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Smart Grid Technologies and Their Impact on Power Quality

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Abstract: *As our power systems move away from large centralized plants toward renewable-based, decentralized setups, traditional grids are transforming into smart, connected networks. These smart grids are more efficient, flexible and eco-friendly but they also bring new problems with power quality (PQ). Issues like unstable voltage, frequency changes and unwanted electrical noise (harmonics) are becoming more common, especially with electricity now flowing in both directions between the grid and active consumers who also produce power. This study looks at how distributed energy storage systems (DESS) when paired with smart control methods can make smart grids more stable and reliable. We propose a multi-layer approach that uses grid-forming inverters, smart prediction for when to use storage and coordinated methods to reduce harmonics. All of this works through real-time monitoring and adaptive control, so storage and renewable sources work together smoothly. Our computer simulations show clear benefits i.e. better voltage and frequency stability, lower harmonic distortion and faster recovery when problems occur. On top of that, the system helps manage peak electricity demand, smooths out the ups and downs of renewable power and recovers quickly from short-term disruptions. By combining smart storage with advanced controls, this approach offers a scalable way to make future smart grids more reliable and resilient helping utilities, engineers, and policymakers handle the challenges of our rapidly changing energy world.*

Keywords*:* Smart grid, Power quality (PQ), Distributed energy storage systems (DESS), Grid-forming inverters, Harmonic suppression, Voltage stability, Frequency stability, Predictive Storage dispatch, Renewable integration, Peak load management, Adaptive control, Real-time monitoring

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