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Optimal Filtering for Grid Event Detection from Real-time Synchrophasor Data

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Abstract
This paper shows the use of optimal filter estimation for real-time data processing to automatically detect dynamic transient effects in phasor data produced in a synchrophasor vector processing systems. The optimal filters are estimated on the basis of phasor data where no disturbances are present and the estimation problem is formulated as a least squares optimization. Event detection bounds are computed from variance estimates and events are detected by formulating conditions on the number of consecutive samples for which the filtered phasor signals are outside of the bounds. Event detection is illustrated on the phasor data obtained from a microPMU system developed by Power Standards Lab.

Keywords: Event Detection, Synchrophasor Data, Grid Monitoring, Estimation, C37.118

1 Grid Monitoring

The intensification of distributed renewable energy resources, along with the deployment energy storage systems to buffer intermittent energy production, has motivated the need to monitor power flow and power quality more accurately in the electricity grid. Complementary to the traditional Supervisory Control And Data Acquisition (SCADA) systems, synchrophasor vector processing systems implemented in (protection) relays, digital fault recorders and specialized Phasor Measurement Units (PMU) can produce time synchronized measurements of 3 phase AC amplitude and phase angle (phasor) of voltage and currents [2].

The enormous volumes of synchronized time stamped data produced at 60Hz sampling by PMUs provides a clear challenge for data management and provides new opportunities for power systems control and protection [13, 14, 3]. Manual observations of PMU data time sequences to observe trends or possibly detect anomalies in the data quickly becomes a unwieldy task. It has been recognized that automated or semiautomated data analysis techniques to identify faults [9], out-of-step conditions [12], power generation anomalies [17], detect PMU data events on multiple PMUs [20], state estimation [11] and possibly extract (dynamic) knowledge from such events [18] are highly desirable. Such applications greatly automate the data management

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task associated to analyzing PMU data and improve automated grid monitoring capabilities [10].

Algorithms for calculation of phasors, local system frequency and rate of change of frequency (RoCoF) that follow the guidelines of the (recent) IEEE Standard C37.118 [4, 8] are abundant. Especially the accuracy of phasor measurement under dynamic conditions, that include transient effects due to load switching, has been improved by dynamic phasor estimates that use (weighted) least squares, discrete-time (moving average) filtering and/or advanced algorithms based on discrete Fourier transforms [2]. Local signal processing (edge processing) of PMU data that exploits the same computational and processing capabilities of PMUs is important to reduce the need to transmit high frequency PMU data to a central repository for analysis and event detection.

This paper describes local synchrophasor based real-time data processing algorithm to automatically detect dynamic transient effects in AC voltage and current signals analyzed by a synchrophasor vector processing systems. The basic output of the algorithm is the time stamp when a dynamic event was detected. The approach is based on real-time discrete-time filtering of phasor data (amplitude and phase angle) to create optimal Filtered Rate of Change (FRoC) signals for each phasor and postulate an event detection algorithm based on the dynamic response of the FRoC signals. The idea of using phasors directly for event detection has been addressed in earlier work [5, 16, 15]. However, optimality of the FRoC signals is addressed in this paper by (recursive) least squares estimation of the parameters of a linear discrete-time filter that minimizes the variance of the FRoC signals for both angle and amplitude data of the phasor for event detection.

It is shown that such optimal filtering of phasor data will lead to FRoC signals that have much better variance properties than the RoCoF signals based on the rate of change of the bus frequency [7] produced by the PMU. The smaller variance properties are achieved by the optimal filter that estimates the dynamics of the noise on the phasor data due to sensor and grid dynamics and can be used to detect the start time of dynamic transient effects in phasors more accurately. For the practical illustration of the algorithm, real-time PMU data acquisition is implemented on a Raspberry PI computer running Python packages under Linux, receiving C37.118 format data from the microPMU system [19], developed by Power Standards Lab as an extension to the well-established low voltage PQube instrumentation by Power Sensors Ltd. It is shown how real-time processing of the phasor data received by C37.118 can be used for local event detection on the basis of data obtained during several local events measured by the microPMU.

2 Synchrophasor Data

2.1 Synchrophasor Data Representation

To explain the basic terminology and the use of phasor data for event detection, consider a measurement of a AC signal $x(t)$, which is either a voltage or current signal. In an ideal steady-state operating mode, the signal $x(t)$ is a pure sinusoidal signal $x(t) = A\cos(2\pi ft + \delta)$ with an amplitude A, frequency f, and phase offset δ. Using the phasor representation, the signal $x(t)$ is represented by the real part of the complex number $x(t) = \mathrm{Re}\{Ae^{2\pi ft}e^{j\phi}\}$ where $X = Ae^{j\phi}$ denotes the phasor of $x(t)$.

Although this is an accurate representation of a steady-state sinusoidal signal, any changes in the signal $X(t)$ with respect to the pure sinusoidal representation would mean that the amplitude A and frequency f would change with respect to time. To characterize these time