DOE/OE Transmission Reliability Program

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

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Webex

Introduction

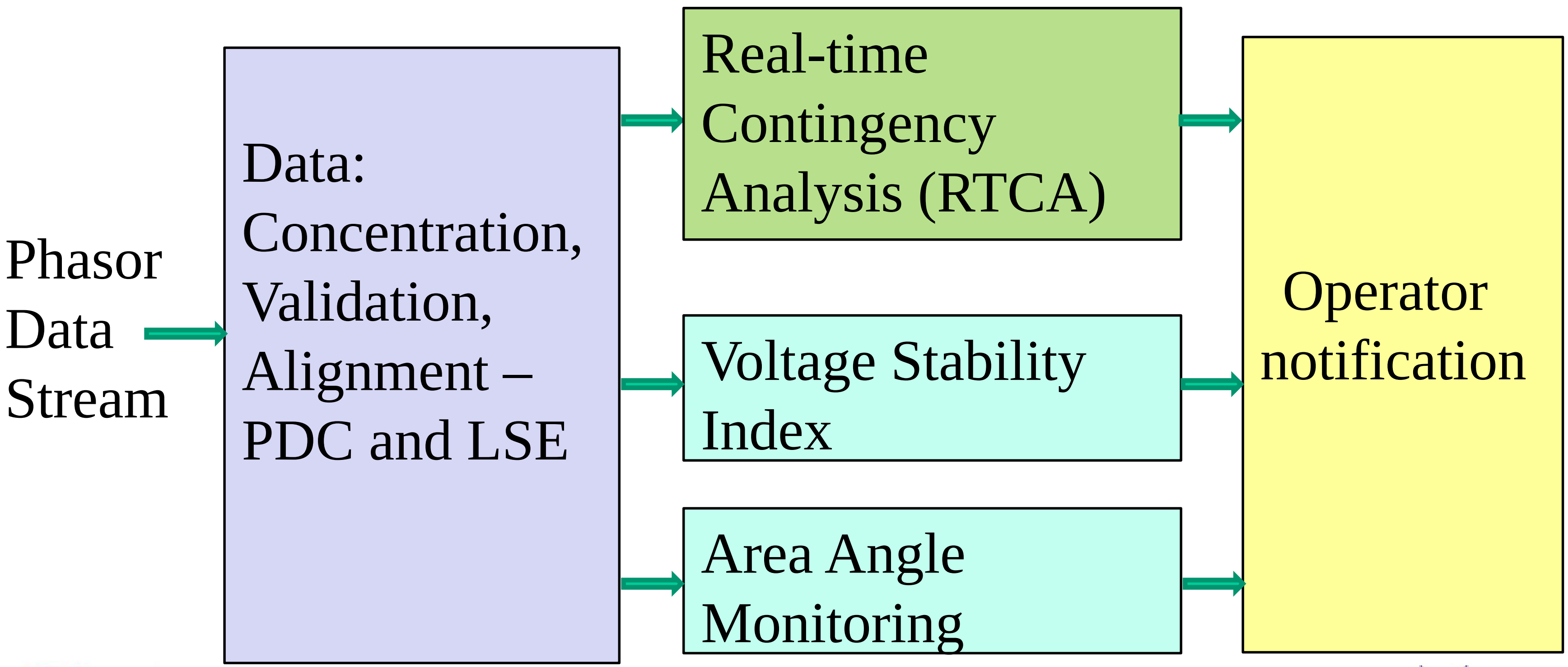
- Project: Real Time Applications Using Linear State Estimation Technology
  - DOE Grant Award DE-OE0000849
- Primary recipient: Electric Power Group, LLC
- Project Partners (host site & cost share):
  - Bonneville Power Administration
  - New York Power Authority
- Added project host site
  - Duke Energy

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 approach

- Implement 3 applications to monitor power system
- Test with simulated and recorded data
- Demonstrate at host utilities

