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

DOE Grant Award #DE-OE0000849

Ken Martin & Lin Zhang, Principal Investigators
Electric Power Group

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Acknowledgement and Disclaimer

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Presentation

• Introduction & participants
• Project objective & approach
• Overview of application developments
• Status & schedule
• Planned activities
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
    • Project lead – Tony Faris/Thong Trinh
  – New York Power Authority
    • Project lead – Atena Darvishi/Alan Ettlinger
• Project host site - Duke Energy
  • Project lead – Megan Vutsinas, Tim Bradbury, Evan Phillips
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 margins, & phase angle limits

• Applications include
  – Real Time Contingency Analysis
  – Voltage Stability Monitoring
  – Area Angle Limit Monitoring
Project approach

- Implement 3 applications to monitor power system
- 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 corridor stability detection
- Area angle stability detection

Operator notification
ENHANCED LINEAR STATE ESTIMATOR (eLSE)
**eLSE Inputs**

- Network Model (CIM format)
  - Converted into eLSE format model
- PMU Data (C37.118)
  - Real-time or recorded
- Topology Info (Breaker status)
  - From EMS or recorded

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**System Topology**

- C37.118 PMU data
  - Real-time

**Utility Network Model (CIM)**

- Estimated Synchrophasor Data
- Virtual PMU’s with Estimated Values
- List of Measurement Anomalies
Flow Chart of eLSE Engine

- eLSE input interface processes inputs and send them to eLSE core modules
- eLSE core modules include:
  - Topology Process
  - Observability Analysis
  - Linear State Estimation
  - Bad Data Detection & Identification
REAL-TIME CONTINGENCY ANALYSIS (RTCA)
RTCA operation

- Tests what can happen next based on the current system
  - Uses a pre-made list of contingencies such as line outages, transformer failure, RAS actions, etc.
  - Checks for low voltage or excessive power flow caused by the outage
- Uses a solved case from the LSE
- Applies each contingency, checks for violations
  - Check power flow and bus voltage limits
  - Rank and list violations
  - Send alerts based on violation level
- Manual operation allows testing user specified cases
  - Special conditions, pre-study before switching
RTCA Challenge – getting good results with small number of measurements (observability)

- Entire Network = G
- LSE observable subnetwork = S
- Systems connected by lines on boundary busses B<sub>i</sub>
- Ps-inj = Power Injection at Boundary Buses

Approach with 2 methods:
- Method 1 – consider only the observable subsystem S
- Method 2 – consider the whole system but update observable portion S
Method 1

- Use only the subsystem that is covered by PMU measurements (this portion is called ‘observable’)
- External System is removed and its effect is represented by constant Power Injections (P & Q)
- Apply contingencies only to subsystem S
Method 2

- Use the entire system G
- Update the observable subset S with measurements from the LSE
- Use the load flow program to adjust the whole system to the observable system
- Apply contingencies to any part of the system (primarily subsystem S)
### Method 2 Results – Contingency Line 16-17

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<th>Bus No</th>
<th>Vmag (pu)</th>
<th>Power (MW)</th>
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**Highlighted – Buses/Lines in Subnetwork S**
Decision & next steps

• Method 2 selected
  – Both methods produced high errors at boundary due to limited observability
  – Method 2 gave better results and also allows testing contingencies near boundary and externally; drawback is longer computation time
  – Testing with IEEE 300 bus test system confirmed improvement on a bigger system and advantages of Method 2

• Testing for deployment at BPA
  – WECC Planning Case 2020 HS (~ 20,000 Buses)
  – Subnetwork – 500 kV BPA System
    • Buses – 162 and Branches – 196
VOLTAGE CORRIDOR STABILITY LIMIT MONITORING
Methodology: Single Line Equivalent for a Transmission Corridor

- The PMU measurements at both ends of a transmission corridor are required.
- Complex power is computed from the complex V & I measurements.
- Using the complex power through the system and current flow in and out of the corridor, the voltage across the corridor can be computed.
- The index is simply the voltage across the system divided by the load voltage.
- Reactive support has to be considered.
VSI reaction to loss of 2 Palo Verde Units

Next steps: determine threshold & determine reactive support
AREA ANGLE LIMIT MONITORING
Area-angle application

- Power flow creates a phase angle
- Higher angles result from
  - Higher power flow
  - Higher impedance (fewer lines carrying flow)
- Angle can indicate excessive stress or a lost transmission line
- Area angle indicates transmission failure or overloads
Methodology: reduce area & relate to angle

- Select an area with a distinct power flow through it, that has PMU measurements at all busses on border of area
- Determine a weighting for each boundary bus based on the network admittances; this uses the Kron reduction on the base case to determine the weighting. This effectively reduces the area to a single line equivalent
- The maximum allowed power flow is determined by studying single line outages; the area angle threshold is given by the worst case outage
Challenges

• With limited PMU coverage, it is difficult to find an area where the boundary is completely monitored by PMUs
• The area needs to have a distinct power flow through it to cause angle changes reflected by power flow
• With a large meshed grid, there may be many exceptional outages (ie, outages where line limits are exceeded but the angle change doesn’t exceed a threshold)
Project status

• Presented paper on RTCA development at the NAPS conference in September 2018
• Project extended 1 year to March 14, 2020
• RTCA and voltage corridor applications have been turned over to the EPG development team
  – User interfaces will also be developed
• We continue to resolve issues in Area angle app
# Extended Project Timeline

<table>
<thead>
<tr>
<th>Task</th>
<th>Deliverable</th>
<th>Completion Date</th>
<th>Documentation &amp; notes</th>
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<tr>
<td>1</td>
<td>Project Management Plan</td>
<td>4/12/2017</td>
<td>Project management plan document</td>
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<tr>
<td>2</td>
<td>Research, Design &amp; Development of Prototype</td>
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<td>2.3</td>
<td>Real time applications prototype, and development and testing</td>
<td>10/1/2018</td>
<td>Test cases and test results</td>
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<td>Completion and testing of deployable applications</td>
<td>1/31/19</td>
<td>Documented test results</td>
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<td>Demonstration at EPG</td>
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<td>Factory Acceptance Test</td>
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<td>Demonstration at utility host site, training and a report</td>
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<td>Outreach</td>
<td>3/14/2020</td>
<td>Industry presentations &amp; briefing documents</td>
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Looking Forward

• Planned next steps
  – Application Implementation in operational code
    • Operational code testing in December 2018
  – Develop area angle application
  – Adapt applications for test site deployment
    • NYPA – November-December 2018
    • Duke – January-February 2019

• Project roadmap
  – FY 2019: Complete application development & deploy at host sites
  – FY 2020: Host site demonstrations with real-time operation & produce commercialization plan
Questions?