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Synergistic Optimization of Wind Energy and Energy Storage Technologies for Enhanced Renewable Energy Utilization

As the global energy system transitions toward low-carbon and renewable sources, wind energy has become a key contributor to clean electricity generation. However, the intermittency and variability of wind power significantly affect its stable integration into the grid and the overall utilization of renewable energy. Relying solely on wind power output may lead to curtailment and energy waste while posing challenges for grid stability. To maximize the benefits of wind resources and enhance renewable energy consumption, the integration and optimization of energy storage technologies are essential.

Energy storage systems, including electrochemical storage (e.g., lithium-ion batteries, sodium-sulfur batteries), mechanical storage (e.g., pumped hydro, compressed air storage), and thermal storage, can balance energy supply and demand between wind generation and load. By smoothing output, shifting energy delivery, and reducing peak demand, storage systems increase wind energy utilization and enhance grid flexibility and reliability. Additionally, storage can provide frequency regulation, voltage support, and reserve capacity, ensuring the technical feasibility of large-scale wind integration.

In practice, the synergistic optimization of wind energy and storage involves multiple dimensions, including capacity sizing, power control strategies, charge-discharge scheduling, and economic analysis. Multi-objective optimization models allow for simultaneous consideration of wind power revenue, storage cost, curtailment reduction, and grid operational constraints, achieving an optimal combination of wind and storage. Moreover, intelligent control methods, such as artificial intelligence and machine learning algorithms, show great potential for predicting wind conditions, optimizing storage dispatch, and dynamically managing energy flows.

This study aims to systematically analyze strategies for synergistic optimization of wind energy and storage technologies. By establishing multi-objective optimization models and simulation frameworks, it evaluates the impact of different storage configurations on wind energy utilization, system economics, and operational reliability. The results are expected to provide theoretical guidance and technical support for efficient exploitation of wind resources, large-scale renewable energy integration, and the development of low-carbon power systems.