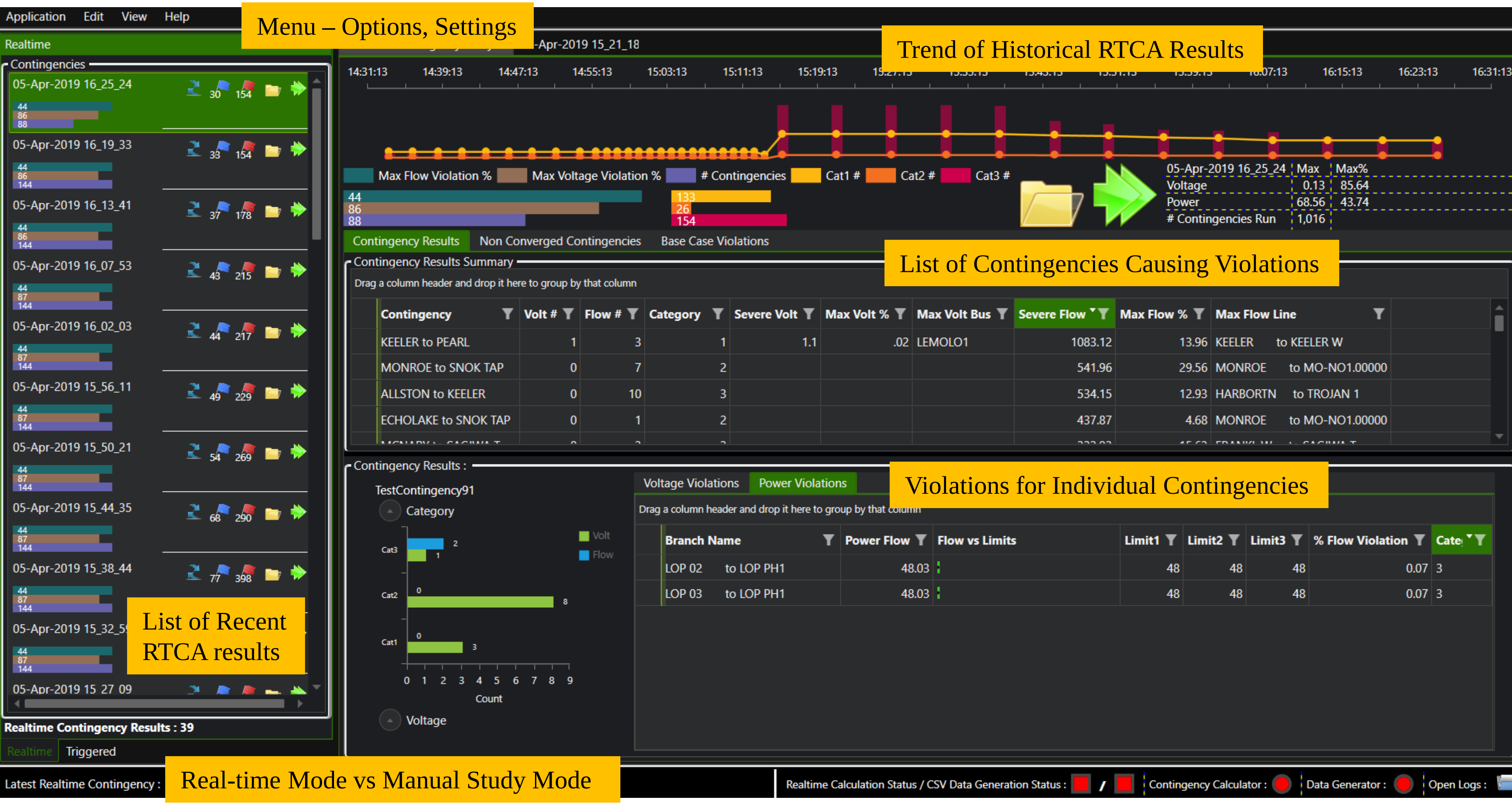


REAL-TIME CONTINGENCY ANALYSIS (RTCA)

Methodology

- Uses a base case (power flow model) as input and updates the observable area using *e*LSE results
- Run all contingencies from a list using Power flow solution (FDLF/NR)
- Detect voltage & power flow limit violations
- Use full system model covering utility with surrounding connections
- Challenges
  - Base case may not match current system
  - Obtaining accurate results with small number of PMU measurements

