PMU ANALYTICS

Big Data Analytics Platforms Architecture Requirements and Analysis Techniques

Tom Anderson – Principal Systems Engineer, SAS

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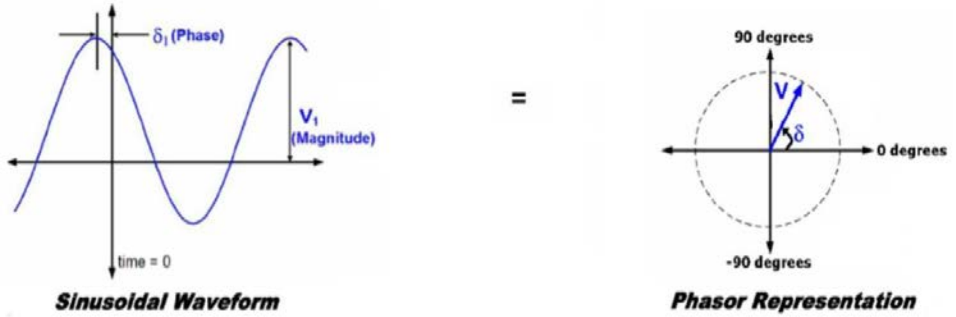
Challenges of Phasor Data

- Phasor Measurement Unit, aka Synchrophasor
- Measures A, B and C phase currents and voltages and uses a recursive algorithm to calculate the symmetrical components via the Discrete Fourier Transform
- Records 30-120 samples per second (SCADA typically samples once every 2-4 seconds)
- Provides local phase angle and frequency measurement (SCADA measures magnitude and estimates phase angle)
- Time synchronization of PMUs via GPS aligns phase angles to a common time reference allowing for observability across a wide area

