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

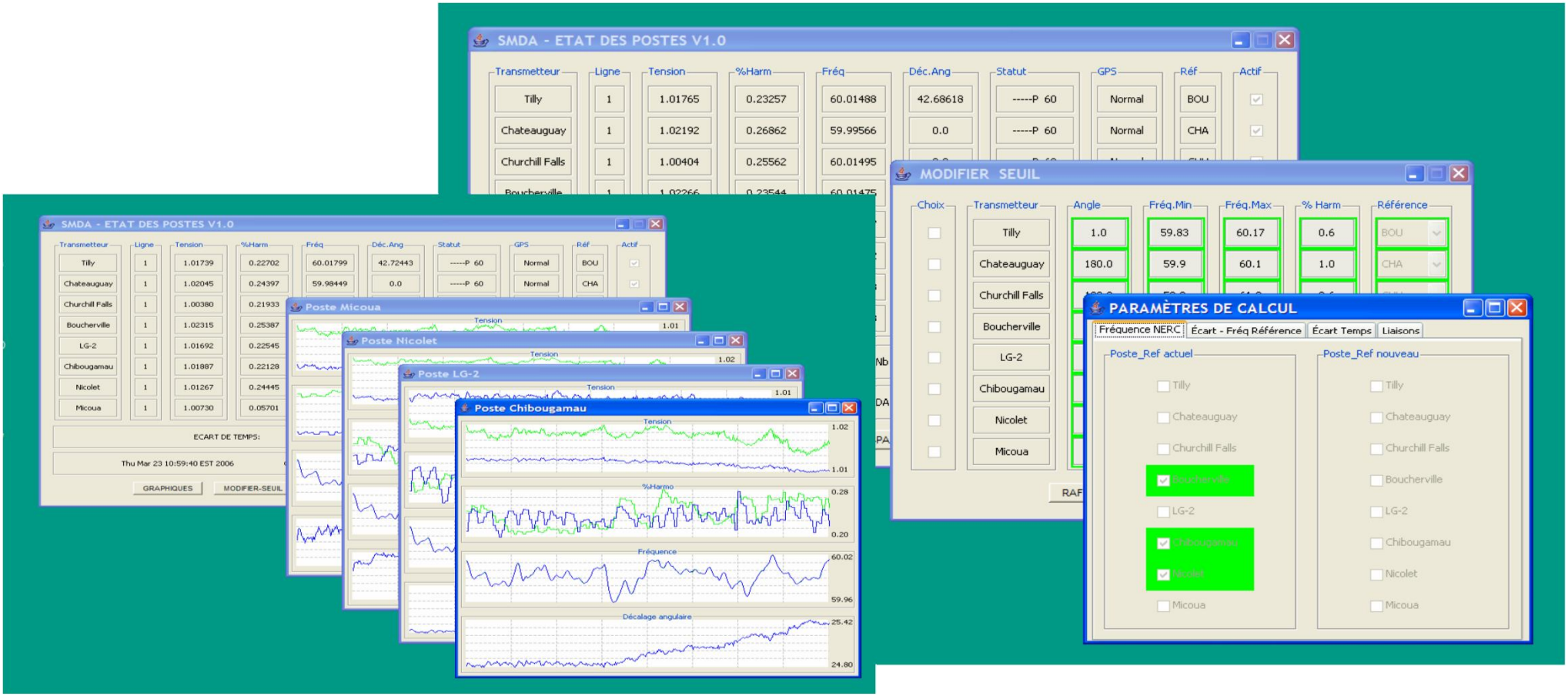
- **Since 2012, Hydro-Québec and IBM Research have been collaborating on *in situ* network of synchrophasors (WASA)**
- **But first, let's review how it all began with SMDA**
  - HQ was the pioneer in angle shift measurement system (wide-area measurements)

Hydro-Québec leadership in PMU space (1976-2004)

Year (version)	Synchronizing Signal (Accuracy)	# of PMUs	Rate (Hz)	Data concentrator features
1976 (0.0)	LC (46 μs) – 1 degree electrical angle	2	1	Custom database
1981 (3.0)	GEOS	3	30	4000 records possible
1988 (4.0)	IRIG-B (20 μs)	4	60	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
1991 (4.0)	IRIG-B (20 μs)	8	60	4 more PMUs
1995 (4.0)	IRIG-B (20 μs)	8	60	Computation of bus voltage harmonic content up to the 10th
1998 (4.1)	IRIG-B (20 μs)	8	60	Continuous record up to 6 months
2004 (5.0)	**GPS (1 μs)**	**8 (10 in 2008)**	**60**	**Change from IREQ-made PMU to Macrodyne commercial PMU. Change from Raima to ORACLE database.**

Table from: I. Kamwa, J. Beland, G. Trudel, R. Grondin, C. Lafond, and D. McNabb. "Wide-area Monitoring and Control: Past, Present, and Future," in *Proceedings of the IEEE Power & Energy Society General Meeting*, Montreal, Quebec, July, 2006.

