DOE/OE Transmission Reliability Program

Synchro-phasor Data Conditioning and Validation

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Project objective

- **Premise:** Each synchrophasors measurement, whether used for state estimation, control, or alarms, can be subjected to the same preprocessing as the linear estimator demonstrated in Aug'13 by Dominion Virginia Power. The proposed solution is in general a low cost solution. The open PDC is open source and freely distributed and Dominion already possesses a fully functional linear estimator in the openPDC platform. Even if a state estimator is not desired, the linear estimator can be thought of as part of the data conditioning algorithm in that it detects bad data, finds the best estimate, and increases the observability of the network.
- **Deliverable** C# openPDC software, recommendation, and functional specifications
- Dominion had put the linear estimator in the Grid Solutions open source applications library maintained by **GPA (Grid Protection Alliance)**

Major technical accomplishments completed this year-1

brief task statement list-details in proposal

Task

1. Prototype Development Recommendations on synchrophasor infrastructure
2. Commissioning process
3. Algorithms for online determination of Signal to Noise Ratio (SNR) of the PMU data
4. Recommendations for the central PDC architecture design and the ESOC architecture design (ESOC) Emergency System Operation Center
5. Optimized PMU placement scheme

   Placing dual-use line relays/PMUs including multiple buses in a substation, and redundancy at critical buses the issue is selection of substations not buses.

Major technical accomplishments this year -2

6 Provided algorithms for:

a) Loss of data from one or several PMUs
b) Loss of signals in a PMU
c) Stale (non-refreshing) data
d) Inconsistent data, data rates and latencies
e) Off-sets in signal magnitude and phase
f) Corrupted and drifting signals in a PMU
g) Corrupted and drifting time reference in one or several PMUs
h) Combination of several issues described above
i) The failure of the topology processor and/or bad/incomplete topology information

i) A recommendation but implementation is not part of the proposed work.

Major technical accomplishments completed this year-3

- Task 2A: Demonstration at Dominion April 22, 2014
- Test Algorithms on Dominion System
- Task 3: Develop Functional Specifications
- Deliverable C# Open PDC software, recommendation, and functional specifications

Dominion has added the data validation software to the linear estimator in the Grid Solutions open source applications library maintained by GPA (Grid Protection Alliance)

Deliverables and schedule for activities completed under FY13 funding

Tasks	Task Name	Deliverables (please name the reports and clarify other deliverables)	Planned Start Date	Actual Start Date	Planned End Date	Actual End Date
1.1	Prototype Development Recommendations on synchrophasor infrastructure	Report #1	4/13	4/13	9/13	sent on 09/16/2013 Final Progress 10/11/13
1.2	Commissioning process	Report #2	4/13	4/13	9/13	sent on 09/016/2013 Final Progress 10/11/13
1.3	Signal to Noise Ratio(SNR) of the PMU data	Report #3	5/13	5/13	10/13	report sent on 10/11/13
1.4	Recommendations for the central design PDC architecture design and the ESOC architecture	Report #4	5/13	5/13	10/13	Progress report sent on 10/11/13
1.5	Optimized PMU placement scheme	Report #5	9/13	9/13	2/14	Progress report sent on 02/06/14
1.6	Algorithms	Report #6	4/13	4/13	11/13	Progress report sent on 11/18/13
2A.	Demonstration at Dominion	Report #7	4/14	4/22/14	4/22/14	Report submitted 4-22-14
3	Functional Specifications of the Data Validation System	Report #8	11/13	12/13	4/22/14	Final report submitted 4/22/14