RTCA Results Visualization



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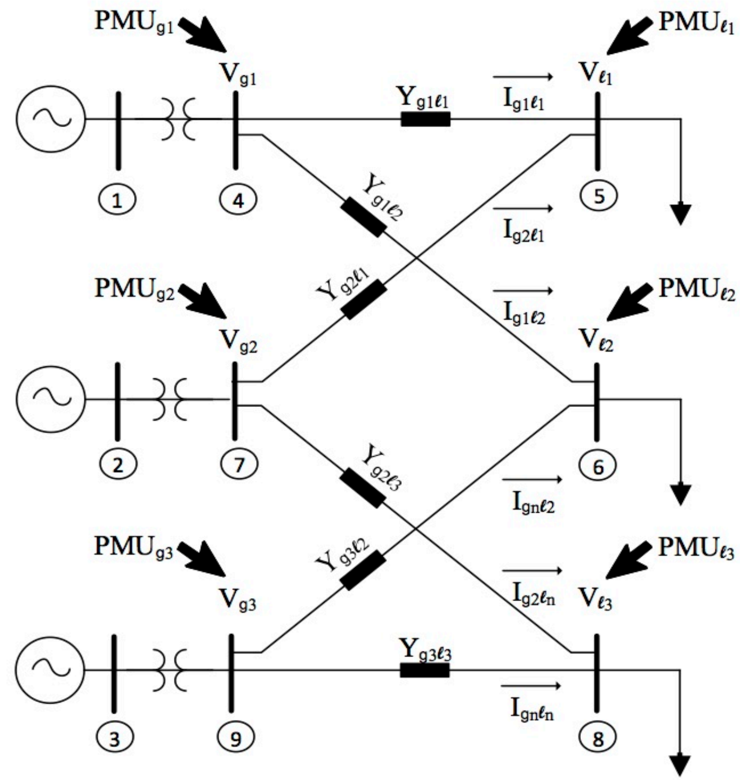
VOLTAGE STABILITY INDEX (VSI)

Transmission Corridor VSI

- Uses PMU measurements of V & I at both ends of a transmission corridor to compute complex power
- Computes a stability index that is simply the voltage across the system divided by the load voltage
- Limits are set based on local limitations
- Technique will handle a transmission corridor with a network of lines and multiple input and output points



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VSI configuration example (BPA)

- Establish VSI limits based on various severe contingencies
- For BPA, used maximum generator & DC intertie
  - Example - Loss of Two Palo Verde Units

