Fusing Models and Data for a Dynamic Paradigm of Power Grid Operations[1]

Advanced Kalman Filter for Real-Time Responsiveness in Complex Systems

Zhenyu Huang*, Greg Welch**, Ning Zhou*, Yulan Li*, Patrick Nichols*, Daniel Chavarria*
*Pacific Northwest National Laboratory, Richland, WA 99352
**University of North Carolina at Chapel Hill, Chapel Hill, NC 27599

Abstract

Power grids face new challenges as a result of grid evolution meeting information revolution. Evolving from a single power line to today's giant networks over the last 120 years, the power grid will continue to see new changes at an accelerated speed. In the next 10-15 years, more than 15% of electricity will come from renewable sources, and more than 15% of loads will actively respond to grid situations and incentive signals, towards the national goal of "80 percent of electricity comes from clean energy sources by 2035" proposed in President Obama's State of the Union speech. This results in emerging stochastic behaviors and dynamics that the grid has never seen nor been designed for. To harness the ever increasingly complex system, the power industry is actively deploying advanced sensors at an unprecedented scale with the hope of better situational awareness and control. Approximately 100 million smart meters and sensors will be installed. Many of them are high-speed sensors at 30 samples per second or higher. They will generate a million times more data. However, without efficient methods for data processing, the system will become data-rich but information-scarce. In this project, Kalman Filter techniques are adapted to fuse sensor data with power grid models to convert the large amounts of data to knowledge of the dynamic behavior of the power grid, achieving better visibility than today's static paradigm of operation. Leveraging high-performance computing technology, the application can be made real-time to transition the power grid operation to a dynamic paradigm towards better reliability and higher efficiency.

High-order Approximation in Ensemble Kalman Filter (EnKF) for Simultaneous Real-time Tracking of States and Parameters: Today's tools for power grid operations are mostly based on steady-state models, unable to capture the dynamic nature and too slow to prevent system failures. Leveraging the high-speed time-synchronized phasor measurements, the EnKF is used to estimate dynamic system states and parameters by finding the best fit of large amounts of high-speed data with the power grid model. The EnKF is improved in several aspects: an iterative process is used to handle the high nonlinearity; a sequential localized method is incorporated to reduce the impact of spurious correlation caused by limited number of ensembles; multiple steps of model prediction are implemented for every measurement correction step to reduce discretization errors while matching the measurement speed; and optimal selection of measurement data is implemented to maximize the reduction of covariance within the allowed time interval. Case studies with realistic conditions have been performed to demonstrate the validity of the developed EnKF application. The developed EnKF is robust with 3% measurement noise, 30 millisecond (ms) time interval, and 20-40% model parameter errors.

Real-time Computation of EnKF Using High-Performance Computing Technology: The EnKF application is computationally intensive because it needs to solve a large set of equations with large amounts of measurement within a time window of 30 ms. For real-time power grid operation, the system states have to be estimated continuously at 30ms intervals. This requires the computation to be done quickly with high certainty. EnKF exhibits reasonable parallelism for high-performance computing implementation as each ensemble point is computed directly from the non-linear equations independent of other ensemble points. The key to the implementation is dense matrix multiplies and Cholesky decomposition. We have implemented the EnKF using MPI and Global Arrays. The codes scale to 1000s of cores for the 16,000-node western power grid model, promising for 10,000 cores. Parallel to improving computational speed, approaches are being implemented to reduce computational complexity. Collectively, the EnKF-based estimation of dynamic states is expected to achieve real-time performance and lay the foundation for the dynamic paradigm of power grid operations.

[1] This work is being performed as part of a DOE ASCR project #55036, "Advanced Kalman Filter for Real-Time Responsiveness in Complex Systems," Co-PIs: PNNL – Dr. Zhenyu Huang; and UNC – Dr. Greg Welch. Contributions from the following team members are acknowledged: PNNL – Dr. Barry Lee, Dr. Steve Elbert, Dr. Pengwei Du, Dr. Ruisheng Diao, and Dr. Oreste Villa; UNC – Dr. Gary Bishop, and Jinghe Zhang.