DOE/OE Transmission Reliability Program

Baselining Studies and Analysis

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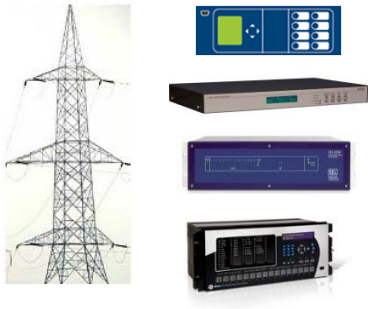
“Big Picture” Objective



Power grid related data (PMUs, State Estimators, Load, etc)

Analytical Tool that provides:

- **Real time analytics, monitoring the state of the grid**
- **Capability to look at historical trends and events**
- **Reliable predictions about the forthcoming state of the grid**

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Project Objectives

- **Investigate power grid data**
  - **Eastern Interconnect (EI) Project**
    - 1 year of state estimator data
    - 2 months of PMU data (down-sampled to 1 sec)
  - **BPA Project**
    - 20 months of PMU data (60 samples per second)
- **Identify atypical events** and characterize **typical patterns**.
- **Frequently meet with EI TAG** (Technical Advisory Group) and **BPA domain experts** to review results and iterate the methodology.

Eastern Interconnect
Major Technical Accomplishments during the Past Year

- **Met quarterly with EI TAG** to discuss Baselining methodology and results.
- Determined a mathematical / automated method to **select phase angle pairs**.
- Ran **updated analyses** including the automated pairs and TAG selected pairs, and other variables (i.e. Voltage).
  - Created a **list of atypicalities** discovered through the analyses.
  - **Compared** the atypicality list to **EI ISO lists of events** during the same time period.
- Worked with the **NASPI Engineering Applications Task Team** (formerly the Planning Task Team)

BPA
Major Technical Accomplishments during the Past Year

- Built the infrastructure to quickly **read and store 48 PMUs** (60 Hz) of data (15 seconds to process 1 minute of data)
- Built a **data quality filter** and applied it to the data.
- **Built a classification algorithm** to classify new PMU data into pre-determined groups.
- Began **identifying atypical events** and determining what, in the data, is contributing to the atypicality.

Eastern Interconnect
Major Technical Accomplishments to be Completed for FY14

- **Continue reviewing and iterating analyses** with the EI TAG.
- **Analyze 2 months of PMU data**, as received by the EI TAG (4 ISOs).
  - Create a **list of atypicalities** discovered through the analyses.
  - Send the list to the EI TAG for review.
- **Document the procedures** necessary to run these analyses.
- Produce a **year end report** summarizing the methodologies and analyses performed in FY2014.
- Continue participation with the **NASPI Engineering Applications Task Team** (including the NASPI meeting in October).

BPA
Major Technical Accomplishments to be Completed for FY14

- **Review analysis results** with BPA and improve the algorithms.
- **Install prototype software** at BPA to analyze new data.
- Produce a **year end report** summarizing the methodologies and analysis results.

Risk Factors Affecting Timely Completion of Planned Activities and Movement Through the R&D Cycle

Eastern Interconnect

- Only two months of EI PMU data to analyze.
- PMU data are sampled at 1 per second, meaning events that occur within a second will not be discovered.

BPA

- Data format is changing from DST to PDAT. A new reader function is needed (shouldn't be an issue, but it is an unknown at this point).
- Hardware needs to be set up at BPA for install of PNNL software in the early fall.
- Schedule – the end of the year is approaching fast.