DOE Demonstration at Dominion 4/22/2014

55 page final report submitted

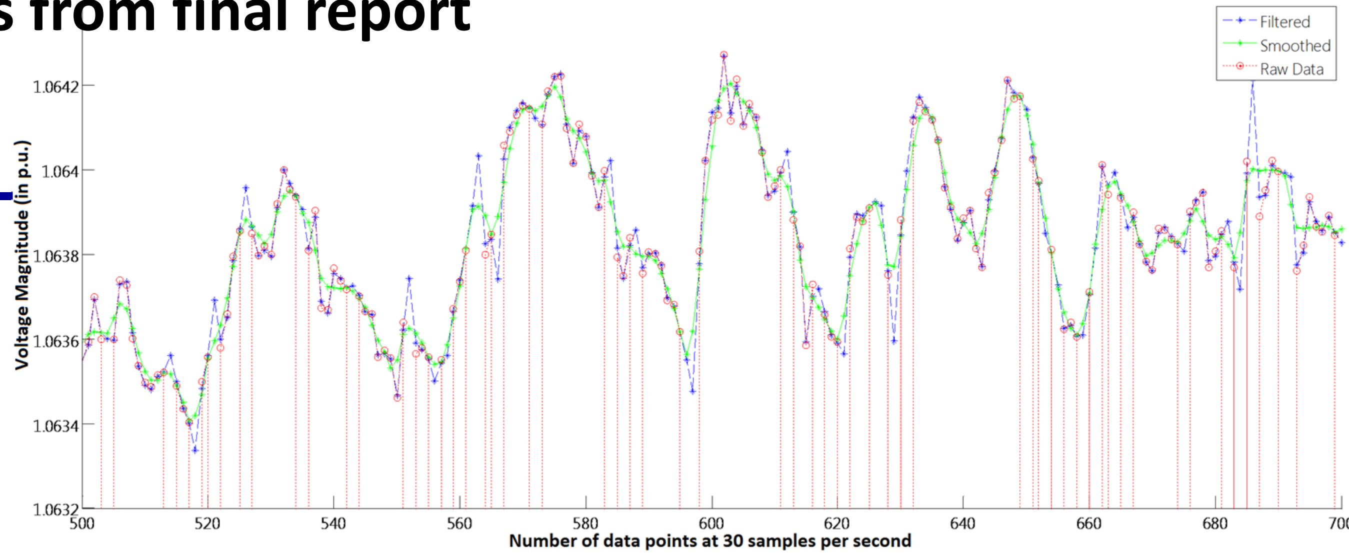
A few new plots from final report

20% drop out

Raw data

smoothed

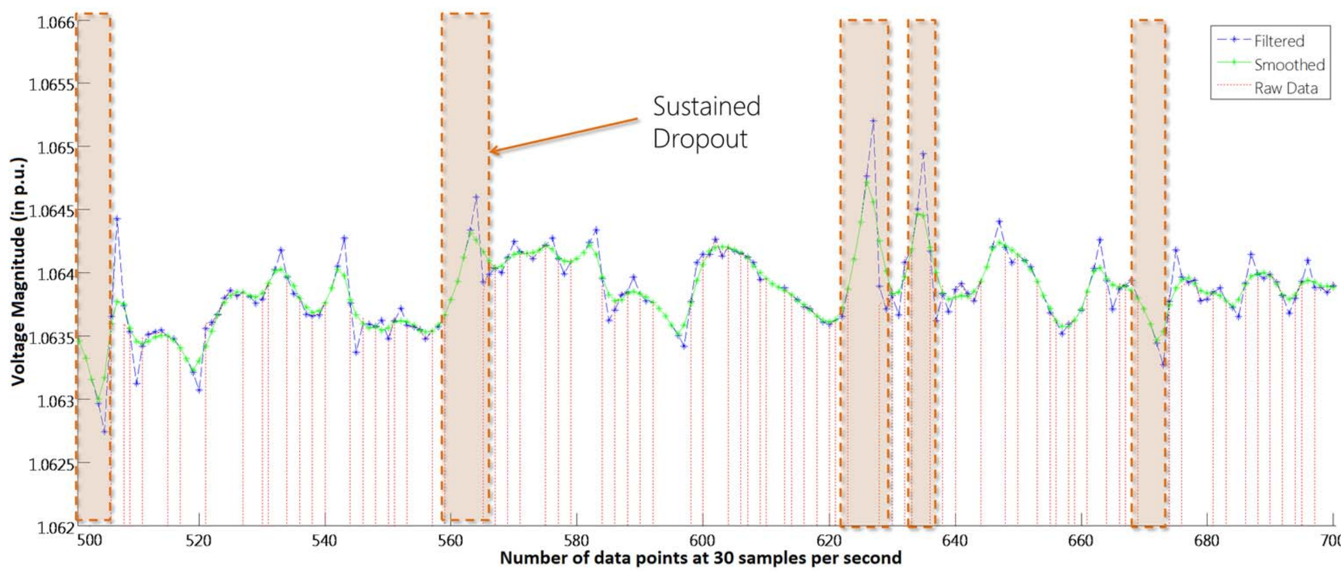
filtered



Filtering – use past data up to the current instant to estimate the current state

