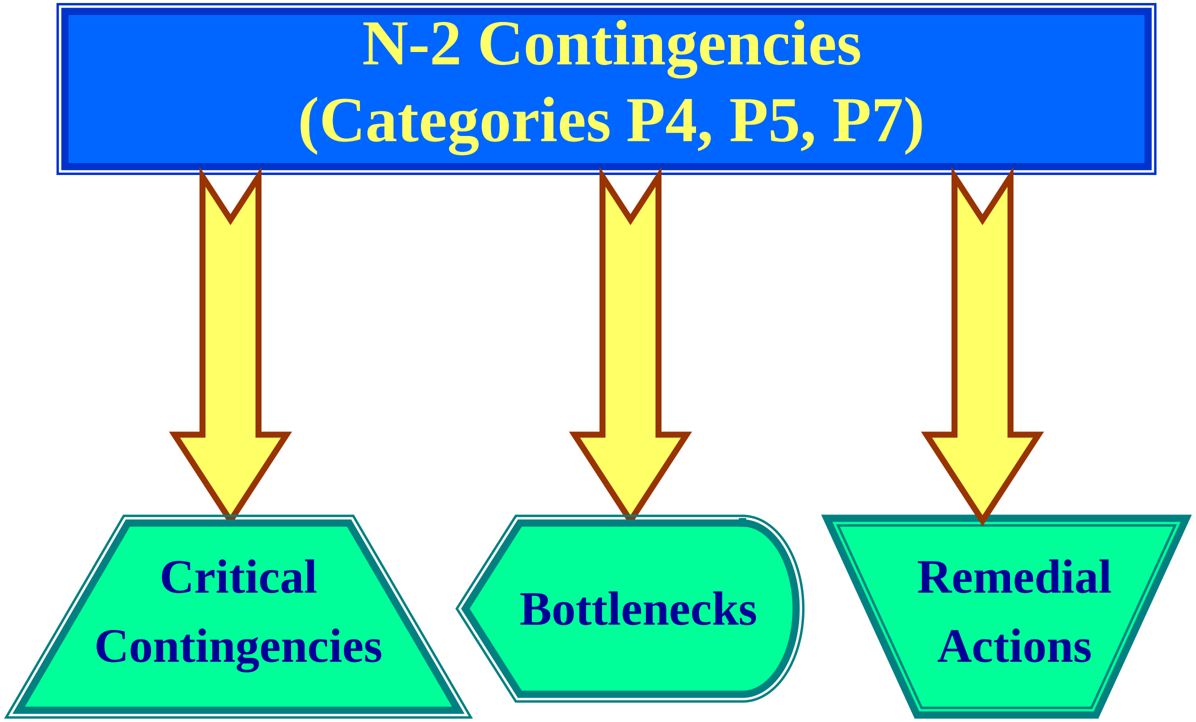
POM Suite Flexibility

- The user may set up different options and monitored elements files within the same runs for:
  - Base case/transfer analysis (N-0)
  - N-1 contingency analysis
  - N-2 contingency analysis

