Baselining Studies and Analysis

(DOE-CERTS Internal Review)

Brett Amidan, M.S.
Thomas A. Ferryman, Ph.D. (retired)
Trenton Pulsipher, M.S.
Spencer Hays, Ph.D.

Pacific Northwest National Laboratory

brett.amidan@pnnl.gov
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Project Objectives and Relevance

- **Project Objectives**
  - Investigate power grid data (PMU and State Estimator Data), including, but not limited to, phase angle differences between site pairs, and mode meter and oscillation derived variables.
  - Identify atypical events and characterize typical patterns.
  - Recommend upper and lower limits for "normal" operation.

- **Relevance**
  - Increase understanding of the significance of phase angle differences and other variables as a metric of grid health.
  - Increase grid reliability.
  - Provide the ability to understand the nuances of the grid during varying operating conditions.

Major Technical Accomplishments to be Completed this Year

- **PMU Baseline Effort**
  - Calculate Mode Meter & Oscillation derived variables.
  - Improve data quality filters.
  - Identify atypical events using SitAAR.
- **EI Baseline Effort**
  - Ingest 2011 data for 4 ISOs.
  - Calculate domain expert selected phase angle differences.
  - Use SitAAR to find atypical events.
  - Use Date/Time Model to predict normal operation limits.

Deliverables and Schedule for FY2012

- PMU Baseline Status Presentation – October 2012
- PMU Baseline Report – October 2012
- EI Baseline Status Presentation – October 2012
- EI Baseline Report – October 2012

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

- Phase angle pairs need to be identified. Input is needed from the participating ISOs.
- Application of Mode Meter and Oscillation calculations on PMU dst files is still pending.
- Interactions with domain experts will be needed to determine the effectiveness of the baselining activities.

Possible Follow-on Work to be Considered in FY2013

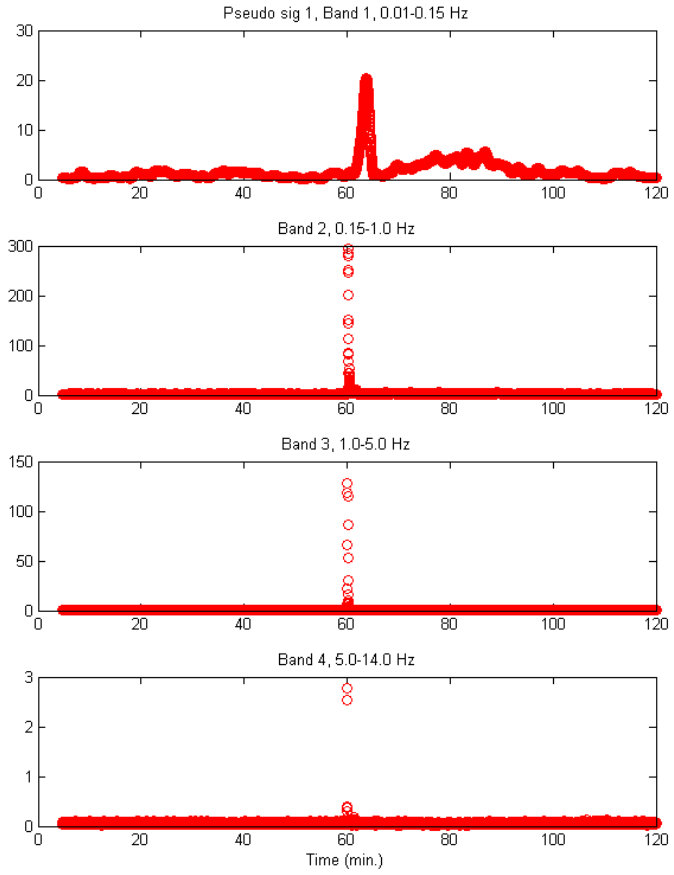
- Add Refinements and Capabilities to the SitAAR approach –
  - Use Domain Experts to help refine data quality filters and analysis inputs to help the user better identify interesting atypical events (decrease false-positives).
  - Add other derived variables to the processing to add insight.
  - Process significantly more data, to add more insight and understanding.
  - Move to a Classification based system, allowing for predictive capabilities and near real-time results.
- Add Refinements to the Date/Time Model
  - Consult with Domain Experts to identify actual variances from normal operation.
  - Correct possible biases in the model estimates.
  - Use this information and possible other modeling capabilities to decrease false-positives.

