DOE/OE Transmission Reliability Program

Real Time Applications Using Linear State Estimation Technology (RTA/LSE)

DOE Grant Award #DE-OE0000849

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Acknowledgement and Disclaimer

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Outline

- Introduction & Project Participants
- Project Objective & Approach
- Overview of Applications
  - Real Time Contingency Analysis
  - Voltage Stability Assessment
  - Area Angle Monitoring
- Schedule & Planned Next Steps
- Cascading Initiative
- Q&A, Discussion

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Introduction

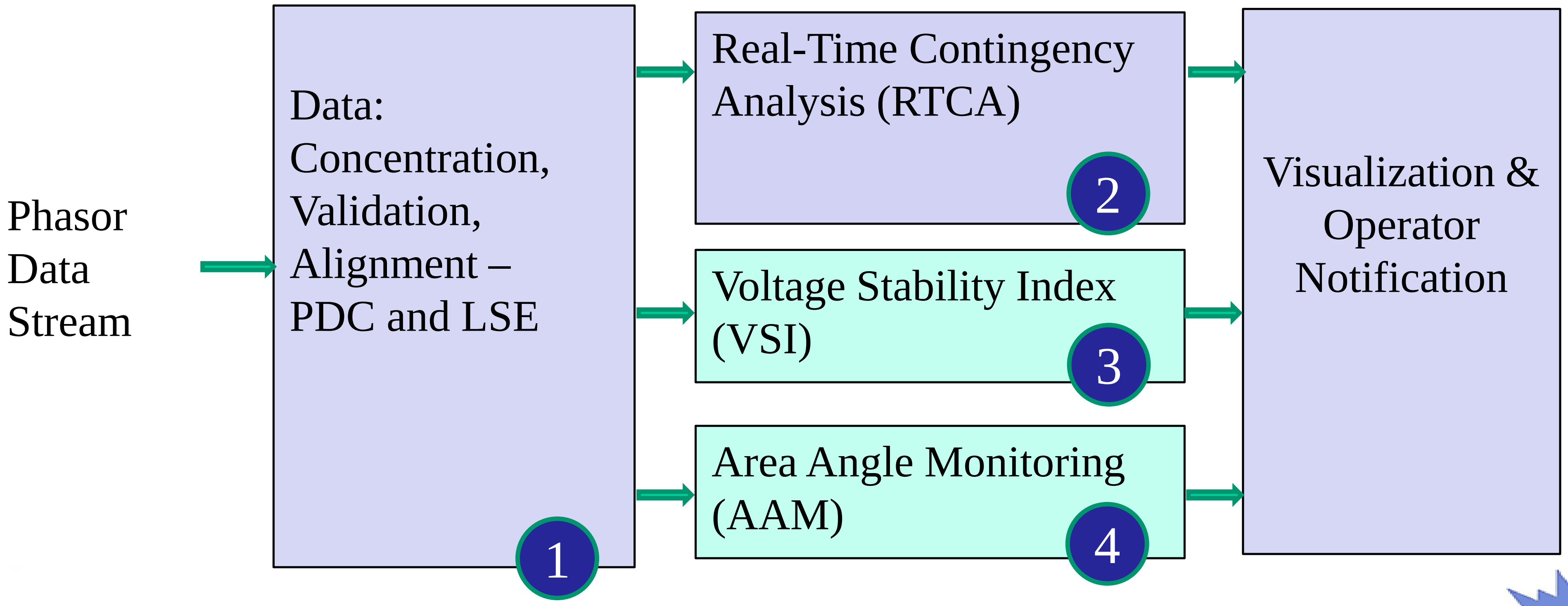
- Project: Real Time Applications Using Linear State Estimation Technology
- Primary Recipient: Electric Power Group, LLC
  - PI - Ken Martin, Team - Neeraj Nayak, Iknoor Singh, Wenyun Ju
- Project Partners (host site & cost share):
  - Bonneville Power Administration (BPA) - Tony Faris, Petr Karasev
  - New York Power Authority (NYPA) - Atena Darvishi, Alan Ettlinger
- Project Host Site - Duke Energy
  - Evan Phillips, Megan Vutsinas, Tim Bradbury
- Project Advisors
  - Anjan Bose, Anurag Srivastava – Washington State University
  - Ian Dobson – Iowa State University
  - Dejan Sobajic – Grid Engineering
- Project Observers
  - Dominion Virginia Power - Kyle Thomas
  - Peak Reliability - Hongming Zhang
  - PJM - Emanuel Bernabeu, Ryan Nice

Project Objective

- Develop Real Time Applications Using Phasor Data and Linear State Estimator Technology
  - Provide operators with actionable intelligence on contingencies, voltage stability, & area angle limits
- Applications include
  - Real Time Contingency Analysis
  - Voltage Stability Assessment
  - Area Angle Monitoring

Project Approach

- Implement three real-time applications using PMU data and LSE
- Test with simulated and recorded data
- Demonstrate at host utilities



