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Power System Data Management and Analysis using Synchrophasor Data

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Introduction

- 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 $\equiv$ 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 ($\approx$ 5 sec.)
- Synchronized Data via Global Positioning System (GPS) timestamps.
- Phasor Data Concentrator (PDC) - single data logging point containing multiplexed PMU data steam.

Project Fundamentals

- 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.

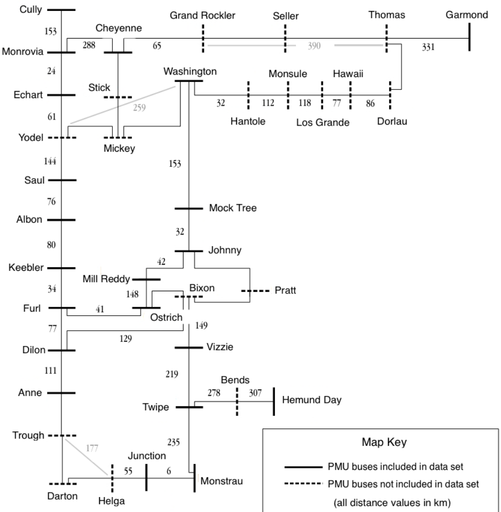
Pearson Correlation

- 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:

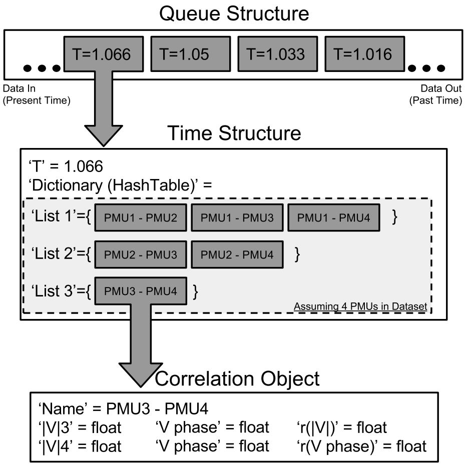
$$r = \frac{\Sigma(XY) - \frac{\Sigma X \Sigma Y}{N}}{\sqrt{(\Sigma(X^2) - \frac{(\Sigma X)^2}{N}) \times (\Sigma(Y^2) - \frac{(\Sigma Y)^2}{N})}}$$

Phasor Data Concentrator (PDC) Engine

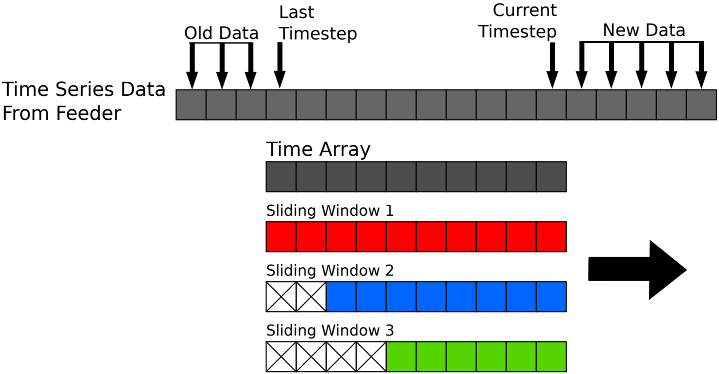
- Phasor Data Concentrator (PDC) Engine
  - Data files 1 – 5 minutes in length
  - Understanding the data:
    - File framework
    - Recorded power system attributes
    - Data discretization rate
    - Topological layout of the PMUs
  - Historical data playback


Cully
153
Monrovia
24
Echart
61
Yodel
144
Saul
76
Albon
80
Keebler
34
Furl
77
Dilon
111
Anne
Trough
177
Darton
Helga
Cheyenne
288
65
Grand Rockler
Seller
390
Thomas
331
Garmond
Stick
259
Mickey
Washington
32
Hantole
112
Monsule
118
Los Grande
77
Hawaii
86
Dorlau
153
Mock Tree
32
Johnny
42
Mill Reddy
148
Bixon
Pratt
41
Ostrich
149
129
Vizzie
219
Bends
278
307
Hemund Day
Twipe
235
Junction
55
6
Monstrau
Map Key
PMU buses included in data set
PMU buses not included in data set
(all distance values in km)