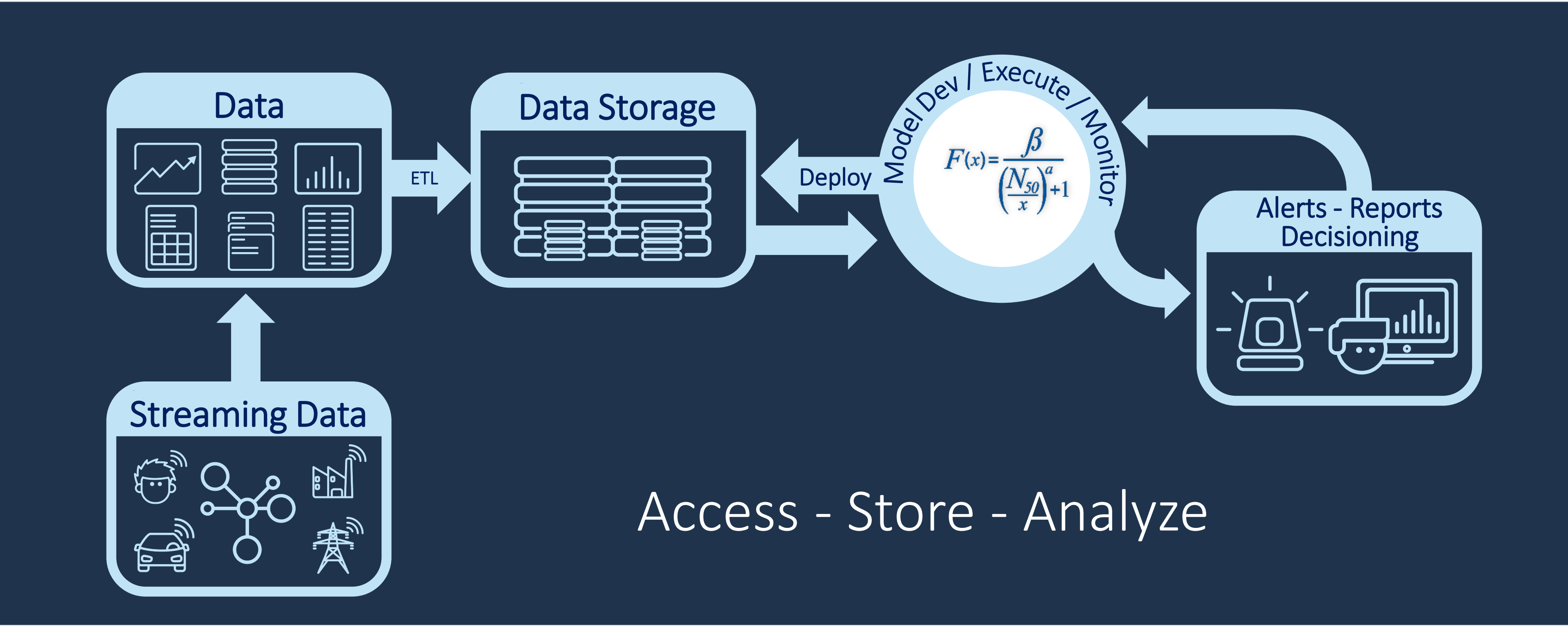


Challenges of Phasor Data

Streaming Data
- High speed, real-time
- Continuous analysis
- Specific historical context

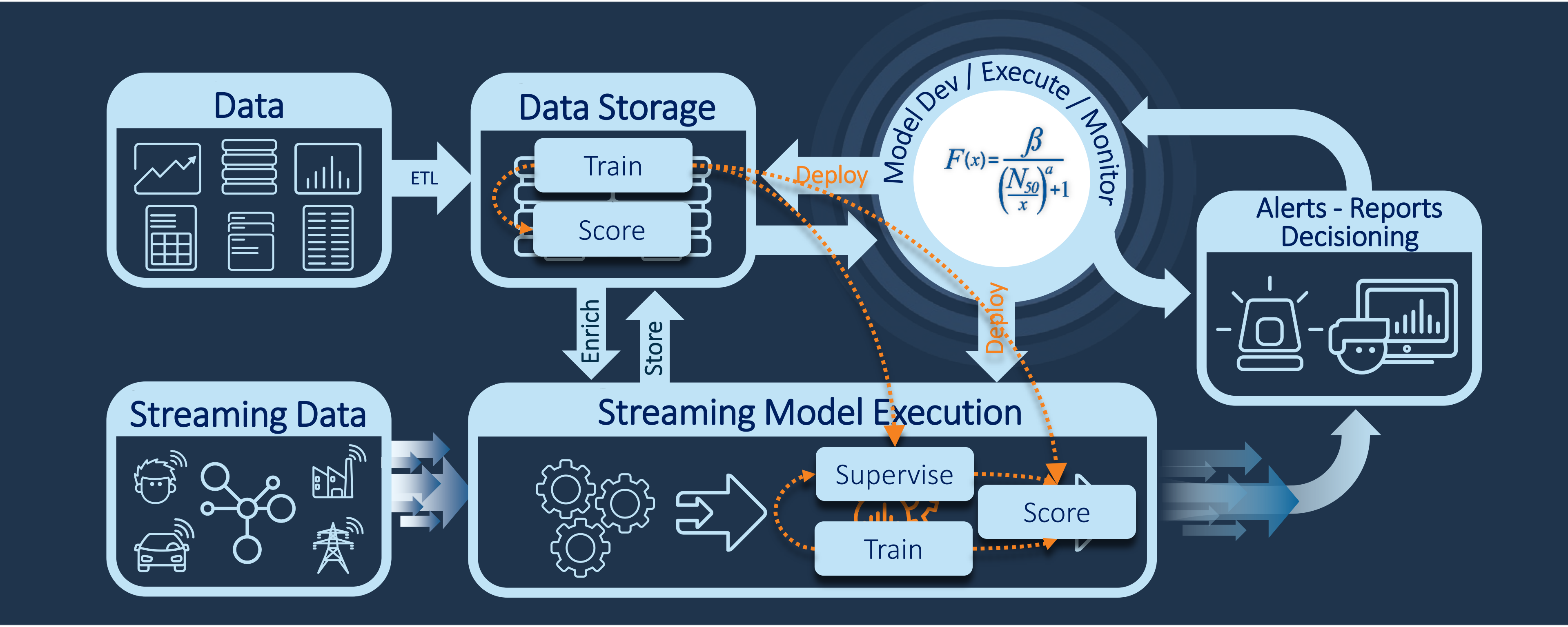
Big Data
- Large volume
- On-demand analysis
- Full historical context