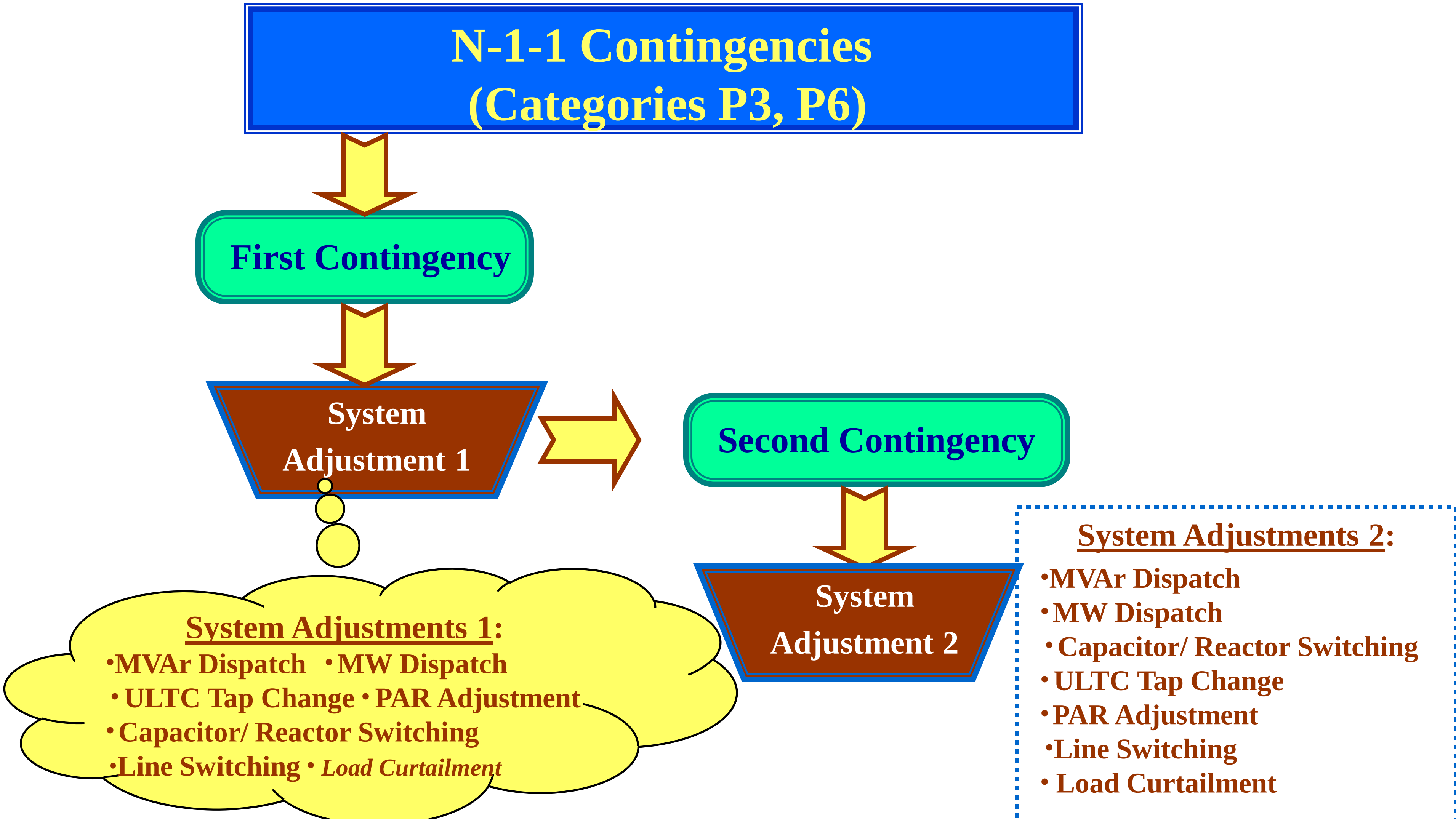
Multiple Contingencies



N-2 Contingency Analysis

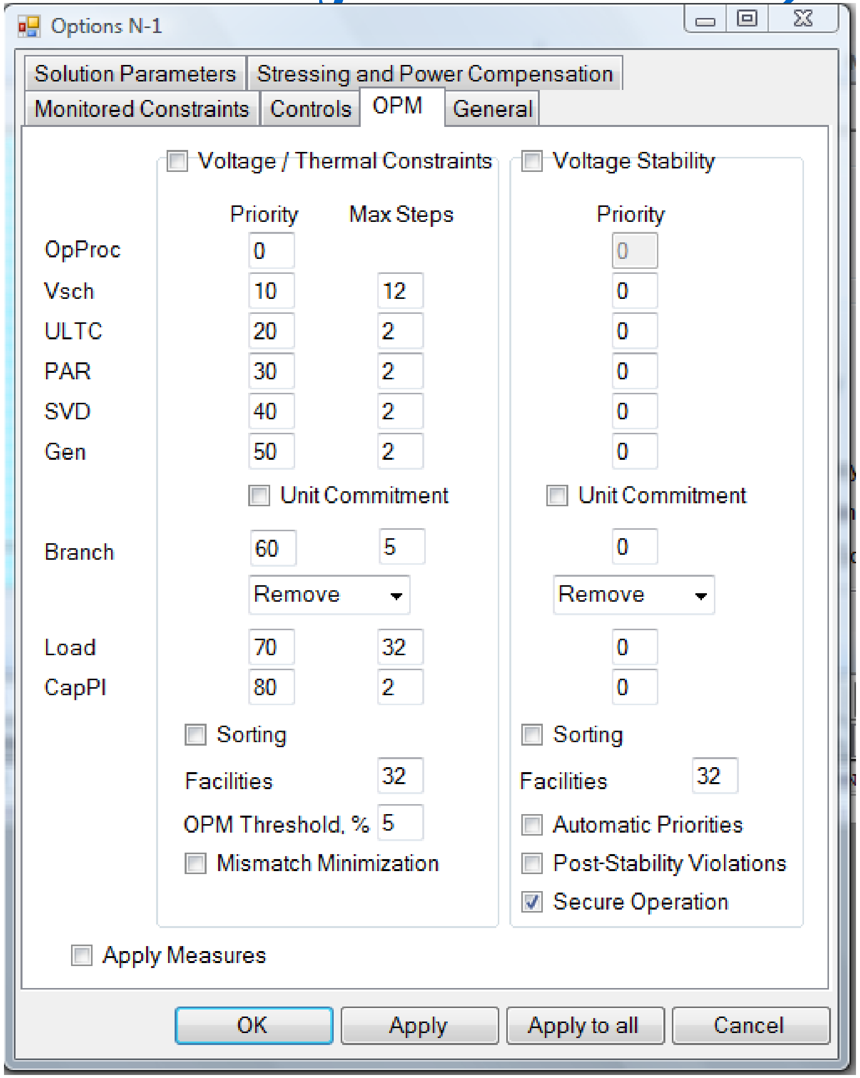


N-1-1 Contingency Analysis with System Adjustments



Determining Optimal Remedial Actions (System Adjustments)

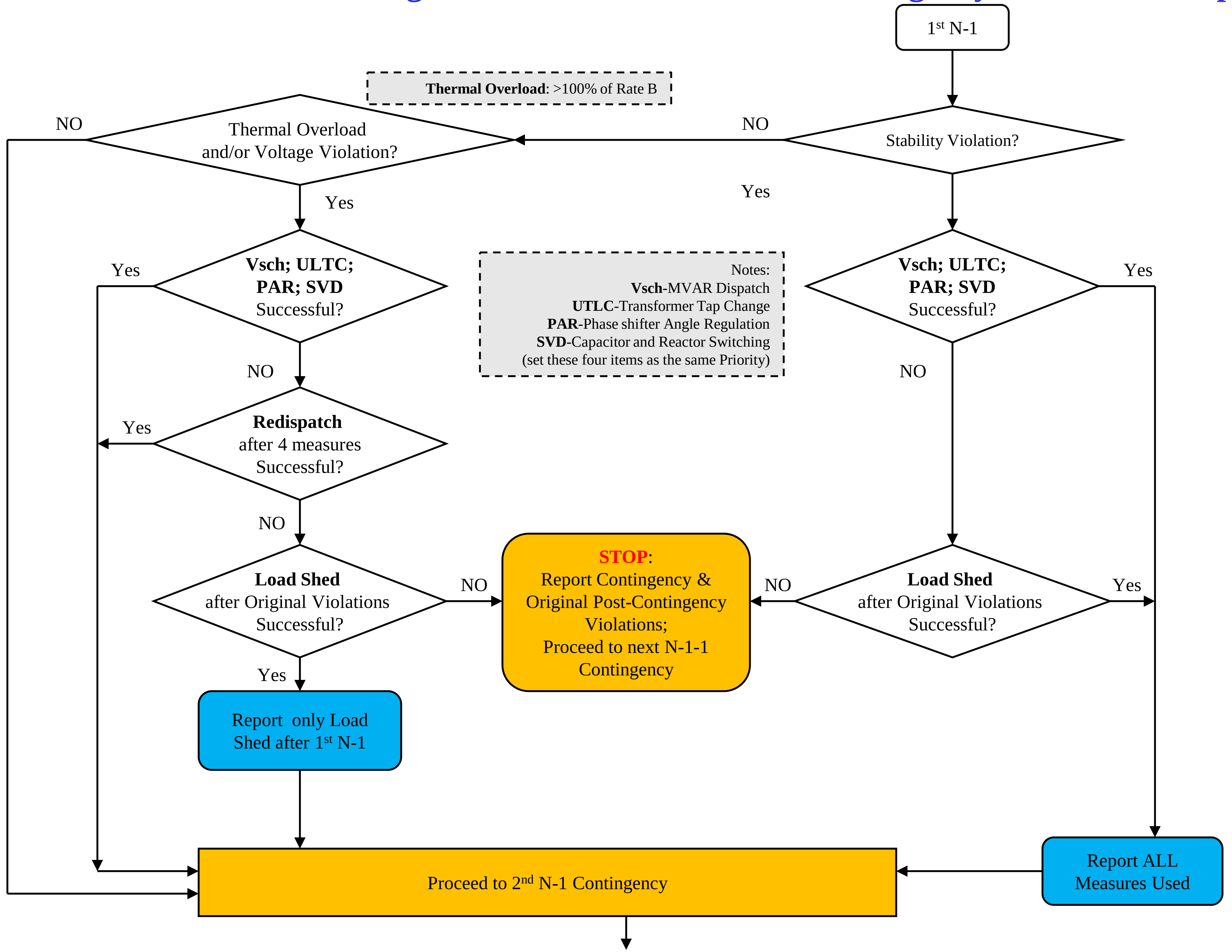
- Fast, powerful and efficient remedial actions tool
- Automatically alleviates violations during massive AC contingency analysis:
  - Alleviates thermal, voltage and voltage stability violations in approximately 10 seconds for one contingency for a 50000-bus case



