DOMINION ENERGY’S PILOT DEPLOYMENT AND EVALUATION OF ENHANCED LINEAR STATE ESTIMATOR FOR GRID RESILIENCY

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APRIL 12, 2022
TODAY’S AGENDA

- eLSE at Dominion Energy
  - Project goals
  - Timeline
  - Key activities
- Visualization and system operation
- Summary & Next Steps
- Q&A
LINEAR STATE ESTIMATION DEPLOYMENT

PROJECT GOALS, HIGHLIGHTS, AND ACTIVITIES
DOMINION’S SYNCHROPHASOR PILOT PROJECT GOALS

- Dominion’s primary goal is to deploy LSE to address the following:
  - Detect and Identify bad PMU data quality measurements
  - Isolate bad measurements affecting real-time applications
  - Substitute poor quality and unavailable measurements with model-based estimations
  - Independent platform to serve as a back-up platform to EMS/SE

- In addition, Dominion deployed additional synchrophasor solutions to provide:
  - Real-Time Phase Angle Monitoring
  - System Frequency Response monitoring
**PROJECT HIGHLIGHTS**

<table>
<thead>
<tr>
<th>Uses protective relays to stream PMU data</th>
<th>Positive Sequence Data from 128 PMUs</th>
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<tbody>
<tr>
<td>cover the 500kV transmission system</td>
<td>Data collected from 29 substations</td>
</tr>
<tr>
<td>Observability increased with LSE</td>
<td>Observability increased to 42 substations (out of 44)</td>
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<tr>
<td>System is fully independent from EMS/SCADA</td>
<td>Breakers and other digitals are directly available from PMUs</td>
</tr>
<tr>
<td>Incorporated zero-injection pseudo measurements</td>
<td>Dynamically evaluates candidate buses for pseudo measurements placement</td>
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PROJECT TIMELINE AND PROGRESS

2020
Project Kick Off, Gap Analysis, Architecture Design

2021
solution Delivery, Deployment & Model Integration

2022
Visualization building, On Site Training, Project Completion and next steps
DATA AND MODELS PROVIDED BY DOMINION

- Models used to commission the LSE
  - CIM Network Model
  - One Line Diagrams in Dominion’s EMS format

- Data provided by Dominion for commissioning and testing
  - PMU Data from the Dominion’s PDC
    - Signals included are Voltage Phasors, Current Phasors, Digitals for breaker/switch statuses, Frequency, DFDT, Status Flags
  - Mapping information to link synchrophasor measurements to CIM model
ACTIVITIES TO DATE

- **CIM Model Integration**
  - Integrated with Dominion’s CIM Network model format to support LSE
  - Mapped PMU Measurements to CIM

- **Testing and Validation**
  - Commissioned hardware for LSE Deployment at EPG’s Lab
  - Deployed the eLSE using played-back measurements from Dominion’s synchrophasor system

- **Deployment and Commissioning**
  - Commissioned LSE Platform at Dominion Energy
  - Working grade LSE now running at Dominion with live data stream
  - Developed visualization screens with focus on transmission system on geo-spatial maps
  - Identified bad data issues in Dominion’s synchrophasor stream
### ELSE PLATFORM AT DOMINION

**PMU Data from Field**
- Data Concentration
- Receive Data from PMUs, synchronize data etc.

**openPDC**
- Data Collection and concentration

**enhanced Linear State Estimator**
- Data Conditioning tool
- Linear State Estimation

**PHASOR/RTDMS® 2022**
- Perform MVA Calculations
- Set Alarm limits
- Stream data to downstream applications

**Visualization**
- Visualization of Real-Time LSE Results
- Replay data and events
- Trends, Maps, Alarms etc.
LINEAR STATE ESTIMATION ARCHITECTURE

LSE Core Engine

- PMU data C37.118
- Breaker/Switch/Transformer taps
- Network Model (CIM)

Real-Time Topology Processing

Real-Time Observability Analysis

Estimation Formulation

Estimations

LSE-based bad data identification

LSE Platform includes: Data quality and model management + Visualization
VISUALIZATION AND SYSTEM OPERATION