Smoothing- use data after time t_0 to estimate the state at time t_0

40% drop out



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Repeated values are actually more trouble than missing values since the phase angle is changing with each new frame (based on the deviation from nominal frequency). Therefore, repeated values cause problems with the quality of the phase angles.

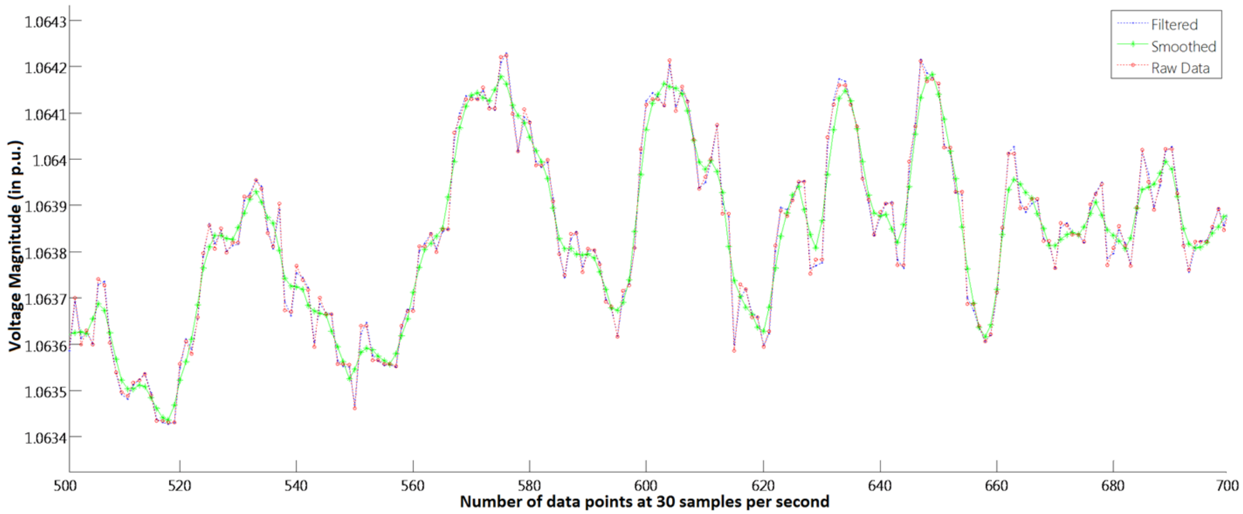


Figure 11 - Performance of Data Conditioning Algorithm with 20% Repeated Values

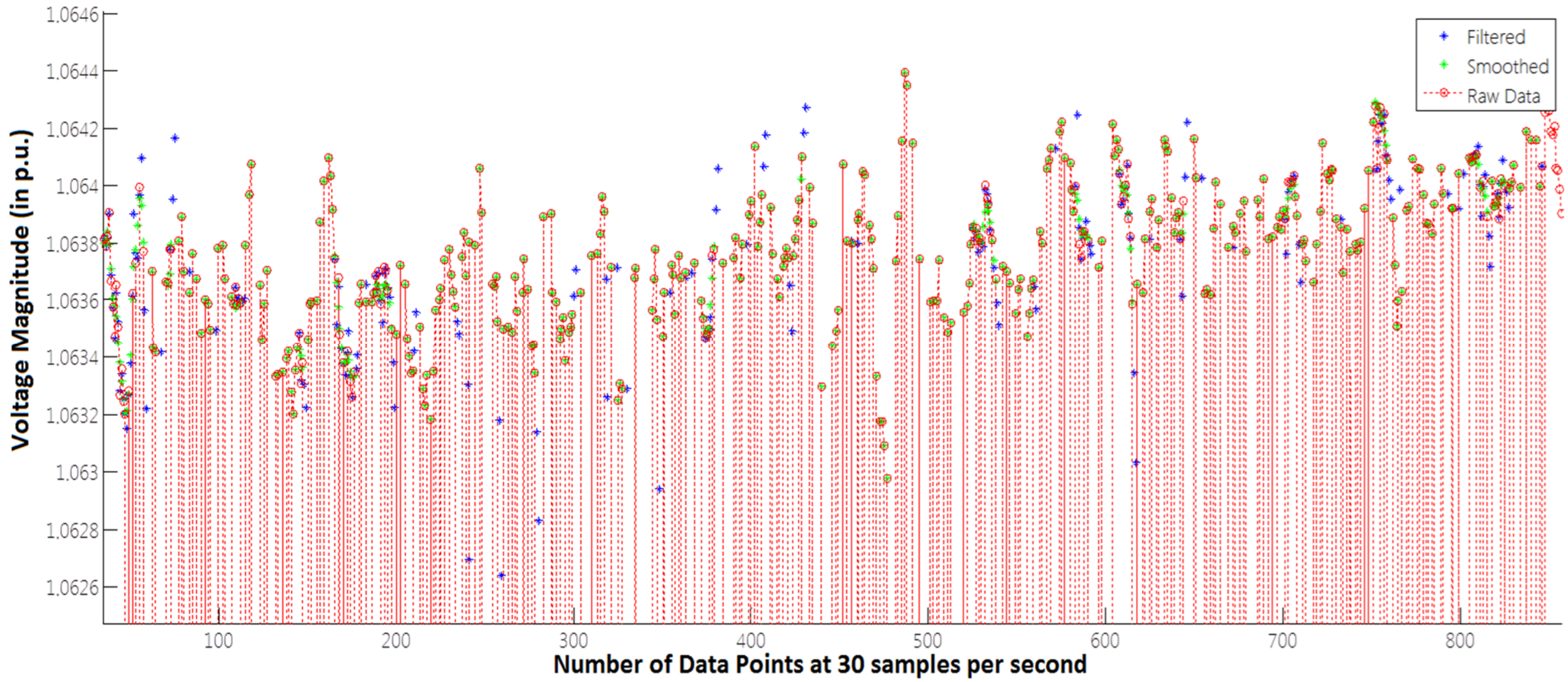
Drop out rates up to 30% and repeated values up to a 20% rate can be followed. With 50% likelihood (probabilistically) that each data point will be lost the it does not take long until so many adjacent data points are lost that the algorithm is unable to make accurate predictions and eventually diverges

Reset function

In order to prevent the algorithm from becoming numerically unstable and diverging, a *reset* function is built-in to it that activates when the smoothing window is completely filled with estimated data. The algorithm will start operating normally once the smoothing window gets filled with raw data (and not estimates). Therefore, for the quadratic prediction model used here, there will be a delay of at least three frames. The steady state error covariance matrix and Kalman-filter gains can be saved and used to re-initialize the algorithm when required.

Another advantage of adding the reset functionality to the data conditioning algorithm is that by using it, contingencies or discrete changes in the system can be properly conditioned. It takes several samples until the window moves past the step change before it can properly track the stream again. However, by resetting the algorithm at the right time, a discrete network change can be immediately acknowledged. The next figure demonstrates the effectiveness of the algorithm's reset functionality.. From the figure it becomes clear that by resetting the algorithm at the correct instant, the optimal smoothed estimate (green star) is able to track the actual measurement (red circle) perfectly.

Figure 13 - Performance of Data Conditioning Algorithm with Reset Functionality on phasor magnitude (50% Dropouts)



There are still holes but the estimate picks up quickly

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Looking Forward

- We are currently in a no-cost extension
- Original proposal had a second stage with a possible demonstration elsewhere. There are no takers as yet.

- Thank you
- Questions?