Embedded Sensor Network for Secure Electric Energy Infrastructure

Vijay Vittal+ and G. Manimaran*
+Dept. of Electrical and Computer Engineering, Arizona State University
*Dept. of Electrical and Computer Engineering, Iowa State University
vijay.vittal@asu.edu; gmani@iastate.edu

Abstract— In the deregulated electric industry, the generation, transmission, and distribution systems have become highly decentralized due to which estimating the state of the grid has become extremely complicated. Current state estimation methods are severely limited due to the lack of adequate interaction among subsystems in terms of exchanging electric measurements. There has been surge of research addressing this critically important issue using wide area measurement techniques, e.g., phasor measurement units, and employing sensor networks. This position paper outlines our research in the novel application of wireless sensor technology for assessing the structural health of transmission lines (mechanical measurements) to improve the observability and reliability of power systems. The use of mechanical measurements - such as temperature, tension, vibration, tilt – together with electric measurements enables not only to better estimate the state of the system, but also to detect imminent faults that are likely to occur in the system. We demonstrate the efficacy of the proposed methodology through simulation studies using AREVA dispatch training simulator. Our work opens up several research avenues in real-time embedded sensor network design, electromechanical state estimation, fault diagnosis algorithms, and power system application algorithms.

I. MOTIVATION

With the increasing threat of terrorism around the world, more attention is being paid to the security of the electric transmission infrastructure. Experiences in countries like Colombia, which has faced as much as 200 terrorist attacks on its transmission infrastructure per year 0, demonstrate the vulnerability of the power system to these kinds of events. Although it is very difficult to avoid or predict when and where these terrorist acts can occur, quick assessment of the situation can help operators to take optimal actions to avoid cascading events and the consequent partial or total blackouts.

The mechanical failures resulting from malicious attacks on a transmission line are basically the same as those that would result when extreme natural events affect a portion of the transmission line. Thus, any analysis conducted in this regard can also help in taking preventive and corrective action when acts of sabotage are directed on the transmission infrastructure.

The current method to assess the damage caused by any unexpected physical event on the transmission grid is the visual inspection of the transmission infrastructure 0. With problems that occur in concentrated environments, like substations or generating plants, it is not difficult to find and assess the damage with a fairly small crew or with adequately localized video surveillance. But in transmission lines which are geographically dispersed over hundreds of miles, this task is more difficult. Nevertheless, once an event occurs, the operator in the control center only receives indication that an electrical fault occurred, but not if it is temporary or permanent. Therefore, the operating standards state that he/she has to try to reinsert the faulted line in order to check the temporary/permanent condition of the event. Once all the attempts fail, then the line is marked as permanently out of service. The recent blackout events in the U.S. 0 and Italy 0 have shown that failure to assess and understand the condition of the power system and delay in taking appropriate corrective actions after just a single outage can lead to widespread blackouts of large areas of the power system.

II. OUR RESEARCH AND RESEARCH CHALLENGES

We propose the utilization of wireless sensor network technology for detection of mechanical failures in transmission lines such as: conductor failure, tower collapses, hot spots, extreme mechanical conditions, etc. The proposed application involves the installation of sensors for mechanical monitoring in predetermined towers of a transmission line and communicating via a wireless network. The main goal is to obtain a complete physical and electrical picture of the power system in real time, and determine appropriate control measures that could be automatically taken and/or suggested to the system operators once an extreme mechanical condition appears in a transmission line.

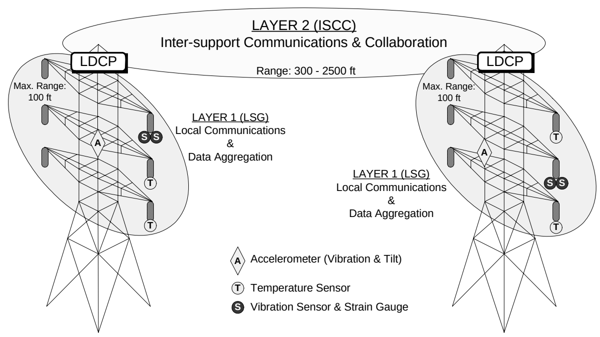

Fig. 1: Schematic of embedded sensor network in transmission line segment

For evaluating the feasibility of the concept, a dispatcher training simulator (DTS) based on the energy management system (EMS) platform from AREVA T&D was used for simulating the operation of the electric power system in real time as it is monitored at an actual energy control center. Our experimental studies show that the electro-mechanical state estimation of the system (using sensors) aids to take preventive measures that lead to significantly alleviating cascading faults and voltage collapse in the grid. We are in the process of a building test-bed involving sensor network interfaced with DTS to evaluate the various contingency scenarios using real measurements and decision algorithms.

Research Issues: The use of sensor network for real-time monitoring of critical components of transmission lines opens up several research issues:

1. Embedded sensor network design: Thus involves design and analysis of robust sensor network that satisfies real-time, reliable and secure communication requirements of the electric grid. The medium access protocol must support periodic and aperiodic (event-driven) messages with real-time constraints. Failure or compromise of one or more sensors should not compromise the reliability and integrity of the messages. Redundancy and security must be builtin the network architecture to address these requirements. Another important issue is to explore energy source for these sensors and also issues like minimizing the energy consumption are equally important.

2. Distributed sensing and control: The challenge here is to design controllers and decision algorithms that account network latency and channel loss characteristics. The issue becomes further complicated when the interaction among system controller and network controller (routing control) is explicitly modeled in order to understand the inter-dependency between these controllers.

3. Electro-mechanical state estimation algorithms: Traditional state estimation algorithms in electric grid are based on electric measurements. Need exists to develop state estimation algorithms that take into account the mechanical measurements (through sensor networks) as well as electrical measurements of the grid so as to arrive a significantly better state of the grid, which will lead to better decision algorithms.

4. Fault diagnosis algorithms: Mechanical measurements enable predicting imminent faults that are likely to occur by observing features such as the rate of change of values for a given parameter (e.g., temperature change). Using several independent measurements, composite measurements can be derived, which will provide a good indication on the predicated mechanical health of the grid and its impact on the electrical health.

5. Power system application algorithms: There are several applications, such as power flow analysis and security analysis, that use the output of the state estimation to carry out the required analysis. Most of these application algorithms can be redesigned leveraging the electro-mechanical state estimation of the grid.

Our ongoing research and future research focus on issues 1, 3, 4, and 5. Together with them, we plan to leverage the research developments for issue 2 to realize a more robust embedded sensor network for secure energy infrastructure. The fundamental knowledge of this research can be applied to other critical infrastructures, wherein the role of embedded sensor network has a significant role to play in improving the reliability and security of such systems.

References

[1] *Internal reports on Guerrilla attacks on the National Interconnected* System, Interconexión Eléctrica S.A., Medellín, Colombia, 1998 – 2004.

[2] A.J. Pansini, *Transmission line reliability and security*, Liburn, GA: Fairmont Press, 2004.

[3] U.S.-Canada Power System Outage Task Force, Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations, April 2004.

[4] Interim Report of the Investigation Committee on the 28 September 2003 Blackout in Italy, UCTE, 27 October 2003.