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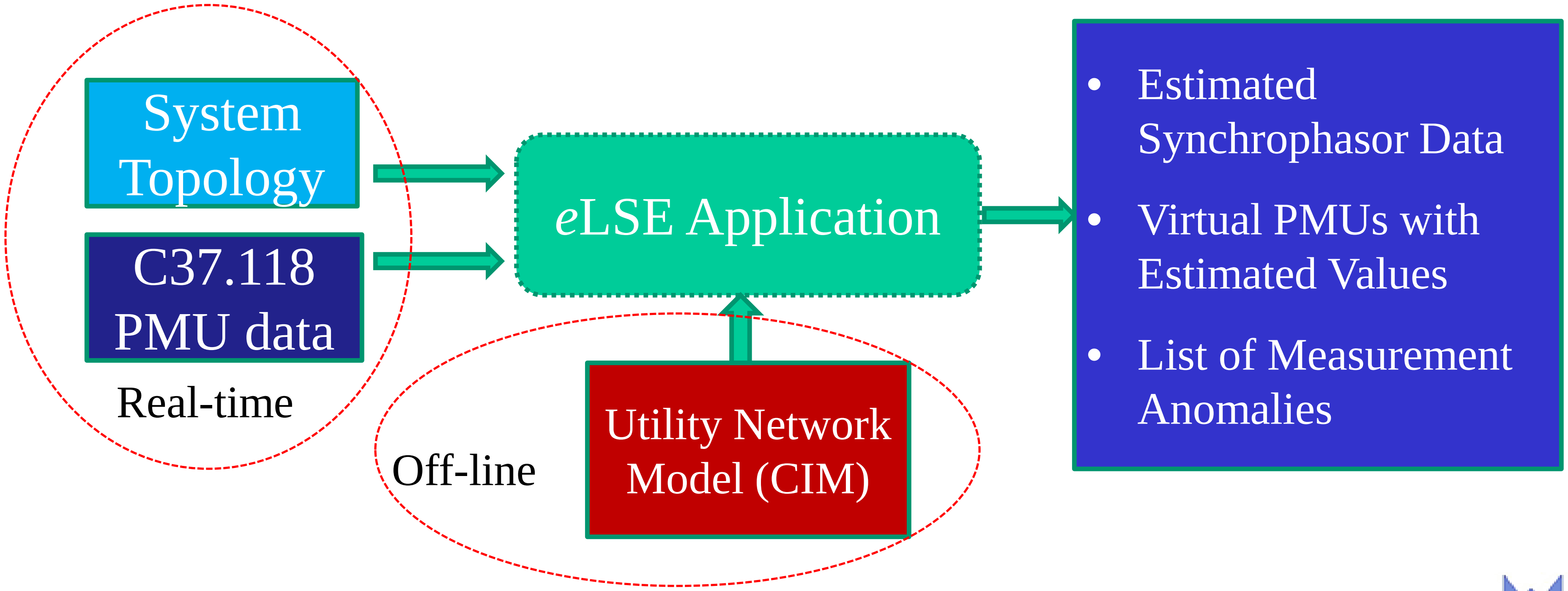
enhanced LINEAR STATE ESTIMATOR (*e*LSE)

Phasor Data Validation & Extended Observability

*e*LSE - Operation

- Uses Network Model and PMU data for linear state estimation
- Uses breaker status from EMS to update Topology
- Passes dataset (results) to Real-Time applications
- **Provides data validation and extended observability for downstream RT Applications**



REAL TIME CONTINGENCY ANALYSIS (RTCA)

