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
- Summary

Introduction

- Project: Real Time Applications Using Linear State Estimation Technology
  - DOE Grant Award DE-OE0000849
- Primary recipient: Electric Power Group, LLC
  - Principal Investigators: Ken Martin & Lin Zhang
- Project Partners (host site & cost share):
  - Bonneville Power Administration (BPA)
    - Project lead – Tony Faris/Petr Karasev
  - New York Power Authority (NYPA)
    - Project lead – Atena Darvishi/Alan Ettlinger
- Project host site - Duke Energy
    - Project lead – Megan Vutsinas, Tim Bradbury, Evan Phillips

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Advisors & Observers

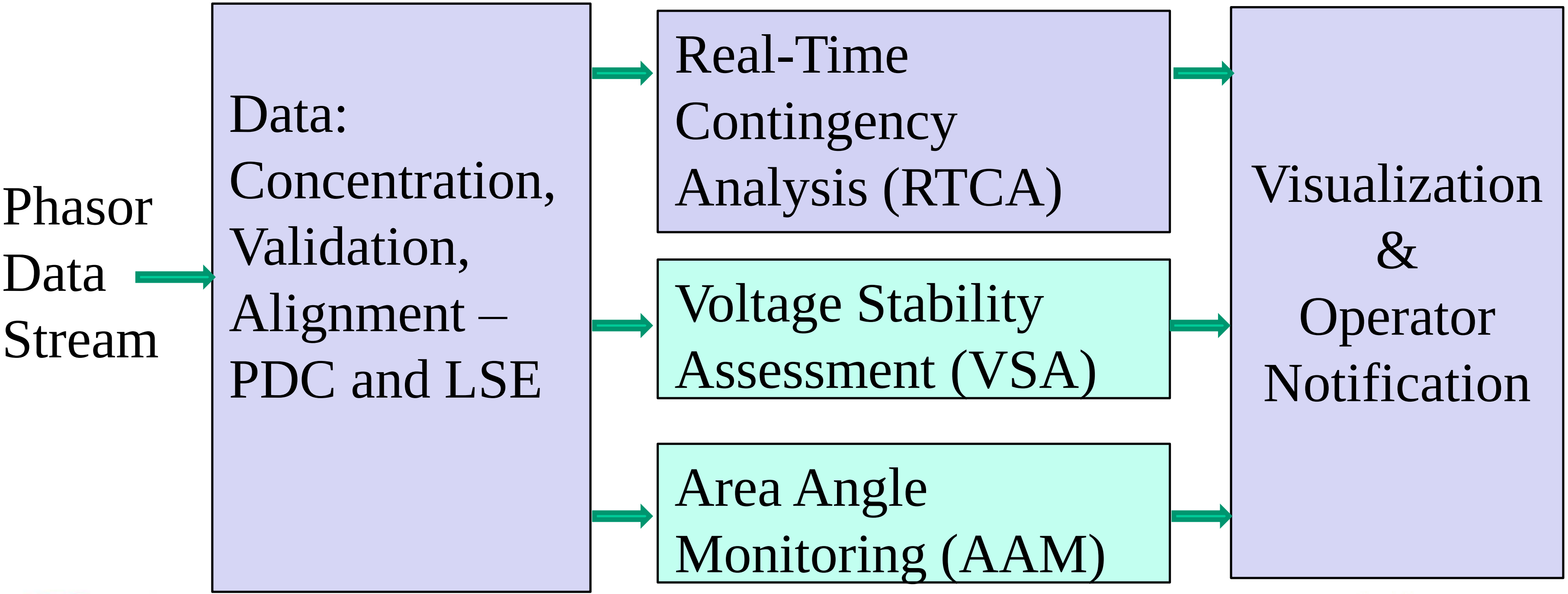
- Project Advisors
  - Anjan Bose – Washington State University
  - Ian Dobson – Iowa State University
  - Dejan Sobajic – Grid Engineering
  - Anurag Srivastava – Washington State University
- Project Observers
  - Dominion Virginia Power (Dominion) - Kyle Thomas
  - Peak Reliability - Hongming Zhang
  - 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 3 real-time applications using PMU data and LSE
- Test with simulated and recorded data
- Demonstrate at host utilities



