

Intelligent Condition Monitoring and Predictive Maintenance for V2G-Integrated Smart Grids under Uncertainty

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The rapid proliferation of electric vehicles (EVs) and their integration into power systems through Vehicle-to-Grid (V2G) technology is transforming conventional grids into highly dynamic, bidirectional, and data-intensive smart grids. While V2G offers significant opportunities for grid flexibility, peak shaving, and renewable energy support, it also introduces substantial uncertainties related to stochastic charging behavior, intermittent renewable generation, power electronic converter interactions, and evolving cyber-physical threats. These uncertainties pose critical challenges to the reliability, stability, and lifespan of grid assets. This lecture will present an advanced framework for intelligent condition monitoring and predictive maintenance of V2G-integrated smart grids under uncertain operating environments. The focus is placed on monitoring critical components such as EV charging infrastructure, power electronic converters, transformers, and battery systems, which are subjected to increased thermal, electrical, and harmonic stresses due to bidirectional power flows. The lecture explores the integration of sensor technologies, Internet of Things (IoT) platforms, and data-centric techniques for real-time asset health assessment and fault diagnostics. Furthermore, the role of advanced analytics, including machine learning and hybrid physics-informed models, is discussed in enabling accurate fault prediction and remaining useful life estimation. The lecture will also highlight the impact of cyber-physical vulnerabilities on condition monitoring systems and emphasizes the need for resilient and secure monitoring architectures. Practical insights, emerging trends, and application perspectives—particularly in the context of developing and evolving power systems—are presented to demonstrate how intelligent monitoring strategies can enhance system reliability, reduce maintenance costs, and support the sustainable deployment of V2G technologies.