Traditional Approach to Data Analysis

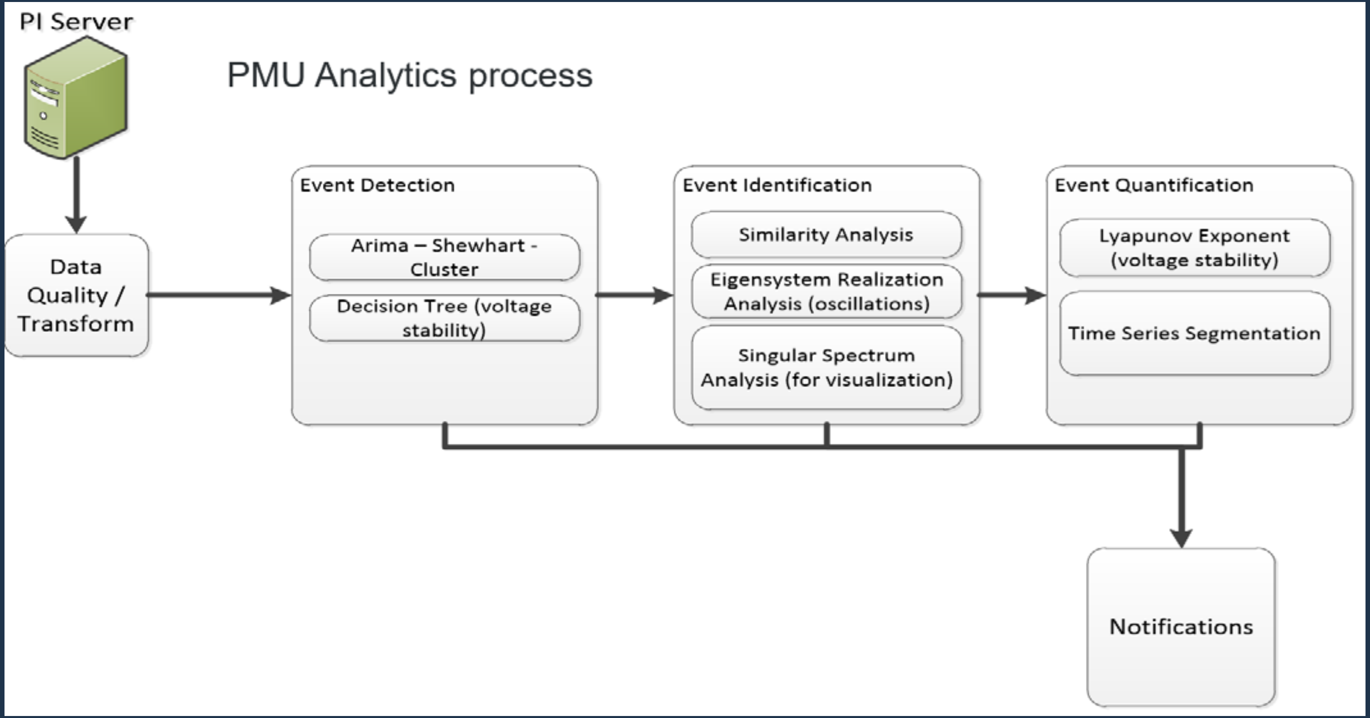


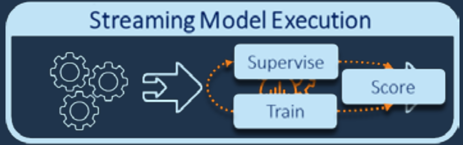
SAS® Approach to Data Analysis

Stream – Understand – Act



Analytics In PMU Time





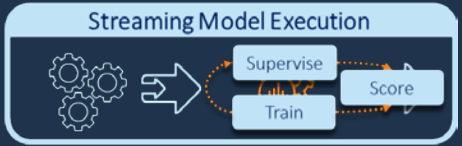
- Data Quality
- Event Detection
- Event Identification
- Event Quantification

Analytics In PMU Time

Data Quality

Data Preparation and Quality

- Working with PI System compressed data
- Use uncompressed tag (Frequency) to detect missing time periods
- **Difference between missing data and bad data**
- **Monitor status tag**. Status may be updated at multiple points in the data chain (At the PMU, at the data collector, in the PI System)
  - Sometimes status in the measurement field
- **Cross check values for consistency**
  - Freq = 0, Angle = 45 (loss of GPS signal)
  - Some PMUs were configured differently (Freq tag), this was corrected
  - Missing measurement during phase angle “wrap” – do not interpolate
- Calculate phase angle differences between PMU pairs
- Automate data preparations and analytics



