Next Generation Alarm Systems for large-scale, Complex Cyber-physical Systems

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Critical infrastructures are backbones of many countries' economy, security and health. Many critical infrastructures are **large-scale, complex cyber-physical systems (CPSs)** that are continuously growing in size and complexity. The sustainability of such systems relies heavily on alarm systems for safe, secure, and reliable operation. Emerging alarm tools focus primarily on developing new techniques to process and extract information out of massive data sets. Those approaches tend to ignore the fact that operators play an important role in the data processing and analytic link. Introducing new data/information to existing alarm systems, if not well organized and presented, will overload, confuse, or even mislead operators when making critical operational decisions.

The next generation smart alarm system should not only helps human operators detect system anomalies, but also assists operators to identify causes of the anomalies, respond to them optimally, and take proactive actions to prevent similar issues in the future. Most importantly, advanced data analytic tools will be enhanced by findings from psychological studies to account for operators' mental models, work flow, and information visualization needs, achieving smooth human-machine interaction.

The next generation alarm system design should be an interdisciplinary research effort and request multidisciplinary teams including researchers in engineering, computer science, sociology, and psychology. Close collaboration with CPS operators and control system software developers are also required to collect real operational data associated with selected system events and understand the data and work flows for processing the alarms. Interviews with CPS operators and experts to assess their cognitive patterns and strategies are especially important for designing new alarm system so that it can: 1) tailor the alarm informing process based on an operator's personal capability, experience, and cognitive pattern to enhance the event detection, diagnosis, and reaction performance, 2) assist information exchanges among operators, 3) provide actionable information to solve the operational issues.

I am interested in discussing with the workshop attendees about the design considerations, approaches, and the new architecture of the next generation smart alarm system. My personal interest is designing the next generation power grid alarm system. The integration of renewable generation resources, electric vehicle loads, and other distributed energy resources makes grid operation more challenging than ever before. In a smart power grid setting, the reliable and resilient operation of a modern power grid increasingly relies on the sensor, communication, and IT-based information management systems built on the physical power grid. However, today's information management in power grid operation tools mainly follows a stovepipe process. Each sensor network produces its own domain-specific data (e.g., the phasor measurement units (PMUs), supervisory control and data acquisition (SCADA), and smart meter measurements), and each data source is processed by domain-specific tool sets. The outputs are then presented to grid operators responsible for making decisions. As the number of different data sources increases, the number of possible actions increases exponentially. Assessing the credibility of each source, comprehending its implications, understanding the inter-relationships among different sources, and seeking supporting evidence in a timely manner present a significant cognitive challenge to the human operator, who is pressured to analyze these relationships and/or draw on relevant experience. This situation seriously undermines the DOE goals of improving operator situation awareness.

In the face of these problems, the current practice in the power grid operations community is to run massive offline analyses to derive model-based guidelines for online real-time operations. However, because power system components and configurations change in real time, it is hard for offline model-based analyses to maintain relevance and effectiveness. With the added problem of stove-piping of data, the resultant increased volume and complexity of data will only exacerbate human performance difficulties and lead to information overload and degraded decision making. Early signs may be ignored by operators until massive failures have propagated from one system to another. Important alarm messages may be buried among the hundreds of messages that operators receive when an incident happens. Without the envisioned computational higher-level reasoning and decision support to provide a more integrated analysis, effective utilization of new smart grid data sources will be in doubt.

Automatic, cross-domain, dynamic detection mechanisms are rarely used in power grid energy management systems because of: 1) different network characteristics across domains, 2) limitations in reasoning capability of computer-based expert systems, and 3) difficulty of maintaining and updating current rule-based approaches. Even if we successfully apply new technologies to address these challenges, there will be a need to introduce the new technology in a way that stakeholders and users will accept. Previous studies, including research on the

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Graphical Contingency Analysis tool with experienced power grid operators [1-6] and predictive defense models for smart grid applications [7-9], have shown that training and awareness programs must be incorporated into efforts to introduce and study the impact of such technologies to overcome biases and organizational cultures that work against their acceptance and adoption.

New technologies to provide advanced decision support to analyze, in near real-time, relevant high-resolution data sources from different domains to quickly detect, correlate, and assess abnormal phenomena are needed. The next generation alarm system will bring the computational advantage over an unaided human operator because the new reasoning system can represent expert knowledge that will apply across different power system configurations: i.e., while the power system configuration may change from "A" to "B" to "C", the decision support system maintains expert knowledge about A, B, and C that enables the system to recognize changes in configurations. The human operator, on the other hand, may be ill-equipped (without computational support) to recognize such changes.

I believe this workshop is a good opportunity for me to share my perspectives with other fellow researchers in the following discussion topics:

- Interfaces between energy-related critical infrastructures (gas, transportation, water, etc.)
- Cyber Physical security metrics, risk assessment, and penetration testing
- Self-sustained energy solutions (microgrids)
- Technology barriers and opportunities
- Co-modeling and co-simulation of emerging cyber-controlled energy networks
- Candidate architectures: hierarchical or decentralized
- Cyber physical security, including energy grid security and privacy

I worked with Pacific Northwest National Laboratory (PNNL) for 10 years (2003-2012) prior to my appointment as an Associate Professor at the Electrical and Computer Engineering Dept. at North Carolina State University (Jan. 2013). I have been conducting research projects in the area of integrated information management for grid operation since 2009 and have published a number of papers in the area [10-14]. Another research interest of mine that is in line with the theme of this workshop is the "co-modeling and co-simulation of emerging cyber-controlled energy networks". I led a team of researchers in PNNL modeling impacts of climate mitigation technologies on power grids. Interactions of different building energy management schemes, water management plans, and social and demographical changes on electricity consumptions are studied [15-19] for more efficient power grid operation and planning. I would be happy to present our preliminary results in those two topic areas at the workshop.

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