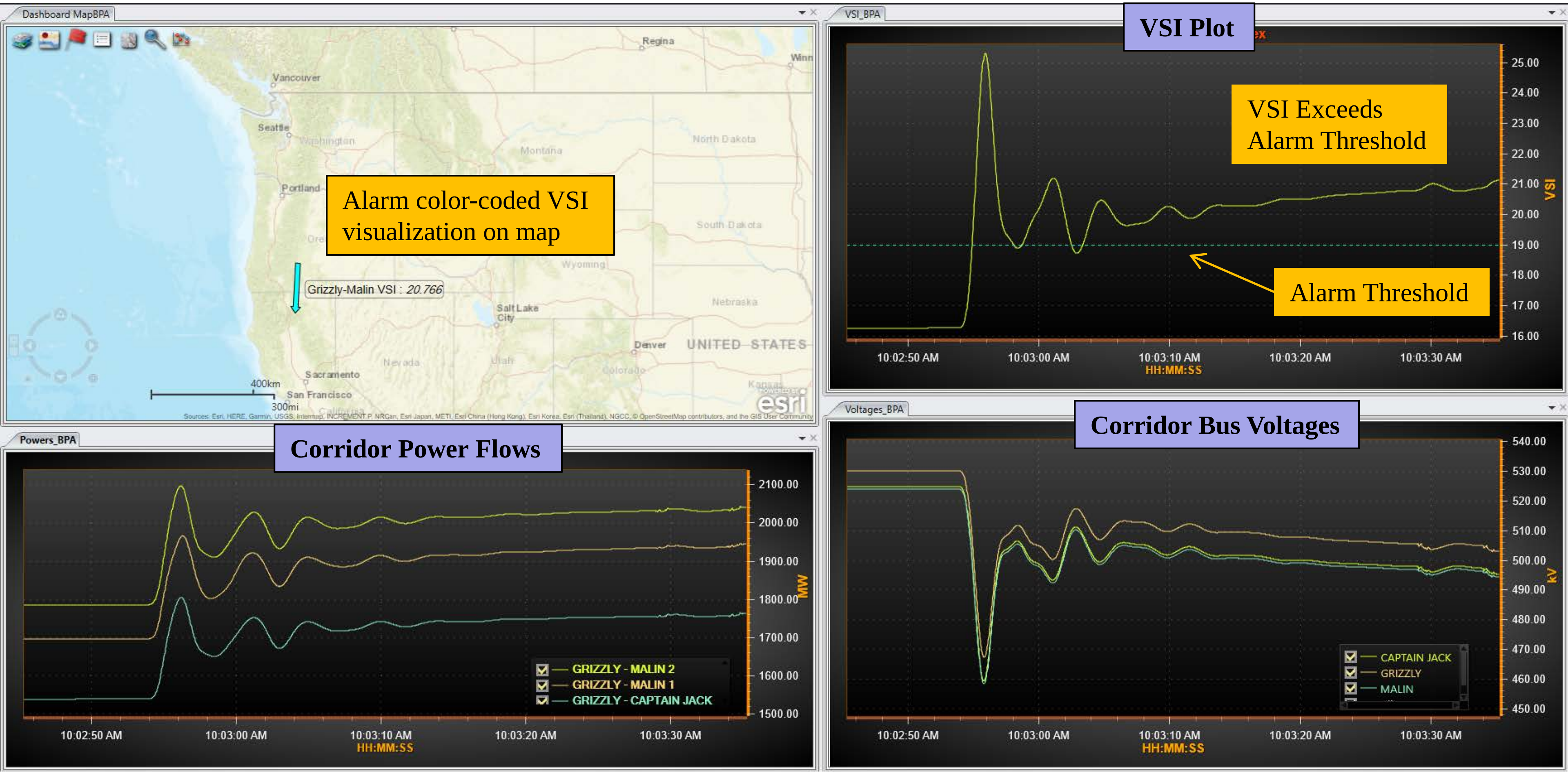
	Loading	Malin Voltage	VSI
1	Base Case (3807 MW)	514.8 kV	16.61
2	4353 MW	504.8 kV	19.11
3	4667 MW	493.7 kV	21.21
4	4917 MW	480.2 kV	23.38
5	5125 MW	472.5 kV	24.87
6	5150 MW	471.5 kV	25.03
7	5160 MW	466.6 kV	25.93
8	5205 MW	NA	Diverges

Alarm levels were determined:

- Alert: 19
- Alarm: 23

VSI Visualization in Real-Time

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



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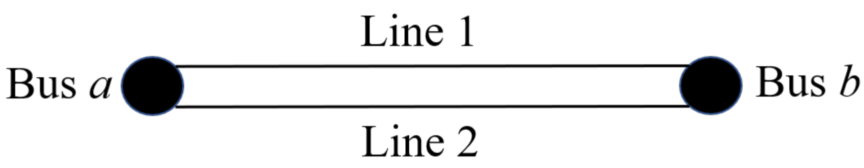
AREA ANGLE MONITORING (AAM)

Monitor Power Transfer Stress using Angle Difference



θ_{ab} – angle difference between *a* and *b*
P_{ab} – power flow from *a* to *b*
$P_{ab,max}$ –maximum power flow from *a* to *b*

- Scenario 1: P_{ab} increases.