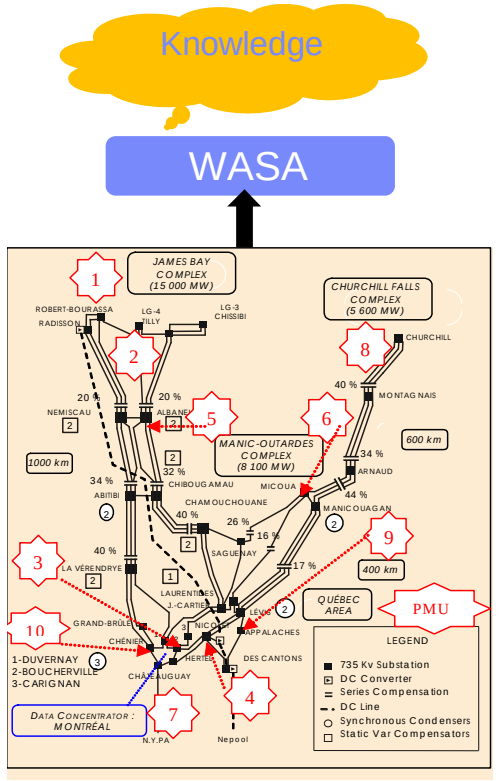
SMDA (version 5.0)



Acquisition Unit Administration and Monitoring

WASA system installed at IREQ

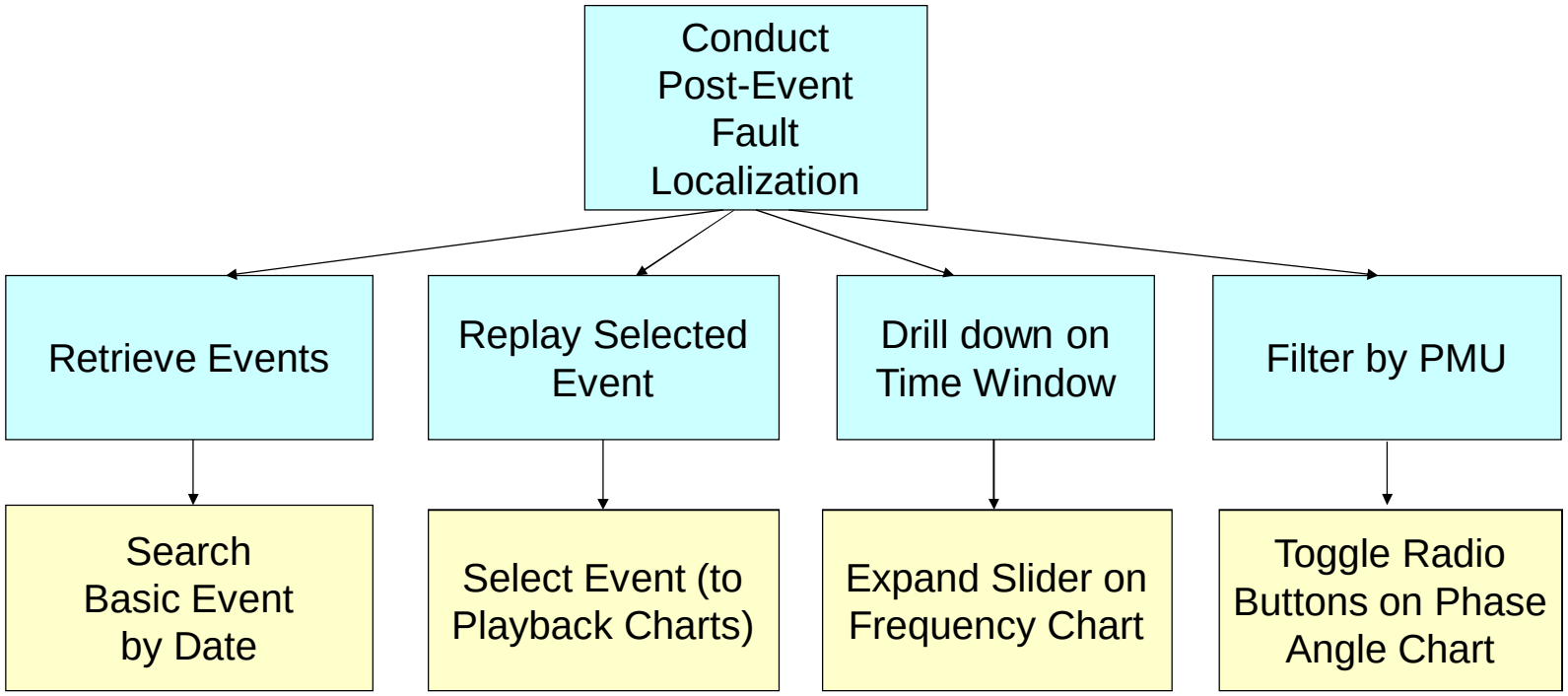
- **We envision WASA system to be the future SMDA**
- **Advanced data concentrator features**
  - High-throughput, low-latency data acquisition using stream computing platform
  - Real-time event detection
  - Tools for visual analytics
  - Real-time correlation analysis and early warning
- **Integrated 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