Phasor Data Stream

Data: Concentration, Validation, Alignment – PDC and LSE

Real-Time Contingency Analysis (RTCA)

Voltage Stability Assessment (VSA)

Area Angle Monitoring (AAM)

Visualization & Operator Notification

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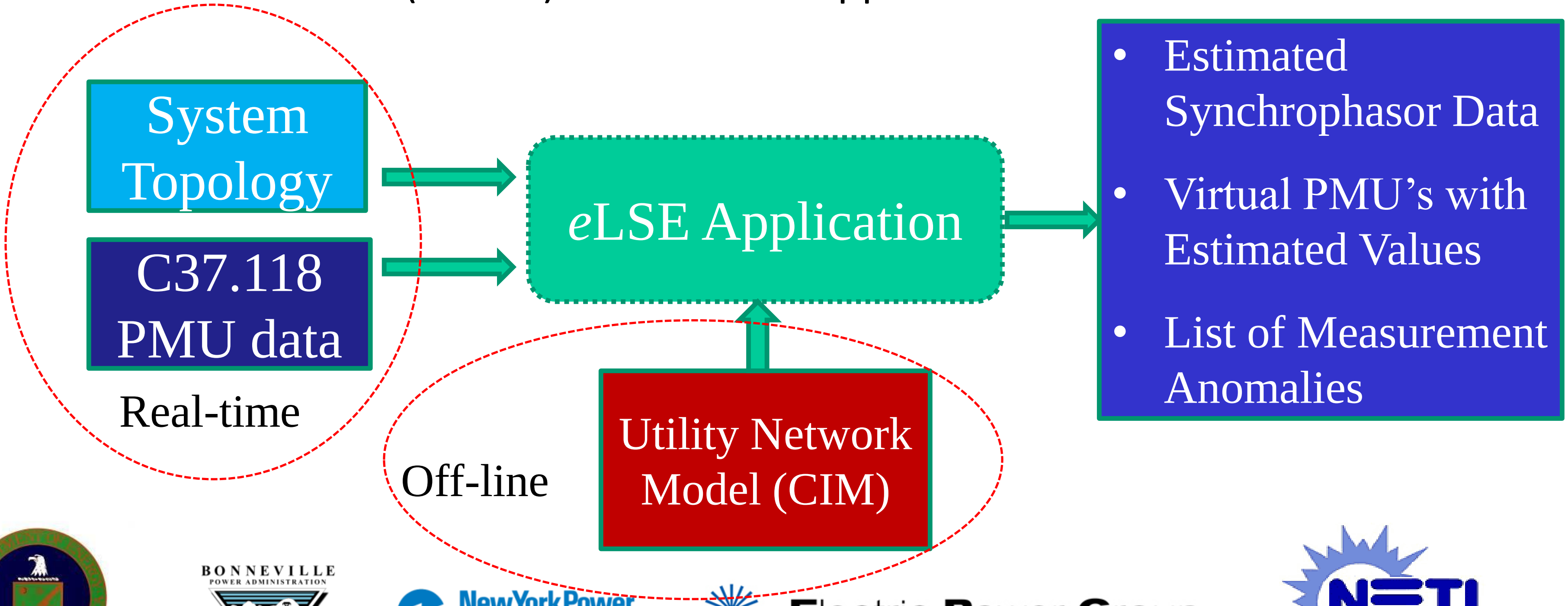
enhanced LINEAR STATE ESTIMATOR (*e*LSE)

*e*LSE Functionality

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



System Topology

C37.118 PMU data

Real-time

*e*LSE Application

Off-line

Utility Network Model (CIM)

- Estimated Synchrophasor Data
- Virtual PMU's with Estimated Values
- List of Measurement Anomalies

