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Impact Analysis of Power Electronic Interfaces on the Stability of Distributed Energy Systems

With the widespread deployment of distributed energy systems (DES) in urban and industrial energy supply, power electronic interfaces have become critical for ensuring reliable operation and efficient energy conversion. Distributed photovoltaic, wind, storage, and microgrid systems typically rely on inverters, converters, and power regulation devices to connect with the grid or local loads. While power electronic interfaces offer fast response, flexible control, and high efficiency, their nonlinear characteristics, control strategies, and interactions with system dynamics can significantly impact overall system stability.

High penetration of renewable energy in DES introduces considerable uncertainties and dynamic behavior, including voltage fluctuations, frequency disturbances, and load variations. The control modes, response speed, and protection strategies of power electronic interfaces directly affect both short-term and long-term system stability. For example, fast inverter regulation may induce voltage oscillations or interact with the inertial response of conventional rotating machines, potentially compromising operational safety. Optimizing interface parameters and control strategies is therefore key to enhancing DES stability.

This study presents an analysis methodology for evaluating the impact of power electronic interfaces on DES stability. A dynamic system model incorporating voltage, current, and power characteristics is developed, and simulations are performed under varying load fluctuations, renewable generation variability, and disturbance scenarios. Stability indicators and performance metrics are used to quantify the effects of interface characteristics on system dynamic response and stability margin, and optimization strategies are proposed to improve overall system robustness.

The results indicate that properly designed and controlled power electronic interfaces can significantly enhance the operational stability of DES, reducing power fluctuations and mitigating potential failure risks. This research provides engineering guidance for planning, control design, and operational management of distributed energy systems, supporting safe, efficient, and sustainable operation under high renewable penetration.