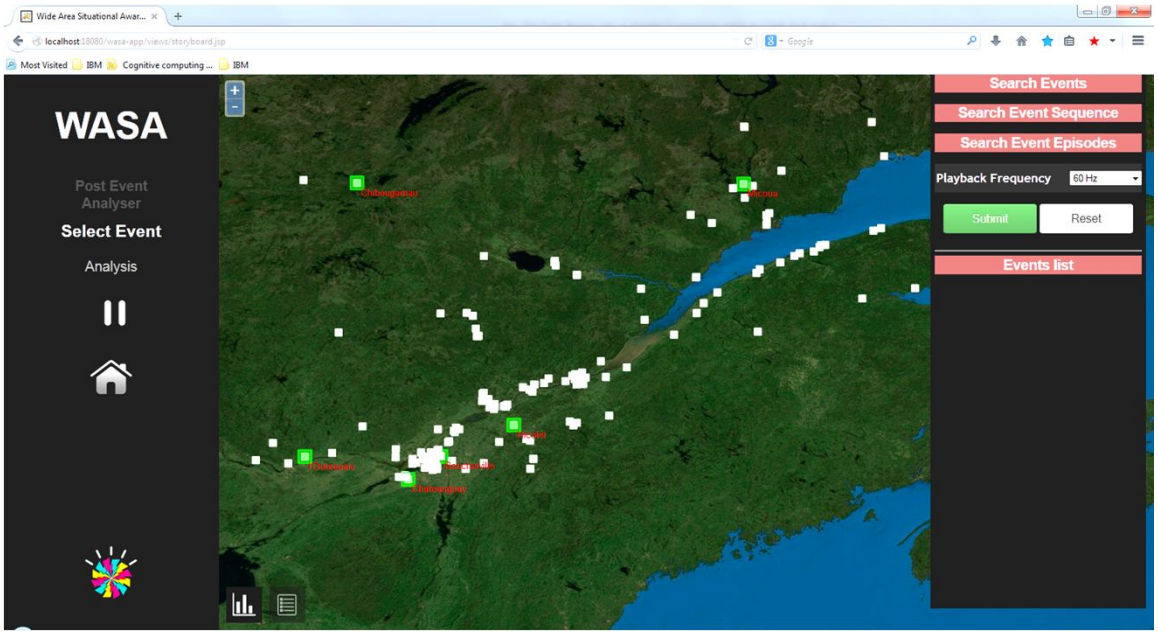
1. **Localize fault for a complex event by drilling down on PMU data**
2. **High-level summarization of grid data**
3. **Generate early warnings for geomagnetic disturbances (GMDs)**

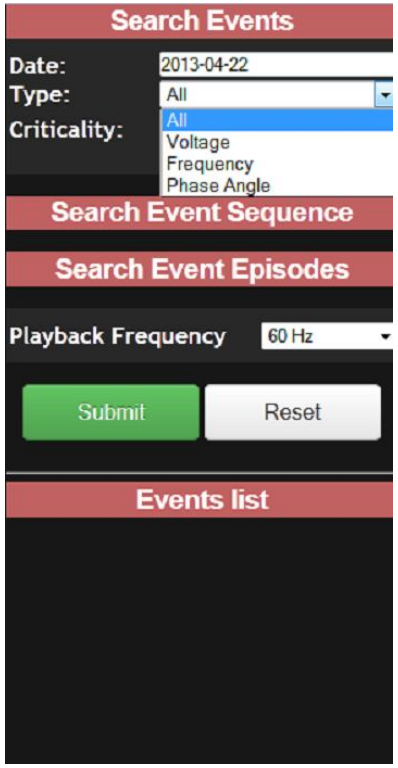
Capability 1 – Post-event fault localization in the control room

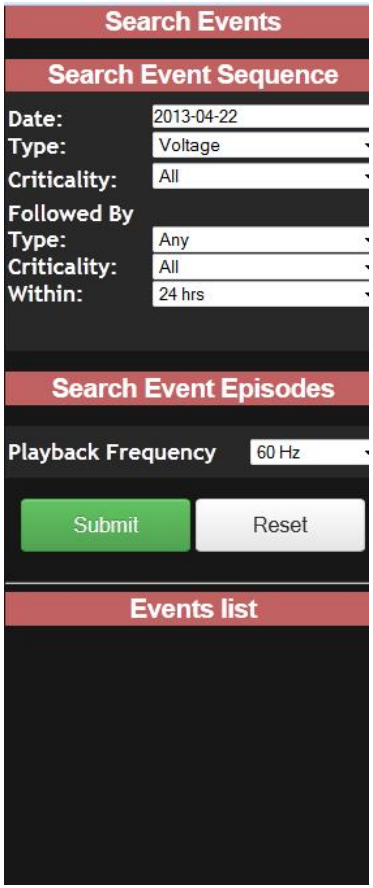


Leaf-level boxes in cognitive task analysis chart above are associated with user "actions" in WASA system.