Possible Follow-on Work to be Considered in FY15

Eastern Interconnect

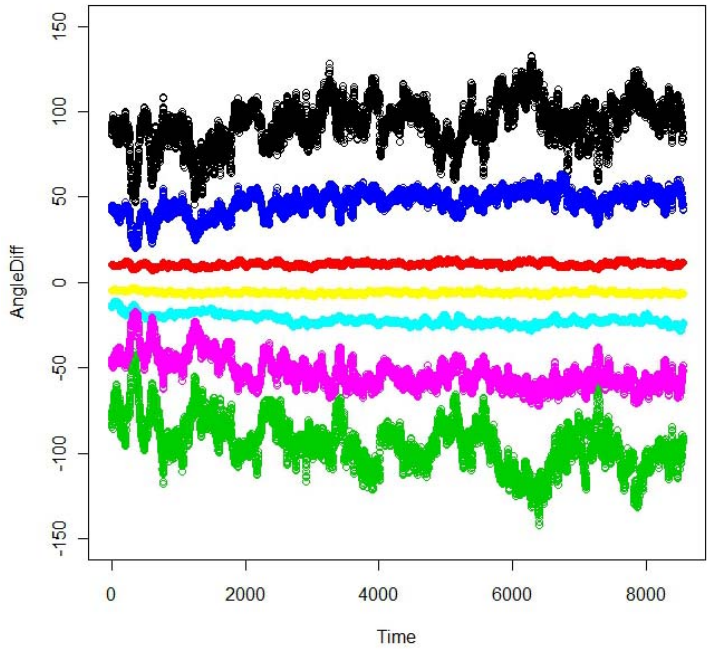
- Process additional PMU data (over a longer time period).
- Refine data quality filters and review analysis results with domain experts to improve the methodology by reducing the number of false-positives.
- Move to a classification driven system, so that results may occur in near-real-time.

BPA

- Add additional data streams to the analyses (load, oscillations, dampening, etc.)
- Model atypical events in order to build predictive capabilities into the system.

Mathematical Selection of Phase Angle Pairs

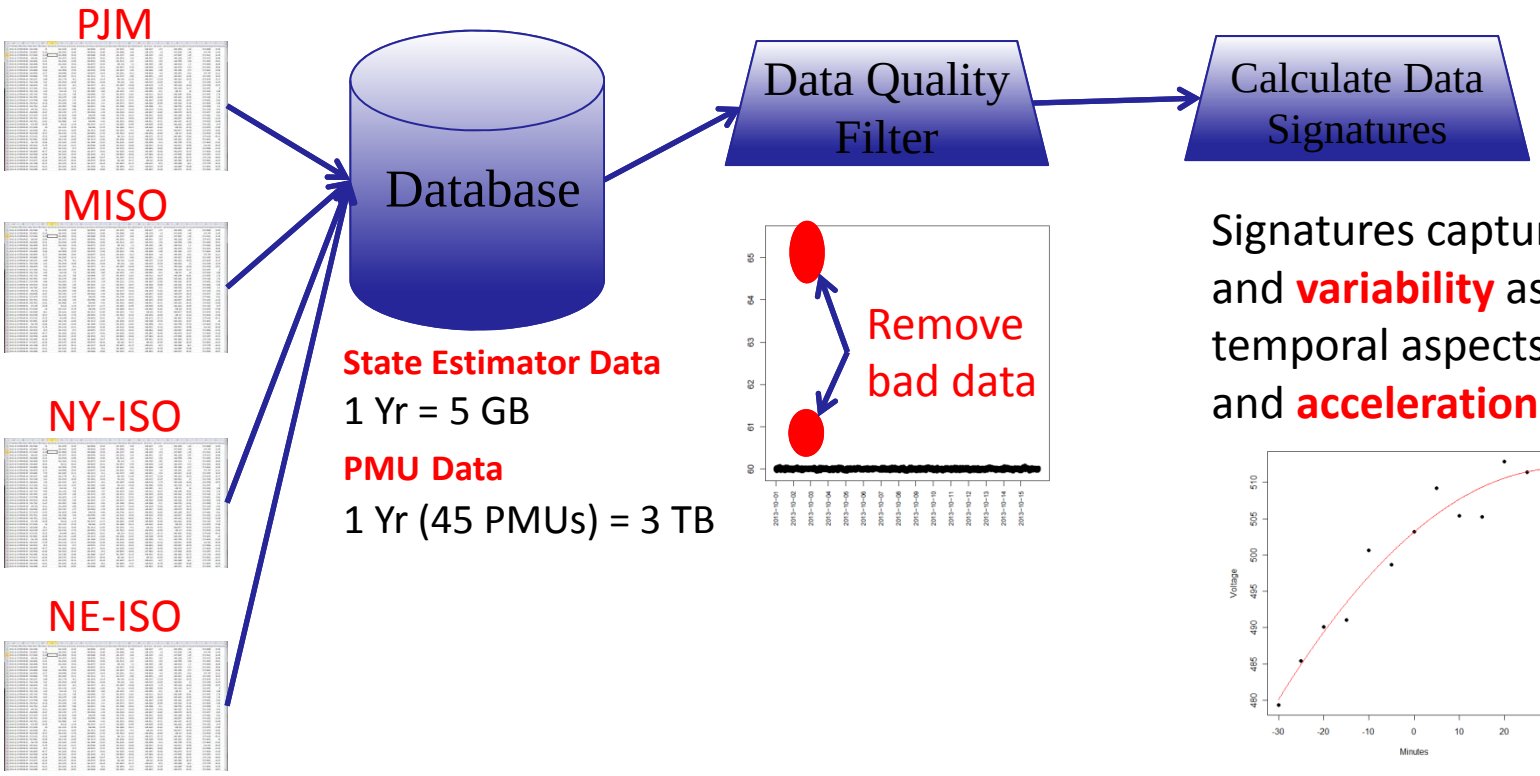
- Calculate **all possible angle pair differences** over a set time period.
- **Cluster** all pair differences into groups, such that similar differences are in the same group.
- Within each cluster (group), **select the best** representative phase angle pair.