REAL-TIME CONTINGENCY ANALYSIS (RTCA)

RTCA - Overview

- Real-time Contingency Analysis - Application that runs Contingency Analysis using PMU Data and *enhanced* Linear State Estimation (*e*LSE)
- Study What if Contingency Scenarios to assess System Violations
- Contingencies Include – Loss of Lines, Transformers, Generators (N-1, N-2, N-k) etc.
- Automatic and Manual Operation Mode
- Results Visualization
  - Contingencies Causing Violations & List Violations by Category
  - Detailed Results for each contingency
  - Historical Results Trend
- Grid Resiliency – Improve Situational Awareness, Actionable Intelligence, Based on *e*LSE which always solves, Provides Backup to Conventional RTCA

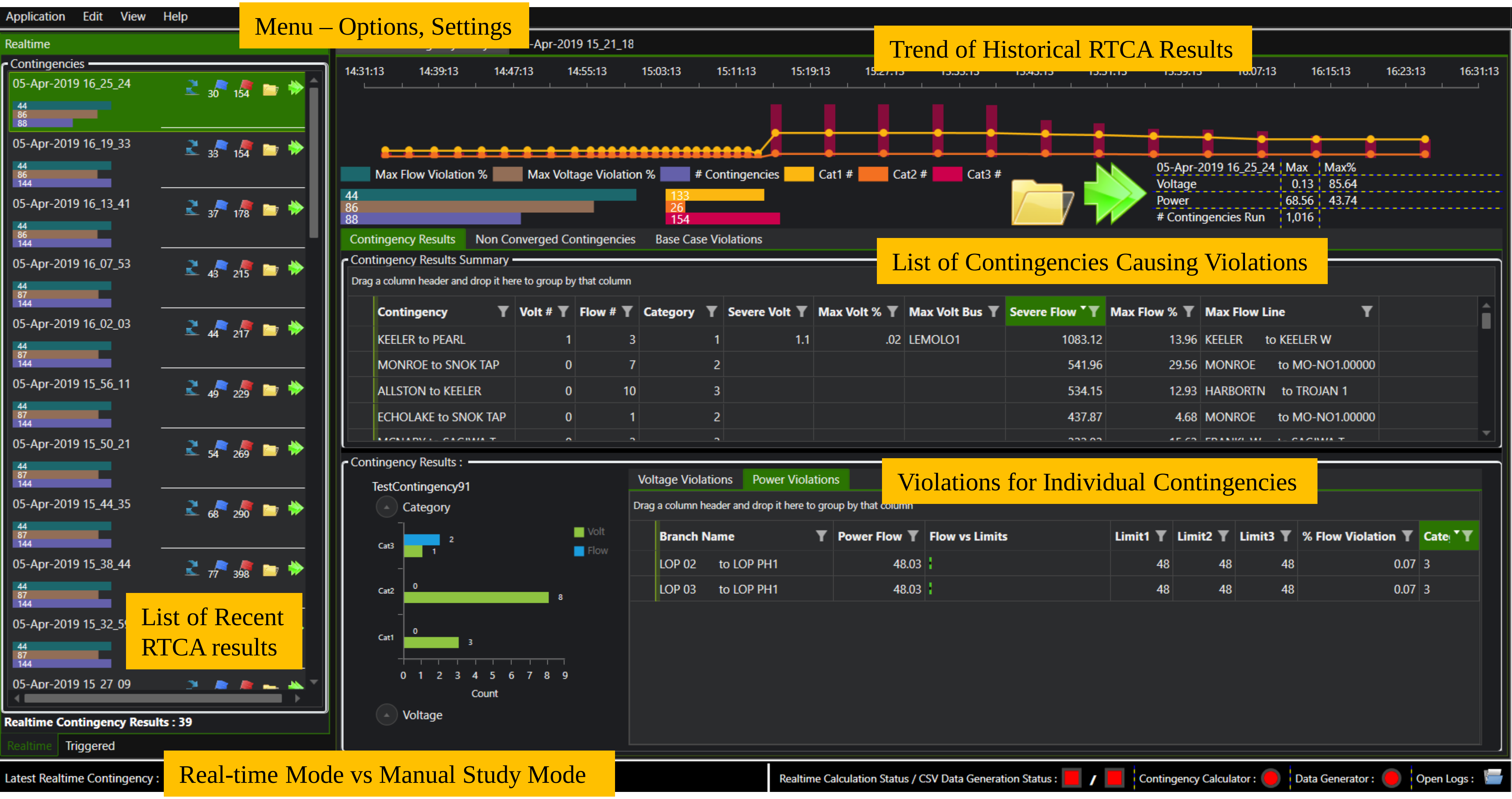
Methodology

- Challenge – Obtaining results with small number of PMU measurements
- Uses a base case (power flow model) as input and updates the observable area using *e*LSE results
- Run all contingencies from the list using Power flow solution (FDLF/NR)
- Provides List of violations (voltage, power flow, voltage stability index)

RTCA - Visualization User Interface

- High-level View of Key Results and Most Severe Violations
- Drill Down Views for Individual Contingency Results
- Real-time Mode vs Manual Study Mode
- Resolution independent 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 Results Visualization



Menu – Options, Settings

Trend of Historical RTCA Results

List of Contingencies Causing Violations

Violations for Individual Contingencies

List of Recent RTCA results