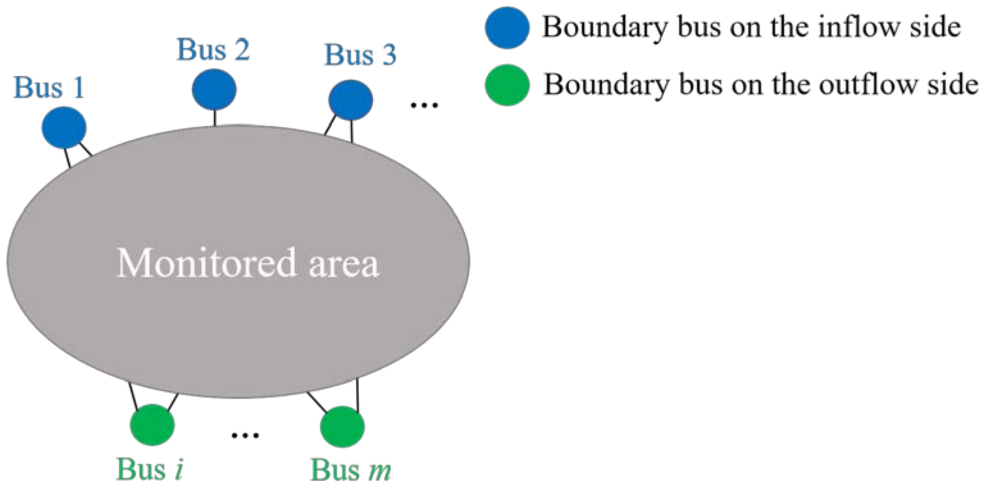
  when P_{ab} increases, θ_{ab} increases proportionally, indicating the increased stress of power flow. The maximum power flow $P_{ab,max}$ does not change.

- Scenario 2: Line 1 is tripped and P_{ab} does not change.

  Line 1 trips, $P_{ab,max}$ decreases and θ_{ab} increases.

