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# Hydrogen Storage Systems for Enhanced Grid Balancing Services in Wind Energy Conversion Systems

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**Abstract :** The growing adoption of renewable energy sources, such as wind power, in electricity generation is a significant step towards a sustainable and decarbonized future. However, the inherent intermittency and uncertainty of wind resources pose challenges to the reliable and stable operation of power grids. To address this, hydrogen storage systems have emerged as a promising and versatile technology to support grid balancing services in wind energy conversion systems. In this study, we propose a supplementary control design that enhances the performance of the hydrogen storage system by integrating wind turbine (WT) pitch and torque control systems. These control strategies aim to optimize the hydrogen production process, ensuring efficient utilization of wind energy while complying with grid requirements. The wind turbine pitch control system plays a crucial role in managing the turbine's aerodynamic performance. By adjusting the blade pitch angle, the turbine's rotational speed and power output can be regulated. Our proposed control design dynamically coordinates the pitch angle to match the wind turbine's power output with the optimal hydrogen production rate. This ensures that the electrolyzer receives a steady and optimal power supply, avoiding unnecessary strain on the system during high wind speeds and maximizing hydrogen production during low wind speeds. Moreover, the wind turbine torque control system is incorporated to facilitate efficient operation at varying wind speeds. The torque control system optimizes the energy capture from the wind while limiting mechanical stress on the turbine components. By harmonizing the torque control with hydrogen production requirements, the system maintains stable wind turbine operation, thereby enhancing the overall energy-to-hydrogen conversion efficiency. To enable grid-friendly operation, we introduce a cascaded controller that regulates the electrolyzer's electrical power-current in accordance with grid requirements. This controller ensures that the hydrogen production rate can be dynamically adjusted based on real-time grid demands, supporting grid balancing services effectively. By maintaining a close relationship between the wind turbine's power output and the electrolyzer's current, the hydrogen storage system can respond rapidly to grid fluctuations and contribute to enhanced grid stability. In this paper, we present a comprehensive analysis of the proposed supplementary control design's impact on the overall performance of the hydrogen storage system in wind energy conversion systems. Through detailed simulations and case studies, we assess the system's ability to provide grid balancing services, maximize wind energy utilization, and reduce greenhouse gas emissions.

**Keywords :** active power control, electrolyzer, grid balancing services, wind energy conversion systems
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