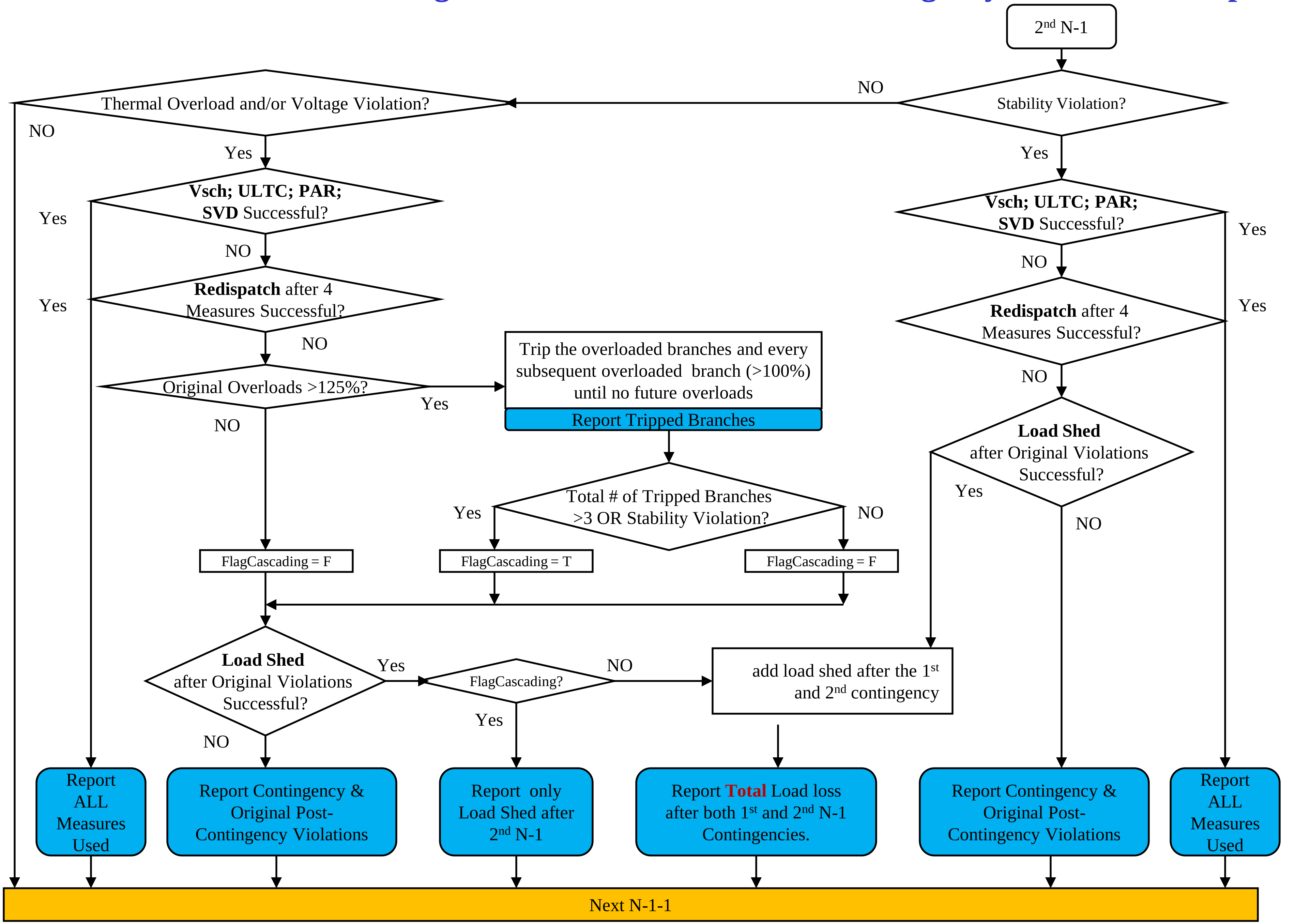
Remedial Actions Used in OPM

- Applies a minimum amount of mitigation measures based on a user-defined priority schedule
- Available remedial actions include:
  - MW Dispatch
  - MVar Dispatch
  - Capacitor and Reactor Switching
  - Transformer Tap Change
  - Phase Shifter settings
  - Line Switching (In and Out)
    - Switching Not Affected Lines
  - Load Curtailment
  - Optimal Capacitor, Reactor Placement and Size
  - Defined Operating Procedures

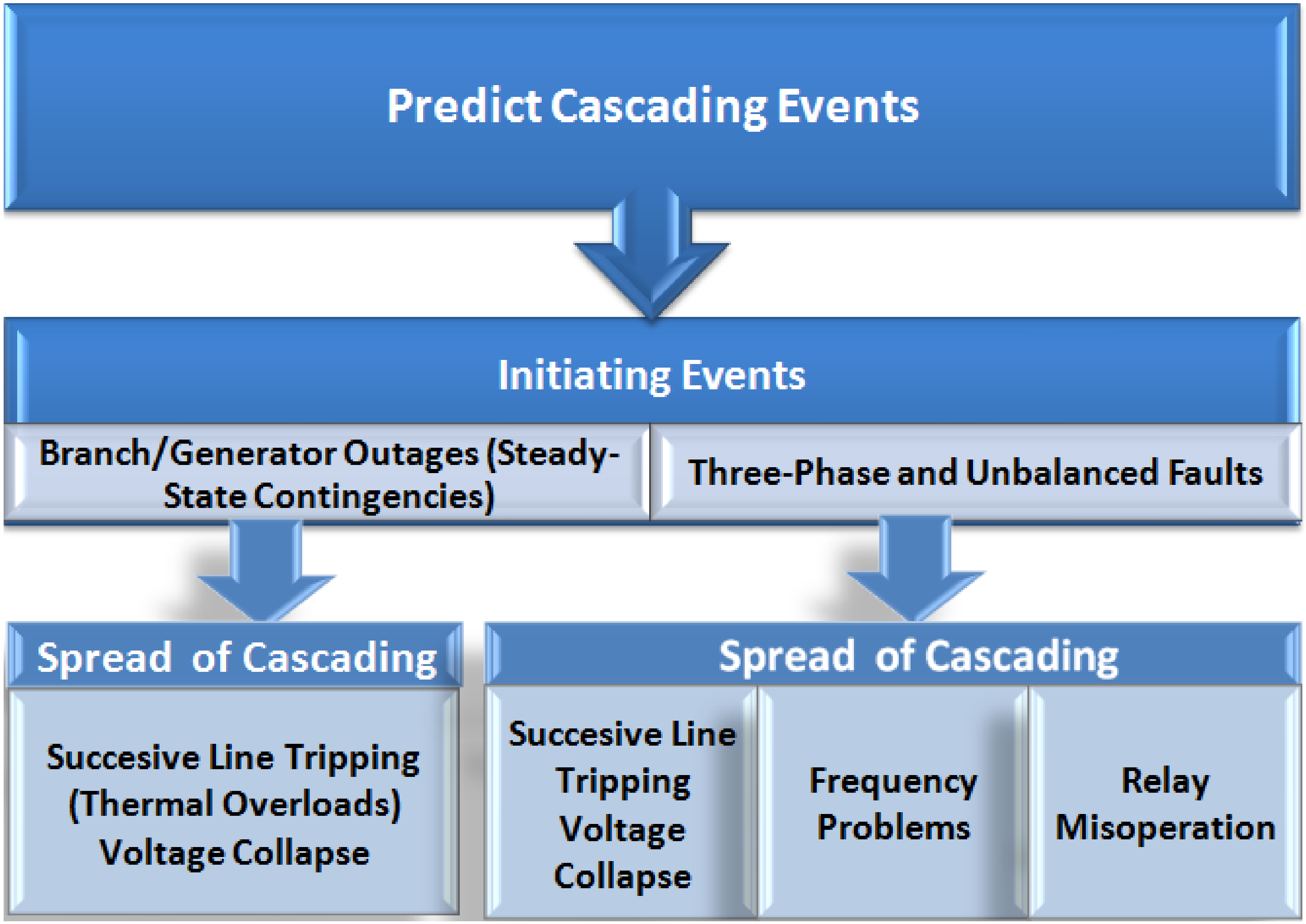
POM-OPM Mitigation Process after 1st N-1 Contingency: MISO's Example