Real-time Mode vs Manual Study Mode

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

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_5		
05-Apr-2019 15 27 09		

Realtime Contingency Results : 39

Contingency Results Summary

Drag a column header and drop it here to group by that column

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

Contingency Results :

Drag a column header and drop it here to group by that column

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

Latest Realtime Contingency :

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

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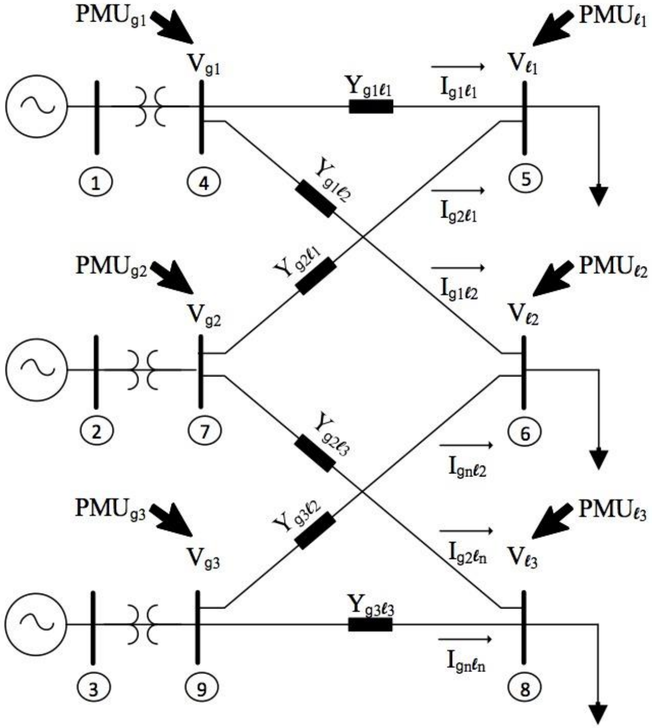
VOLTAGE STABILITY ASSESSMENT

Overview and Methodology

- Objective: Perform Voltage Stability Assessment in real-time using PMU and LSE data
- Based upon Dr. Ian Dobson's work at Iowa State University
- Reduces multiple lines of transmission corridors to a single line using synchrophasor measurements of complex power and current at each end of each line in the transmission corridor

Transmission Corridor VSI Index

- Uses PMU measurements to compute power flow across a transmission corridor
  - From this it computes an index that indicates the corridor voltage security
- This technique will handle a transmission corridor with a network of lines and multiple input and output points.
- Voltage is critically important to keeping transmission capacity high. This application provides a timely indication to operators when capacity is decreasing so they can take action to restore it