ISO	# of Phase Angles	# of Possible Pairs	# of Mathematically Determined Unique Pairs
NE	136	9180	35
NY	36	630	9
PJM	1642	1,347,261	60

Baselining Analysis

- Read and store raw **State Estimator data** (recorded every ~5 minutes) from 4 Power Grid Entities
- Apply a data quality filter and calculate signatures (features) for analysis



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Identifying the Typical Patterns

- The data is grouped using a clustering algorithm. Each data point is grouped with data points that are similar.
- Data points that are unlike other data points form their own group. These points are called outliers or inliers.
- In this case, each data point = five minutes of time

2-D Graphical display of the patterns

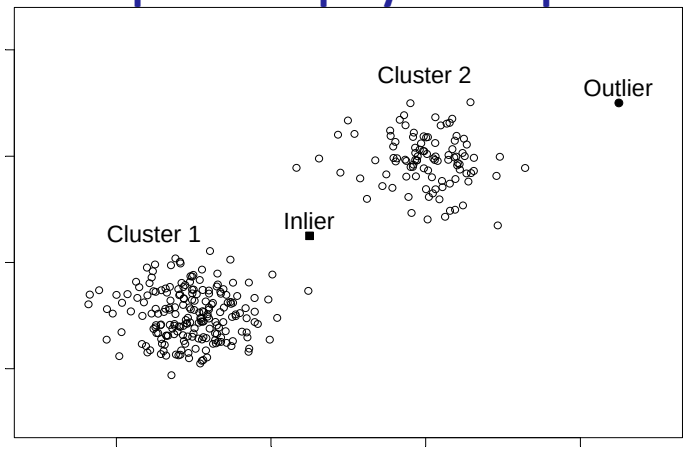
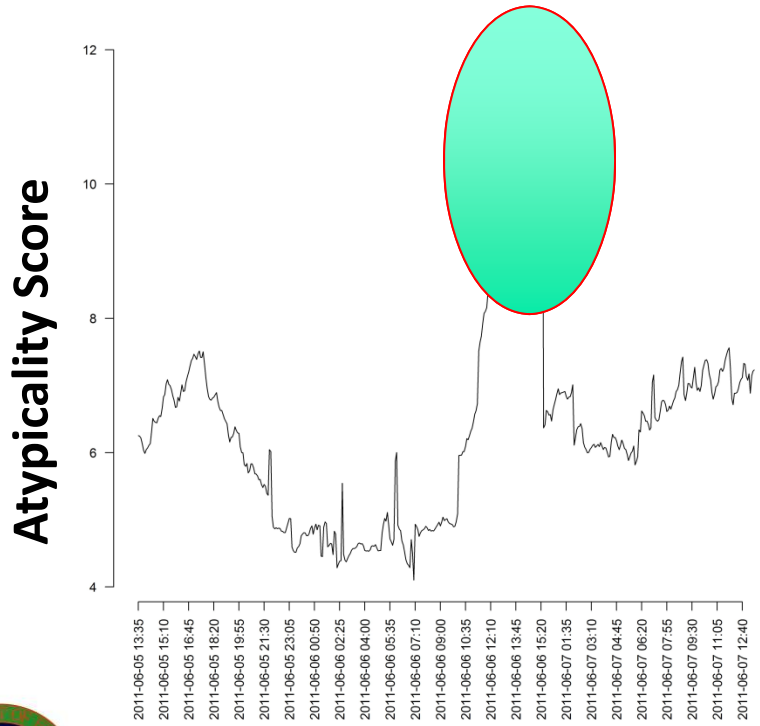


