Data Visualization, Daily Operations Review and Event Analysis

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PJM Interconnection
NASPI
Houston, TX - October 2014
PJM as Part of the Eastern Interconnection

KEY STATISTICS

MWs of generating capacity: 183,604
Miles of transmission lines: 62,556
2013 GWh of annual energy: 791,089
Generation sources: 1,376
Square miles of territory: 243,417
Externally facing tie lines: 191

As of April 2014

• FERC
  – Regional Transmission Organization

• NERC
  – Reliability Coordinator
  – Balancing Authority
  – Transmission Operator
  – Transmission Planner
  – Planning Coordinator
Phasor Measurement Units in the PJM Grid

- More than 370 PMUs Installed
- In over 100 Substations

As of April 2014
• Event Detection & Post-Event Analysis

• Operations Integration

• Data Exchange
Event Detection & Post-Event Analysis

- Develop Event Criteria that Triggers Analysis
- Develop Process, Tools, & Training
- Integrate into Daily Review Team
Event Detection & Post-Event Analysis
Post – Event Analysis Triggers

Identify Significant Disturbances on the Grid

- Leverage NERC Established Event Criteria
- Frequency Deviations ≥ 40 mHz in any rolling 16 second interval (BAL-003 Frequency Response)
- EHV Transmission Trips / Outages – Initially monitoring EHV lines that are components of IROL transfer interfaces
- Large Generator Trips ≥ 900 MW (BAL-002 Disturbance Control Performance)
### Operations Metrics Dashboard - Sunday, April 13, 2014

<table>
<thead>
<tr>
<th>Metric</th>
<th>Metric Value</th>
<th>Metric Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Forecast Shape - (RTO)</td>
<td>97.76%</td>
<td>Neutral</td>
</tr>
<tr>
<td>1200 Forecast Fit %</td>
<td>97.36%</td>
<td></td>
</tr>
<tr>
<td>1800 Forecast Fit %</td>
<td>98.17%</td>
<td></td>
</tr>
<tr>
<td>Transmission Actuals</td>
<td>100.00%</td>
<td>Good</td>
</tr>
<tr>
<td>Total BES Events</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>IROL Exceedances</td>
<td>0</td>
<td>Good</td>
</tr>
<tr>
<td>Total IROL Exceedences &gt; 10 Seconds</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>IROL Exceedences &gt; 30 Minutes</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Transmission Contingencies</td>
<td>100.00%</td>
<td>Good</td>
</tr>
<tr>
<td>Total BES Events</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>MISO Flowgates &gt; 20 Minutes</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Manual Dispatch</td>
<td>-</td>
<td>Good</td>
</tr>
<tr>
<td>Total Wind Limits</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Grid Disturbances &amp; PMU Analysis</td>
<td></td>
<td>Needs Review</td>
</tr>
<tr>
<td>Frequency Deviations (&gt;=40mHz)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>EHV Transmission Trips (&gt;= 500kV)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Large Unit Trips (&gt;= 900MW)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>BAAL</td>
<td>99.10%</td>
<td>Good</td>
</tr>
<tr>
<td>Total Minutes</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Longest Excursion (Mins)</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>CPS-1</td>
<td>136.22 (Neutral)</td>
<td></td>
</tr>
</tbody>
</table>
Event Detection & Post-Event Analysis
Daily Dashboard Metrics and PGDA

GRID DISTURBANCES & PMU ANALYSIS - 4/13/2014

Frequency Deviations

<table>
<thead>
<tr>
<th>No</th>
<th>Event Start</th>
<th>Starting Freq</th>
<th>Freq Deviation</th>
<th>ACE Deviation</th>
<th>Gen Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13APR14:13:25:02</td>
<td>60.0025</td>
<td>-0.0448</td>
<td>-1935</td>
<td>-877</td>
</tr>
<tr>
<td>2</td>
<td>13APR14:21:12:52</td>
<td>60.0208</td>
<td>-0.0011</td>
<td>-1109</td>
<td>-1171</td>
</tr>
</tbody>
</table>