Study Procedure

- Run VSI for various loading scenarios on the Corridor and for severe contingencies:
  - Loss of Two Palo Verde Units
  - Loss of Three Palo Verde Units
  - Loss of Pacific DC Inter-tie
- Establish VSI Alert/Alarm thresholds to indicate stressed Voltage conditions

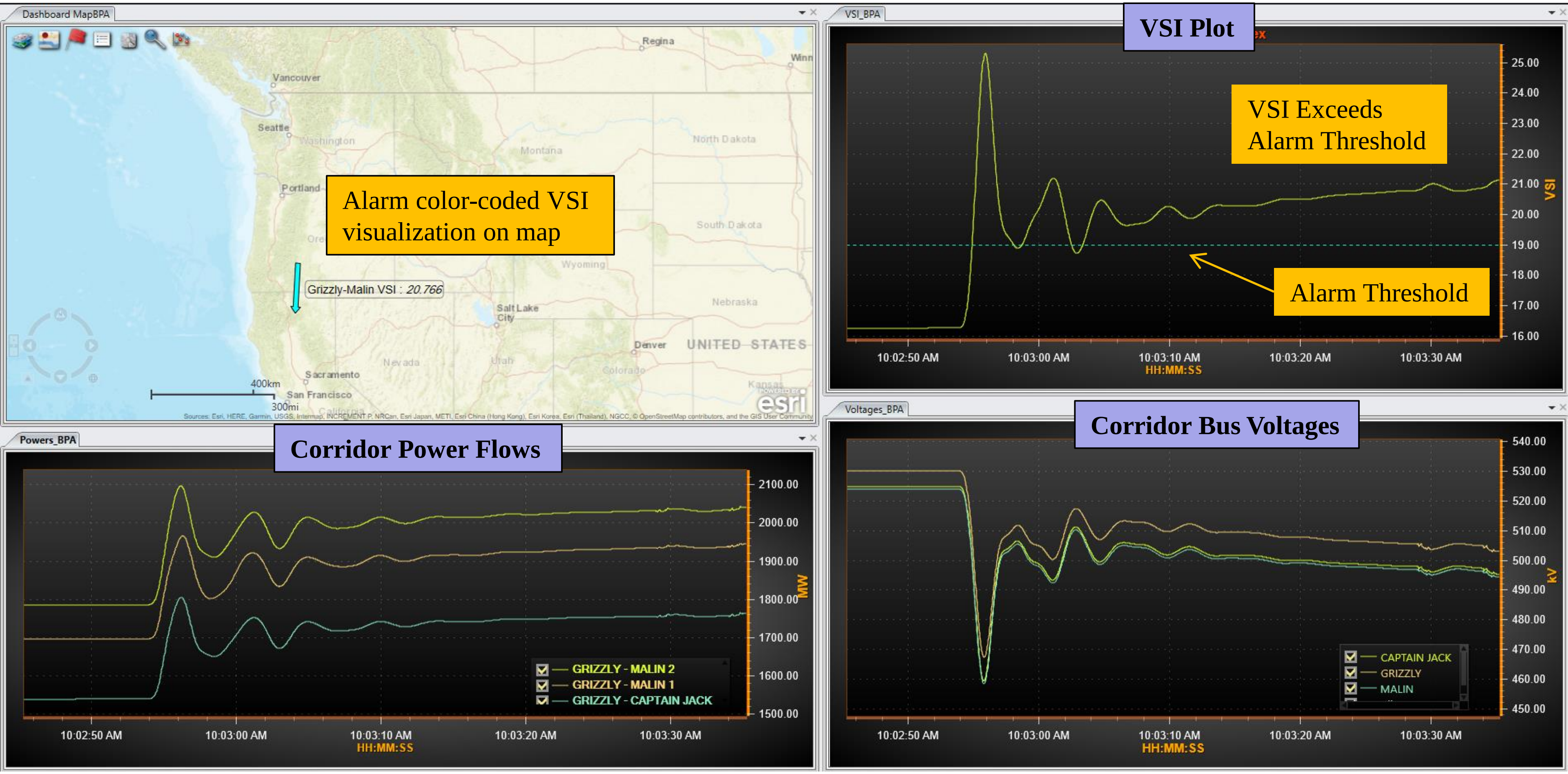
VSI Example – Loss of 2 Palo Verde Units