Capability 1 – Search events

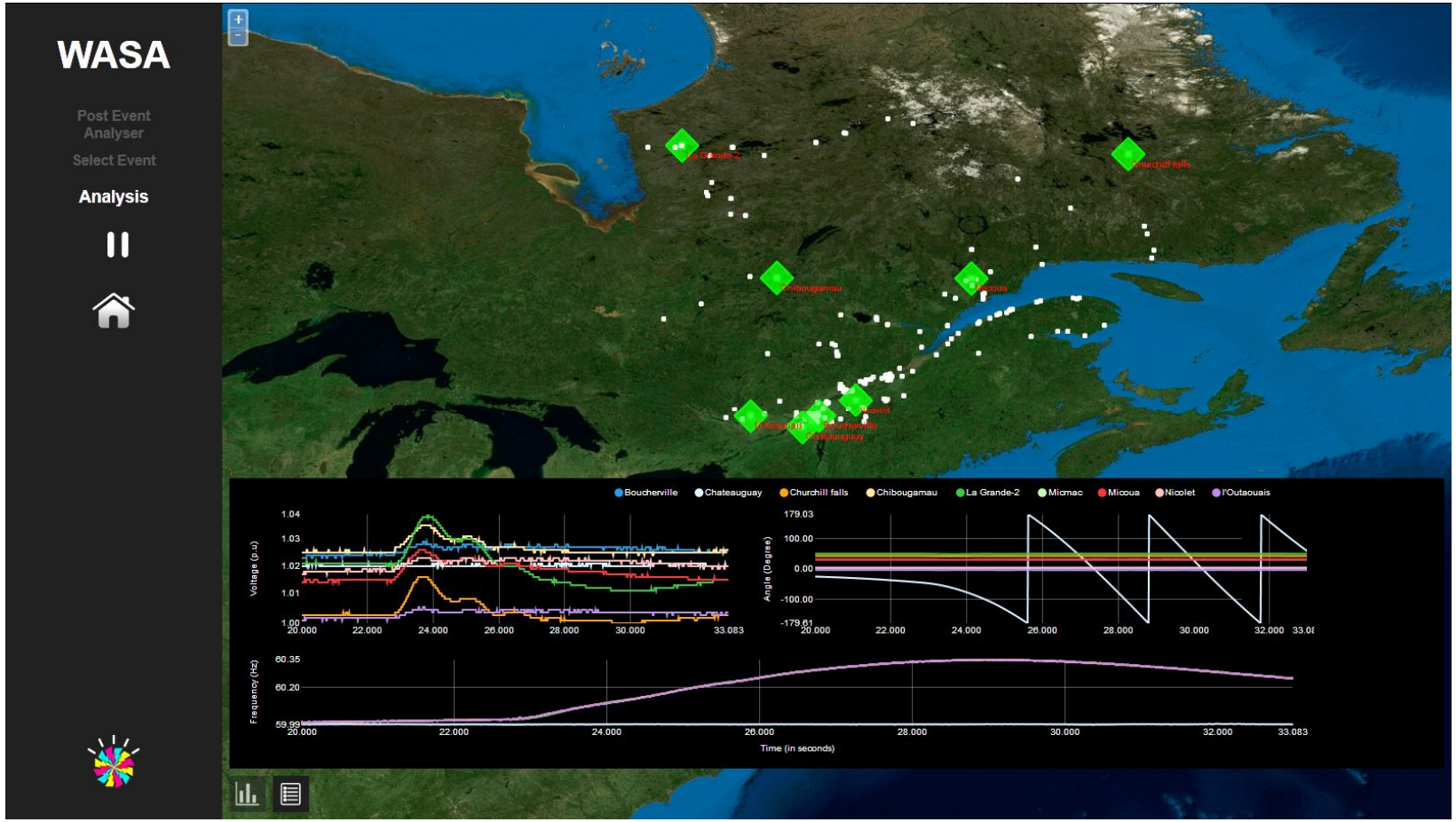






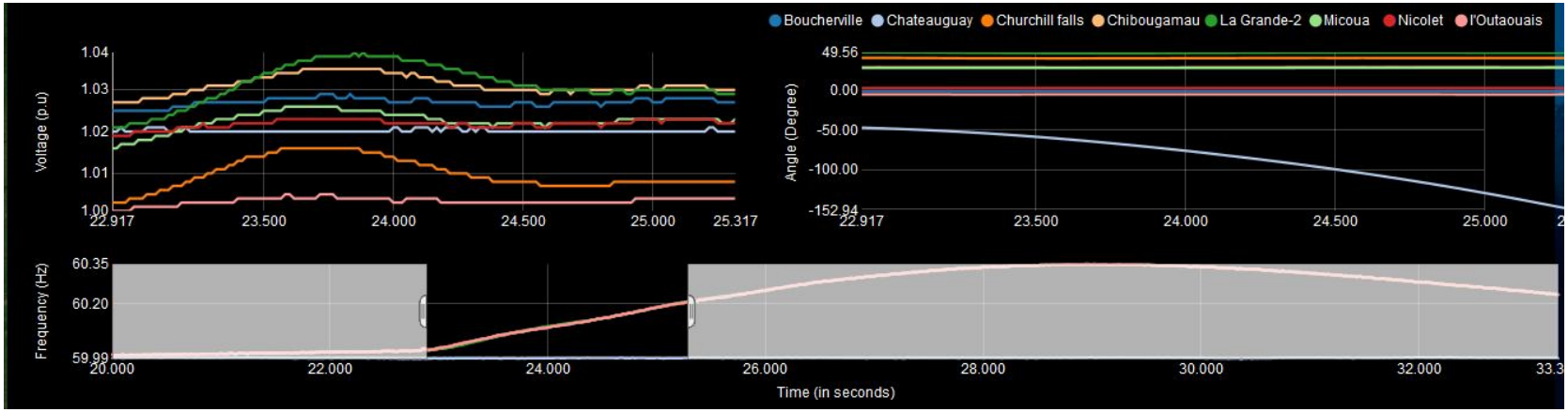
GIS Map View and Search Panel in WASA system