POM-OPM Mitigation Process after 2nd N-1 Contingency : MISO's Example



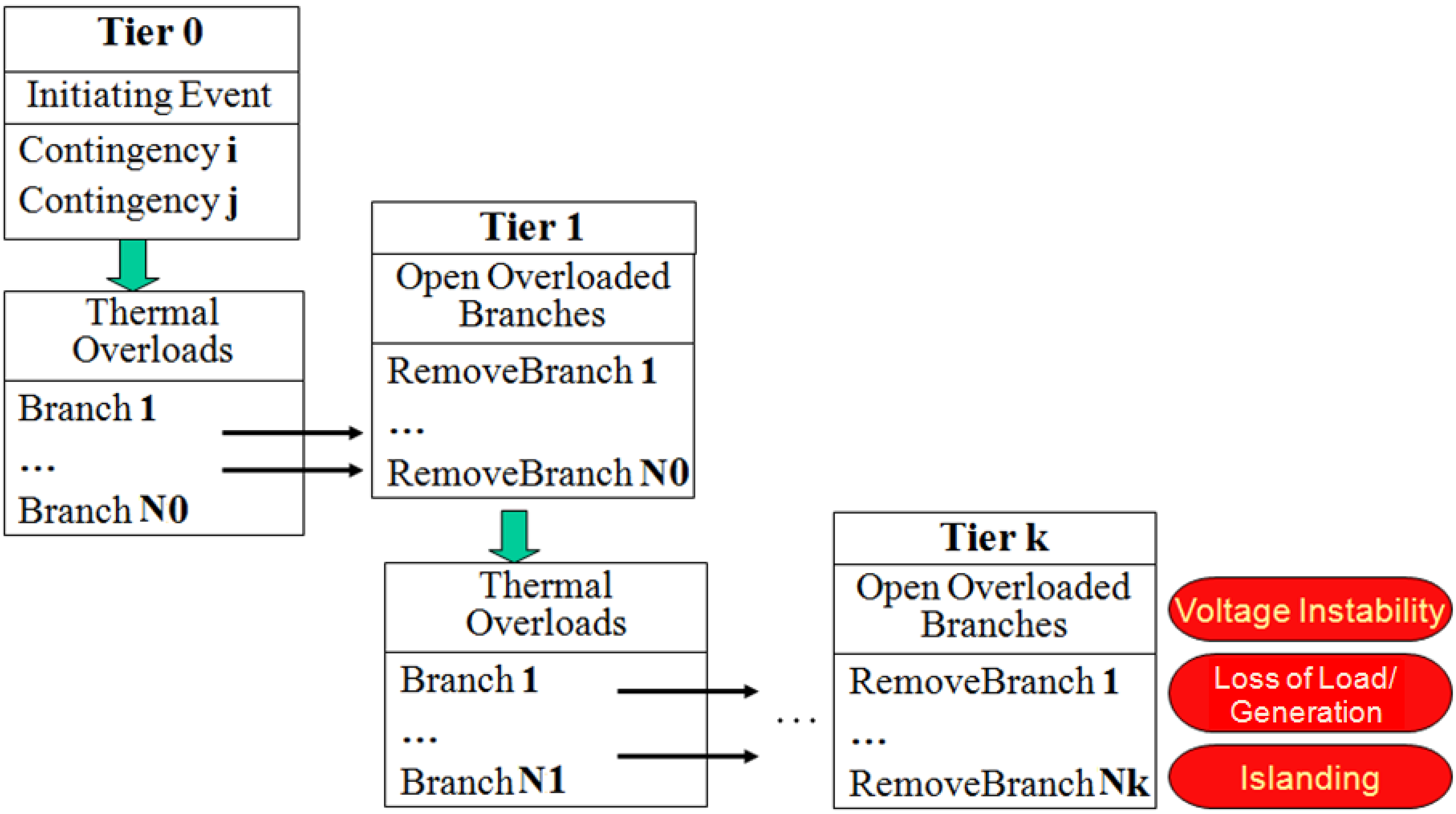
Analysis of Cascading Outages



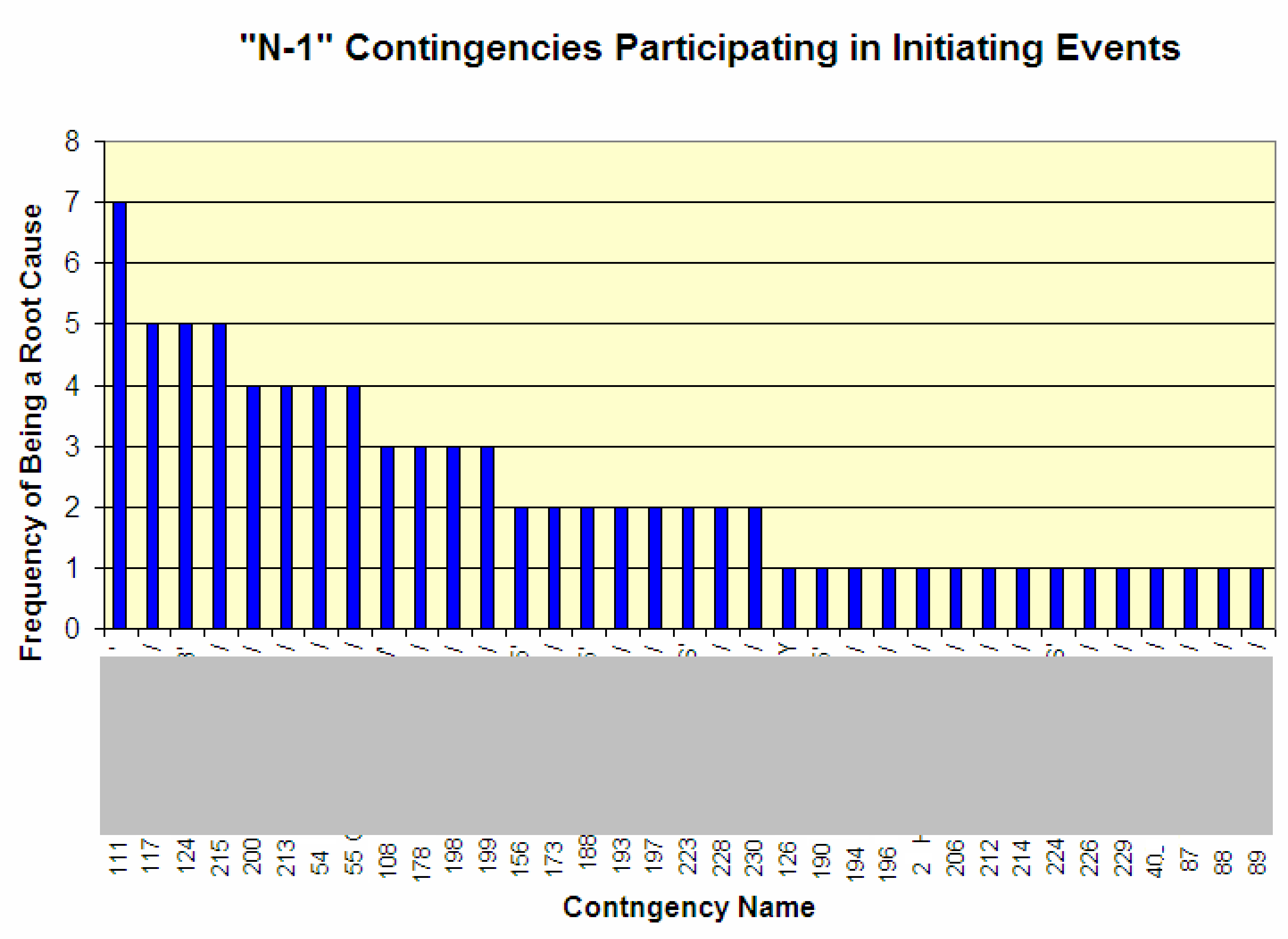
Analysis of Extreme Events

- Analysis scenario:
  - Quantify a power system's ability to withstand cascading outages caused by successive tripping of lines
- Quickly identify initiating events that may lead to cascading events
  - Impractical to apply all N-k contingencies in a bulk power system
- Automatically identify potential cascading modes