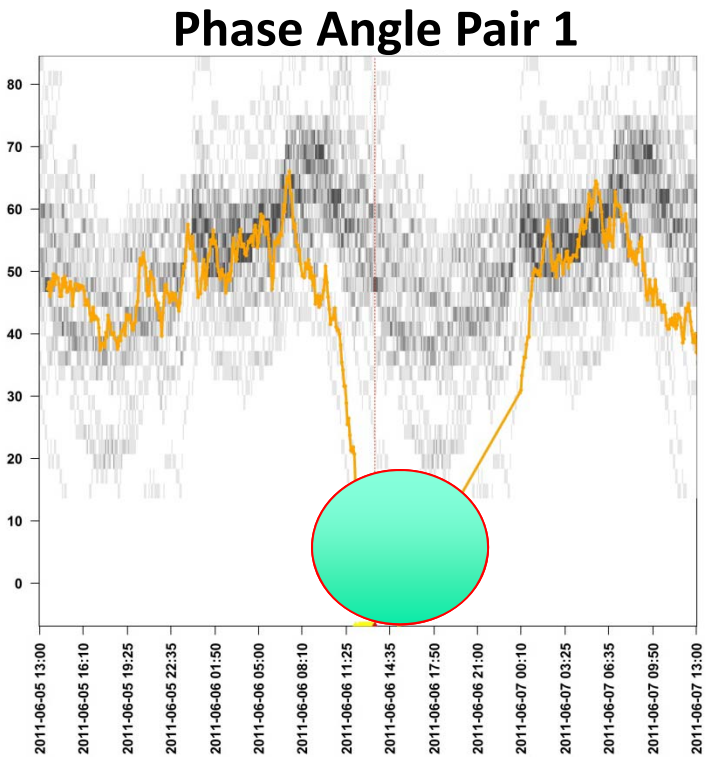
Table providing information about each pattern

Proportion	ClusterDefinition
13.595% (98253 min in 502 days)	FREQ mean is Normal(60.0016028658655). FREQ sd is Normal(0.0227979519670305). V mean is Normal(1.07909797523863). V sd is Normal(0.0175563686561582).
8.833% (63834 min in 502 days)	FREQ mean is medHigh(60.0196459525338). FREQ sd is Normal(0.0227979519670305). V mean is Normal(1.07909797523863). V sd is Normal(0.0175563686561582).
8.265% (59734 min in 502 days)	FREQ mean is Normal(60.0016028658655). FREQ sd is Normal(0.0227979519670305). V mean is medHigh(1.08293329141404). V sd is Normal(0.0175563686561582).
8.202% (59279 min in 502 days)	FREQ mean is medLow(59.9835597791971). FREQ sd is Normal(0.0227979519670305). V mean is Normal(1.07909797523863). V sd is Normal(0.0175563686561582).

Identifying the Atypical Events

Using state estimator or PMU data and multivariate statistical techniques to **establish baselines of typical behavior**, atypical moments in time can be discovered and the variables responsible can be identified.