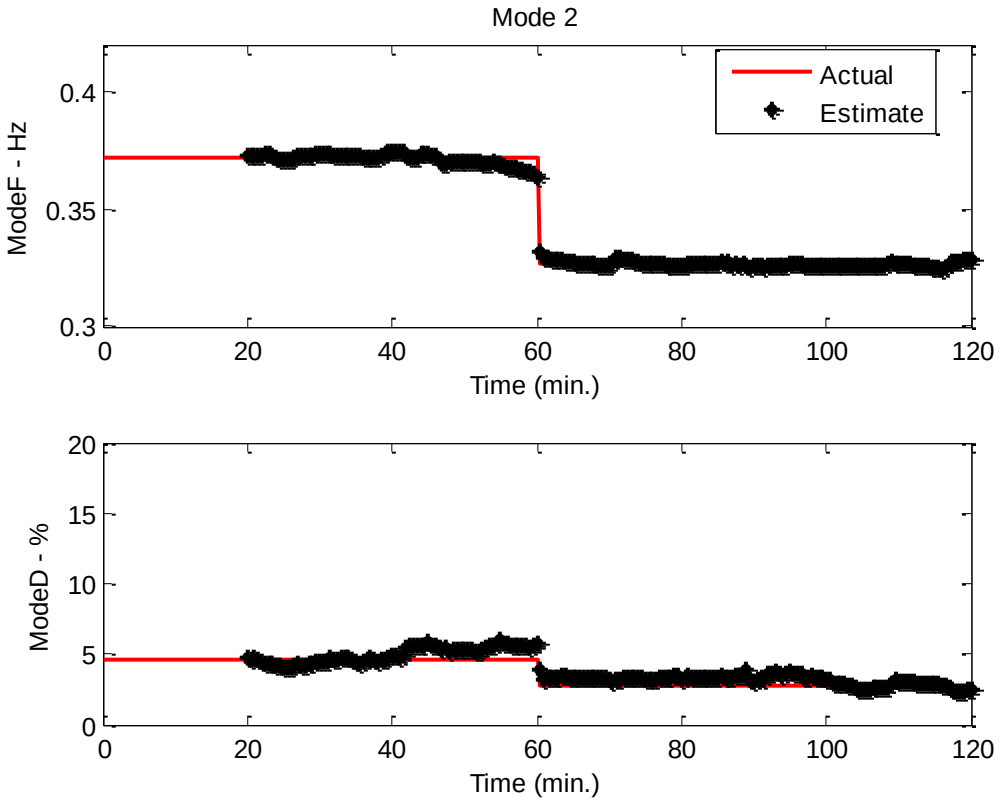
PMU Analyses Using SitAAR (Situational Awareness and Alerting Report)

- **SitAAR has been applied to 9 months of PMU data looking at Voltage, Current, Phase Angle Differences**
  - Initial results shown to Domain Experts – interesting events and data quality issues were revealed.
  - Resulted in improvements made to the Data Quality.
- **Next Steps**
  - Add Oscillation and Mode Meter Data.
  - Process more data.
  - Review refined and improved findings with domain experts.

Oscillation Detection and Mode Meter Progress

- We've got the Matlab code working on example data (see plots below).
- In the process of applying it to .dst files (raw PMU data).





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Analysis Methods for State Estimator Data

- Focus analyses on Phase Angle Differences between two sites.
- Method 1 – SitAAR approach to study typical patterns and atypical events.
  - Applied to PMU data.
  - To be applied to latest state estimator data.
- Method 2 – Date/Time Model
  - Predict phase angle for each pair for each 3-hour period in 2011. Refinements will move this to 1-hour periods.
  - Calculate candidate statistical Quality Control limits for monitoring phase angle pairs.
  - Could lead to a near-real-time monitoring and alerting system to:
    - Alert the operator if the phase angle for pairs of sites appears to be notably unusual.
    - Inform the operator of specific pair(s) identified.