	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

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



Alarm color-coded VSI visualization on map

VSI Plot

VSI Exceeds Alarm Threshold

Alarm Threshold

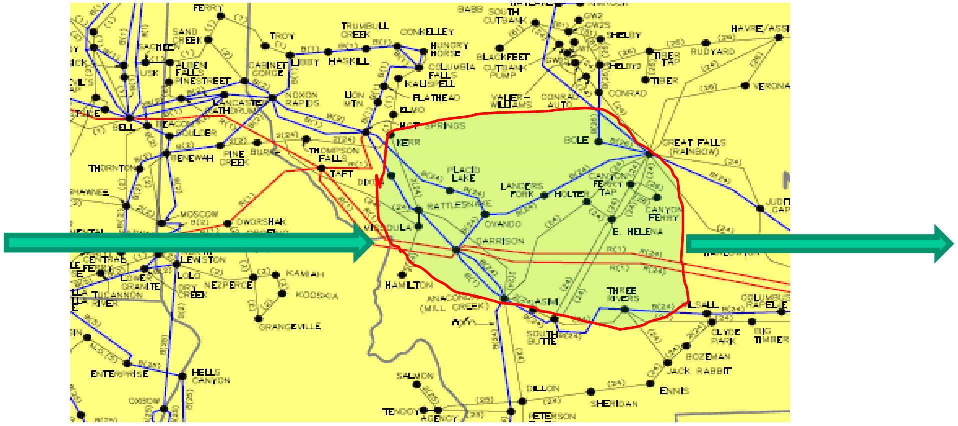
Corridor Power Flows

Corridor Bus Voltages

AREA ANGLE 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 excessive stress or a lost transmission line
- Area angle indicates transmission failure or overloads
- This application provides an important measure of transmission capacity that is not directly indicated by other techniques. It can alert operators to a loss in capacity that is overlooked by other methods

