

DOE/OE Transmission Reliability Program

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

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NASPI

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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, Iknor 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



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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

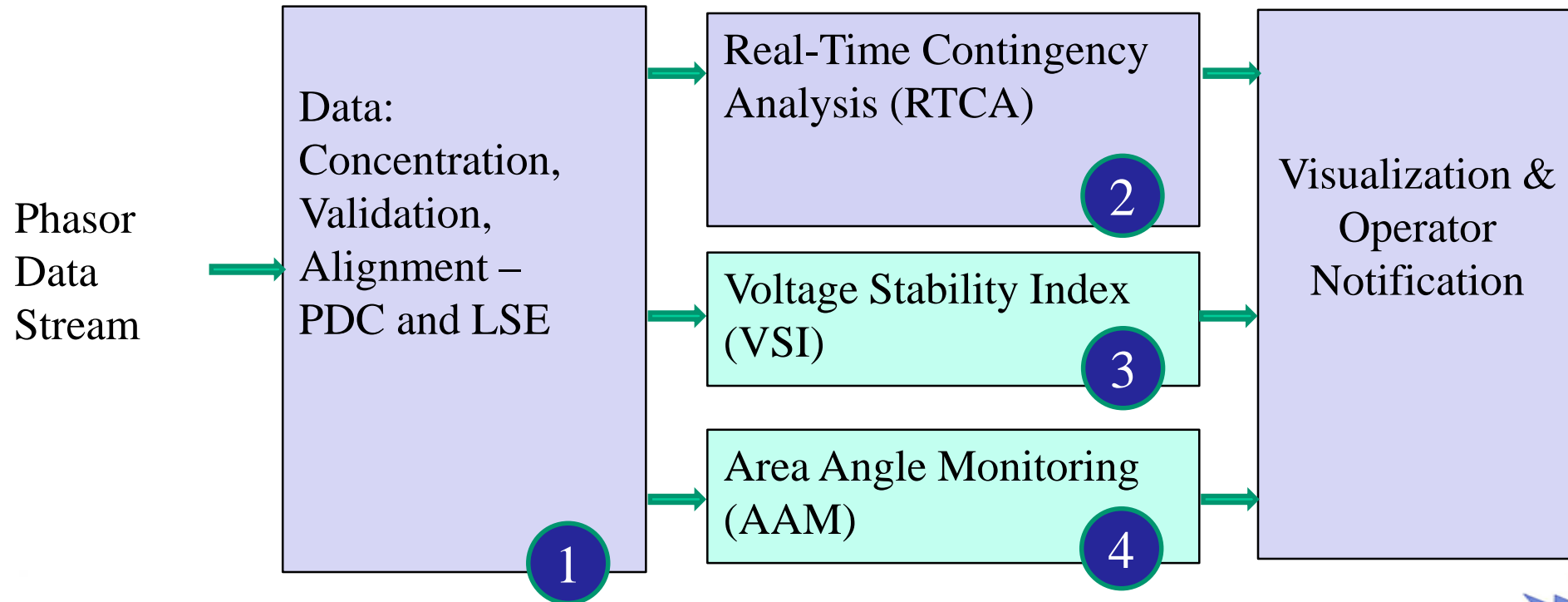


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Project Approach

- 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 (eLSE)

