Abstract of PhD Thesis

"Control of Wind Driven-DFIG-SPV Array-Battery Based Microgrids with Synchronization"

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The global shift toward sustainable energy sources has driven significant advancements in renewable energy technologies, particularly in wind and solar power. As these sources become increasingly integrated into global energy grid, challenges related to stability, power quality, and efficient management of energy resources in microgrids have emerged. Microgrids, especially deployed in distribution systems and in remote and semi-urban areas, have gained considerable attention due to their ability to integrate renewable energy sources, offer localized control, and enhance grid support functionalities. Among various renewable energy technologies, wind energy, particularly through doubly fed induction generators (DFIG), has gained prominence due to absence of costly rare earth magnets and potential for bulk power generation with partially rated power converters, while solar photovoltaic (SPV) arrays are a key renewable source due to their widespread availability, low cost, and minimal maintenance requirements due to absence of rotating parts. However, integration of these sources leads to power variability at point of common coupling (PCC) and fluctuations in PCC voltage parameters associated with voltage phase angle jumps and amplitude fluctuations. Moreover, loads demanding currents polluted with harmonics, negative sequence, and reactive currents further demean system power quality increasing line copper losses and degrading wind transformer performance. Such currents challenge fundamental estimation capabilities required for inverter control. Additionally, voltage disturbances propagate through inter-coupled estimation loops of phase and frequency locked loops (PLLs/FLLs), necessitating implementation of sophisticated control strategies with advanced filters for fast and accurate fundamental signal estimation to enhance inverter control. To address these issues, multimode, multifunctional control strategies are essential for ensuring reliable operation, improved power quality and seamless system transition among various operating modes with smooth synchronization performance.

To address evolving needs of solar photovoltaic (SPV) array and wind driven DFIG-based microgrids, various topological advancements are explored in this thesis, each offering specific advantages in terms of power quality, reliability, and energy management. Initially, batteryless single-stage SPV microgrids offered a cost-effective and simple design by eliminating intermediate converters and energy storage. However, they struggled with DC link fluctuations that may lead to operation of solar inverter in overmodulation zone. Further, varying DC link voltage also increases inverter losses, which is reduced with a two stage or double stage configuration with an intermediate DC-DC boost converter that ensures adaptive DC link voltage to ensure optimal DC link voltage regulation with grid voltage to ensure optimal losses within inverter. Further, transitioning from a three-phase three-wire (3P3W) to a three-phase four-wire (3P4W) configuration has addressed critical issues related to unbalanced and single-phase loads, which caused phase overloading and voltage instability in 3P3W systems. 3P4W AC systems, with a neutral conductor, has provided better load balancing and voltage regulation across loads, ensuring safe operation of sensitive equipment. However, burden on neutral conductor during connected nonlinear loads leads to neutral overloading or overheating and possible bursting of neutral wire, necessitating neutral current compensation with the solar inverter alongside load harmonics, negative sequence, and reactive power compensation. Despite these improvements, absence of energy storage in batteryless configurations limited their capability during periods of low solar irradiance or grid outages. Integrating a battery energy storage system (BES), particularly with a bidirectional converter (BDC), has enabled regulated power supply by storing excess energy and providing backup during peak demand or nighttime, thereby enhancing system self-sufficiency and power quality. BDC also minimized 100Hz ripple currents, reducing stress on both BES and SPV array. Moreover, transition to dual-stage SPV architectures—with dedicated converters for SPV array and BES has allowed independent control and optimized power processing. These systems could flexibly switch between grid-forming (GFM) and grid-following (GFL) modes, enabling better compensation for harmonics, negative sequence currents, and load imbalances in both grid-tied and standalone operations. The need for improved resilience and multi-source integration has led to configurations combining SPV arrays with DFIG-based wind energy systems (WECS). These systems have enabled hybrid renewable operation across four modes—grid-connected or islanded, with DFIG stator connected or disconnected—allowing eight possible transition states. Control strategies ensure fast synchronization with grid or DFIG stator to support seamless transitions and continuous power delivery. More advanced microgrid topologies are also analysed incorporating an alternate power converter (APC) to reduce WECS transformer rating and burden of load harmonics, reactive and neutral current and ensure continuous load neutral and harmonics compensation.

The research presented in this thesis employs both experimental hardware results and simulation studies to validate the proposed solutions into the explored microgrid topologies. Through comprehensive hardware testing, the thesis demonstrates effectiveness of the proposed control algorithms in improving system reliability with improved power quality performance. Simulation results are presented to support experimental findings.