- ➢ **Data Quality**
- ➢ Event Detection
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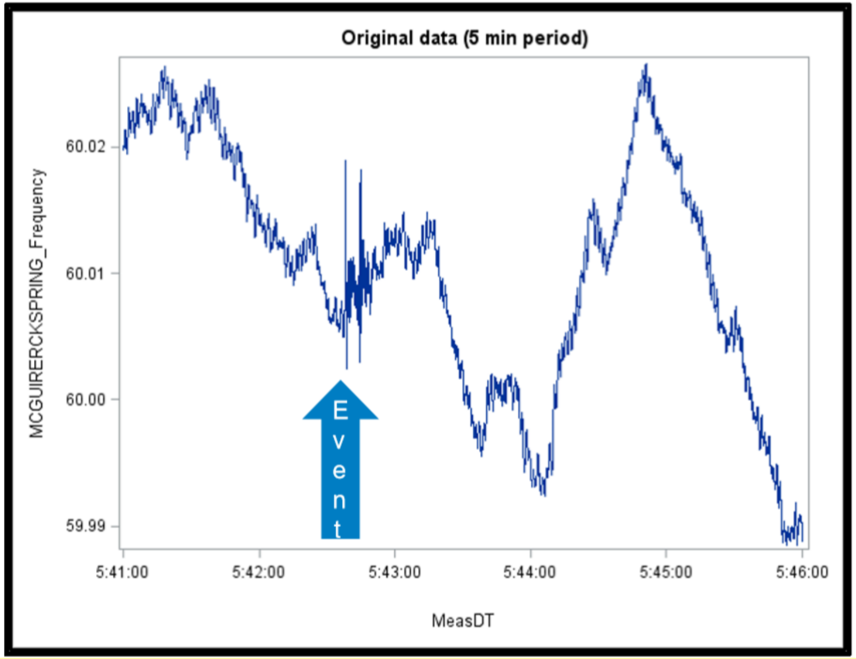
Analytics In PMU Time

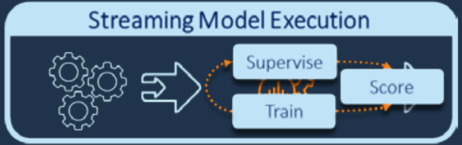
Event Detection

Event Detection

Problem: how to detect events that occur within specs

- Frequency varies within engineering specifications
- Events occur, but are still within specification





- Data Quality
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Analytics In PMU Time

