PhD Dissertation titled:

Smart IoT-Enabled Monitoring and Control of Modern Power Grid Networks

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Abstract:

The growth of power systems, influenced by rising demands and industrialization has led to complex challenges. The integration of renewables alongside traditional sources has introduced unpredictability in the generation, transmission, and distribution processes, resulting in wideband disturbance generation and propagation in modern grids. The integration of modern communication technologies into grid monitoring emphasizes the need for rigorous surveillance for ensuring a reliable power supply. Leading the transition to modern grid systems are Internet-of-Things (IoT) devices such as smart meters, digital relays, and notably, phasor measurement units (PMUs). PMUs offer accurate, time-stamped readings of essential system metrics, allowing for remote monitoring and potential real-time control via phasor data concentrators (PDCs). However, the voluminous PMU data presents processing challenges at PDCs.

While wireless connectivity offers adaptability and cost-effectiveness, it faces unique electromagnetic interference, especially in high-voltage scenarios. Phenomena like ‘corona discharge’ significantly impact wireless performance, making it essential to undertake its mathematical characterization. Characterizing these disturbances requires a broader perspective, encompassing electromagnetic spectra, emphasizing the significance of real-time communication and wideband impedance understanding. This dissertation research aims to fill this gap, wherein it investigates and proposes novel strategies for stability and control of perturbation-prone power networks by using smart IoT-based grid monitoring and control. Throughout the study it explores the relationship between power system-specific noise and wireless IoT node communication essential for real-time monitoring and control of such grids. Using PMU-to-PDC communication as an example, the study aims to address challenges and potential solutions in this domain.

Specifically, the study focuses on: 1) analyzing perturbation-prone power networks, 2) optimal placement of grid monitoring nodes, 3) analysis of wireless communication in smart grid environment, and 4) analysis of real-time data from grid monitoring IoTs. The research starts with modeling wideband power network disturbances and understanding their propagation. A novel device design for identifying harmonic sources in perturbed power networks is proposed. The high sampling rate requirement by these devices for capturing the precise perturbation characteristics, motivated the need to develop a real-time multivariate data pruning framework. The proposed data pruning strategy is validated on real-time data from field deployed PMUs. The proposition of node-level data pruning is extended to develop a network-level data pruning framework in optimally deployed PMUs in a network-wide setup. The PMU placement optimization is revisited in the process to ensure efficient communication bandwidth utilization while attaining a optimal power network observability. Analysis of IoT data transfer over smart grid wireless communication channels is undertaken and methods to mitigate the smart grid specific performance deterioration are suggested. To implement the channel state-aware solutions proposed through the performance analysis, a channel estimation strategy for smart grid impulse noise-ridden channels is introduced. Finally, the received data from the grid monitoring IoTs is utilized in characterizing the wideband disturbance profile in modern-day perturbed power networks. Consequently, a novel optimization formulation is proposed for the grid monitoring IoT nodes, which can ensure a real-time reliable control of perturbed power networks. All the optimizations and their solutions are validated on standard IEEE test systems of various capacities, network size, and architecture.