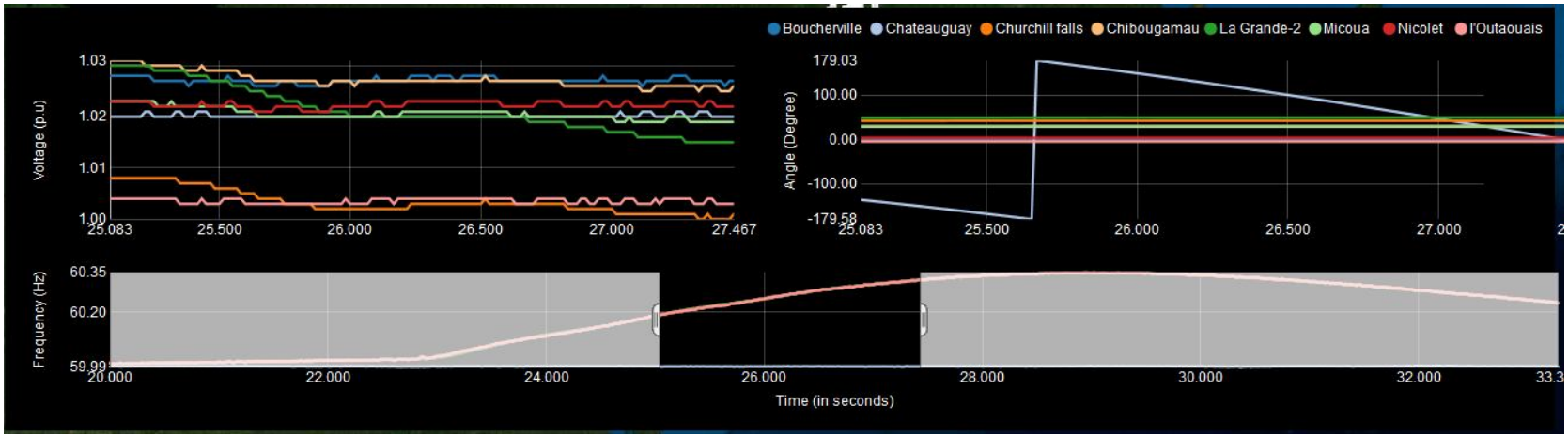
Capability 1 – Playback charts for a complex event



Ground truth: *loss of load* followed by *over-frequency*

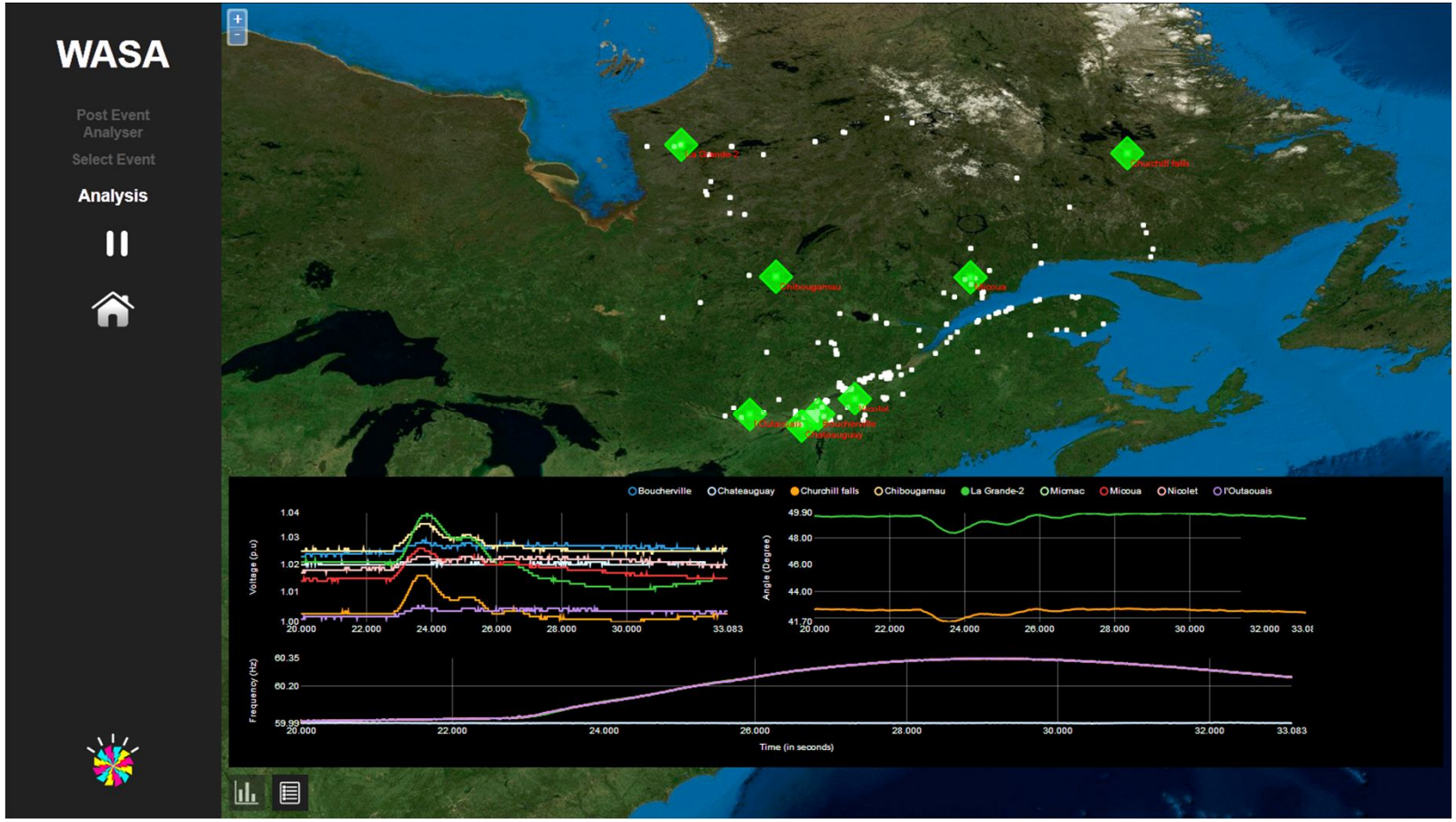
Capability 1 – Adjust focus of attention