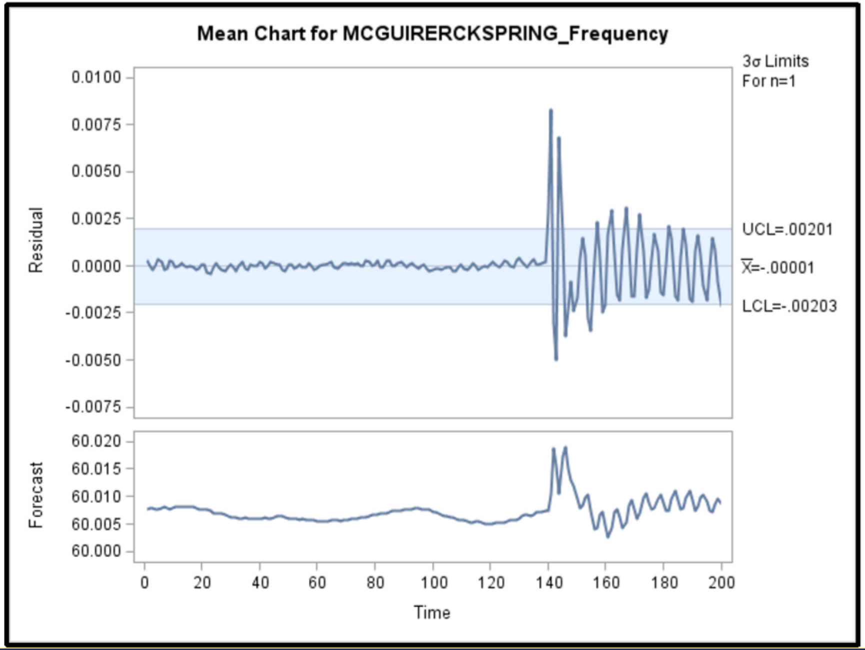
Event Detection

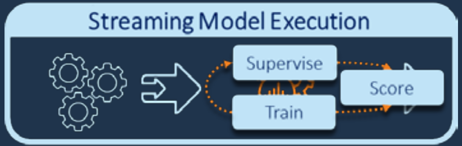
Event Detection

Solution: Forecast expected values and detect deviations

Residual – difference from expected value

Expected value based on times series model





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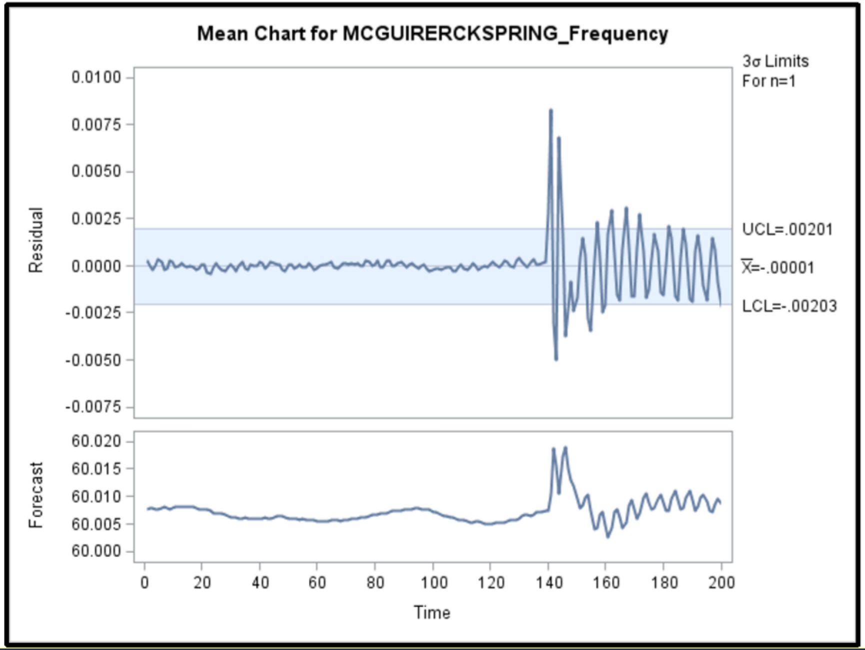

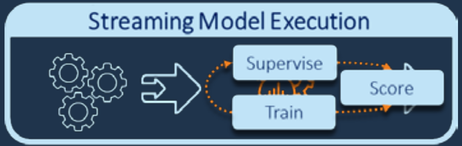

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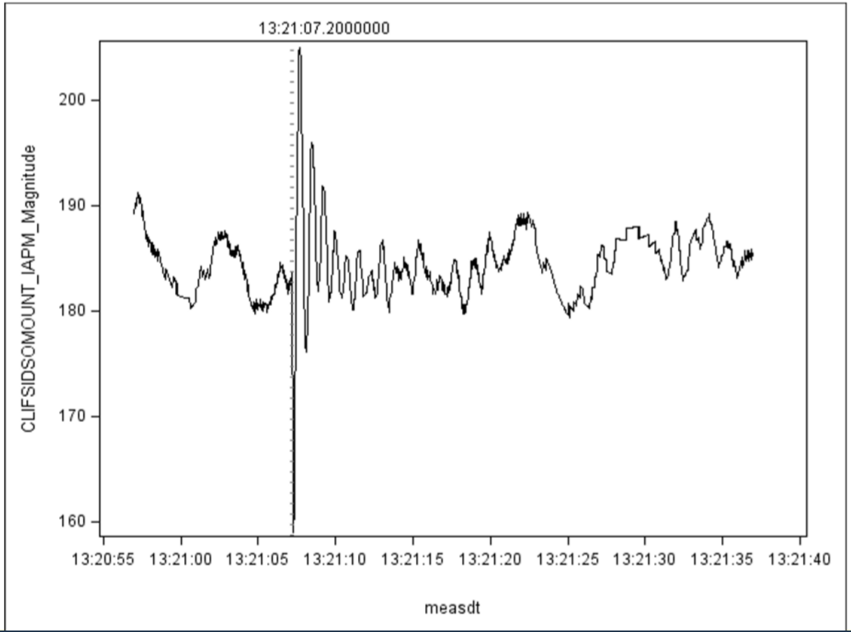
Analytics In PMU Time