Angle difference can indicate the increase of stress caused by either increased power flow or line outage.

Area Angle Monitoring (AAM)



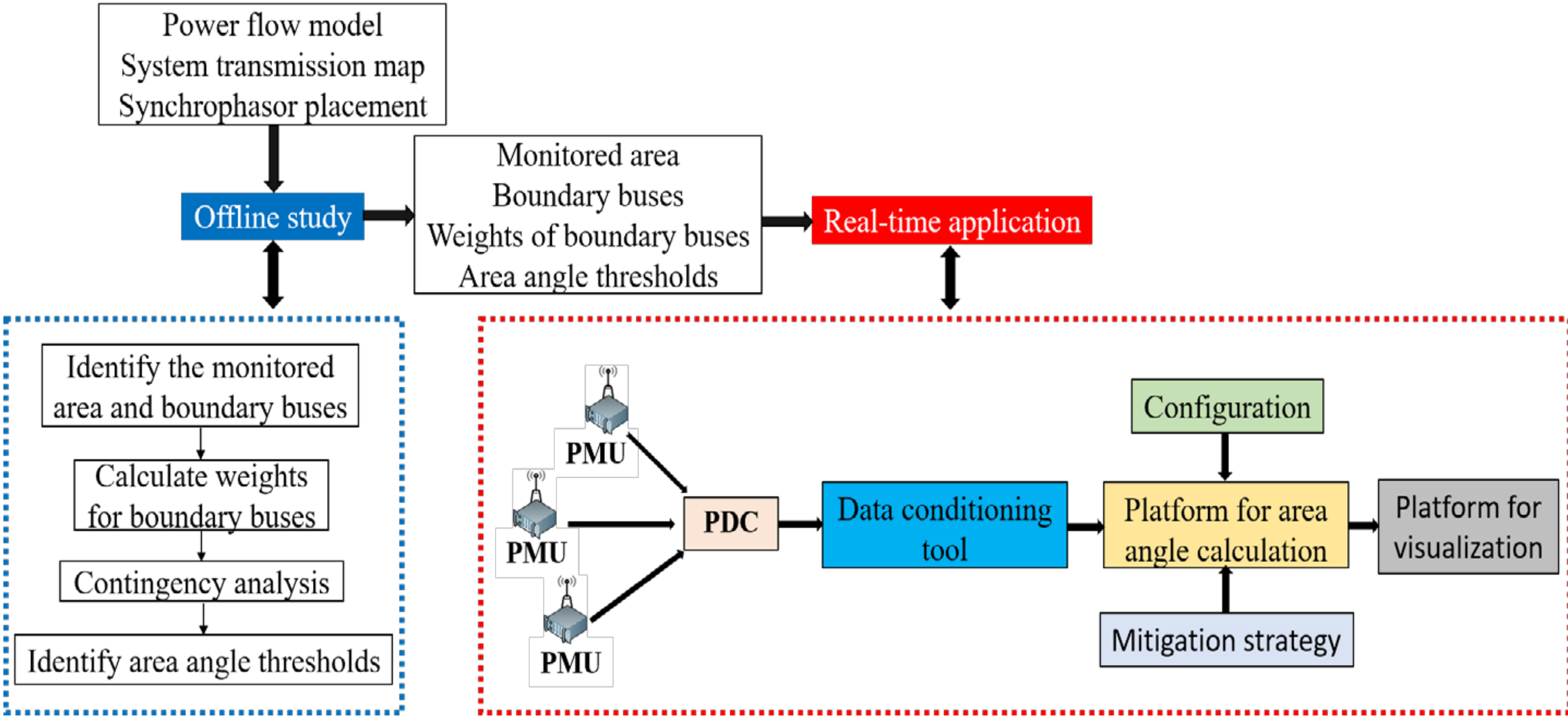
Area angle [1],[2] generalizes angle difference between buses to angle difference across an area. The stress of bulk power transfer through the area is indicated by a weighted combination of phase angles at the boundary buses of this area.