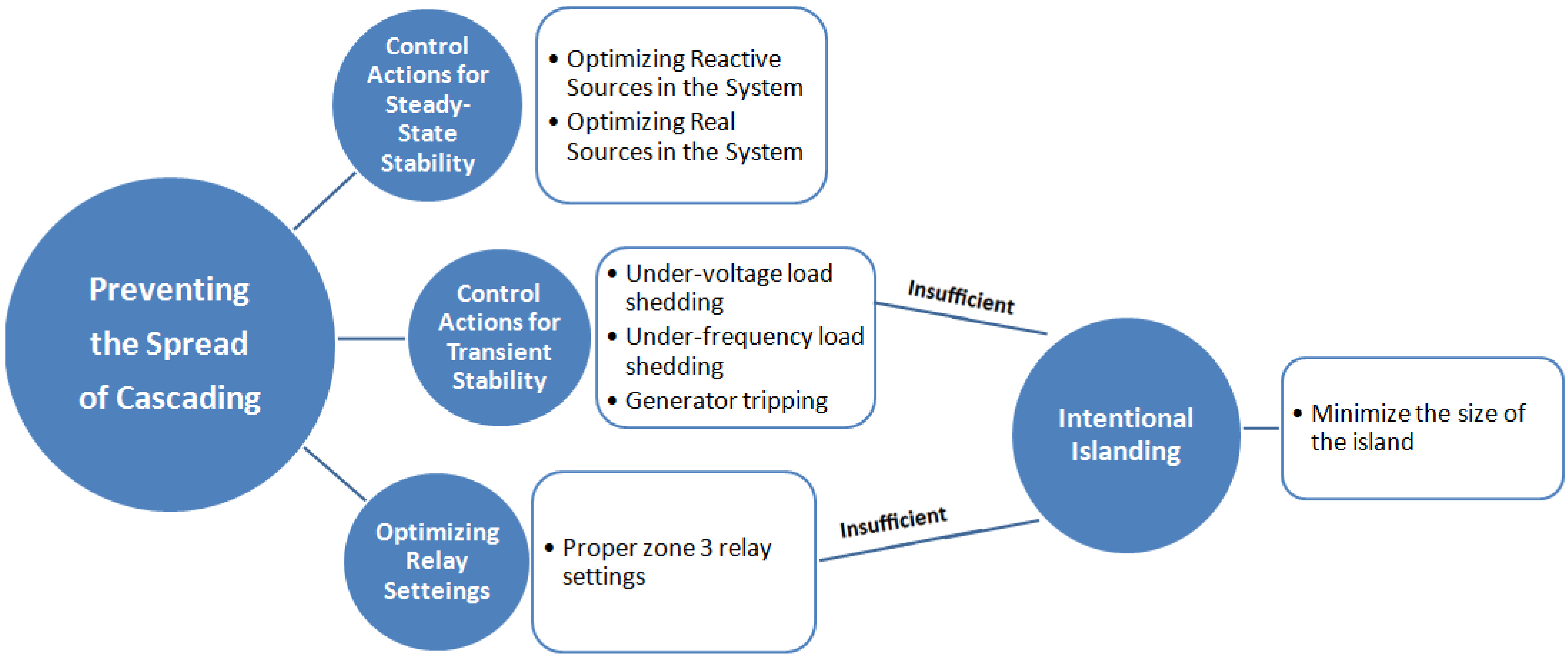
Analysis of Cascading Outages



"N-1" Contingencies Forming "N-2" Initiating Events



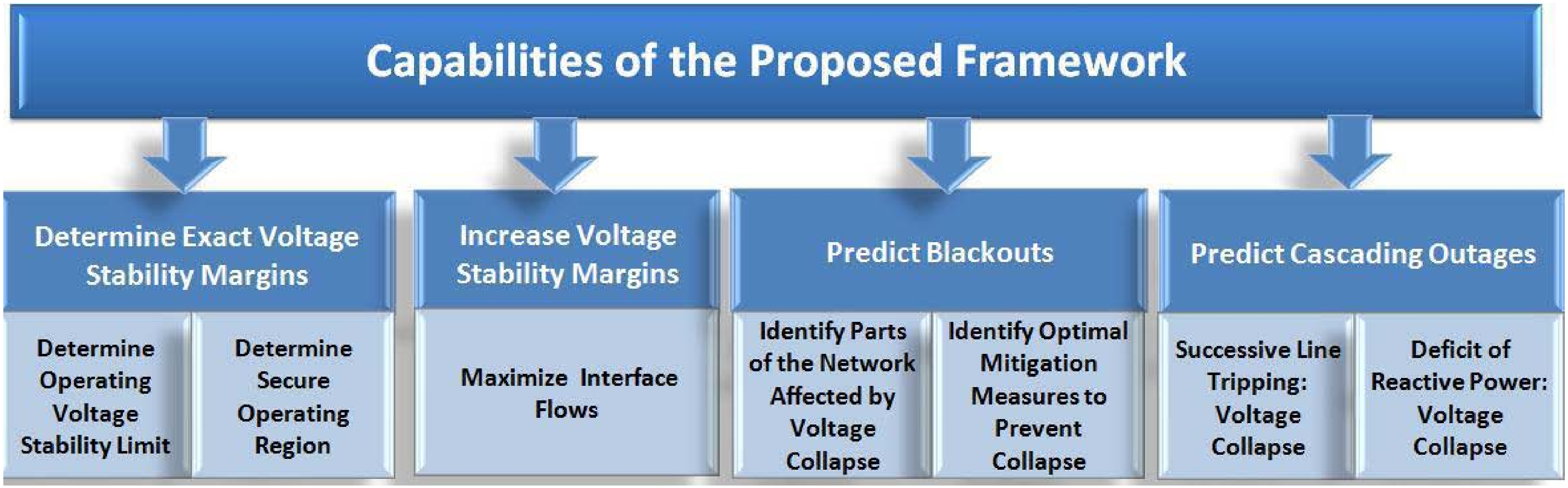
Preventive Measures/Islanding



Advanced Voltage Stability Analysis

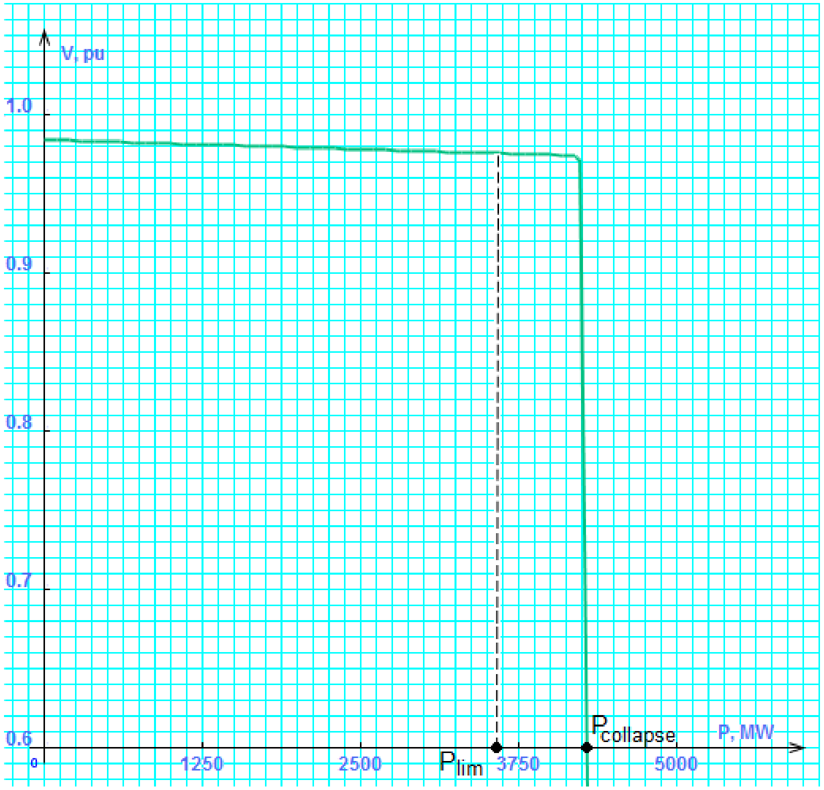
- Determine Critical System Parameters that Impact Steady-State Stability
- Identify Part of the Region of Existence of Power Flow Solution (Voltage Stability Region) where Operation is Secure (Operating Region) and Its Boundary
- Display the Operating Region on the Plane of Critical Parameters
- Compute the Exact Value of Voltage Stability Limit
- Apply Remedial Actions to Increase Voltage Stability Margins