EHV Transmission Trips
No Data Available

Large Unit Trips

<table>
<thead>
<tr>
<th>No</th>
<th>Event Start</th>
<th>Facility</th>
<th>Gen MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13APR14:21:13:29</td>
<td>Anonymous Nuclear Unit in Eastern PJM</td>
<td>1238</td>
</tr>
</tbody>
</table>

Phasor Grid Dynamics Analyzer (PGDA)
Event Detection & Post-Event Analysis
Daily Review Team Morning Meeting

- Consists of Managers, Supervisors, Engineers, & Economists from Operations & Markets Divisions
- Review Daily Dashboard Metrics & Dispatcher Logs
- Discuss Previous Day’s Operational Performance & System Events
- Discuss Events that had Market Impacts
- Discuss Anticipated Current Day & Day Ahead Operations
Integrate PMU data into:

- PJM’s Energy Management System (EMS) and assess impact
- One-line Displays
- Intelligent Event Processor to provide alarming
Operations Integration
EMS Incorporation – State Estimation (SE)

- Incorporated configuration changes to include phasor measurements (Voltage & Current Magnitude/Angle) within PJM State Estimation
- Data feed to provide PMU data to PJM SE is now in place
- Currently in the process of evaluating the impact of the including PMU data within our SE calculation in our stage system.
— Select PMU data will be displayed within PJM SCADA.

— Including Phase Angle data.

— Refresh rate is being determined. It will be down-sampled from 30/sec!

— Initial effort will be to incorporate 765kV & 500kV data with associated Tryback display for a given facility.
PJM & Majority of our 12 TO’s with PMU data are capable of sharing real time Wide Area Monitoring Systems [WAMS] views via EPG’s RTDMS application.

- Fine tuning alarm triggers via base-lining efforts.

- Adding Rate of Change of Frequency alarming.

Electric Power Group’s [EPG] Real Time Dynamics Monitoring System [RTDMS]
Data Exchange

- PJM is exchanging data with neighbors DUKE/VACAR, NYISO, MISO. TVA is in progress.

- We are working with SOCO to exchange data as a non-contiguous neighbor.
PJM has developed an in-house Linear SE beta application based off similar work being done at DOM & VA Tech.

Initial use will be as a feedback mechanism and trigger for Data Quality related issues & reporting.

Potential use as Data Conditioning Tool for any PMU data prior being used in PJM Traditional SE.

Non-Linear State Estimation

\[ \text{Calculate } x_n \]

\[ \text{Calculate Jacobian} \quad J_{ij} = \frac{\partial f_i(x)}{\partial x_j} \]

\[ \text{Calculate Mismatch} \quad f(x_{n+1}) = f(x_n) + J\Delta x \]

If mismatch > tolerance

Linear State Estimation

\[ Z = \text{Measurement Matrix} \]

\[ H = \text{System transfer function} \]

\[ \{ \Delta \} = ([B^{T}B]^{-1}B^{T})\{ z \} = \{ H \} \{ z \} \]
Future / Other Developments
Oscillation Detection

- New oscillation detection algorithm based off PNNL’s Oscillation Detection module;
- Aiding in detecting Oscillations in near real-time and distinguishing between Forced & Transient Oscillations.
- In place within production RTDMS by 2015;
- Operator Training & Procedures in effect by 2015.
- Eastern Interconnect Data Sharing Network is a replacement for NERCNet.
- SCADA and PMU data sharing.
- Expected to replace the existing network in 2015
- Facilitates agreed upon monitored angle pairs for the Eastern Interconnection with all ISO/RTO's having visibility. [CERTS/DOE project]
Future / Other Developments
Model Validation

- PJM Planning trained on use of Tool.
- Tool validated using external generation data.
- 1st PJM generator side PMU data targeted for late 2015, early 2016.
Future / Other Developments

— Detection of Planning Criteria Violations
  • Oscillation Frequency & Damping Ratio
— Continue to Improve PMU Data Quality
  • PDQTF – Phasor Data Quality Task Force
— Enhancement of Analysis Tools & Training