Discovering Geomagnetic Disturbance Patterns for Synchrophasor-based Event Prediction in Québec: A Knowledge-based approach to Understanding PMU Data

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Agenda

- Introduction: Situational awareness for the power grid
- Brief history of wide-area measurements at Hydro-Québec (SMDA)
- Overview of Wide-Area Situational Awareness System (WASA)
- Advanced capabilities of WASA
- References
Situational awareness for the power grid

- Since 2012, Hydro-Québec and IBM Research have been collaborating on *in situ* network of synchrophasors (WASA)

- But first, let’s review how it all began with SMDA
  - HQ was the pioneer in angle shift measurement system (wide-area measurements)
<table>
<thead>
<tr>
<th>Year (version)</th>
<th>Synchronizing Signal (Accuracy)</th>
<th># of PMUs</th>
<th>Rate (Hz)</th>
<th>Data concentrator features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976 (0.0)</td>
<td>LC (46 μs) – 1 degree electrical angle</td>
<td>2</td>
<td>1</td>
<td>Custom database</td>
</tr>
<tr>
<td>1981 (3.0)</td>
<td>GEOS</td>
<td>3</td>
<td>30</td>
<td>4000 records possible</td>
</tr>
<tr>
<td>1988 (4.0)</td>
<td>IRIG-B (20 μs)</td>
<td>4</td>
<td>60</td>
<td>1) Central unit on a HP-1000 computer. Visualization on a sun computer using a X-Windows based multi-users operating system 2) Voltage asymmetry computation 3) New “Raima” database with 10,000 records of angle and 600 records of voltage asymmetry</td>
</tr>
<tr>
<td>1991 (4.0)</td>
<td>IRIG-B (20 μs)</td>
<td>8</td>
<td>60</td>
<td>4 more PMUs</td>
</tr>
<tr>
<td>1995 (4.0)</td>
<td>IRIG-B (20 μs)</td>
<td>8</td>
<td>60</td>
<td>Computation of bus voltage harmonic content up to the 10th</td>
</tr>
<tr>
<td>1998 (4.1)</td>
<td>IRIG-B (20 μs)</td>
<td>8</td>
<td>60</td>
<td>Continuous record up to 6 months</td>
</tr>
<tr>
<td>2004 (5.0)</td>
<td>GPS (1 μs)</td>
<td>8 (10 in 2008)</td>
<td>60</td>
<td>Change from IREQ-made PMU to Macrodyne commercial PMU. Change from Raima to ORACLE database.</td>
</tr>
</tbody>
</table>

SMDA (version 5.0)

Acquisition Unit Administration and Monitoring
WASA system installed at IREQ

- We envision WASA system to be the future SMDA

- Advanced data concentrator features
  - High-throughput, low-latency data acquisition using stream computing platform
  - Real-time event detection
  - Tools for visual analytics
  - Real-time correlation analysis and early warning

- Integrated system that supports decision making from raw PMU data
  - Current industry state-of-the-art is more focused on monitoring than decision-making

- WASA will provide prediction models for GMD events

- Applying cognitive techniques
  - Infer knowledge (e.g., about complex events) based on PMU measurements
  - Create abstraction model of granular sensor data reported by PMUs
  - Develop a cognitive model of the grid operator, engineer or analyst
Advanced capabilities of WASA

1. Localize fault for a complex event by drilling down on PMU data
2. High-level summarization of grid data
3. Generate early warnings for geomagnetic disturbances (GMDs)
Capability 1 – Post-event fault localization in the control room

Conduct Post-Event Fault Localization

- Retrieve Events
  - Search Basic Event by Date
- Replay Selected Event
  - Select Event (to Playback Charts)
- Drill down on Time Window
  - Expand Slider on Frequency Chart
- Filter by PMU
  - Toggle Radio Buttons on Phase Angle Chart

Leaf-level boxes in cognitive task analysis chart above are associated with user “actions” in WASA system.
Capability 1 – Search events

GIS Map View and Search Panel in WASA system
Capability 1 – Playback charts for a complex event

Ground truth: *loss of load* followed by *over-frequency*
Capability 1 – Adjust focus of attention

Slider window can be adjusted to shift focus of attend on increase in frequency (top) and sharp fluctuation in phase angle (bottom).
Capability 1 – Toggle PMU measurements to isolate behaviors
Capability 2 – High-level summarization of grid events

- Filter events
- What are low probability events during the year?
Capability 3 – Real-time prediction for geomagnetic disturbances (GMDs)

- Utilities primarily rely on forecasted / actual values of magnetic activity (indices) but do not couple with grid activity automatically
- We bring in new data sources and correlate with PMU data, *relaxing the constraints of strict time alignment*
**Capability 3 – Example model: correlating geomagnetic/electric and grid behaviors**

_Hypothesis:_ Geomagnetic/geoelectric field data are good predictors of GMD-related harmonics activity on the grid and can be used to alert operators in advance of large-scale events.
We find that $E_y$ is a good predictor of grid activity during a GMD.
Take-aways …

- PMUs provide operators data, but they do not provide operators knowledge
- Knowledge of the past (post-event analysis), present and future (real-time early warnings) enables better decision making
- In addition, we are using machine learning techniques to find richer relationships/patterns across multiple data sources (space weather) for robust GMD prediction
References


PMU References