Summary of the Benefits



Advanced Voltage Stability Analysis

- Identifies the "operating" voltage stability margin:
  - Important when PV-curve analysis does not yield useful information; for example, when the voltage profile (PV curve) remains almost unchanged, and then is followed by a sharp decline
  - Operating the system beyond the "operating" margin and until the point of voltage collapse would be undesirable

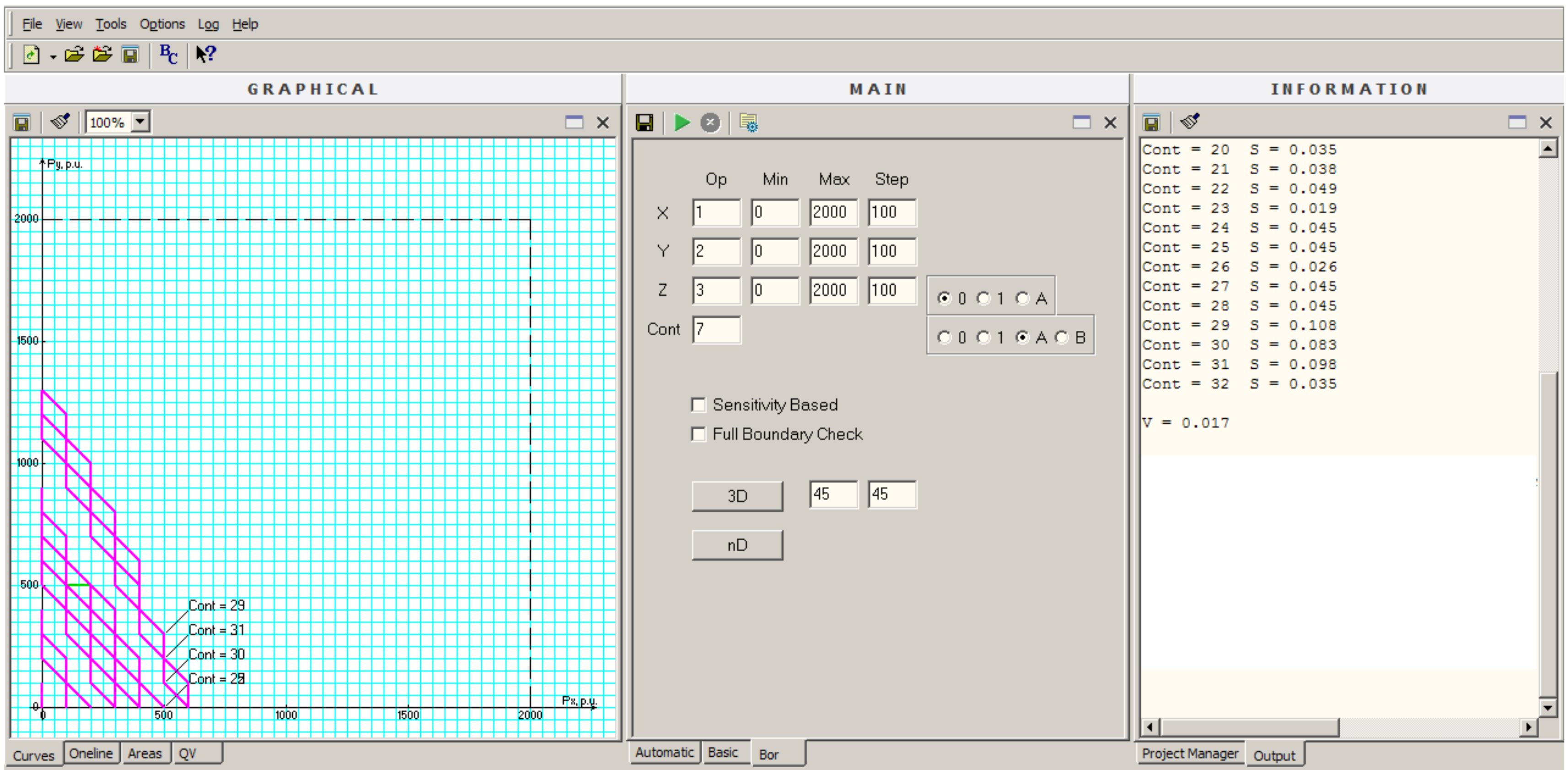


Boundary-Based Solution

- Automatically identifies operating region that satisfies N-1/N-1-1/N-2 reliability criteria
- Addressed conditional firm requirements (Order 890)
- Finds AC limits for transfer scenarios based on voltage stability, voltage constraints, and thermal constraints
- Computes dynamic security region

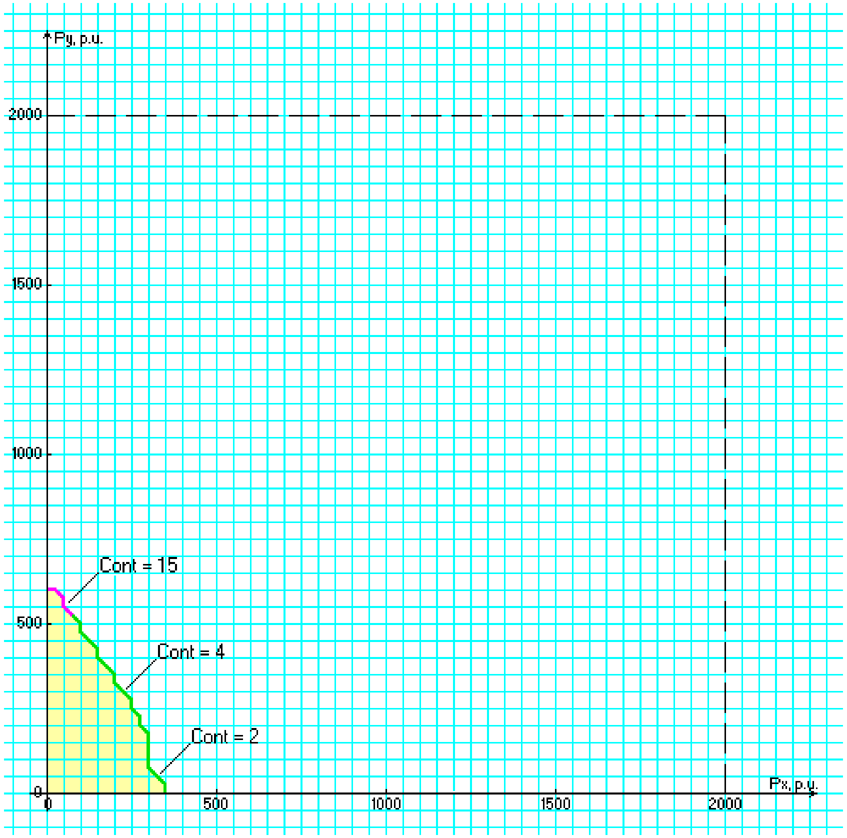
Ranking Contingencies

- Computes an index that corresponds to area of each projection, S
  - S index is computed for each contingency
  - Contingencies are ranked based on the S index