Phase Angle Difference Analysis of Eastern Grid State Estimator Data

- **Calculating Angle Difference from the same ISO**
  - Angle data recorded at the same time
  - Straight forward calculation

	Angle1.ISO1	Angle2.ISO1	Angle1.ISO1-Angle2.ISO1
00:00:00	-35.385	-37.810	2.425
00:00:30	-33.148	-35.565	2.417
00:01:00	-32.478	-34.918	2.440
00:01:30	-32.243	-34.677	2.433
00:02:00	-32.119	-34.547	2.428

- **Calculating Angle Difference from different ISOs**
  - Angle data NOT usually recorded at the same time
  - Complicated calculation

	Angle1.ISO1	Angle3.ISO2	Difference
00:00:00	-35.385	NA	?
00:00:07	NA	-34.850	?
00:00:30	-33.148	NA	?
00:02:00	-32.119	NA	?
00:02:30	-32.634	NA	?
00:03:00	-33.080	NA	?
00:03:06	NA	-34.850	?

- **SOLUTION:**

FIDUCIARY METHOD

Fiduciary Method

- **Calculate Angle Differences between Angles from Different ISOs by Using Other Angles Both ISOs Have in Common**

Angle 1 ISO 1

	Angle1.ISO1	FidAngle1.ISO1	Difference
00:00:00	-35.385	-12.301	-23.085
00:00:30	-33.148	-10.247	-22.901
00:01:00	-32.478	-9.275	-23.202
00:01:30	-32.243	-9.170	-23.073
00:02:00	-32.119	-9.419	-22.699
00:02:30	-32.634	-9.964	-22.671
00:03:00	-33.080	-10.202	-22.879
00:03:30	-33.480	-10.462	-23.019

Angle 3 ISO 2

	Angle3.ISO2	FidAngle1.ISO2	Difference
00:00:07	-34.850	-27.168	-7.682
00:03:06	-34.850	-27.307	-7.543
00:06:06	-34.883	-27.738	-7.145

Angle 1 ISO1 – Angle 3 ISO 2

	Difference
00:00:30	-15.647
00:01:00	-15.779
00:01:30	-15.721
00:02:00	-15.587
00:02:30	-15.619
00:03:00	-15.754
00:03:30	-15.955

Calculating Phase Angle Difference Using 3 or more Fiduciaries – Example

Results from multiple fiduciaries summarized by calculating the median at each time period.

(This reduces any problems introduced due to having to use fiduciaries)

Time

Date/Time Modeling

- For each of the 54 pairs recommended by PJM,
  - Calculate angle differences for every State Estimator data point (every 5-minutes for 15 months)
  - Fit a linear model based on date/time:
- Version 0.1 (fit based on 15 months of data)

$$\text{EstimatedAngle} = \text{Overall Mean} + \text{SeasonFactor}_{(i)} + \text{DayOfWeekFactor}_{(j)} + \text{TimeOfDay}_{(k)} + \text{error}_{(i,j,k)}$$