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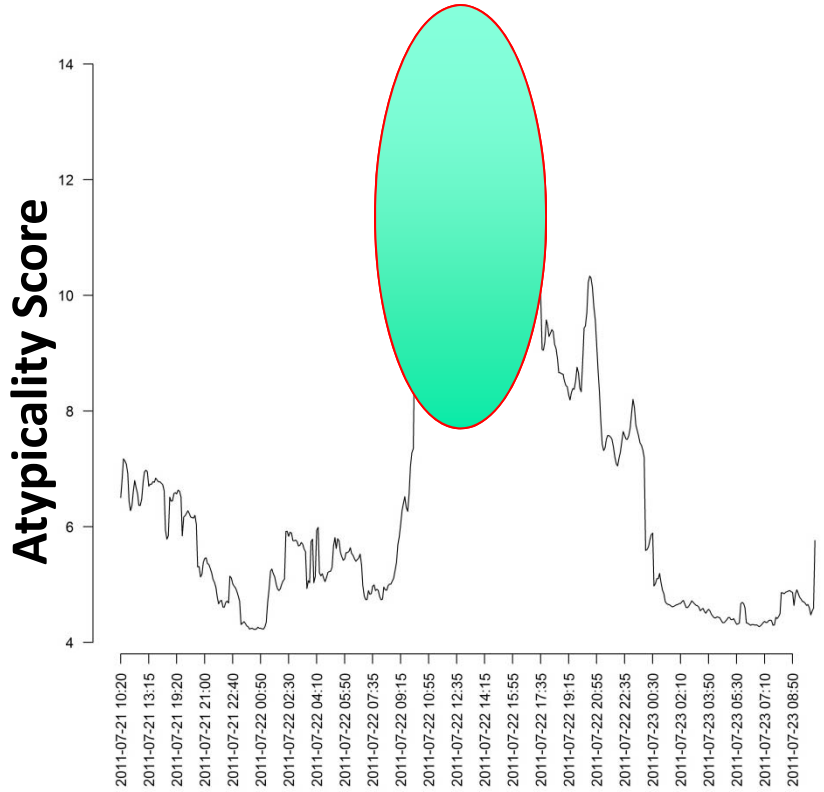
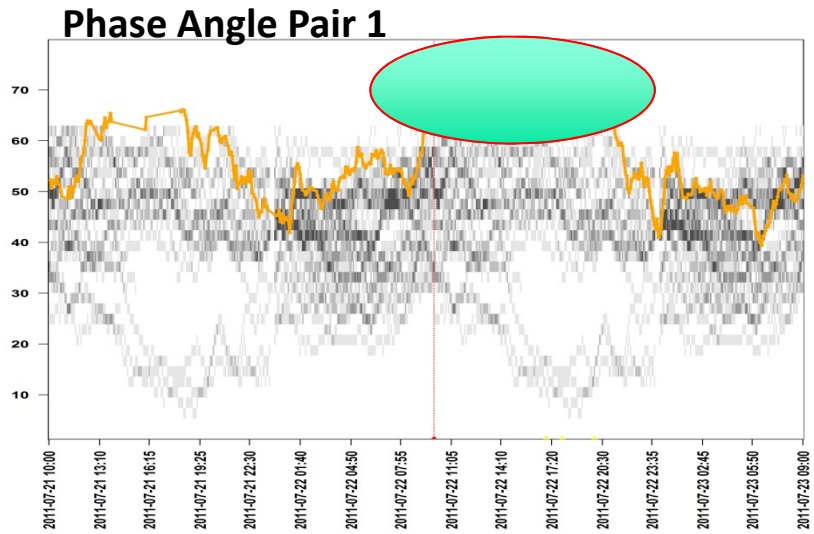
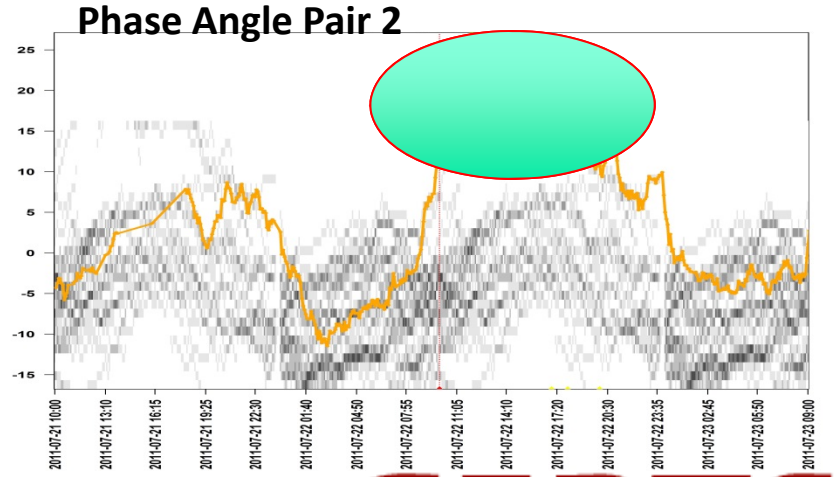
EI – Atypical Events
Heavy Load (Summer)