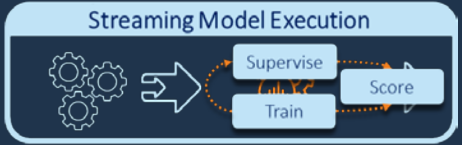
Event Identification

Event Identification

Problem: How to take incoming events and categorize them

- Current oscillates after event, but then dampens down to normal





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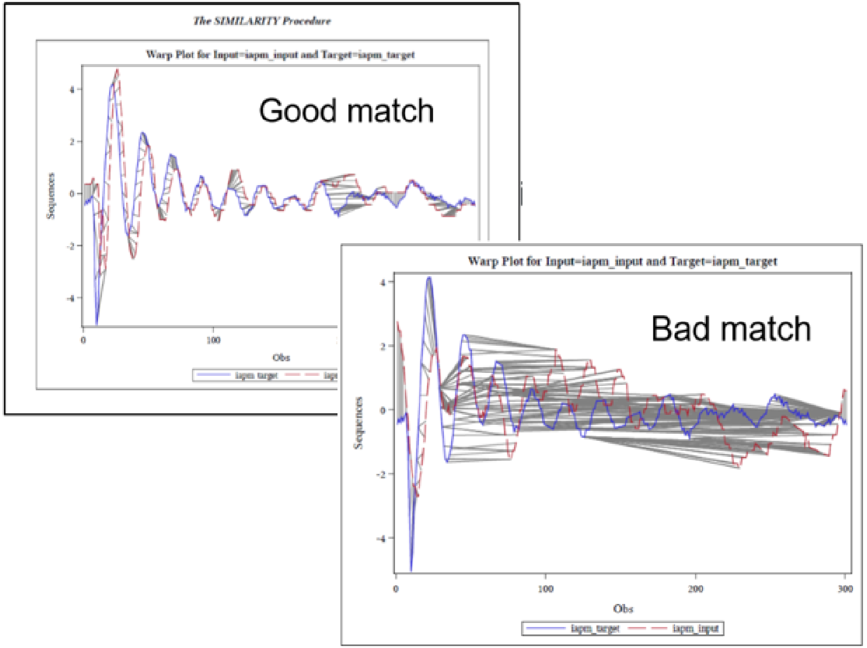
Analytics In PMU Time

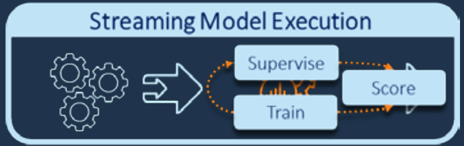
Event Identification

Event Identification

Solution: Use similarity analysis and time-series data mining to categorize data streams

- Similarity between incoming stream and reference time series are measured and quantified





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Analytics In PMU Time

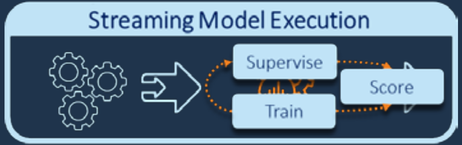
Event Quantification

Problem: How to predict events which are rare

- situations that are vulnerable to voltage collapse

Solution: Learning loop system using simulation data to create predictive models

- Use PSS/E simulation software to generate cases for voltage stability
- Build decision tree and use Lyapunov Exponent to identify vulnerable situations



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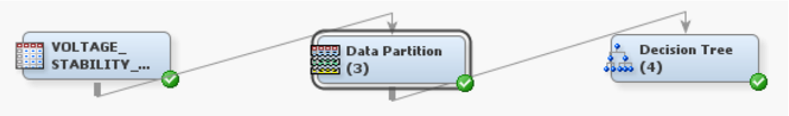
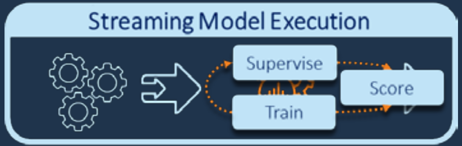
Analytics In PMU Time

Event Quantification

Decision Tree

- Decision Tree
  - Data mining technique that uses large set of data with a desired object of analysis (target) and creates rules from the data that has the highest prediction of the target value
  - Benefits - simple to use and understand, robust to different data types and quality issues
- Using the Decision Tree to Predict Voltage Collapse
  - PSSE – Simulations
    - Ran 3,128 dynamic simulations of a generation loss event using different combinations of load and operating conditions
    - Collected voltage and power data from system PMU locations
    - Classified each simulation as either Voltage Stable or Voltage Collapse
  - SAS Enterprise Miner – Decision Tree Builder
    - Input snapshot of simulated PMU data prior to generation loss event and the simulation classification
    - Builder partitions data for tree creation, validation and testing
    - Builder finds a given number (4 in this case) of the highest predictors
    - Builder tests the results with the data partitioned for testing





