Adaptive Kalman Filtering for Robust Power System State Tracking[1]

Advanced Kalman Filter for Real-Time Responsiveness in Complex Systems

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Abstract

For decades, the Kalman filter (KF) has been extensively studied and applied as a powerful method for dynamic state estimation. The possibility of applying the KF to the dynamic state estimation of modern power grid systems has always seemed appealing, however it has proven challenging given the highly complex and dynamic nature of the state in modern power systems, and the relatively low measurement rate of traditional Supervisory Control and Data Acquisition (SCADA) systems (intervals of several seconds). However, given new phasor measurement technologies the KF once again seems promising for estimating dynamic power system states.

Lower Dimensional Measurement-space (LoDiM) state estimation with Dynamic Measurement Selection: For large-scale and wide-area interconnected power systems, the required computation makes real-time on-line estimation a major challenge. We have presented a new Kalman filter-based method we call Lower Dimensional Measurement-space (LoDiM) state estimation. LoDiM features a *dynamic measurement selection* procedure: a measurement subset that benefits the estimation the most is dynamically chosen for each cycle. Thus compared to traditional KF-based state estimation methods, which handle all measurements, it only deals with a lower dimensional measurement subspace during each cycle. The smaller measurement space incorporates less information each cycle, but has higher estimation rates. We can analyze and adjust the trade-off to achieve optimal performance. The simulation results illustrate a promising future of LoDiM in large-scale dynamic state estimations, for the power systems and beyond. Moreover, it can be parallelized for further optimizations.

An Adaptive Kalman Filter with Inflatable Noise Variances (InNoVa): Kalman filters achieve optimal performance only when the system noise characteristics have known statistics that obey certain properties (zero-mean, Gaussian, and spectrally white) and those statistics are known. However in practice the process and measurement noise models are usually difficult to obtain. When the theoretical models do not match the actual models, the estimated state can diverge from the true state, sometimes rapidly. To address this problem, we have proposed a more general approach: an adaptive Kalman filter (AKF) with inflatable noise variances (InNoVa), to achieve more robust state estimation. This novel AKF approach is lightweight and remarkably efficient in dealing with (distinguishing between) inaccurate system models AND un-modeled measurement errors.

Our approach is to employ a normalized *a priori innovation* test as well as a normalized *a posteriori innovation* test to help separating the process and measurement factors when facing statistically unlikely estimations. As a result, the estimator is able to appropriately adjust the noise model parameters in an on-line fashion. More specifically, the inflation of process noise covariance indicates fast changing state or even an incorrect model, while the inflation of measurement noise covariance implies potentially bad measurements. Simulations demonstrate the robustness of our algorithm under various adverse conditions, such as sudden changes of system dynamics and/or false measurements.

Because the adjusted noise parameters provide useful information about the system, it should be possible to incorporate AKF with InNoVa into the LoDiM algorithm. Intuitively, larger elements of process noise covariance point us to the faster changing state subspace (*e.g.* the fault area); LoDiM will focus on this subspace and select corresponding measurements to estimate it more frequently. On the other hand, larger elements of measurement noise covariance indicate poor measurements, so LoDiM tends to avoid selecting them.

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