Phasor Based Contingency Analysis for Operations

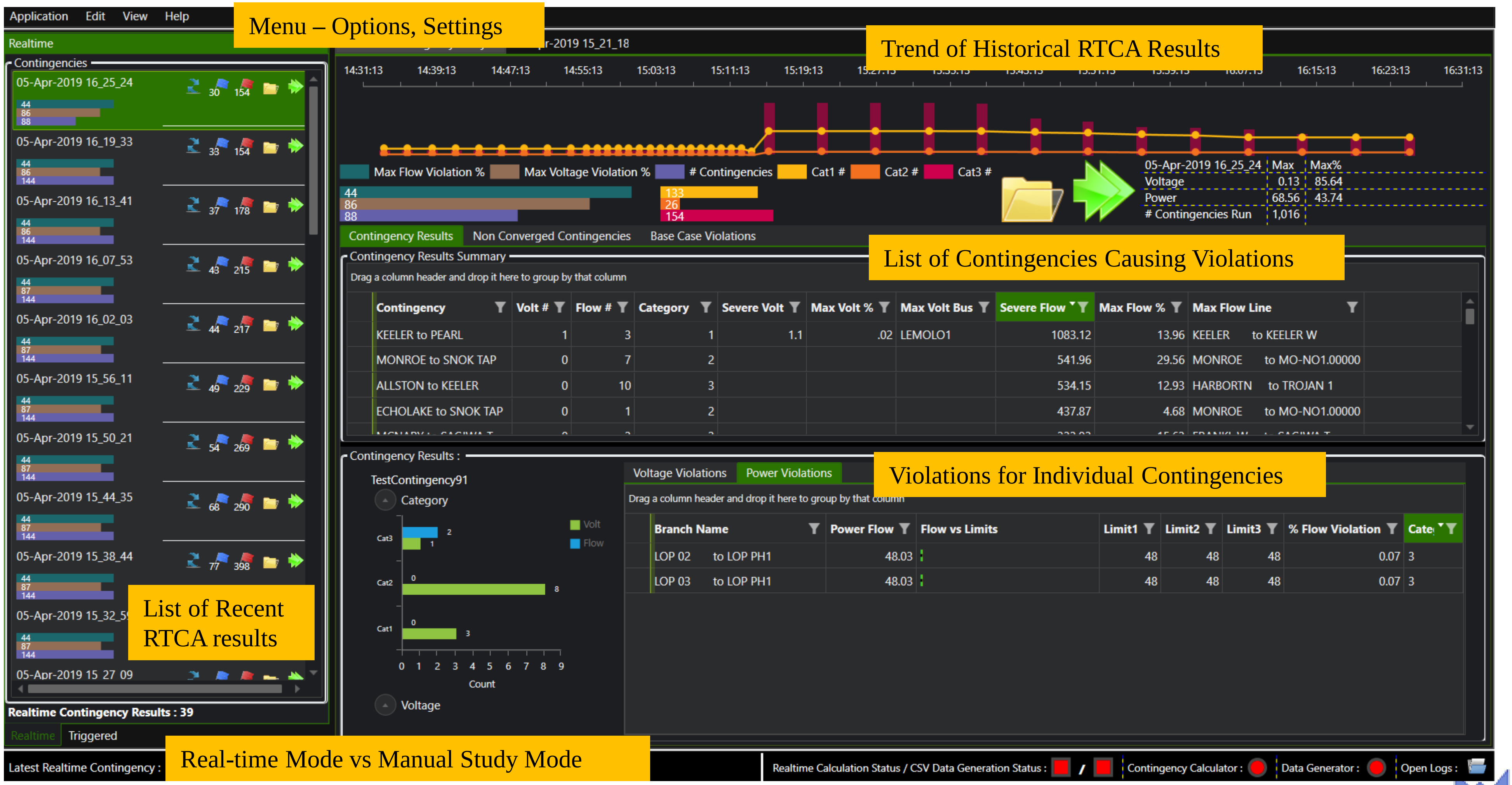
RTCA Methodology

- Uses a base case as the initial system input and updates the observable area using *e*LSE results
  - The base case covers the whole system in the monitored area, not just the PMU observable subset
  - The RTCA is designed to run with small number of PMU measurements
- Run all contingencies from the list using Power flow solution (FDLF/NR)
- Provides list of violations (voltage, power flow, voltage stability index)

RTCA - Operation

- Data Input: Real Time *e*LSE Data Stream
- Contingency Analysis Including "What If" Scenarios: Runs in Real Time; Provides Violations
- Types of Contingencies: Loss of Lines, Transformers, Generators (N-1, N-2, N-k)
- Two Operating Modes: Automatic and Manual
- Results Visualization
  - Contingencies Causing Violations & List Violations by Category
  - Detailed Results for each contingency
  - Historical Result Trends

RTCA Results Visualization



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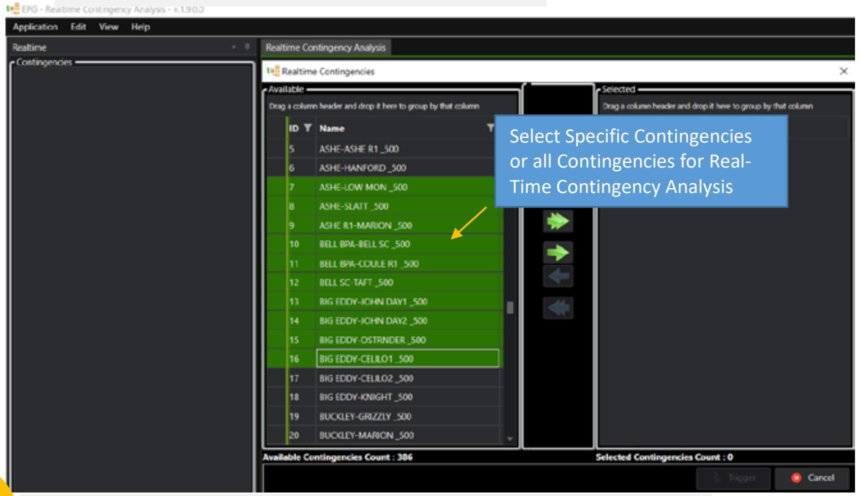
RTCA - Visualization Summary

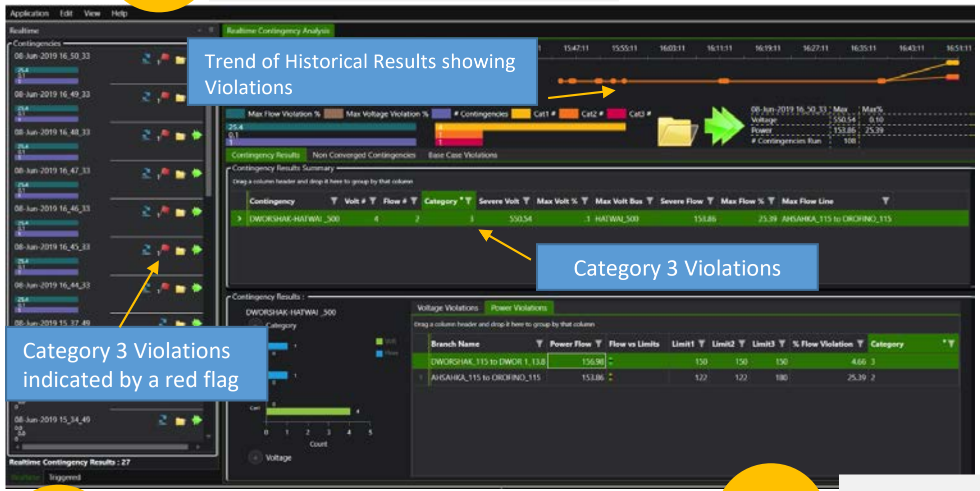
- High-level View of Key Results and Most Severe Violations
- Drill Down Views for Individual Contingency Results
- Real-time Mode vs Manual Study Mode
- Rich UI developed using Microsoft Windows Presentation Foundation (WPF)
- Sort, Filter, Search Results
- Historical Trend – Overview of previous results
- User Configurable Settings – Time Interval for Execution, Retention Settings for Storing Data, Results, Cases
- Alert/Indicators when no results, in case of errors