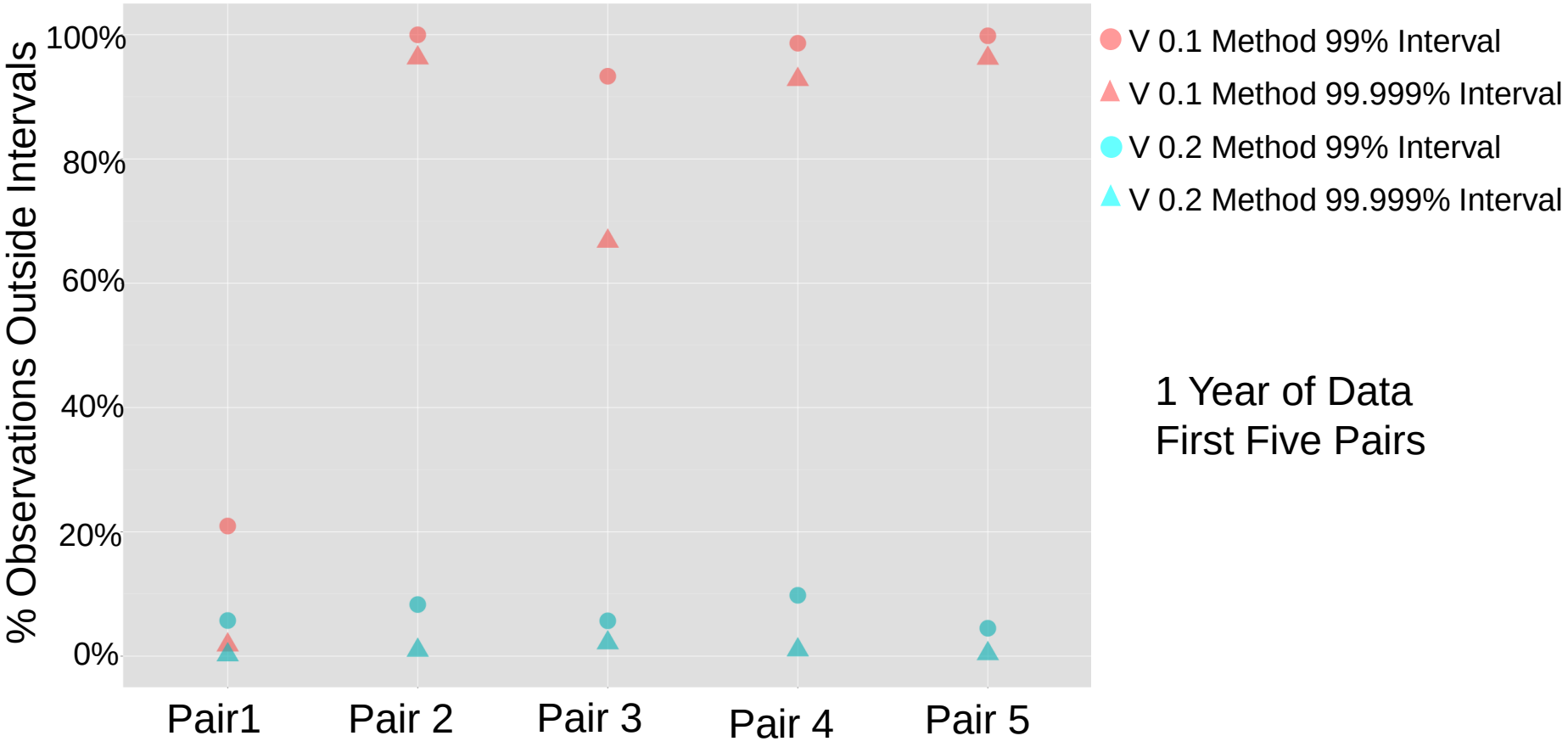
where: $i = 1, 2, \ldots, 13$; $j = 1, 2, \ldots, 7$; $k = 1, 2, \ldots, 8$

- Version 0.2 (fit based on moving window of 4 weeks)

$$\text{EstimatedAngle} = \text{Overall Mean} + \text{DayOfWeekFactor}_{(j)} + \text{TimeOfDay}_{(k)} + \text{error}_{(j,k)}$$

where: $j = 1, 2, \ldots, 7$; $k = 1, 2, \ldots, 24$

Version 0.2 vs Version 0.1



1 Year of Data
First Five Pairs

- **Revised method significantly improved phase angle difference predictions. Further testing and revisions are necessary, to improve and quantify its ability to predict.**

Progress Summary

- **Situational Awareness Analysis of PMU Data**
  - 9 months of PMU data processed and analyzed, including phase angle differences.
    - Results shown to domain experts, iterations performed on data to reduce data quality issues.
  - In the process of adding oscillation and mode meter data.
- **Analysis of State Estimator Data**
  - 9 months of State Estimator Data processed from 3 ISOs.
  - Fiduciary Method created to calculate differences in phase angles from different ISOs.
  - V0.1 Date/Time Model created to determine prediction limits for future phase angle differences.
  - V0.2 Date/Time Model – using a moving window of 4 weeks (8 weeks also tried).
  - Additional refinements have been identified.

Conclusions

- Analysis progress continues and looks encouraging.
- SitAAR approach finding ways to mitigate data quality issues and allow the user to focus more on actual grid phenomena and better monitor the grid.
- SitAAR approach finds interesting grid behavior and provides insight to the domain experts.
- V 0.2 Date/Time prediction model showing promise in effective use of phase angle pair difference data.
- Additional R&D is necessary to mature the promising nature of the work to date.