Phasor Data Validation & Extended Observability

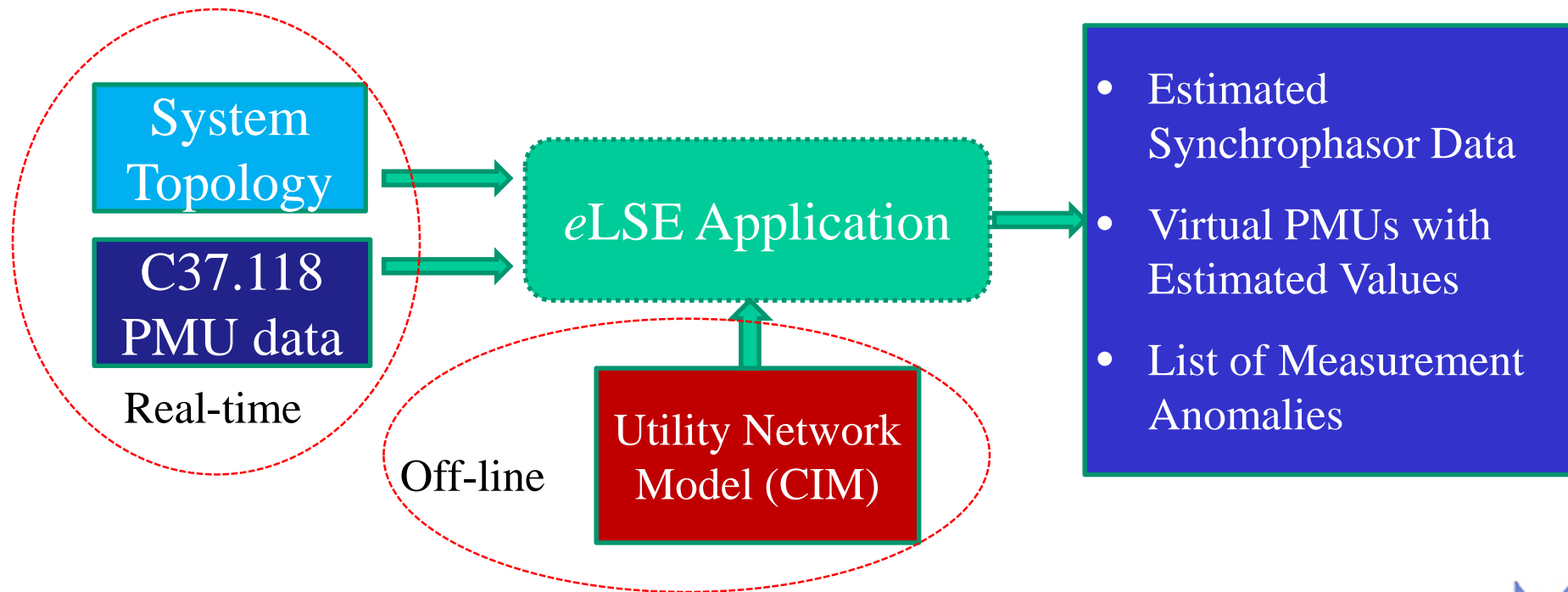


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eLSE - Operation

- 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**



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REAL TIME CONTINGENCY ANALYSIS (RTCA)

Phasor Based Contingency Analysis for
Operations



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RTCA Methodology

- Uses a base case as the initial system input and updates the observable area using *eLSE* 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)



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RTCA - Operation

- Data Input: Real Time eLSE 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



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RTCA Results Visualization

Menu – Options, Settings

Application Edit View Help

Realtime

Contingencies

- 05-Apr-2019 16_25_24 (30, 154)
- 05-Apr-2019 16_19_33 (33, 154)
- 05-Apr-2019 16_13_41 (37, 178)
- 05-Apr-2019 16_07_53 (43, 215)
- 05-Apr-2019 16_02_03 (44, 217)
- 05-Apr-2019 15_56_11 (49, 229)
- 05-Apr-2019 15_50_21 (54, 269)
- 05-Apr-2019 15_44_35 (68, 290)
- 05-Apr-2019 15_38_44 (77, 398)
- 05-Apr-2019 15_32_51
- 05-Apr-2019 15_27_09

List of Recent RTCA results

Realtime Contingency Results : 39

Realtime Triggered

Latest Realtime Contingency :

Trend of Historical RTCA Results

05-Apr-2019 16_25_24 Max Max%
Voltage 0.13 85.64
Power 68.56 43.74
Contingencies Run 1,016

List of Contingencies Causing Violations

Contingency	Volt #	Flow #	Category	Severe Volt	Max Volt %	Max Volt Bus	Severe Flow	Max Flow %	Max Flow Line
KEELER to PEARL	1	3	1	1.1	.02	LEMOLO1	1083.12	13.96	KEELER to KEELER W
MONROE to SNOK TAP	0	7	2				541.96	29.56	MONROE to MO-NO1.00000
ALLSTON to KEELER	0	10	3				534.15	12.93	HARBORTN to TROJAN 1
ECHOLAKE to SNOK TAP	0	1	2				437.87	4.68	MONROE to MO-NO1.00000

Violations for Individual Contingencies

TestContingency91

Category

Cat3: 2 (Volt), 1 (Flow)

Cat2: 8 (Volt)

Cat1: 3 (Volt)

Branch Name	Power Flow	Flow vs Limits	Limit1	Limit2	Limit3	% Flow Violation	Cate
LOP 02 to LOP PH1	48.03		48	48	48	0.07	3
LOP 03 to LOP PH1	48.03		48	48	48	0.07	3