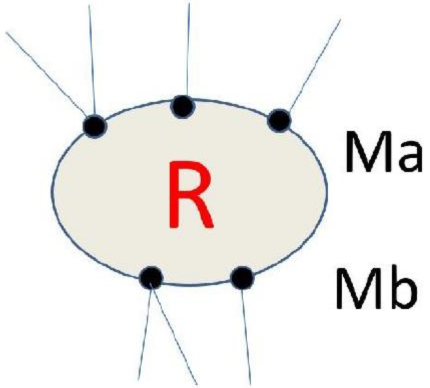


Power flow into an area

Power flow out of an area

Calculation of Area Angle

An area with border buses



Area R with Border buses Ma and Mb

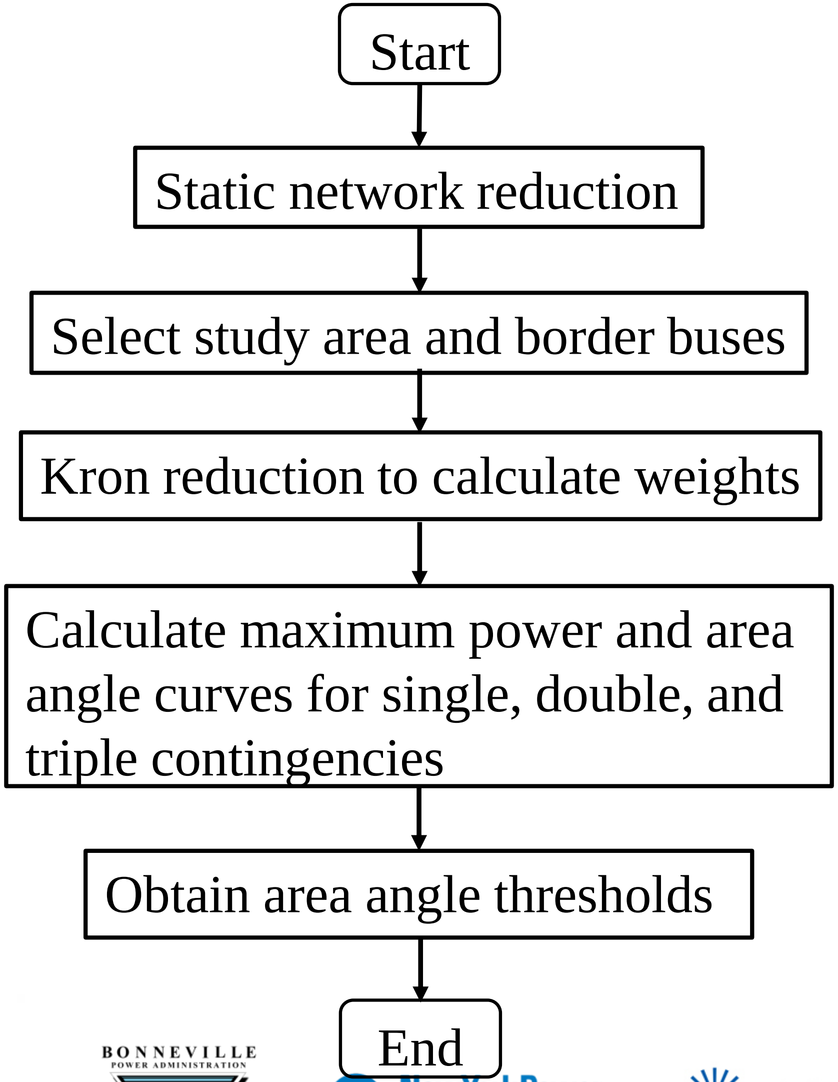
Area angle calculation

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

$$\sum_{i=1}^{M_a} w_i = 1, \sum_{j=1}^{M_b} w_j = -1$$

Weights of border buses are calculated with Kron reduction

Procedure to Obtain Area Angle Thresholds



Start

Static network reduction

Select study area and border buses

Kron reduction to calculate weights

Calculate maximum power and area angle curves for single, double, and triple contingencies