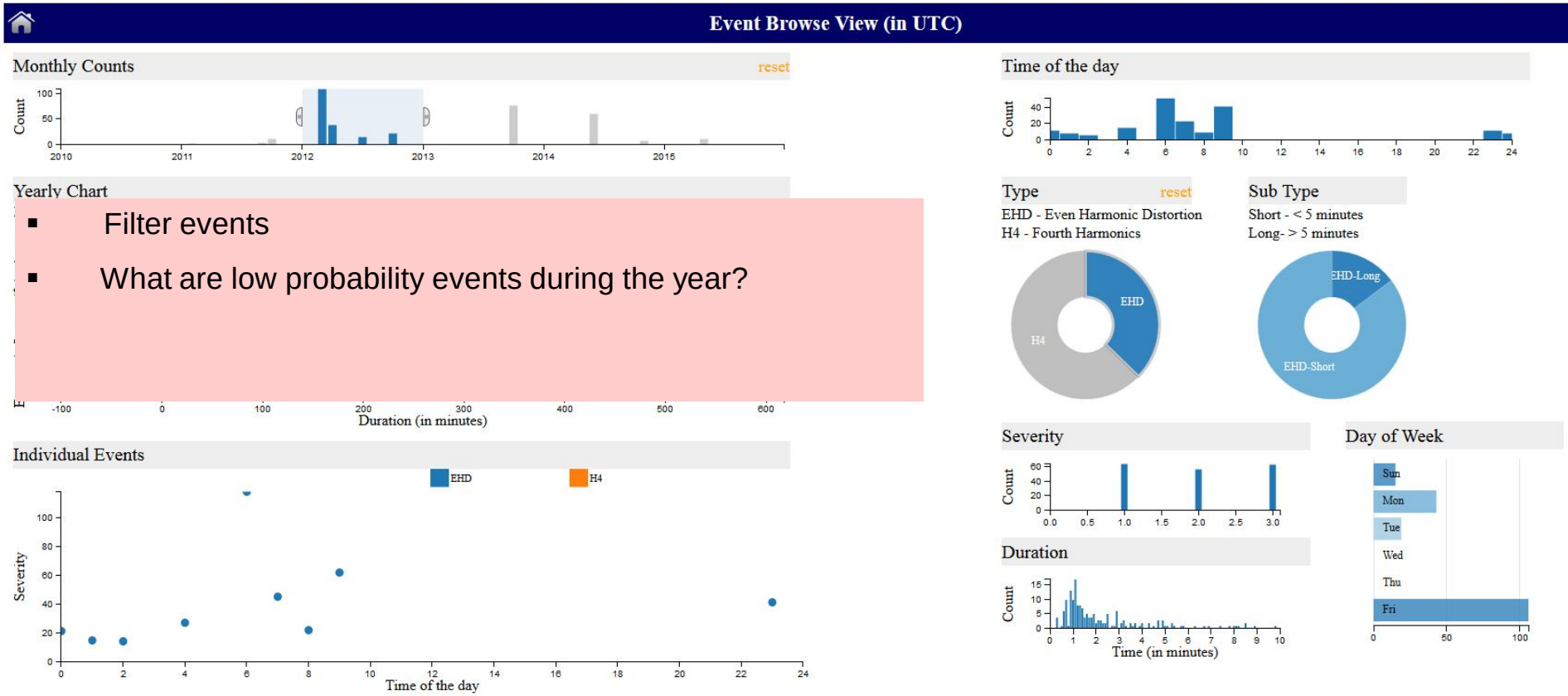


Slider window can be adjusted to shift focus of attend on increase in frequency (top) and sharp fluctuation in phase angle (bottom).