$$\theta_{area} = w_1\ \theta_1 + w_2\ \theta_2 + \ldots + w_m\ \theta_m$$

[1] A. Darvishi, I. Dobson, "Threshold-based monitoring of multiple outages with PMU measurements of area angle," *IEEE Trans. Power Syst.*, vol. 31, no. 3, pp. 2116-2124, May. 2016.

[2] W. Ju, I. Dobson, K. Martin, et al, "Real-time area angle monitoring using synchrophasors: a practical framework and utility deployment," *IEEE Trans. Smart Grid*, DOI:10.1109/TSG.2020.3020790.

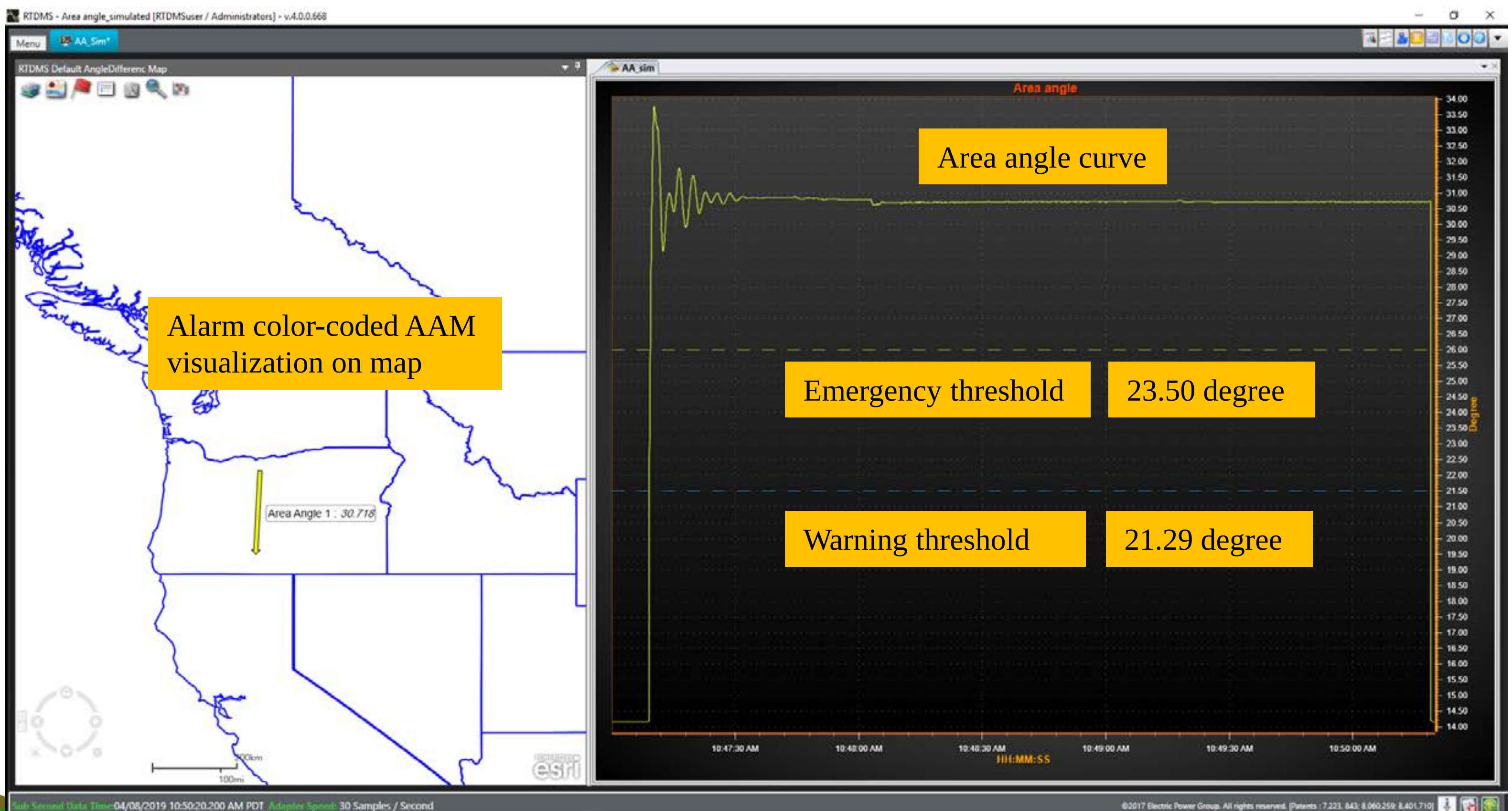
Implementation of AAM



[2] W. Ju, I. Dobson, K. Martin, et al, "Real-time area angle monitoring using synchrophasors: a practical framework and utility deployment," *IEEE Trans. Smart Grid*, DOI:10.1109/TSG.2020.3020790.

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**



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Applications Benefits

- RTCA Improves Situational Awareness & provides Actionable Intelligence
  - Based on *e*LSE which always solves
- Provides Backup to Conventional RTCA
- VSI covers transmission corridors rather than specific lines
  - Covers less well defined transmission flows
- Area angle can track the bulk power stress due to line outages inside the area using synchrophasor measurements.
  - ➢ It is approximate but faster when compared with SCADA and state estimation.
  - ➢ It is associated with a particular pattern of power flow through the area, which allows thresholds for area to be set up.

Project status

- Project completed in March 2020
- Demonstration was made 2019 & early 2020
- Implementations completed in June 2019
  - BPA in June 2019
  - NYPA and Duke in summer 2020
- Final technical report in October 2020
- Due to the pandemic we have not been able to proceed with further testing or gathering of data from events