Obtain area angle thresholds

End

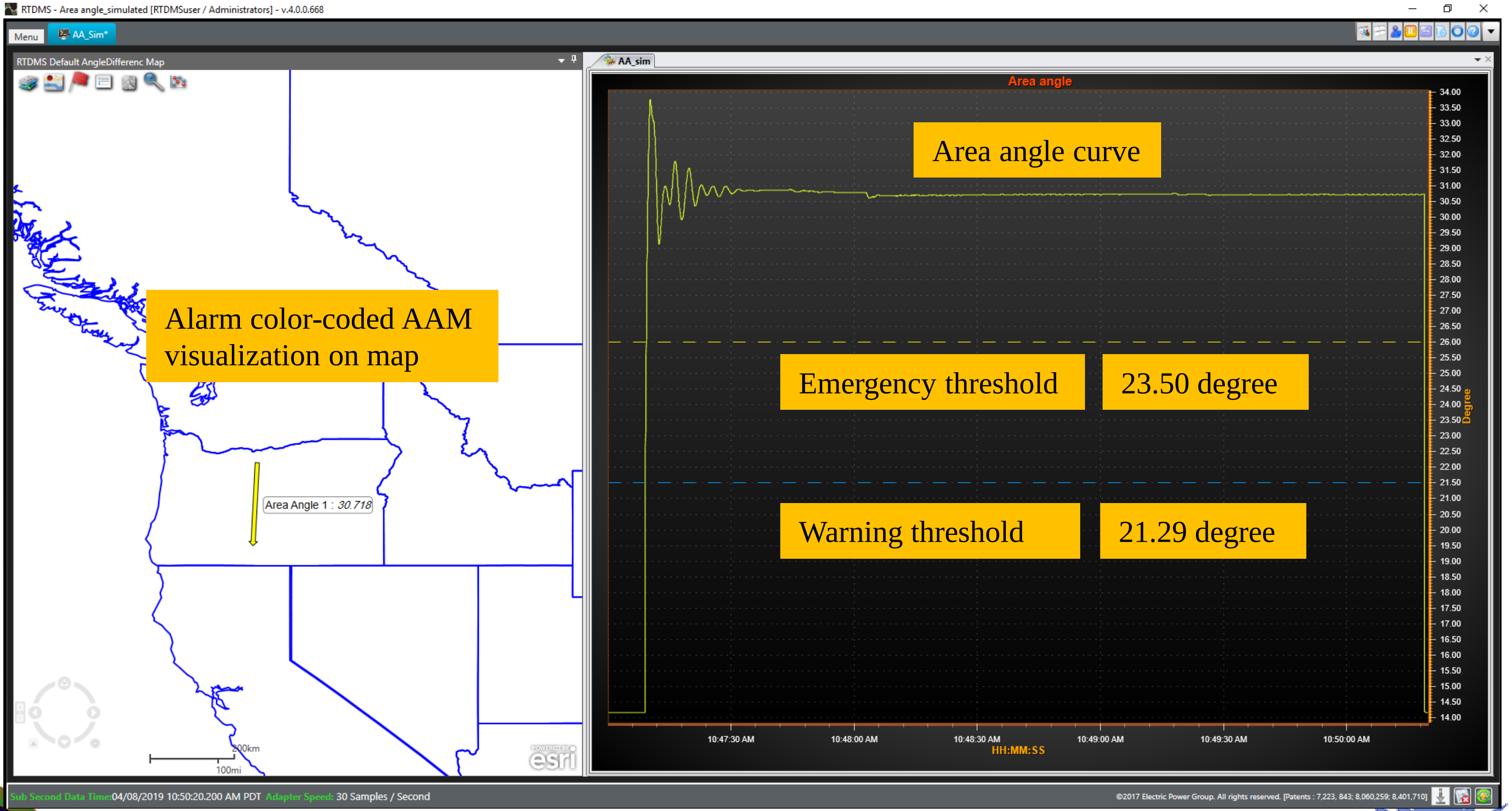
$\theta_{area} \geq \theta_{thr}$ ⟹ **Alarm**

$\theta_{area} < \theta_{thr}$ ⟹ **No alarm**

Two thresholds:
Warning threshold
Emergency threshold

Visualization of AAM On RTDMS Client

- Monitor an area in BPA
- Contingency: Loss of John day–Grizzly #1 and #2 and the line Grizzly–Malin



Alarm color-coded AAM visualization on map

Area angle curve

Emergency threshold 23.50 degree

Warning threshold 21.29 degree

Sub Second Data Time:04/08/2019 10:50:20.200 AM PDT Adapter Speed: 30 Samples / Second

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Looking Forward

- Adapt applications to utility footprint
  - BPA completed, testing in Progress
  - NYPA – March-April 2019
  - Duke – April-May 2019
- Factory tests
  - BPA – April 2019
  - NYPA – May 2019
  - Duke – May-June 2019
- Site Installation
  - BPA – May 2019
  - NYPA – June-July 2019
  - Duke – July-August 2019
- Site tests follow site installations

Summary

- Developed 3 Applications using Phasor Data and Linear State Estimator
  - Real-time Contingency Analysis (RTCA)
  - Voltage Stability Assessment (VSA)
  - Area Angle Monitoring (AAM)
- Demonstrated applications to participants and observers in February 2019
- Implementation for BPA – Completed
- Next Steps
  - Implementation for NYPA & Duke Systems
  - Factory Acceptance Testing for BPA, NYPA, Duke

Thank You