Abstract

Achieving High-Resolution Situational Awareness in Ultra-Wide-Area CPS

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Motivation: Energy infrastructure is a critical underpinning of modern society. To ensure its reliable operation, a nation-wide or continent-wide situational awareness system is essential to provide high-resolution understanding of the system dynamics such that proper actions can be taken in real-time in response to power system disturbances and to avoid cascading blackouts. The power grid represents a typical highly dynamic cyber-physical system (CPS). The ever-increasing complexity and scale in sensing and actuation, compounded by the limited knowledge of the accurate system state have resulted in major system failures. Therefore, methods and tools for monitoring and control of these and other such dynamic systems at high resolution are of significant importance and vital to emergent generation of tightly coupled, physically distributed CPS.

Impact: The transformative nature of this research is to turn a large volume of real-time data into actionable information and help prevent potential outages from happening.

Highlight: This project employs the power grid as a target application and develops a high-resolution, ultra-wide-area situational awareness system that synergistically integrates sensing, processing, and actuation.

First, from sensing perspective, high resolution is reflected in both measurement accuracy and potential for dense spatial coverage. Wide area, precise, synchronized, and affordable sensing in voltage angle and frequency measurements for large-scale observation is sorely needed to observe system disturbances and capture critical changes in the power grid. The crucial innovation of this work is to make accurate frequency measurement from low voltage distribution systems through the wide deployment of Frequency Disturbance Recorders (FDR).

Second, from processing perspective, high resolution is reflected in finer-scale data analysis to reveal hidden information. In practical CPS, events seldom occur in an isolated fashion. Cascading events are more common and realistic. A new conceptual framework is presented in the study of event analysis, referred to as event unmixing, where real-world events are considered a mixture of more than one constituent root event. This concept is a key enabler for the analysis of events to go beyond what are immediately detectable in the system. The event formation process is interpreted from a linear mixing perspective and innovative sparsity-constrained unmixing algorithms are presented for multiple event separation and spatial-temporal localization.

Third, from online implementation perspective, we tackle the challenging problem of online data programming and processing through novel programming abstractions such as DataSQL. Probabilistic and fault-tolerant methods and compact data structures are developed that are particularly suitable for large amount of online data processing and data programming abstractions on resource constrained platforms. This descriptive language allows embedding pattern descriptions on the desirable and undesirable interactions between events in the system, which will then be compiled into distributed runtime constructs to be executed in deployed systems.

Fourth, from the actuation perspective, the system pushes the intelligence toward the lower level of the power grid allowing effective local load participation to react quickly to contingencies based on the high-resolution understanding of the system state, enabling a more direct reconfiguration of the physical makeup of the grid.

Finally, the methods and tools are implemented and validated on an existing wide-area power grid monitoring system, the North American frequency monitoring network (FNET), as well as the hardware testbed constructed at our partner institute, the NSF/COE CURENT Center.