February 23, 2022
Webinar Questions and Answers

# "Applications of Time Synchronized Measurements in the Electric Grid"

## with Dr. Mohini Bariya

**Question**: Can you confirm that microPMU granularity is only 120 Hz or 2 samples per cycle in a 60 Hz US frequency. Or is it 120 samples per cycle?

**Answer:** *The microPMU I describe reports phasor parameters at a 120 Hz, ie twice per cycle in a 60 Hz system.*

**Question**: Have you done Kron top algorithm in mesh or loop network topology model not radial network topology?

**Answer:** *To obtain full network recovery, our Kron algorithm requires the network to be radial. However, the Kron reduced model—which captures the voltage/current relationship at network nodes but does not explicitly indicate the connectivity structure—can be estimated from measurements using the techniques we describe in both radial AND mesh networks. The Kron model is highly structured, and we can certainly use it to detect, and possibly even localize, changes in mesh networks, though I have not delved greatly into these possibilities. The "justified heuristic" algorithms I describe later in the talk are useful for monitoring structural patterns and can be applied to both radial and meshed networks.*

**Question**: Which of these methods have been tested with field data, and what were the performance? And have you run sensitivity analysis to determine what PMU accuracy/stability is needed to enable these applications?

**Answer:** *The first algorithm I describe, termed corr-top, was tested using micro-PMU data from an operational distribution feeder. The feeder was radial, and PMU deployment across it was sparse. The algorithm successfully identified a few connectivity changes that were known to us from utility logs. You can find the original paper (which is also available open-access) here: [https://ieeexplore.ieee.org/abstract/document/8373624](https://ieeexplore.ieee.org/abstract/document/8373624).*

*Sensitivity analysis is difficult to perform with field data, as our ability to intervene or alter the operational system is limited. Obtaining field sensor data of any sort is challenging, and procuring corresponding utility event logs or model information is even more so. There is a big need to build open access sensor data along with enriching system information (logs, models) to encourage and spur research in our field.*

*In my other work, we were able to perform noise sensitivity analyses with simulated data, though creating synthetic noise and signal that accurately resembles field data is exceedingly challenging.*

**Question**: What are the important considerations for optimally placing the micro-PMUs in the Distribution system (for example IEEE34 node test feeder)? what are techniques used for this? How Can we classify and locate the fault using micro-PMU data ? What are the most varying parameters when detecting, classifying and location the fault. main parameter for consideration is V or I or angles or ROCOF? or combination of any of these?

**Answer:** *So many great questions here! There is a large research on optimal microPMU placement which should provide a lot of insight, but it is good to keep in mind that the answer to what is optimal can depend greatly on what you are interested in being able to do. I can give a broad, qualitative, engineering answer to the question based on my experience with real sensor data. Sensors should be distributed evenly throughout the network, with coverage across topological clusters. Deploying several sensors close together within a single topological cluster is unlikely to yield much additional benefit. If you are interested in monitoring changes in connectivity, think about the pairs of nodes whose relative connectivity to each other (the effective impedance between them) will be altered by the structural changes you are interested in. Placing sensors at these nodes will give you visibility into the occurrence of these changes, potentially even enabling identification of which out of a set of changes occurred. Given the structures we deal with, and the constraints on what can change, I believe we can actually obtain significant insight with limited sensing.*

*With regard to faults: microPMU data does capture fault signatures (though of course there is loss of information compared to the point-on-wave recordings made by many fault recorders) and methods for time series classification—such as the kShape clustering I described—could be used to classify faults by type based on these signatures. I have not been able to validate this as I did not have access to datasets of labeled fault data.*

*Voltages and currents captured by microPMUs should be useful for fault location. Here too, the structure of the network would likely allow us to do relatively good localization with little sensor coverage. I think voltage magnitudes alone would reveal a lot. In low sensor coverage settings, voltages are powerful because they capture global information and are impacted by flows throughout the network, while currents capture only a single flow. I believe adding current information into the mix will only be insightful if we have reasonably high measurement coverage. I doubt the ROCOF would be useful here.*

*I hope that my work—which focused on elucidating how network structures manifest in patterns within and relationships between PMU measurement series–could provide a foundation for deriving approaches to fault localization with low measurement demands. I have not yet had the chance to work directly in this space, but please do get in touch with me if you'd like to discuss this further.*

**Question**: Can these unsupervised learning tools be used in real-time for protection & control applications in order of ms?

**Answer:** *Many of these methods are very fast already–running in on the order of a couple seconds–and have not been optimized at all. There is potential to make them much faster. My focus has been on developing tools for monitoring & situational awareness, which does not have as demanding time requirements. I know some of my colleagues, such as Keith Moffat at Berkeley, have taken these methods into the domain of control. I would encourage you to look up his work to get a better sense of the possibilities.*

**Question**: Why you have selected cluster k=7? How many periods (days/months) data you have selected before considering shape method as optimal one? Also what method you have used for classification and how's the accuracy?

**Answer:** *The kShape algorithm that you refer to was demonstrated on events extracted from microPMU data streams from an operational distribution network. There were no labeled event logs associated with the sensor data so it was not possible to validate classification accuracy. Instead, we tried to show the efficacy of the approach in grouping together similar events. After clustering, we conducted other data driven analyses on a couple of the resulting clusters to bolster our hypothesis that the cluster members were of a common type. For example, the events in clusters which we believed corresponded to tap changer operations indeed occurred at times in the day consistent with steps up and down in voltage.*

*The number of clusters (7) was chosen by analyzing the intra-cluster distance with different choices of k and stopping at the "knee" in the resulting curve.*

*The method was run on over seven hundred events extracted from four months of data. You can find more detail in the original paper: [https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9494830](https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9494830).*

**Question**: What are your thoughts on augmenting Time Synchronized data with non-synchronized data such as DFR recordings?

**Answer:** *I do think enriching data sources in general is good and will enable more discoveries from data. There can of course be a challenge with collating synchronized and unsynchronized data, but this may not be a major issue in several use cases. For example, PMU measurements can be useful for exploring data streams over long time periods and honing in on events. Once you've localized an event, the DFR data can provide much richer insight on the specific event. For this, the DFR time just needs to be good* *enough to match it to the event found in the PMU: this may not require more than second accuracy on the timestamps.*

**Question**: Have you compared the synchrophasors with the CPOW data? Have you considered how to deal with the information loss caused by synchrophasors?

**Answer:** *I have worked with both CPOW and synchrophasor data, though not parallel sources where I could directly compare the phasor to the waveform at a given time.*

*Overall, I think that we should use both data types in ways like that discussed in my reply above. Most of the time synchrophasor data has little information loss. We can augment the synchrophasor data with CPOW data in a targeted way, using the CPOW data when the synchrophasor model is too lossy. Having error metrics attached to the synchrophasor indicating how accurately the phasor model reflected the underlying waveform over time (as Harold Kirkham has described) would be useful to do this kind of targeted data augmentation.*

**Question**: For these algorithms, absolute accuracy doesn't matter much, since we are focused on relative comparisons across time?

**Answer:** *I believe this is a comment, not a question, but in either case this is absolutely right for many of the algorithms I discuss. Several are focused on detecting / identifying changes, not obtaining absolutely accurate impedance parameters.*