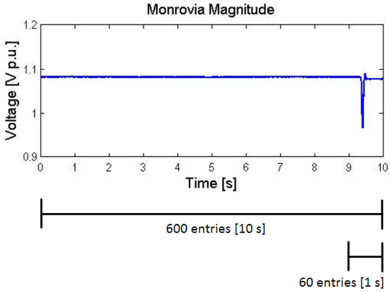
Data Structure

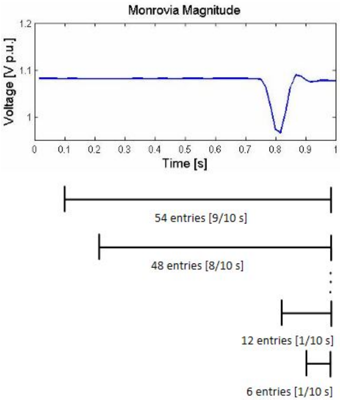


Correlation Algorithm



Window Size Application



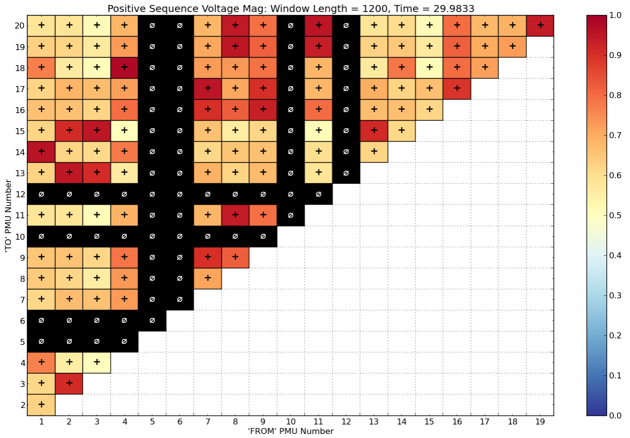


Data & Power System Event Identification

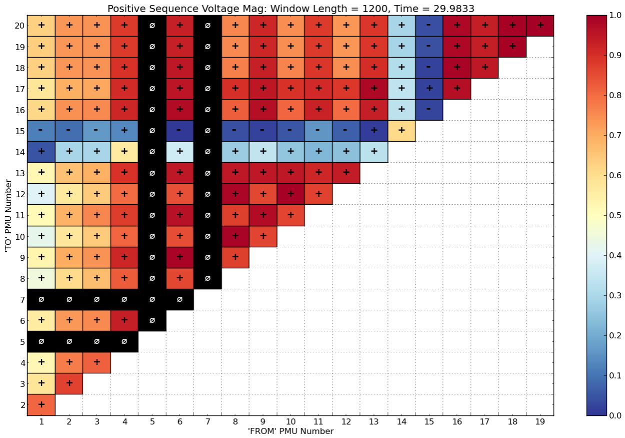
Data Event	**Expected Identifier/Description**
Data Drop	V† and/or ϕ^* data $= 0$
PMU Misread / Communication Error	Identical repeated values
Loss of GPS Synchronization	ϕ drift, PMU units not synced
Power System Event	**Expected Identifier/Description**
Power Flow Contingency	Change in $\frac{d\phi}{dt}$
Generator/Load Trip	Change in voltage and/or $\frac{d\phi}{dt}$
Transmission Line Trip	Change in V and/or change in ϕ
Power Transformer Tap Change	Change in V
Miscalibration of Transformer	Pending further investigation
Capacitor/Reactor Switching	Change in V and ϕ
Inter & Intra Zone Oscillations	Slow-coherent change in V or ϕ

† V = Positive sequence bus voltage magnitude
* ϕ = Positive sequence bus phase angle