Real-time Mode vs Manual Study Mode

Realtime Calculation Status / CSV Data Generation Status : ■ / ■ Contingency Calculator : ● Data Generator : ● Open Logs :



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



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RTCA Run - Example

1 Select Contingencies

Available Contingencies Count : 306
Selected Contingencies Count : 0

2 Check Violations

Category 3 Violations

Contingency	Volt #	Flow #	Category	Severe Volt	Max Volt %	Max Volt Bus	Severe Flow	Max Flow %	Max Flow Line
DWORKSHAK-HATWAN_300	4	2	3	500.54			15.88	23.39	AHSAHKA_115 to OROFINO_115

3 Drill Down – Detailed Results

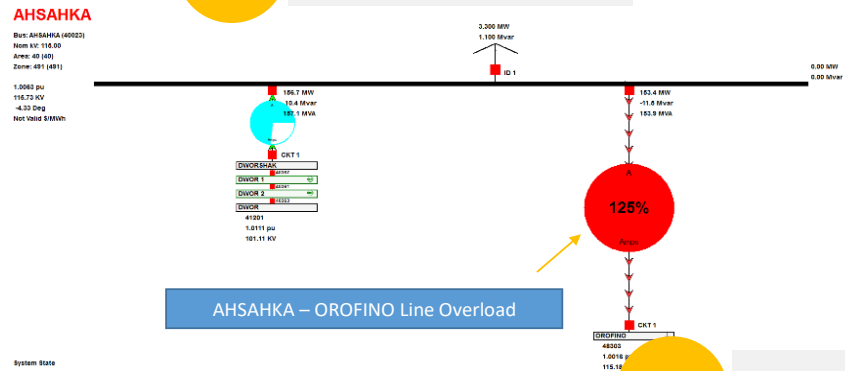
Detailed Violations for Each Contingency

Category for each violation

Power Flow level

Limits that are violated

4 Verify Results



5 Offline Analysis/Study

Fetch the CSV file and Model file for the selected time range

CSV file for selected time range

Model file for selected time range

6 Save Results



VOLTAGE STABILITY ASSESSMENT

Phasor Based Voltage Stress Monitoring

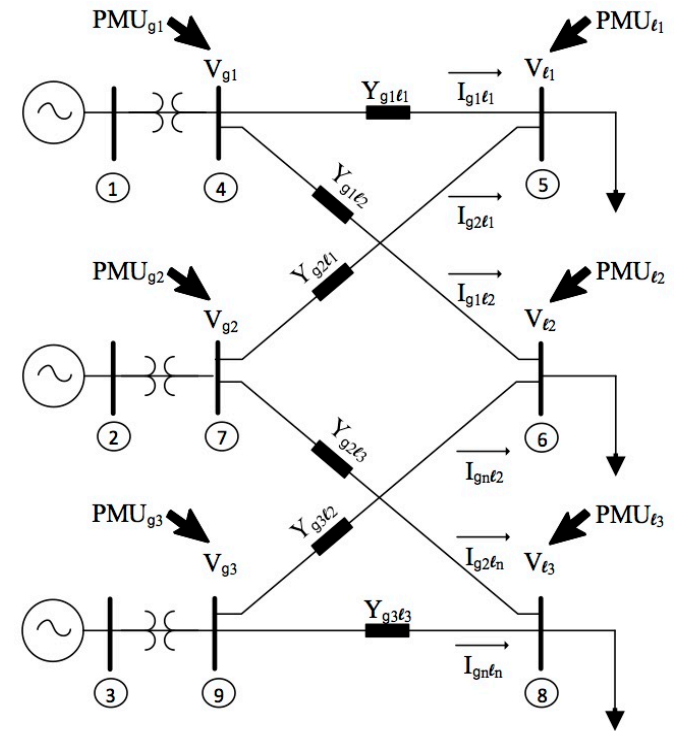


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Transmission Corridor VSA Index (VSI)

- 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



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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



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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