RTCA Run - Example

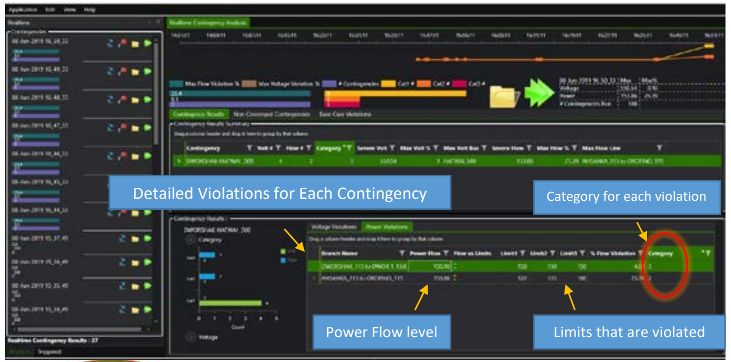
1 Select Contingencies



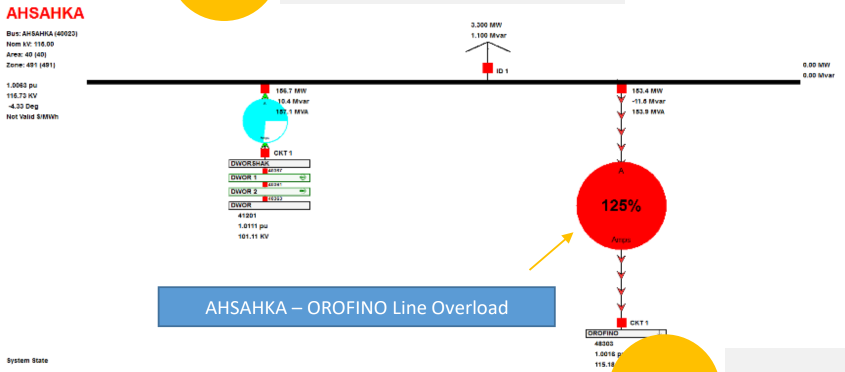
2 Check Violations



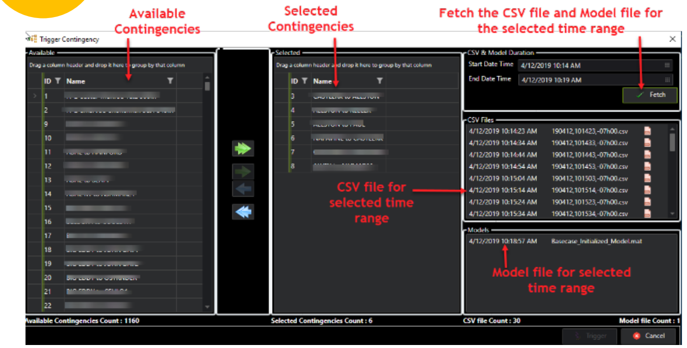
3 Drill Down – Detailed Results



4 Verify Results



5 Offline Analysis/Study



6 Save Results

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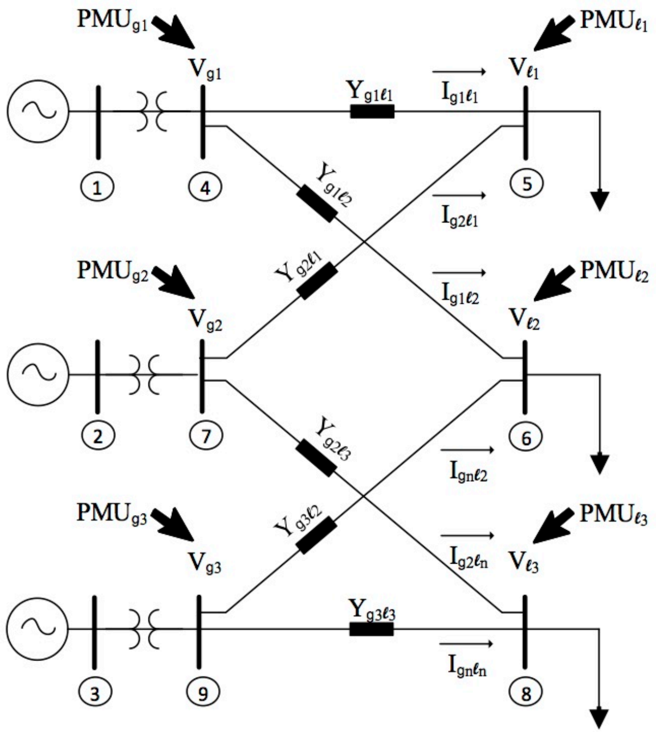
VOLTAGE STABILITY ASSESSMENT

Phasor Based Voltage Stress Monitoring

Transmission Corridor VSA Index (VSI)

- Objective: Perform Voltage Stability Assessment in real-time using PMU and LSE data
- This technique will handle a transmission corridor with a network of lines and multiple input and output points.
- Uses PMU measurements to compute power flow through a transmission corridor
  - Only requires measurements on boundary busses
  - From this, it computes an index that indicates the corridor voltage security



Study Procedure

- Run VSI for various loading scenarios on the Corridor and for severe contingencies
  - Establish VSI Alert/Alarm thresholds to indicate stressed voltage conditions
- For BPA implementation:
  - The transmission corridor is on the Pacific NW – SW Intertie
  - Limiting loading conditions are caused by loss of generation in SW
  - These include:
    - Loss of Two Palo Verde Units
    - Loss of Three Palo Verde Units
    - Loss of Pacific DC Inter-tie