Operating Region that Satisfies Reliability Criteria

- Automatically determines the most limiting contingencies
  - Secure operating region may be formed by several contingencies
- The area formed by the most limiting contingencies is the area that satisfies N-1 and/or N-2 reliability criteria
- Power system is secure only when operating within this area
  - Can be used in real-time, on-line and planning environments



Region of Stability Existence (ROSE): Utilizing PMU Data

- ROSE utilizes phasor measurements to predict steady-state instability and alarm the operator about the impending crisis
- ROSE uses PMU, SCADA and SE data for on-line calculation and visualization of the current operating point and its proximity to the stability boundary

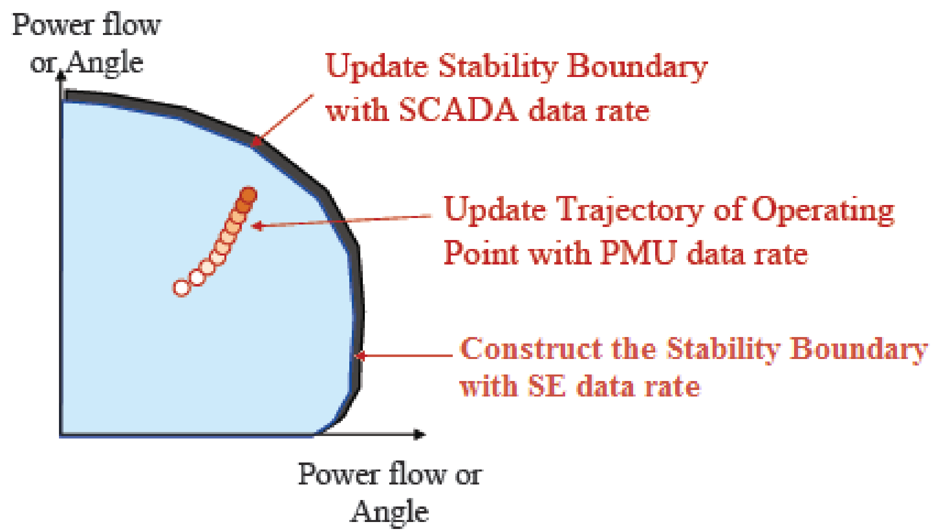


Figure p. 27, see http://ewh.ieee.org/reg/1/809/Litvinov.pdf.

ROSE Data Sets

- State Estimator case to compute an initial operating point and the boundary of stability existence
  - Every 3 to 15 minutes
- SCADA data to update the boundary of stability existence
  - Every several seconds
- PMU data to compute the current operating point
  - Average 30 times/sec

ROSE Analysis

- Read a SE case using ROSE-based POM Suite each X-minute interval.
- Compute ROSE boundary and display it on the plane of two phase angles.
- Show the current operating point within the region.
- The position of the operating point changes at the PMU sampling rate. Thus, the continuous trajectory of the current system condition (e.g., regime) is displayed within the boundary.
- The boundary itself is updated every several seconds (e.g., sampling intervals of SCADA).
- The boundary is shown on the plane of two most rapidly changing phase angles.

ROSE Analysis

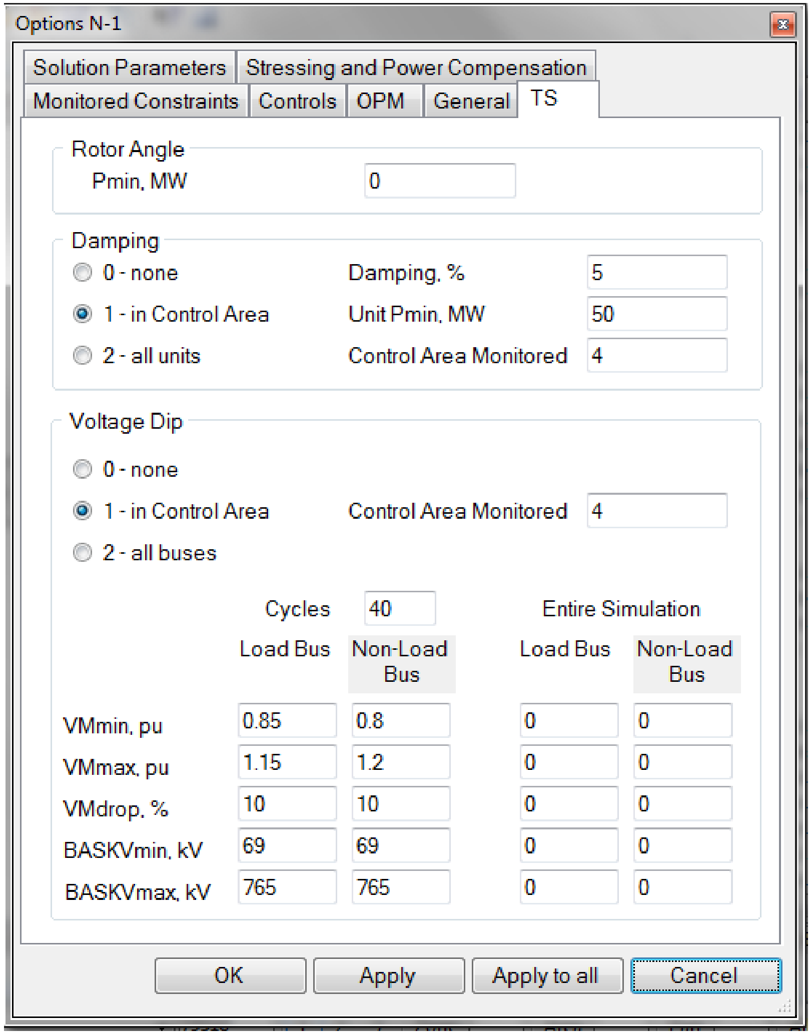
- Each second to several seconds ROSE determines system conditions – closeness of the current operating point to the boundary of stability.
- In addition to displaying the boundary on the plane of two phase angles, the boundary is also displayed on the plane of “critical” power systems parameters (for example, on the plane of the critical interfaces).
- Operator should be alarmed if the operating point and the boundary are moving towards each other.
- If the operating point and the boundary are moving towards each other, the operator is able to initiate preventive actions before the new SE case arrives (and before system collapse).