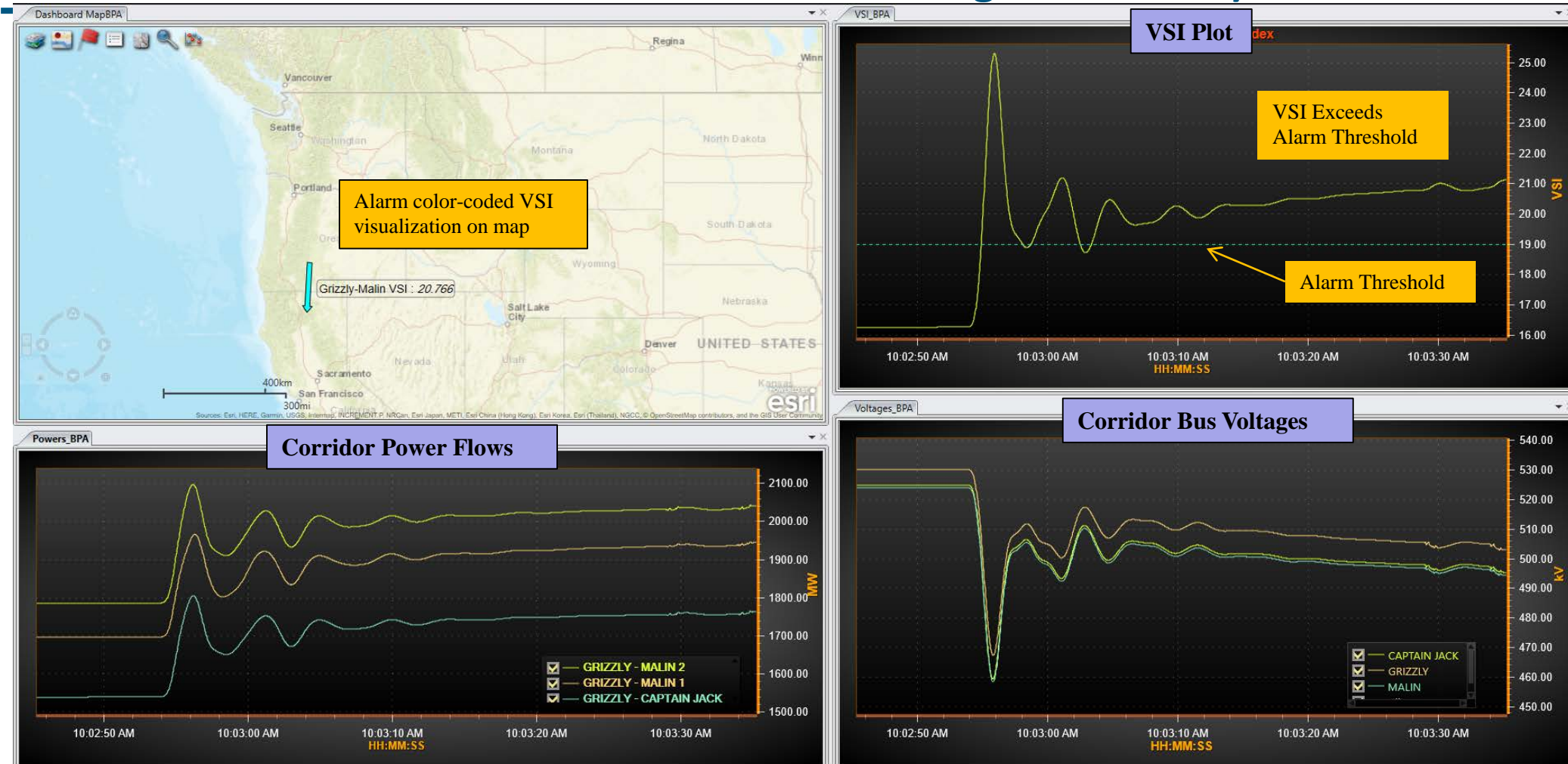


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VSI Visualization in Real-Time on RTDMS Client

