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Harmonic Disturbance Analysis and Active Filtering Control in Grid-Connected Wind Power Systems

With the rapid growth of renewable energy, large-scale integration of wind power into electrical grids poses new challenges to system stability and power quality. Unlike conventional power sources, wind turbines—especially those using power electronic converters such as rectifiers and inverters—introduce non-linear and time-varying characteristics, making the grid more susceptible to harmonic distortion, voltage fluctuations, and reduced power quality.

Among these issues, harmonic disturbances are particularly problematic in grid-connected wind energy systems. Harmonics can interfere with sensitive equipment, trigger protection malfunctions, and even lead to resonance phenomena in the grid. Understanding the mechanisms of harmonic generation and propagation is therefore essential for ensuring safe and efficient operation of wind-integrated power systems.

Traditional passive filters offer a simple solution for harmonic suppression but lack adaptability and are sensitive to system parameter variations. In contrast, Active Power Filters (APFs) provide a dynamic and flexible approach to harmonic compensation. APFs are capable of identifying and canceling a wide range of harmonic frequencies in real time, making them especially suitable for power quality management in wind power integration scenarios.

This study aims to analyze the mechanisms of harmonic generation and propagation in grid-connected wind energy systems and assess their impacts on power quality and system operation. A representative wind farm model is developed, and both time-domain and frequency-domain simulations are conducted to evaluate harmonic behavior under varying operating conditions. An advanced control strategy for APFs is then proposed, based on instantaneous reactive power theory and improved current control techniques, to effectively identify and compensate both low-order and high-order harmonics.

Simulation validation is performed using the MATLAB/Simulink platform. Key performance metrics such as total harmonic distortion (THD), power factor, and voltage/current waveform quality at the point of common coupling (PCC) are analyzed to verify the effectiveness of the proposed filtering method.

The results of this study are expected to provide theoretical insights and practical solutions for improving power quality in modern power systems with high wind penetration, thereby supporting the safe and reliable integration of renewable energy into the grid.