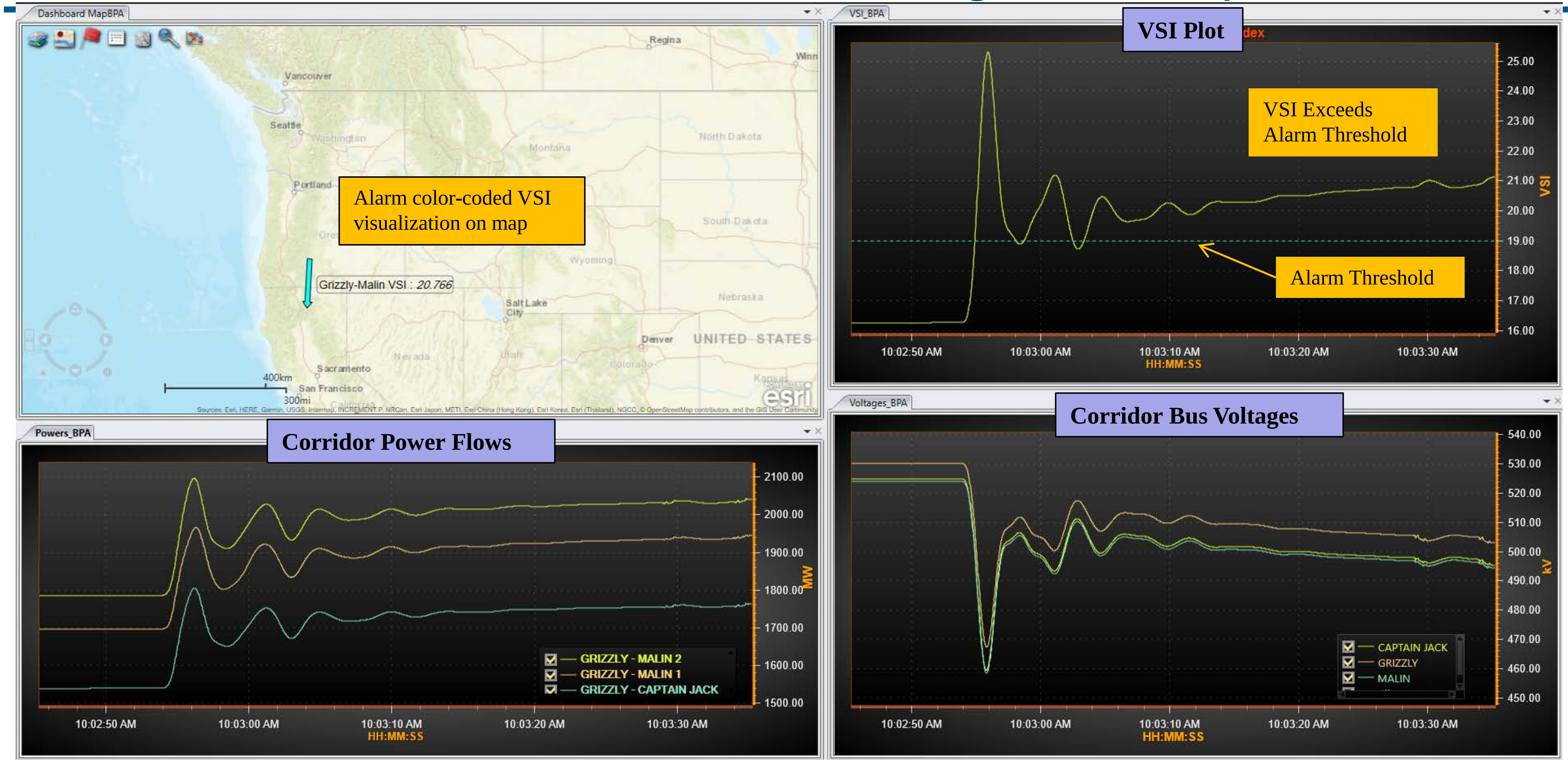
VSI Example - Loss of 2 Palo Verde Units

	Loading	Malin Voltage	VSI
1	Base Case (3807 MW)	514.8 kV	16.61
2	4353 MW	504.8 kV	19.11
3	4667 MW	493.7 kV	21.21
4	4917 MW	480.2 kV	23.38
5	5125 MW	472.5 kV	24.87
6	5150 MW	471.5 kV	25.03
7	5160 MW	466.6 kV	25.93
8	5205 MW	NA	Diverges

- Alert: 19
- Alarm: 23

VSI Visualization in Real-Time on RTDMS Client

(Loss of 2 Palo Verde Units with 4667 MW initial loading on corridor)



VSI Deteriorates (Increases) upon Increased Power Transfer and Decrease in Bus Voltages