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



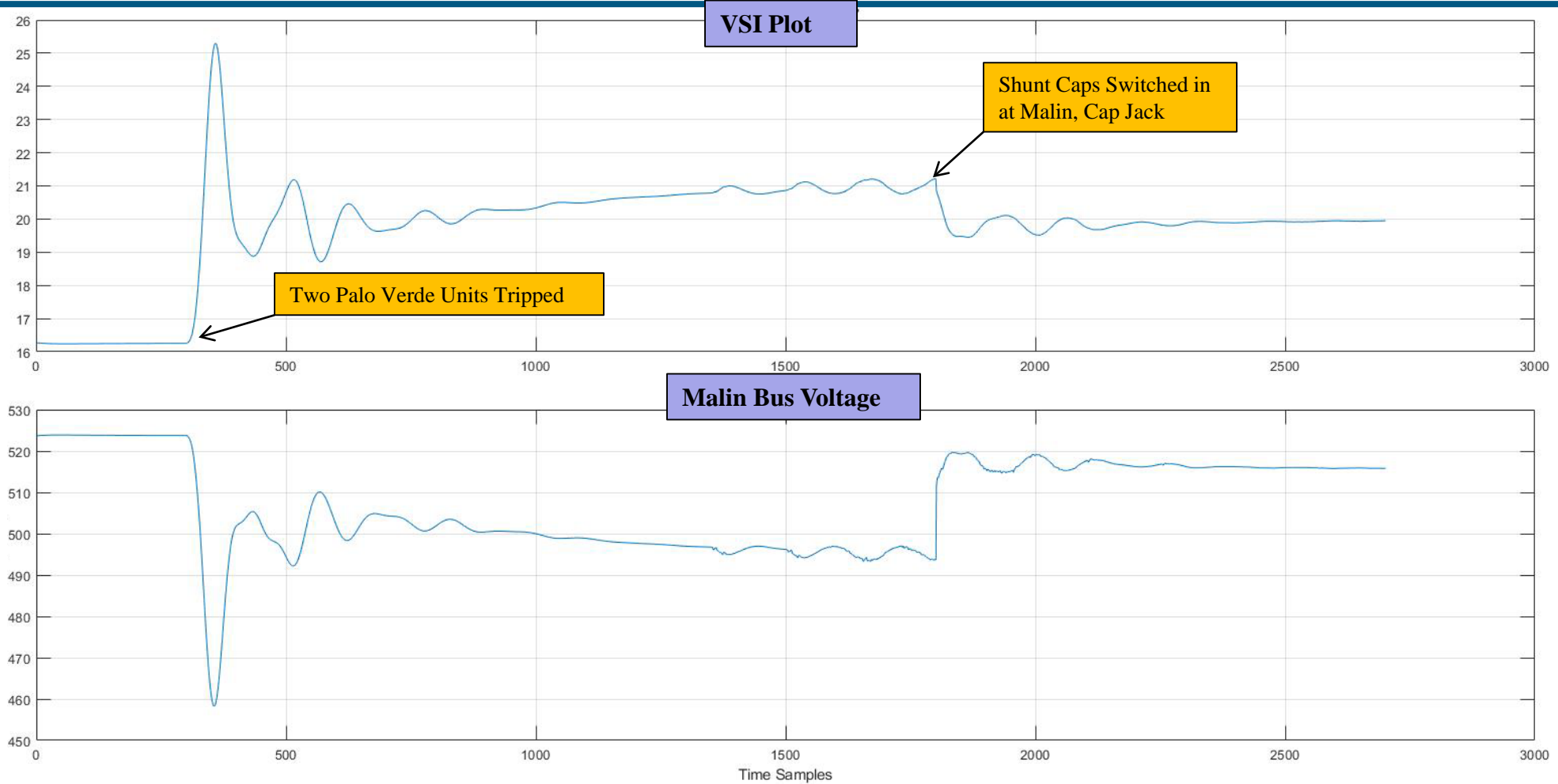
VSI Deteriorates (Increases) upon Increased Power Transfer and Decrease in Bus Voltages



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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



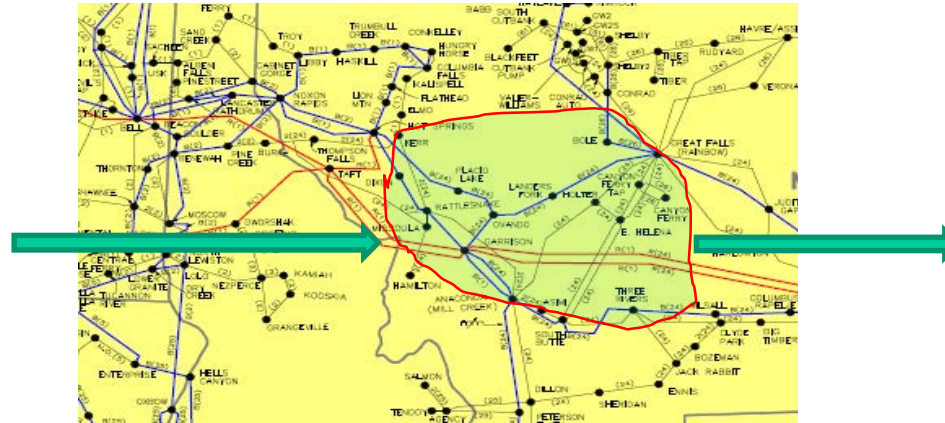
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Area Angle Monitoring (AAM) – Overview

