Title: Designing Model-Free Time Derivatives in the Frequency Domain for Ambient PMU Data Applications

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Summary of proposed presentation (1-3 paragraphs):

Estimating frequency is fundamentally a problem of estimating the phase angle time-derivative, Phasor Measurement Units (PMUs) provide a frequency estimate derived from the measured angle, , i.e., $\hat{f} = d\theta/dt$. However, these estimates can vary drastically between manufacturers, even in ideal testing conditions. More importantly, under practical field operation, such estimates can be affected by time-synchronization or internal clock errors. In addition, many steady state stability and control applications have the estimation of sensitivities as part of their core analysis function, e.g. $\partial V/\partial P$and $\partial V/\partial Q$ for voltage stability applications, which is a time-derivative estimate problem in disguise. Lately, there has been a lot of interest in developing similar applications to work with ambient PMU data. Providing robust derivate estimates under ambient conditions is especially challenging due to a poor signal to noise ratio. Furthermore, every application has a timescale of interest and validity, which needs to be accounted for when obtaining the estimates, which further adds to the complexity. Consequently, alternative means to reliably estimate a signal's derivatives of arbitrary order can be useful for PMU applications, particularly data-driven dynamic stability assessment applications such as detecting out of step condition, inertia estimation, etc.

To address the challenges, the current work proposes an *n-th* order derivative design framework for PMU applications that allows the user to account for the application's validity in relation to the time scale of interest. Not only this approach helps to address the numerous challenges surrounding derivative estimation, it also fills a gap in the state-of-the-art by providing a practical and generic framework for this purpose. Furthermore, because the framework is wholly in the frequency domain, it may be used with spectrum analysis tools to build derivatives for ambient PMU data applications, which has gone entirely unaddressed in the current literature.

The proposed framework is illustrated using both synthetic and real-world data from Dominion Energy's service territory. Practical cases that involve derivative estimation are illustrated and include an example for Thevenin equivalent circuit estimation and frequency estimation under internal PMU clock-errors.

Statement of novelty or impact, answering the question why would the NASPI community benefit from receiving this presentation? (1 paragraph): While multiple applications depend on PMU signals' derivatives, surprisingly, the problem of computing derivatives hasn't been examined in depth in the power system literature, especially for ambient data. Previous work in the literature consider each application in a case-by-case basis and therefore, there is a lack of a generic framework for derivative design that can be applied to any type of synchrophasor signal. Often, not much thought is given to their actual effect on a signal's content and, at most, data is smoothed before/after an ideal type of numerical differentiation.

This work shows, for the first time, how to apply a generic framework to robustly estimate derivatives from PMU data under real-world conditions and internal PMU clock-errors. The framework is also the first to design approach the derivative estimation problem from a frequency-domain design perspective, which is instrumental for ambient PMU data applications, and allows to consider the timescale of the dynamics of interest embedded withing a signal's spectrum during the design phase.