Capability 1 – Toggle PMU measurements to isolate behaviors



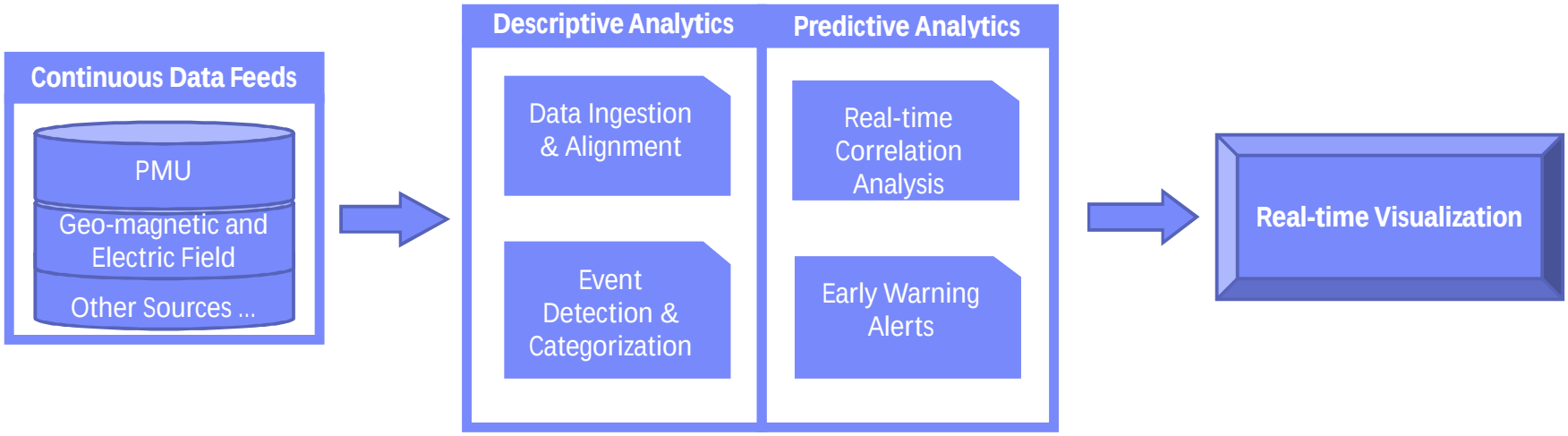
Capability 2 – High-level summarization of grid events



- Filter events
- What are low probability events during the year?

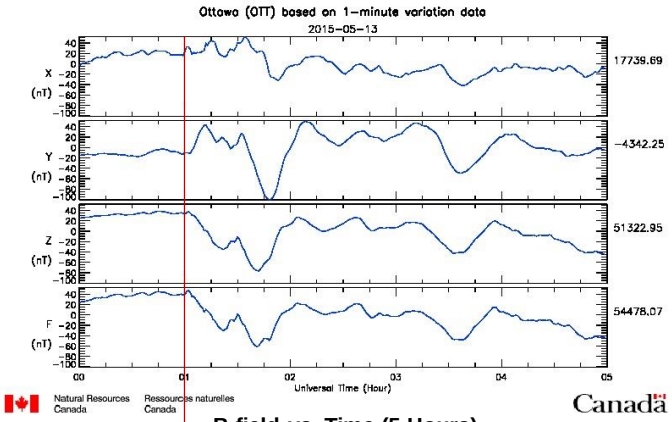
Capability 3 – Real-time prediction for geomagnetic disturbances (GMDs)

- 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*

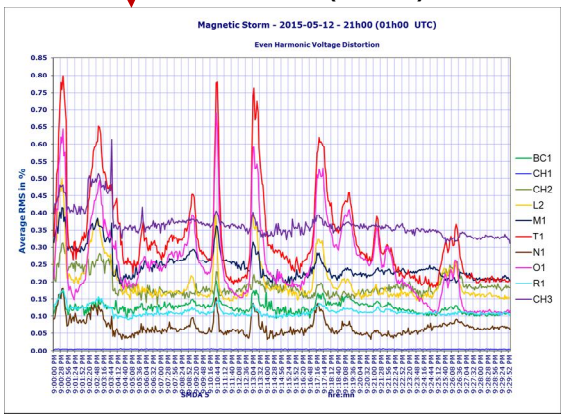


Capability 3 – Example model: correlating geomagnetic/electric and grid behaviors

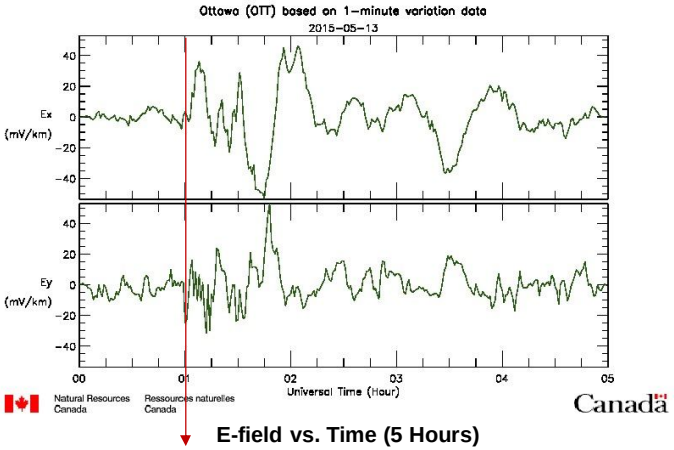
Hypothesis: Geomagnetic/geoelectric field data are good predictors of GMD-related harmonics activity on the grid and can be used to alert operators in advance of large-scale events



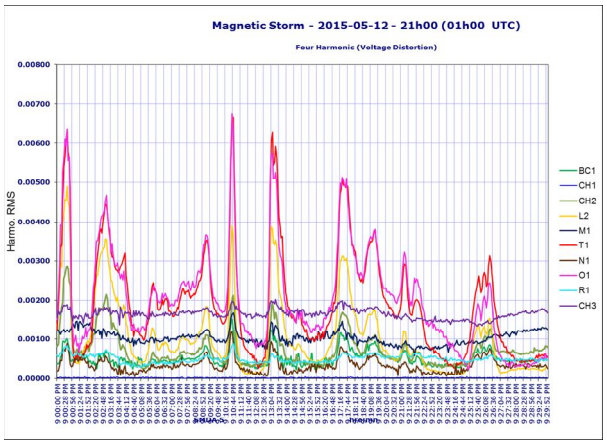
B-field vs. Time (5 Hours)