- 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



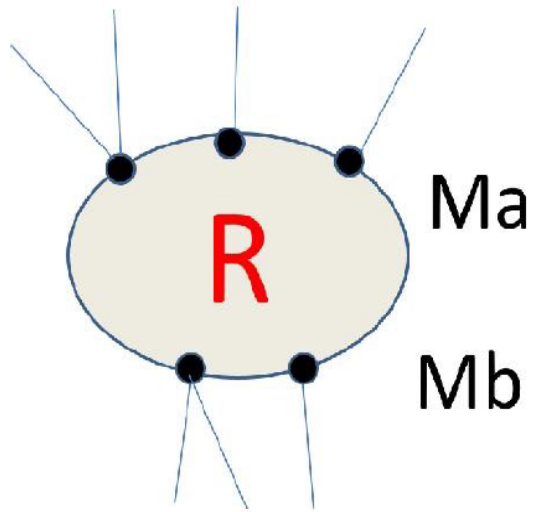
Power flow
out of an
area



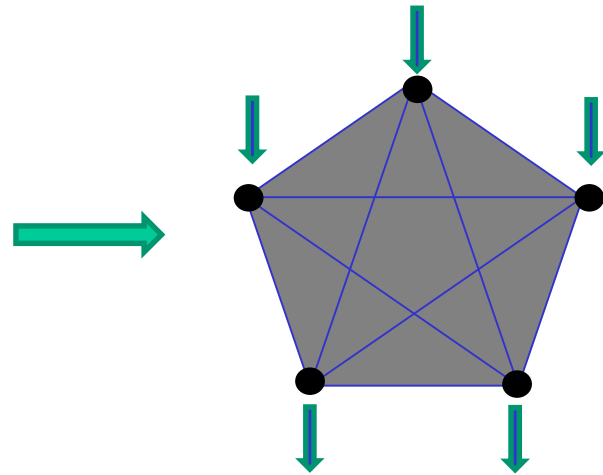
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Calculation of Area Angle