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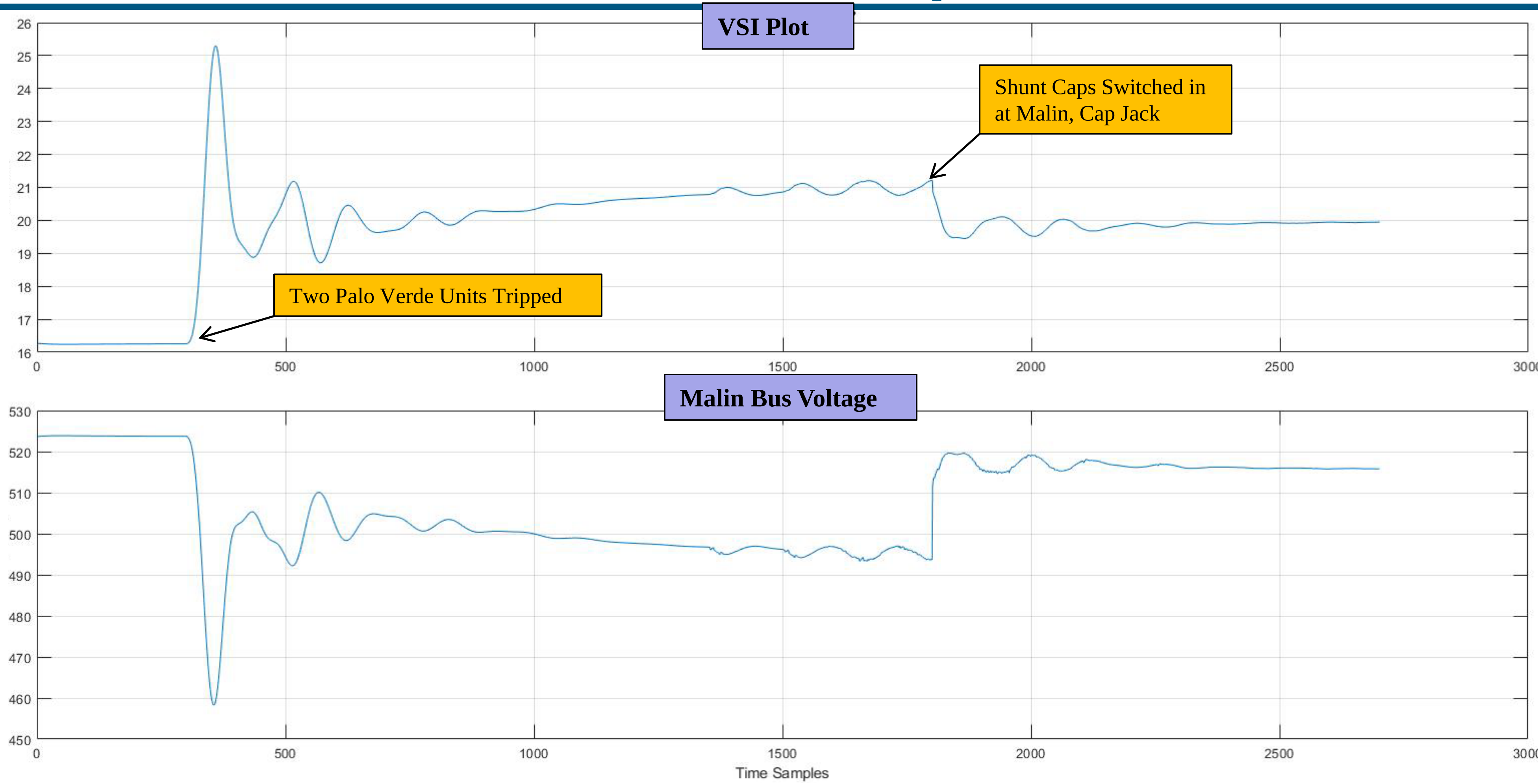
VSI – Corrective Action Example



VSI Improves (Decreases) upon Switching in Shunt Capacitors

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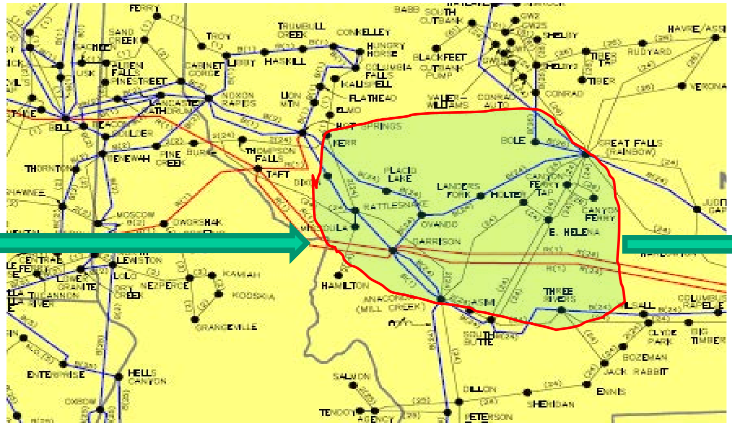
AREA ANGLE MONITORING (AAM)

Phasor Based Power Flow Stress Monitoring

Area Angle Monitoring (AAM) – Overview

- Power flow creates a phase angle. Higher angles result from:
  - Higher power flow
  - Higher impedance (fewer lines carrying flow)
- High Angle can indicate a lost transmission line excessive power flow
- Area angle indicates transmission failure or overloads

Power flow into an area



Power flow out of an area

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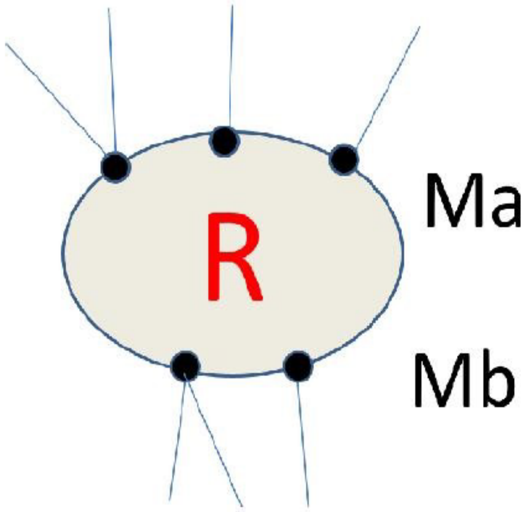
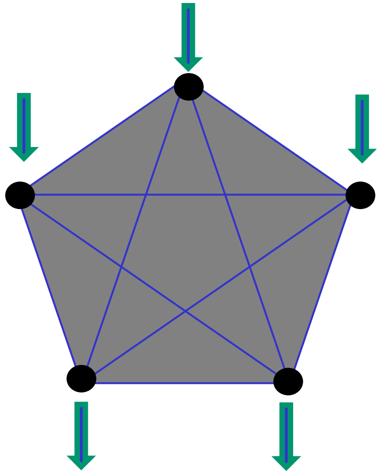
Calculation of Area Angle



Area R with Border buses Ma and Mb



Equivalent network using Kron reduction for weights at border busses

$$\theta_{area} = \sum_{i=1}^{M_a} w_i \theta_i - \sum_{j=1}^{M_b} w_j \theta_j$$