Even Harmonics vs. Time (30 mins)

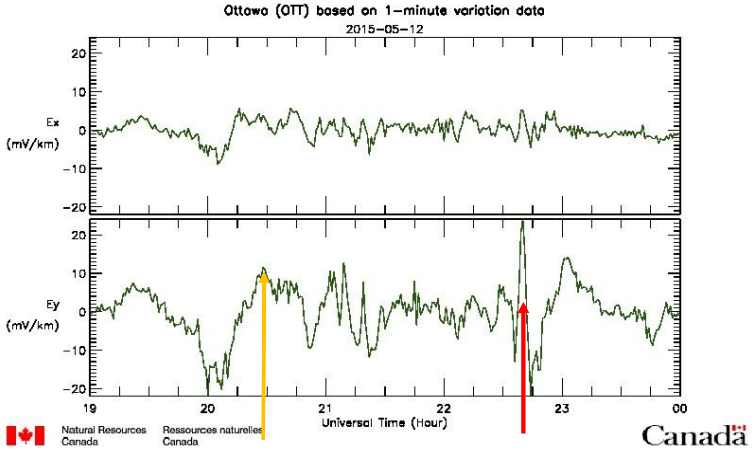


E-field vs. Time (5 Hours)

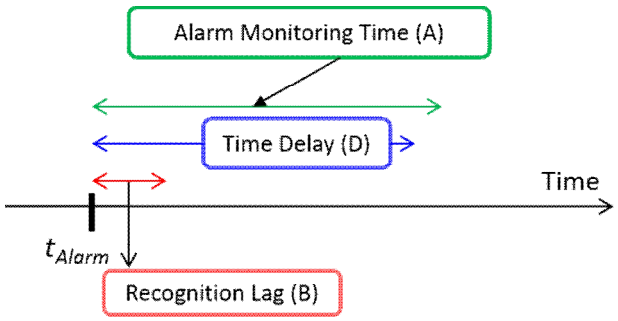


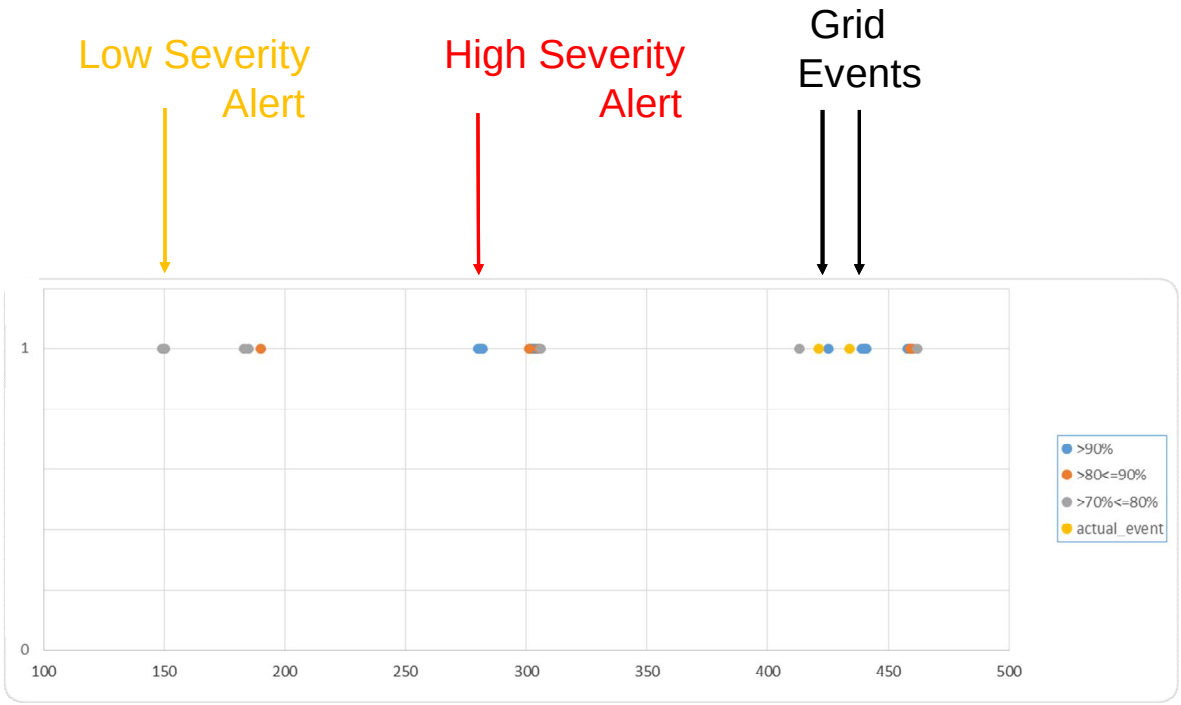
Fourth Harmonics vs. Time (30 mins)

Capability 3 – Example model: using predictions to enable mitigating actions (cont.)



Ey during Low & High Severity Alerts





We find that Ey 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

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