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

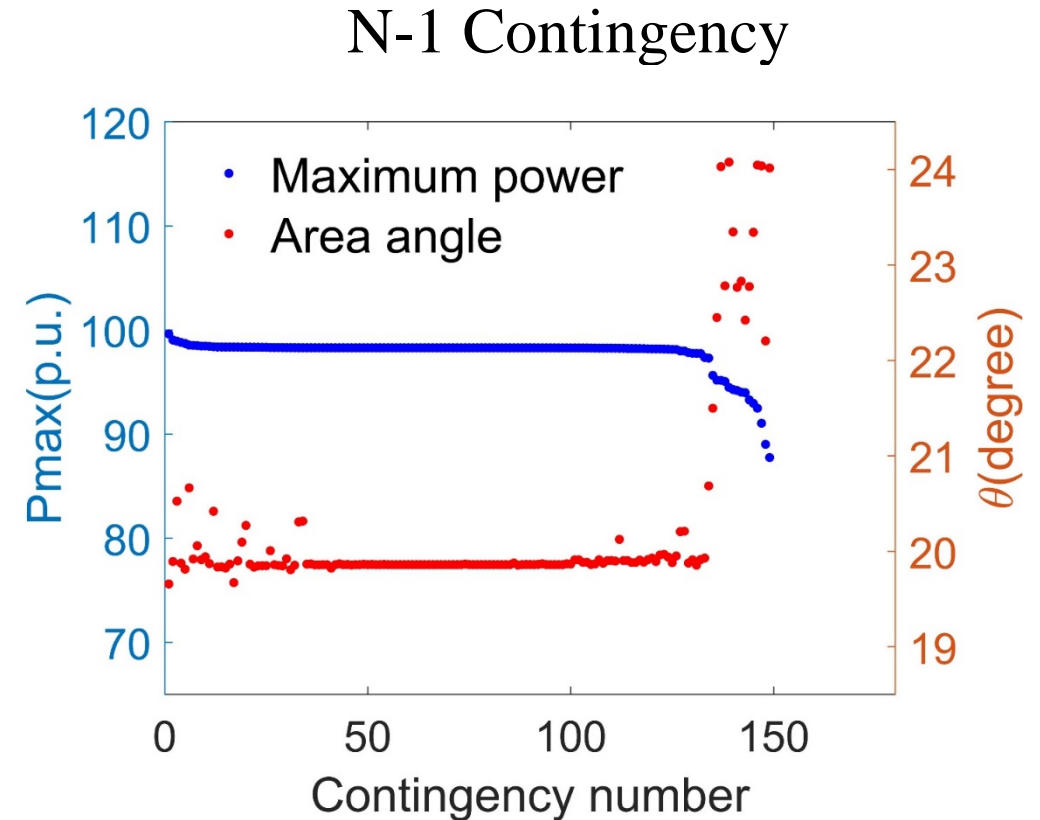


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Study to Determine Area Angle Thresholds

- 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°



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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



Authority



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Applications Benefits

- RTCA supports Grid Resiliency – Improves Situational Awareness
 - Actionable Intelligence
 - Based on eLSE 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

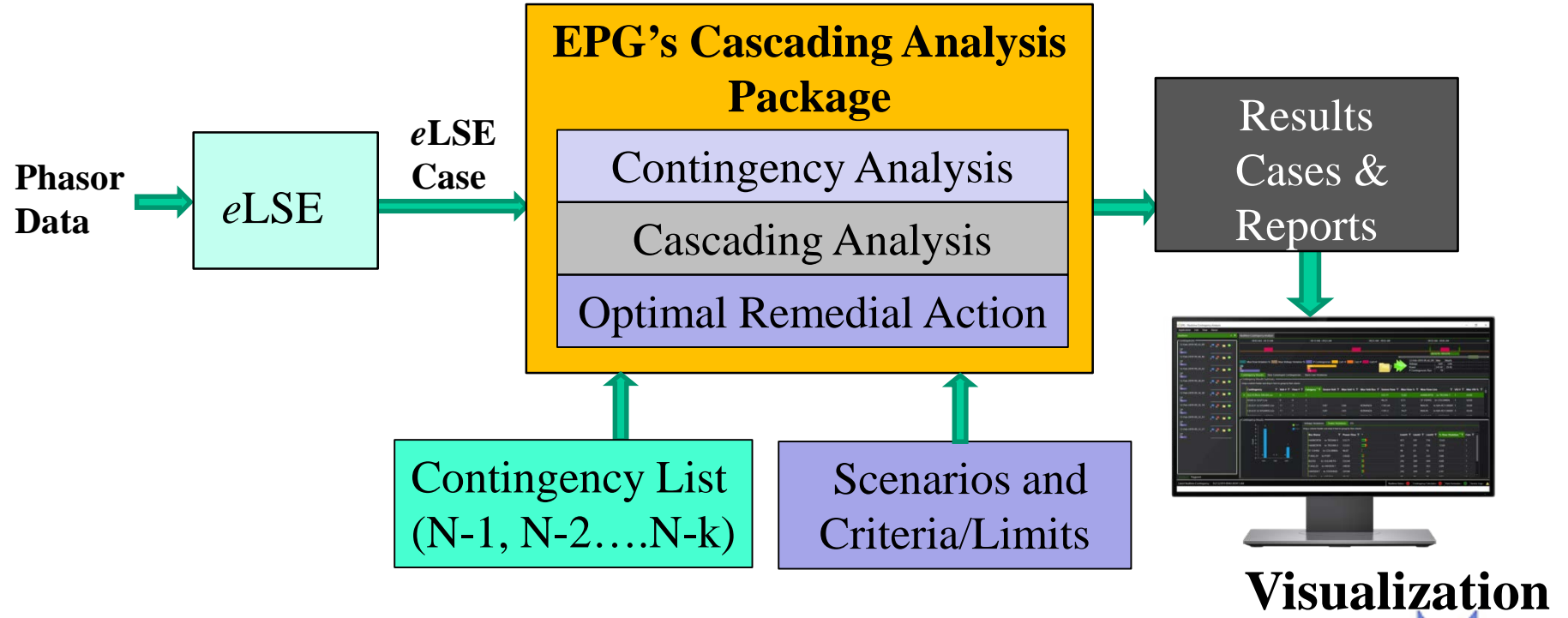


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Cascading Analysis & Remedial Action Addition

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



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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



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