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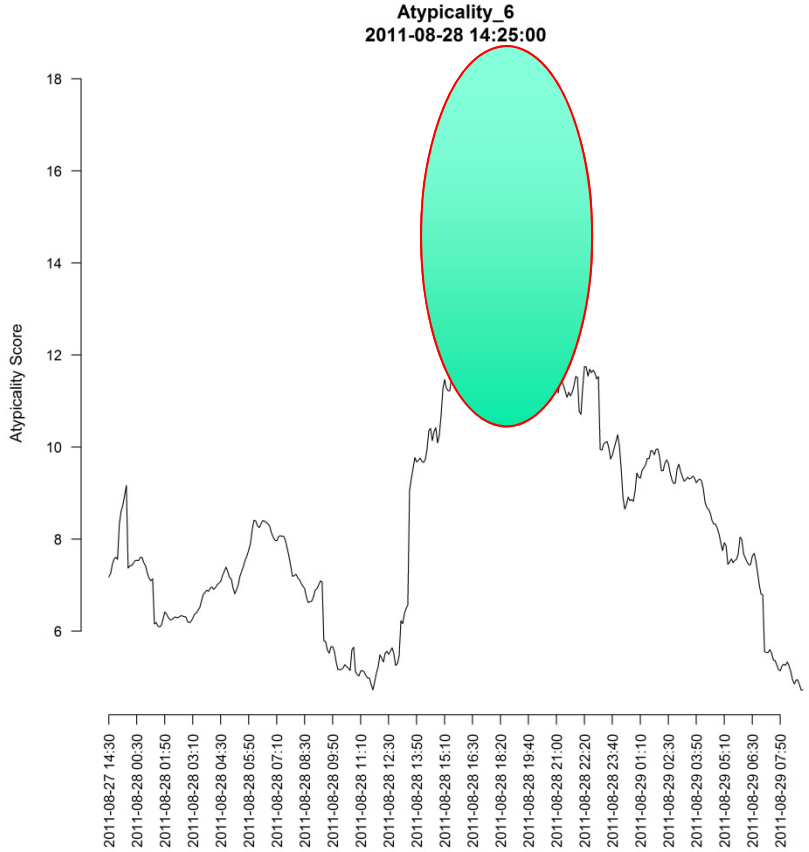
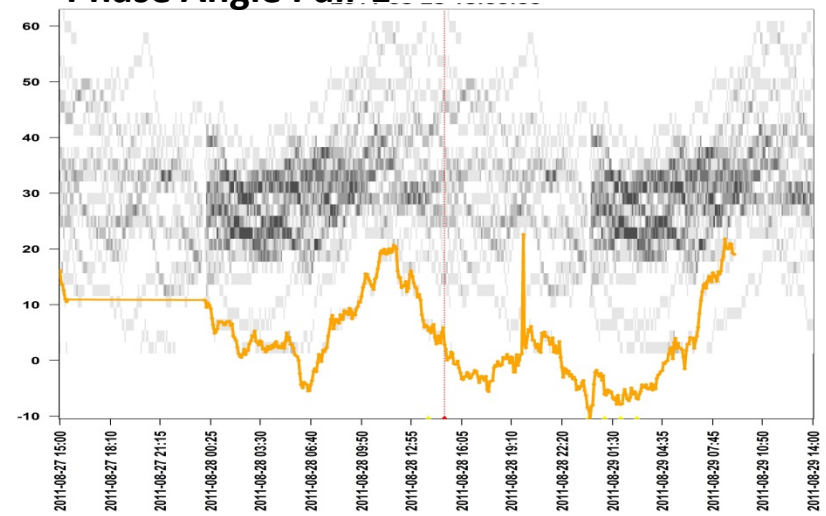
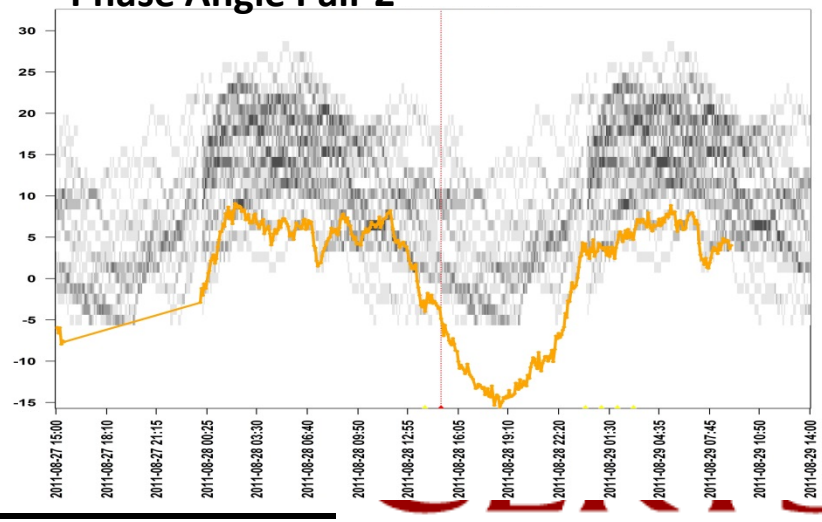
EI – Atypical Events
Hurricane Irene