OPERATOR DISPLAYS
SYSTEM MONITORING WITH ALARMS AT DOMINION ENERGY

Geographical overlay of the transmission system with PMU Locations

Transmission Lines on Map

Alarms based on Geographical Location

Frequency Monitoring

Alarms on Individual Metrics
LSE ESTIMATIONS – VOLTAGE MAGNITUDE AT 500 KV SUBSTATION

DATA PRESENTED WAS SIMULATED/PLAYED-BACK AT EPG LABS

Voltage Tolerance
Level < 1%
LSE ESTIMATIONS – CURRENT MAGNITUDE AT 500 KV SUBSTATION

Current Magnitude

Raw Value

Estimated Value

DATA PRESENTED WAS SIMULATED/PLAYED-BACK AT EPG LABS
FREQUENCY MONITORING AT DOMINION ENERGY

Frequency Signal at Substation

System Frequency on a Gauge

60.013

Data Quality for System Frequency
PHASE ANGLE MONITORING AT DOMINION ENERGY

Angle Pair A-B

Angle Difference on Trend Chart

Angle Pair B-C

Angle Pairs on Map with Direction and Alarms
CALCULATED MVA FROM ESTIMATED REAL AND REACTIVE POWER
• Color-coded visualization of PMU data side-by-side with eLSE estimations
• Ability to display measurements from PMU. (voltages, currents, phase angles, power, etc.)
• Ability to display digital values (breaker status, switches, etc.)
• Ability to change element properties based on Signal Values
LSE PERFORMANCE REPORTS

- Real Time Information about the following metrics:
  - Model Summary – Number of Observable Islands, Observable Buses, Branches, Breakers, Switches etc
  - Island Observability – Substations in each island at specific voltage level with measured or estimated observability
  - Island Signals- Signals in each island with substation name and Node/Line name
  - Breaker Status Change – Track Breaker Status changes in real-time
  - Measurement Status Change – Report any status changes in each measurements

<table>
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<tr>
<th>Model Summary</th>
<th>Island Observability</th>
<th>Island Signals</th>
<th>Breaker Status Changes</th>
<th>Measurement Status Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observable Islands</td>
<td>Observable Buses</td>
<td>Branches</td>
<td>Breakers</td>
<td>Switches</td>
</tr>
<tr>
<td>1</td>
<td>Island A</td>
<td>41</td>
<td>49</td>
<td>261</td>
</tr>
<tr>
<td>2</td>
<td>Island B</td>
<td>1</td>
<td>0</td>
<td>4</td>
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SUMMARY & NEXT STEPS
ELSE DEPLOYMENT AT DOMINION SUMMARY

- EPG’s eLSE have been successfully installed and commissioned at Dominion Energy
- Application has detected and identified bad quality PMU measurements
- Observability of substations have increased from 29 to 42 substations
- MVA values for individual lines have been calculated from estimated real and reactive power values and proper alarm thresholds are established
- Frequency and Phase angle monitoring have been configured
- LSE Performance Reports have been commissioned to better assess the model summary
- Zero Bus Injections have been properly mapped in the model and commissioned
- System overview diagrams representing the 500kV have been commissioned
- Substation level One Line Diagrams are being deployed with proper mapping of measured and estimated values
PILOT NEXT STEPS

- The following items remain open and to be completed:
  - Integrate breaker statuses from PMU measurements
  - Generate substation one-line diagrams for visualization of all 500kV substations
  - Map measurements/estimations to one-lines

- Gather feedback from operators on user-interfaces, and use-cases.
ON THE HORIZON....

- EPG is working on a next-generation LSE-based platform to provide full Real-Time Assessment capability through:
  - On-demand and periodic powerflow solution capability
  - State Estimator base case generation for downstream advanced applications
  - Real-time Study Capability for “What-if” assessments
  - Full and seamless integration with Real-Time Contingency Analysis
DISCUSSION AND Q&A
Thank You