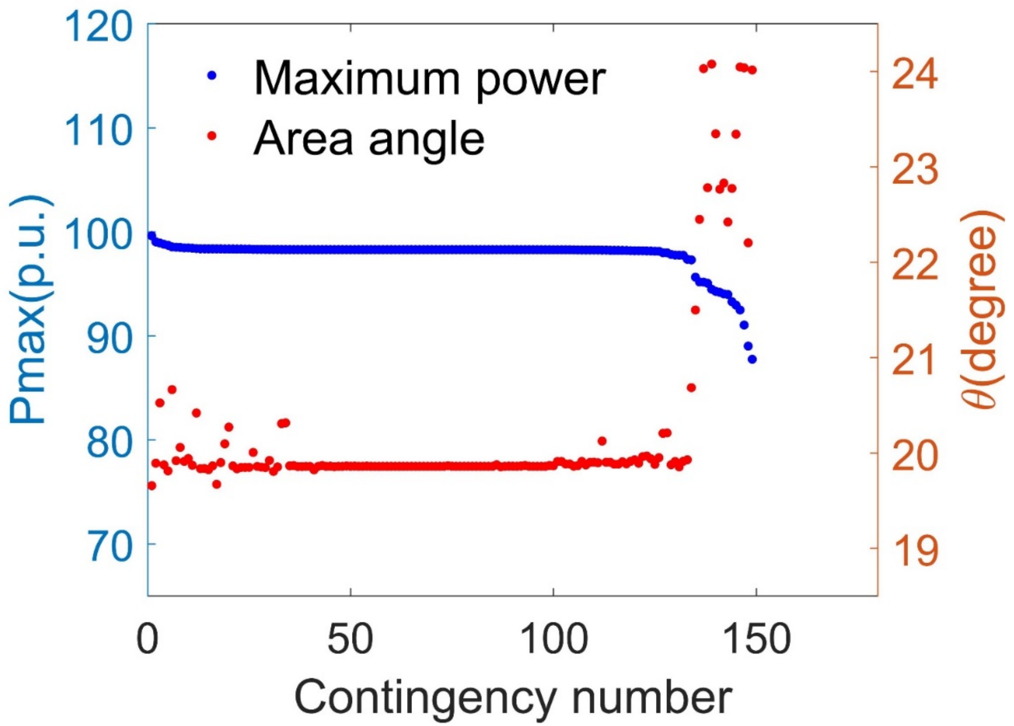
w = bus weight & θ = PMU angle at the input (a) and output (b) sides

Area Angle computed using bus weights & angles

Study to Determine Area Angle Thresholds

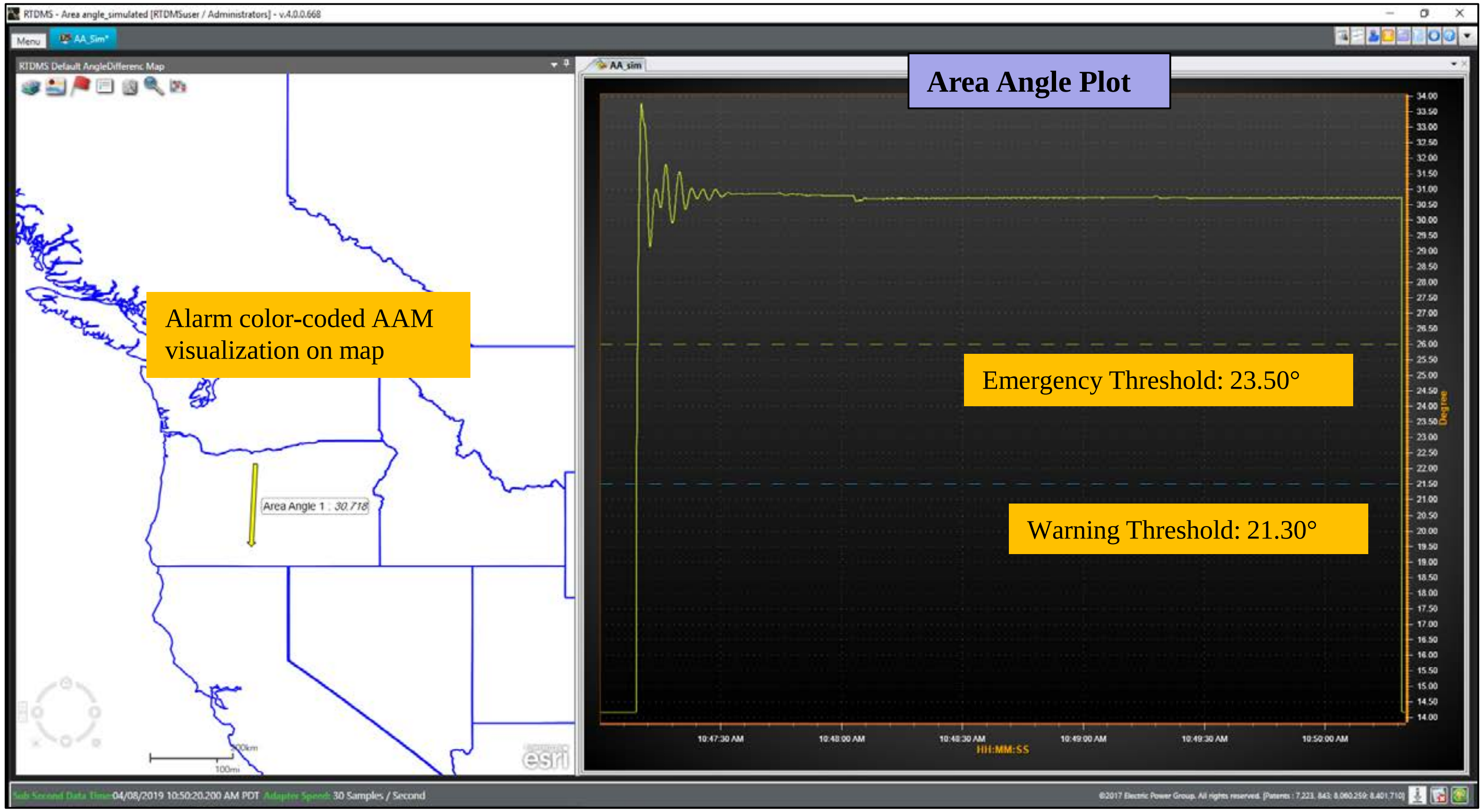
- Plot power flow through area with the resulting area angle
  - Maximum power with N-1, N-2, N-3
- Allowable flow drops as angle increases
- Determine angles where
  - Flows start to drop (warning)
  - Flows exceed allowable N-1 (emergency)
  - Here choose:
    - Warning = 21.30°
    - Emergency = 23.50°