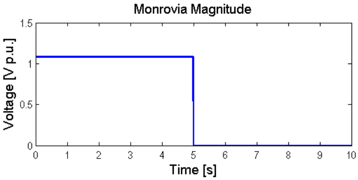
Clean Dataset

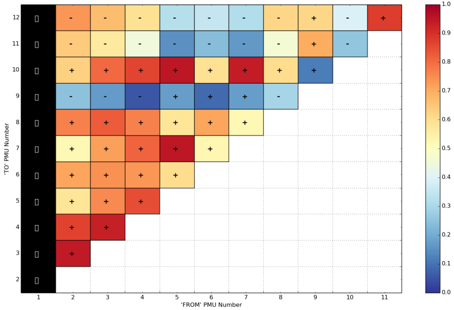


Lightning Event Dataset

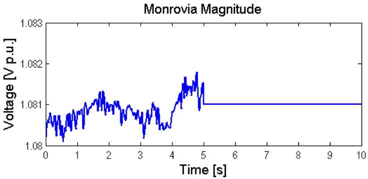


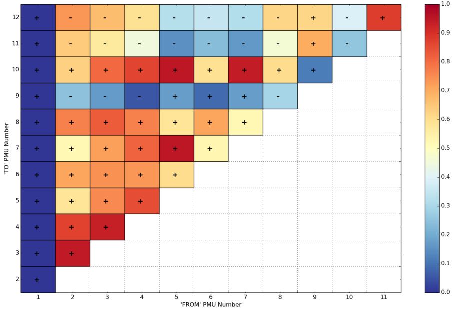
Data Dropout



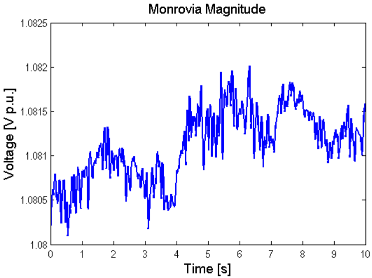


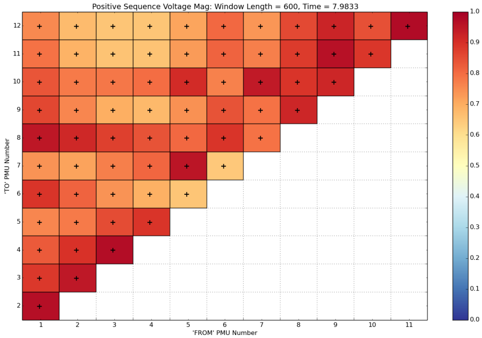
Data Misread

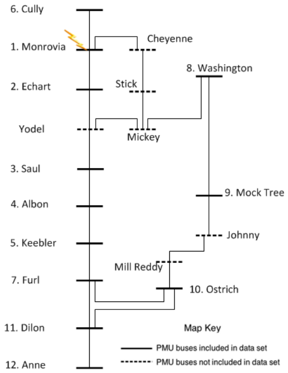




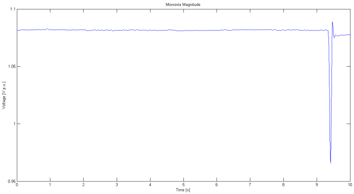
Prior to Event

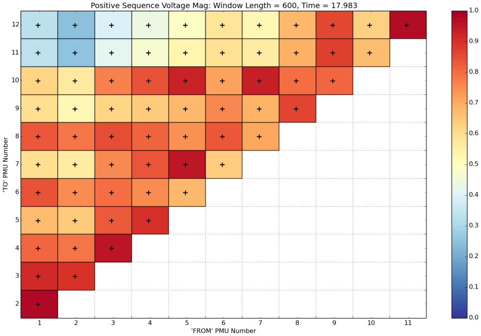




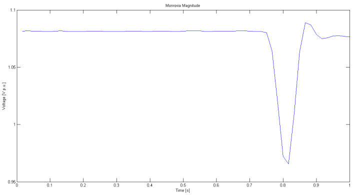

6. Cully
1. Monrovia
Cheyenne
8. Washington
2. Echart
Stick
Yodel
Mickey
3. Saul
9. Mock Tree
4. Albon
Johnny
5. Keebler
Mill Reddy
7. Furl
10. Ostrich
11. Dilon
Map Key
PMU buses included in data set
PMU buses not included in data set
12. Anne

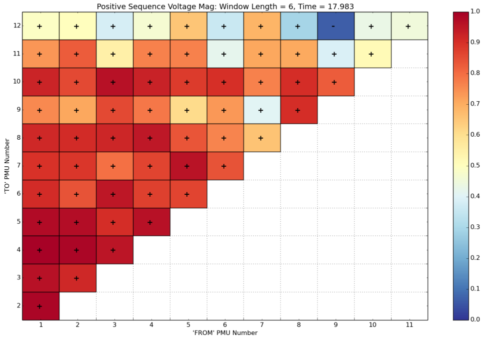
Lightning Event - Window Size: 600 entries





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.

Correlation Noise Qualification

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.

Improved Pattern Recognition

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.

Coupling of Correlation Algorithm & Bitmap Index

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?