POM – Transient Stability (POM-TS)

- Fast and user-friendly dynamic simulation – execution time for a one second simulation is approximately 6 seconds for a 50000 bus case and 17000 dynamic models
- Fully integrated into POM
- Supports Library of dynamic models in Siemens PTI's PSS/E and GE's PSLF formats
- Allows for easy inclusion of user-defined models through use of POM scripting
- Satisfies NERC/WECC criteria
- Performs fast fault screening in order to determine the most severe three-phase and unbalanced faults in the system

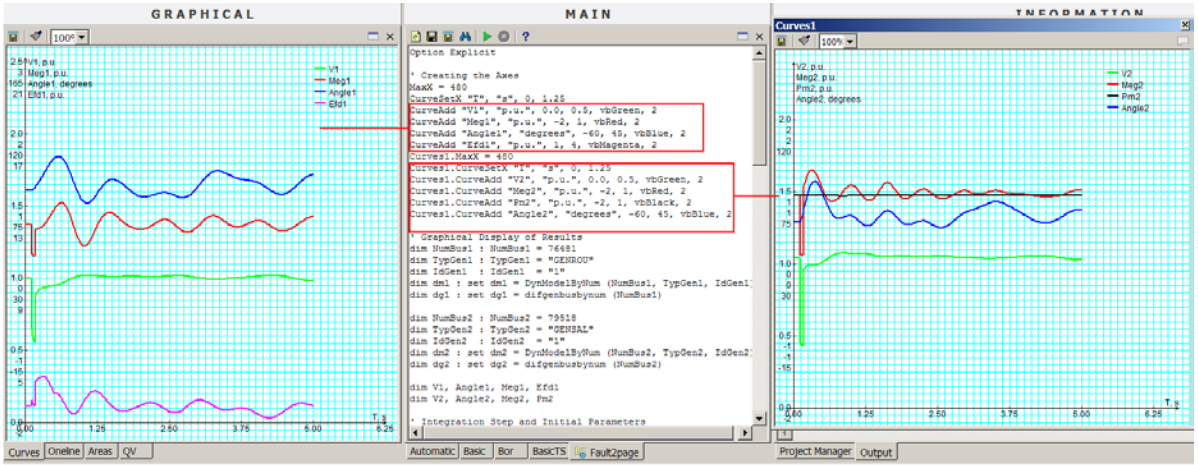
Transient Stability Performance Criteria

- Having the capability to simultaneously monitor multiple criteria during massive fault analysis:
  - Rotor angle
  - Damping
  - Voltage dip
  - Frequency
- Reporting “critical” faults that cause criteria violations



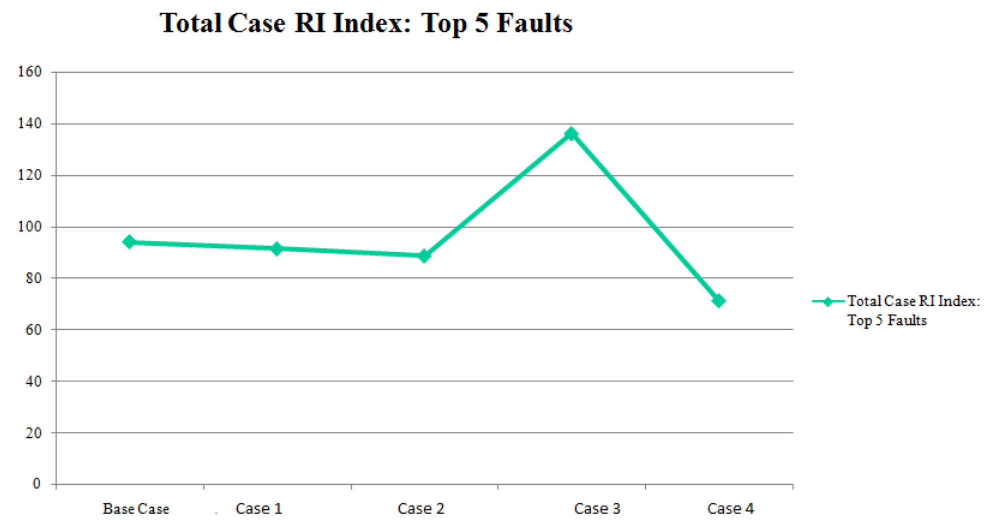
Massive Transient Stability Analysis

- Massive fault analysis using conventional time-domain simulation
  - 100,000s of faults may be applied within one run
  - Performance criteria are monitored



Fast Fault Screening (FFS)

- Quick scanning of the system using FFS:
  - Quickly scans thousands of potential transmission fault locations and identifies the most severe locations



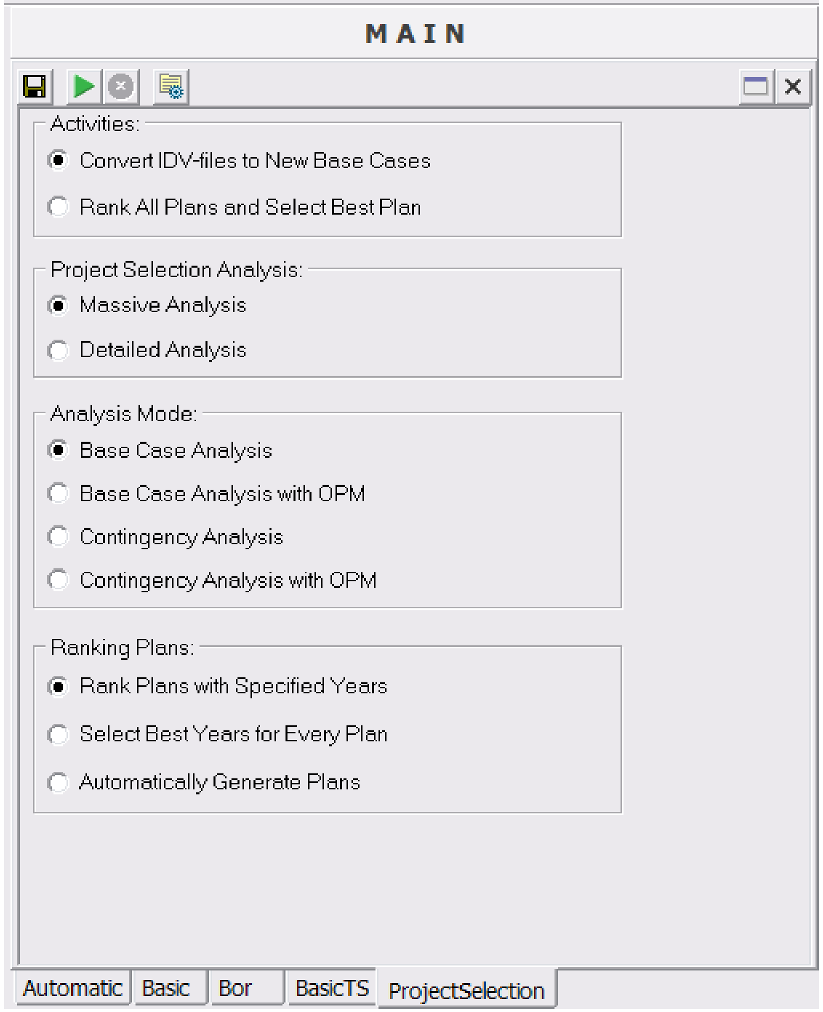
- FFS analysis is performed in two steps:
  - Identify top N fault locations using heuristic approach with several criteria, including:
    - Difference between power flow through a bus and generator power output in the vicinity of the bus,
    - Magnitude of real power leaving a bus
  - Rank these fault locations using a Ranking Index (RI) based on analytical calculations

Fast Fault Screening (FFS)

- FFS has been used by Entergy for NERC-compliance studies
  - SERC 2007 Audit report recognized Entergy’s proactive efforts in utilizing the innovative methodology
  - The current TPL standard TPL-003-0, R.1.3.1 says that "The rationale for the contingencies selected for evaluation shall be available as supporting information.
  - An explanation of why the remaining simulations would produce less severe system results shall be available as supporting information".
  - FFS provides this "rationale" and "supporting information“
- Direct Benefits to Entergy
  - Reduction in computation time of at least 50% on average
  - Saved about 300 man-hours for NERC Reliability Standards compliance-related studies

POM–Project Selection

- Automates selection and prioritization of transmission system expansion projects



Cost - Benefit Analysis

- Determines the cross-dependencies between benefits that the selected reinforcements will provide, and the amount of necessary investment in US$ (or other currency
  - Benefit is user-specified:
    - Additional load served
    - Additional wind generation penetrated
    - Additional flows on the interfaces