N-1 Contingency



AAM Visualization in Real-Time on RTDMS Client

- Example: Area in BPA – central Oregon
- Contingency: Loss of three 500 kV lines in the Pacific AC intertie



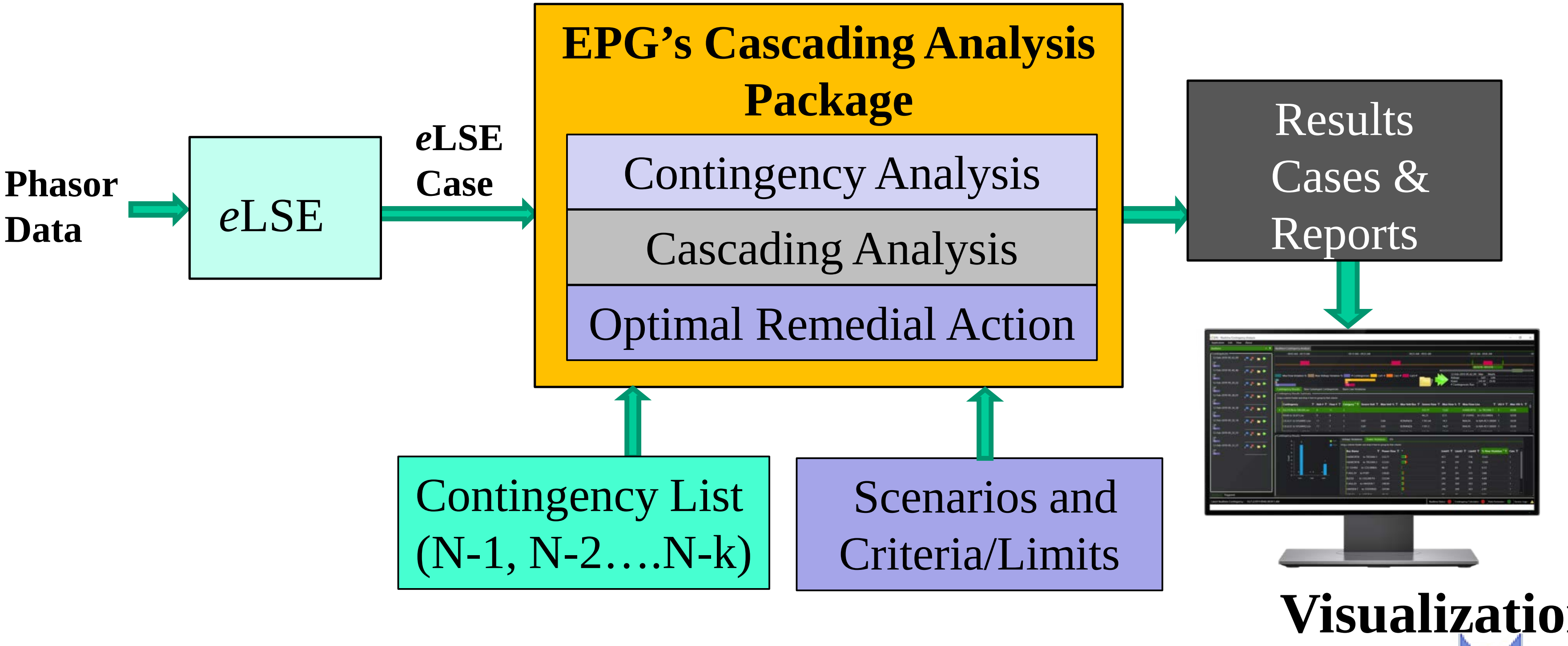
Area Angle Jumps from 14.2° to 30.7° showing greatly Increased Stress in the System

Applications Benefits

- RTCA supports Grid Resiliency – Improves Situational Awareness
  - Actionable Intelligence
  - Based on *e*LSE which always solves
  - Provides Backup to Conventional RTCA
  - Helps meet NERC IRO-008-2 and TOP-001-4 standards in case of EMS Failure/Unavailability
- VSI application
  - Provides a timely indication to operators when capacity is decreasing
  - Can be used to assess effect of remedial actions
- AAM application
  - Provides an important measure of transmission capacity that is not directly indicated by other techniques
  - Can alert operators to a loss in capacity that is overlooked by other methods

Cascading Analysis & Remedial Action Addition

- EPG extension of the project
- Cascading analysis for more comprehensive protection
- Optimal remedial actions for all applications



Summary

- Developed three Applications using Phasor Data and Linear State Estimator
  - Real-time Contingency Analysis (RTCA)
  - Voltage Stability Assessment (VSA)
  - Area Angle Monitoring (AAM)
- Implemented, tested & installed at BPA
- Next Steps
  - Implementation & installation for NYPA & Duke Energy Systems
  - Demonstration (commercialization), training, & final reporting
- Starting development of a Cascading & Remedial Action initiative

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Thank You