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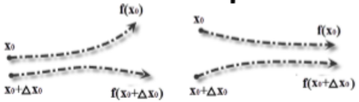
Analytics In PMU Time

Event Quantification

Lyapunov Exponent

- Characterizes the rate of convergence or divergence of non-linear dynamical systems.
- For stable/unstable systems the Lyapunov Exponent will be negative/positive
- General Equation

$$d(f^n(x_0), f^n(x_0 + \Delta x_0)) = e^{\lambda n} d(x_0, x_0 + \Delta x_0)$$



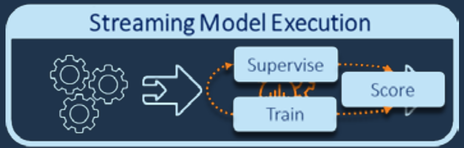
$$\lambda = \frac{1}{n} ln \left[\frac{d(f^n(x_0), f^n(x_0 + \Delta x_0))}{\Delta x_0} \right]$$

[reference 1]

- Time Series Calculation

$$\frac{1}{Nk\Delta t} \times \sum_{m=1}^{N} \log_{10} \frac{|v^i_{(k+m)\Delta t} - v^i_{(k+m-1)\Delta t}|}{|v^i_{m\Delta t} - v^i_{(m-1)\Delta t}|}, k > N$$

[reference 2]



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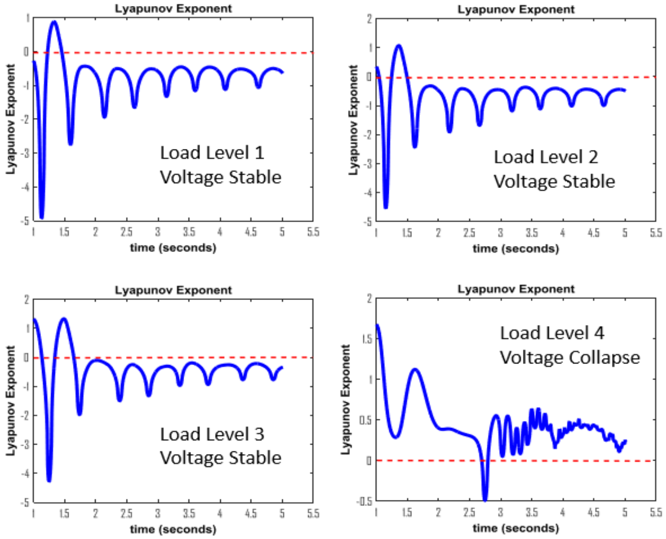
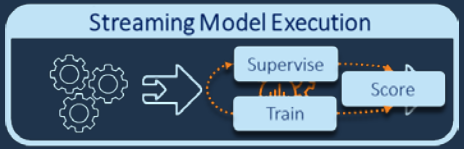
Analytics In PMU Time

Event Quantification

Lyapunov Exponent
500 kV Line Trip



- LE data for 4 cases with the same operating conditions but different voltage sensitive area loads over a window of 5 seconds for a 500 kV Line Trip Event
- For the 3 Voltage Stable cases the final value of the LE is negative and the margin between zero (red dashed line) and LE (blue) decreases as load in voltage sensitive area increases
- For the Voltage Collapse case the final value of the LE is positive



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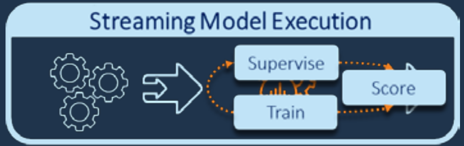
Analytics In PMU Time

Event Quantification

Future Work

- Event Classification:
  - Develop a library of event signatures from PMU data to compare to incoming PMU data.
- Decision Tree:
  - Scan PMU data in real time for current prediction of voltage collapse decision tree rules.
  - Build Decision Tree for more common events and test the results on PMU data in real-time.
  - Create several prediction of voltage collapse decision trees, one for each contingency, and apply the results to PMU data in real-time.
- Lyapunov Exponent:
  - See if there is a faster way to determine the final sign of the LE and take control actions locally in time to prevent voltage collapse.



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