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Power System Data Management and Analysis using Synchrophasor Data

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Electricity and society. Grid as aged well - still operates daily and paces demand.

Grid has experienced:
- Renewables
- Load congestion, demand for quality electric power
- Threats to cyber security / physical infrastructure

National Energy Technology Laboratory (NETL) identifies key technological areas. Applicable areas:
- improved and accurate sensing and measurement capability
- advanced control methods
- decision support
Synchrophasor Fundamentals

- Synchrophasor ≡ Phasor Measurement Unit (PMU)
- Power system sensors for tracking voltage, current, frequency.
- Values recorded in phasor format: magnitude and angle.
- High fidelity (60Hz) vs SCADA (≈ 5 sec.)
- Synchronized Data via Global Positioning System (GPS) timestamps.
- Phasor Data Concentrator (PDC) - single data logging point containing multiplexed PMU data stream.
BPA provides dataset
- 950 GB of positive sequence voltage data.
- Span: August 2012 - August 2013
- 20 PMUs: various locations inside BPA balancing authority.

Our Goal:
1. Develop multidisciplinary methodology to handle high cardinality data.
2. Begin identifying data vs. power system issues.
3. Construct a fast, reliable database for handling big data issues.
Pearson Correlation

- Pearson Correlation determines how well data is linearly correlated.
- Given two independent input sets of data X and Y of length N, the Pearson correlation yields a correlation coefficient $r$ between -1 and 1 based on the following equation:

$$r = \frac{\sum(XY) - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sum (X^2) - \frac{(\sum X)^2}{N}\right) \times \left(\sum (Y^2) - \frac{(\sum Y)^2}{N}\right)}}$$
Phasor Data Concentrator (PDC) Engine

- Data files 1 – 5 minutes in length
- Understanding the data:
  - File framework
  - Recorded power system attributes
  - Data discretization rate
  - Topological layout of the PMUs
- Historical data playback
Data Structure

Queue Structure

Data In (Present Time)

T=1.066  T=1.05  T=1.033  T=1.016

Data Out (Past Time)

Time Structure

'T' = 1.066
'Dictionary (HashTable)' =

'List 1'={PMU1 - PMU2, PMU1 - PMU3, PMU1 - PMU4}

'List 2'={PMU2 - PMU3, PMU2 - PMU4}

'List 3'={PMU3 - PMU4}

Assuming 4 PMUs in Dataset

Correlation Object

'Name' = PMU3 - PMU4
'|V|' = float  'V phase' = float  'r(|V|)' = float
'|V|' = float  'V phase' = float  'r(V phase)' = float
Correlation Algorithm

Time Series Data From Feeder

Old Data

Last Timestep

Current Timestep

New Data

Time Array

Sliding Window 1

Sliding Window 2

Sliding Window 3
Window Size Application

Monrovia Magnitude

Voltage [V p.u.]

Time [s]

600 entries [10 s]

60 entries [1 s]

48 entries [8/10 s]

54 entries [9/10 s]

12 entries [1/10 s]

6 entries [1/10 s]
## Data & Power System Event Identification

<table>
<thead>
<tr>
<th>Data Event</th>
<th>Expected Identifier/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Drop</td>
<td>$V^\dagger$ and/or $\phi^*$ data = 0</td>
</tr>
<tr>
<td>PMU Misread / Communication Error</td>
<td>Identical repeated values</td>
</tr>
<tr>
<td>Loss of GPS Synchronization</td>
<td>$\phi$ drift, PMU units not synced</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power System Event</th>
<th>Expected Identifier/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Flow Contingency</td>
<td>Change in $\frac{d\phi}{dt}$</td>
</tr>
<tr>
<td>Generator/Load Trip</td>
<td>Change in voltage and/or $\frac{d\phi}{dt}$</td>
</tr>
<tr>
<td>Transmission Line Trip</td>
<td>Change in $V$ and/or change in $\phi$</td>
</tr>
<tr>
<td>Power Transformer Tap Change</td>
<td>Change in $V$</td>
</tr>
<tr>
<td>Miscalibration of Transformer</td>
<td>Pending further investigation</td>
</tr>
<tr>
<td>Capacitor/Reactor Switching</td>
<td>Change in $V$ and $\phi$</td>
</tr>
<tr>
<td>Inter &amp; Intra Zone Oscillations</td>
<td>Slow-coherent change in $V$ or $\phi$</td>
</tr>
</tbody>
</table>

$\dagger$ $V$ = Positive sequence bus voltage magnitude  
$^*$ $\phi$ = Positive sequence bus phase angle
Clean Dataset
Lightning Event Dataset
Data Dropout

Monrovia Magnitude

Voltage [V p.u.] vs Time [s]
Data Misread

Monrovia Magnitude

Voltage [V p.u.]

Time [s]

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Prior to Event

**Monrovia Magnitude**

![Graph showing Monrovia Magnitude over time](image)

**Positive Sequence Voltage Mag: Window Length = 600, Time = 7.9833**

![Graph showing positive sequence voltage magnitude](image)
Lightning Event - Window Size: 600 entries
Lightning Event - Window Size: 6 entries
Correlation Algorithm Demo

Demo Page
End Goal and Motivation

- Real-time PMU data analysis machine.
- Automated contingency signature detection.
- Facilitate grid operator ease-of-use.
  - Appealing GUI and visualization methodology.
  - Fast and efficient database back end.
  - Integration of historical event querying.
** GOAL:** Quantify PMU correlation noise levels across varying window lengths.

**PURPOSE:** Further develop specific event identification.

**PROPOSED METHOD:** Statistical analysis of stochasticity in clean PMU data streams over various time durations.
**GOAL:** Optimize accuracy, timing, and amount of information output.

**PURPOSE:** Provide operators with most accurate, efficient, and ample amount of information gathered from the installed PMU sensor network.

**PROPOSED METHOD:** Implement improved correlation, regression, classification, or machine learning algorithms.
**GOAL:** Merging correlation algorithm with the bitmap index

**PURPOSE:** Ability to query correlation values

**PROPOSED METHOD:** Store correlation values in bitmap index
Conclusion

- Recommendations
  - Consistent Formatting of Data
  - Computational Needs
- What we have accomplished
  - Visual tool to identify events
  - Quickly retrieve elements from the database
  - Identify new research directions
THANK YOU

QUESTIONS?