Phase Angle Pair 1



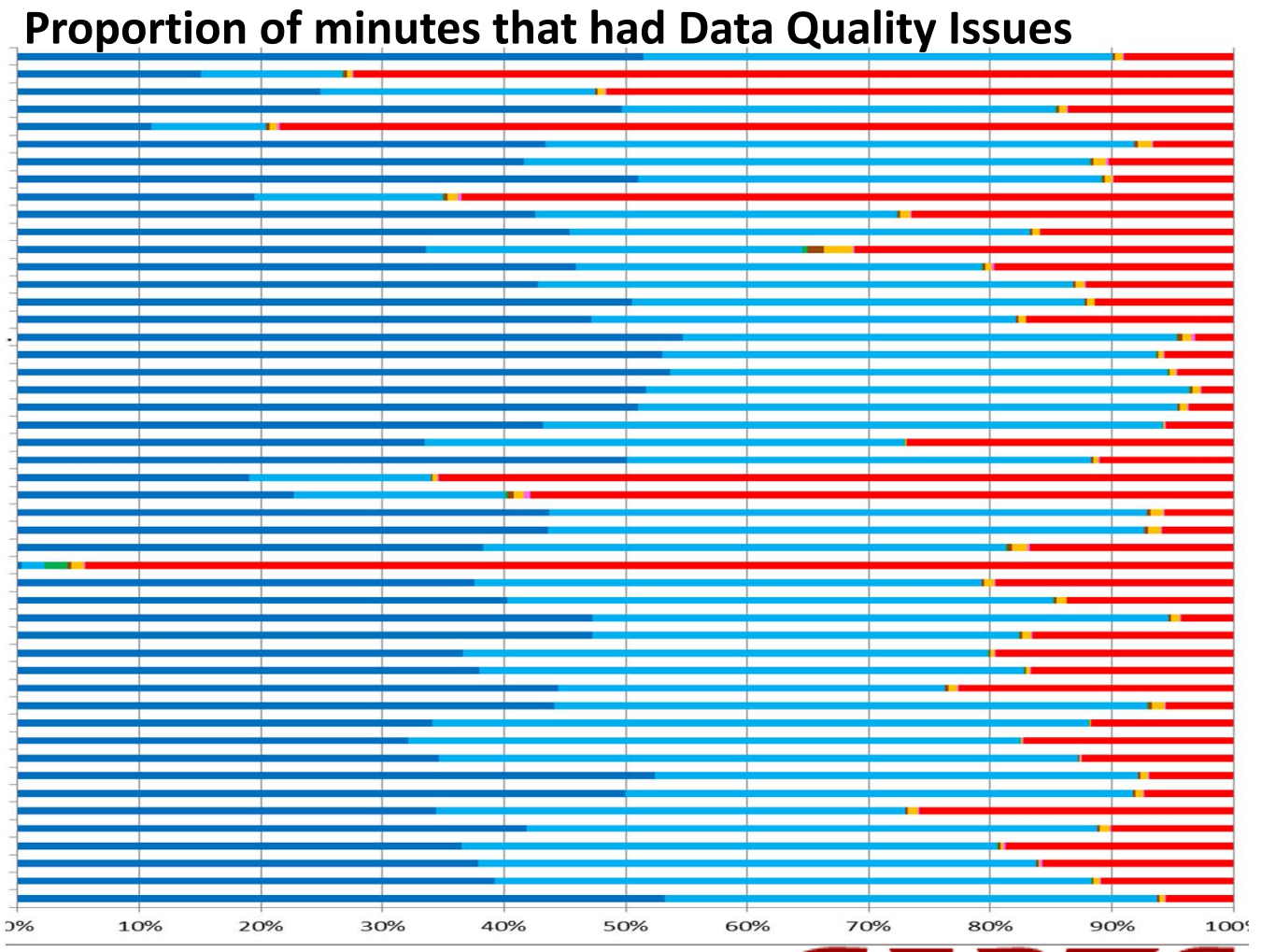
Phase Angle Pair 2



BPA – Data Quality

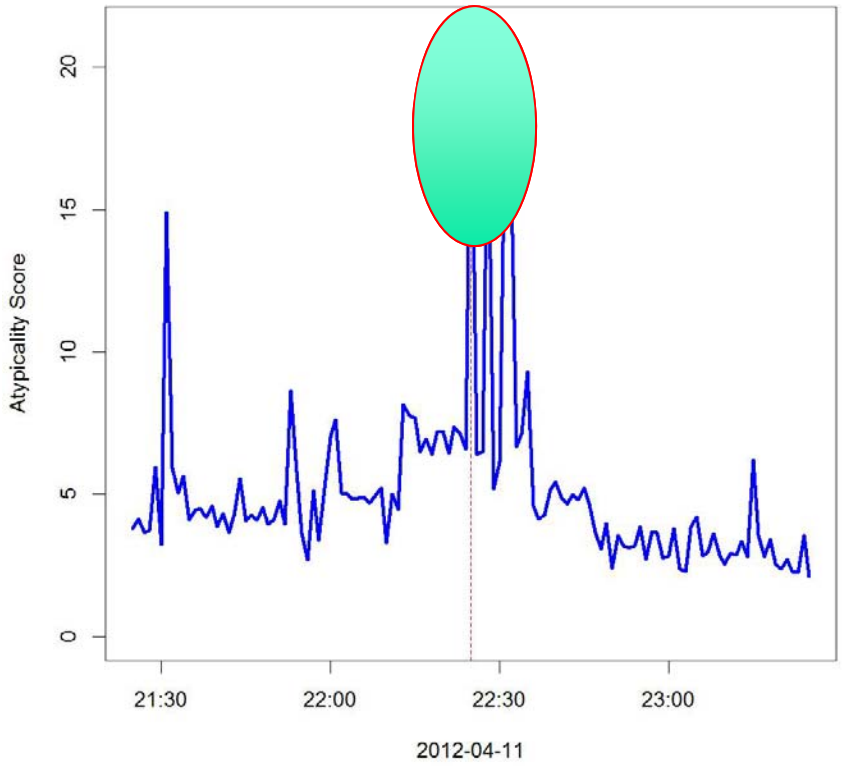
Each Line is a PMU

- No DQ Issues
- A few DQ Issues
- Marginal number of DQ Issues
- Full minute had DQ Issues

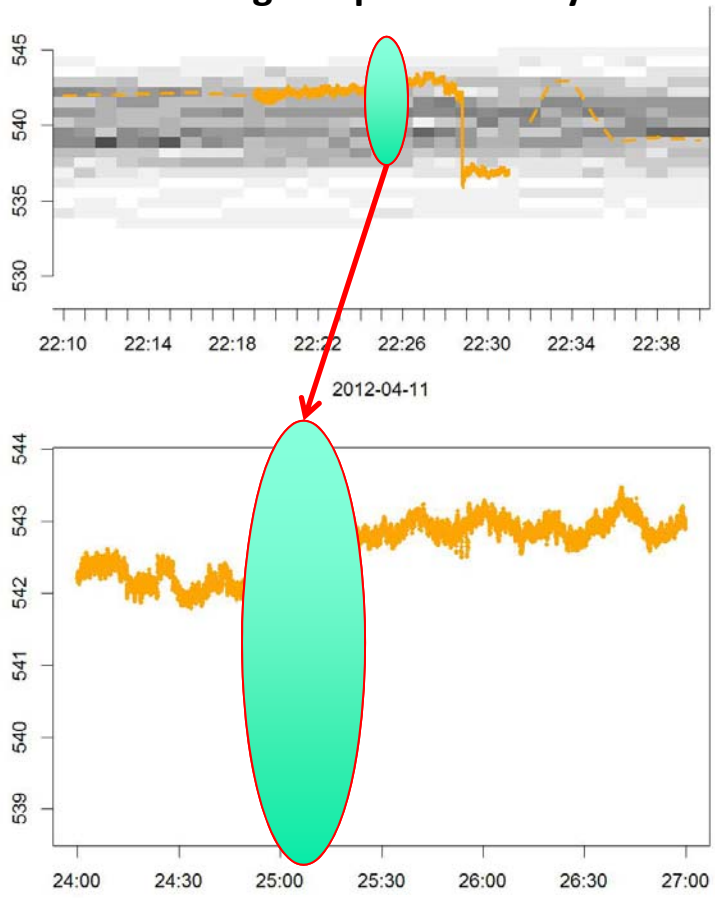


BPA – Atypical Events

Atypicality Score – Voltage Slope Variability



One of many voltage measurements with this voltage slope variability



Conclusions

- **Interactions with domain experts** has been most **helpful** in iterating the methodology.
- **Data quality filters** are improving the data to allow the user to **focus** more on actual grid phenomena and **better monitor the grid**.
- **Atypical events** have been identified, some of which match up with reported events.
- **Additional R&D is necessary** to mature the promising nature of the work to date.