Looking Forward

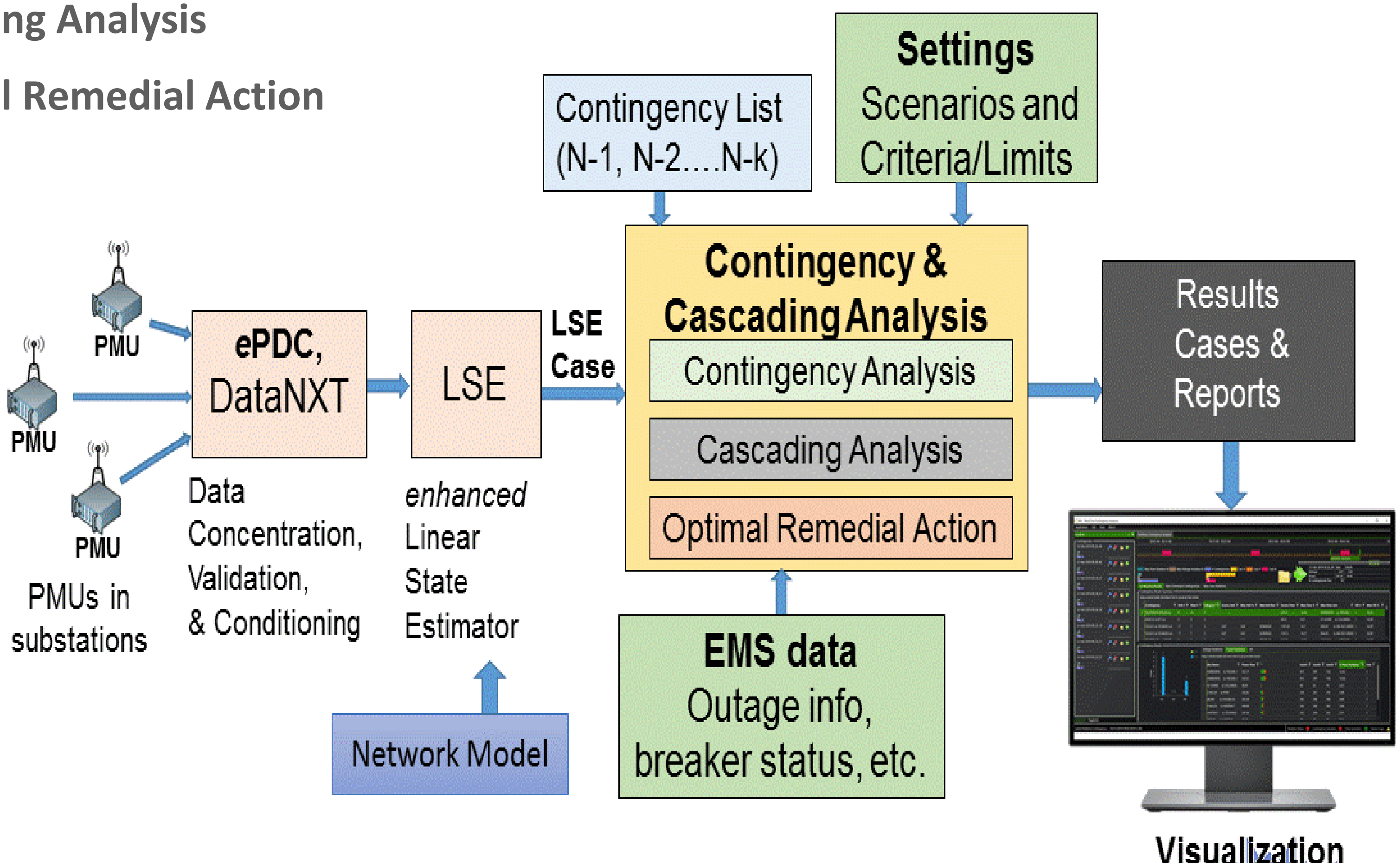
- To achieve the most benefit, EPG plans to:
  - Gather data from participant utilities & analyze operations
  - Upgrade applications as needed for reliable operation
- Incorporate developed applications into products:
  - VSI and AAM into RTDMS operations
  - RTCA into complete platform including Cascading Analysis and Optimal Remedial Action

Utility Operation Risk Assessment

- **Real Time Contingency Analysis (RTCA)**
  - Checks what-if situations during normal operations
  - Prepares for the next problem that can result from unforeseen events
- **Cascading Analysis**
  - Operators need to be advised of cascading risks just the same as other contingencies
- **Optimal Remedial Action**
  - Operators can be overwhelmed during a major outage situation
  - Optimal Remedial Action can offer a list of actions that will alleviate contingencies and include warning for other consequences

Architecture of RTCA, Cascading Analysis, and Optimal Remedial Action

- Enhanced RTCA
- Cascading Analysis
- Optimal Remedial Action



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Thank You!

Questions ?

Thank you

- Best wishes from The Electric Power Group