Abstract of Ph.D. Thesis

"Design, Development and Control of Multifunctional Grid Interfaced Solar PV Systems and Battery Energy Storage Based Microgrids with Grid Supportive Features"

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This work aims to propose multiple solutions to address various challenges associated with integrating PV generation systems into modern low voltage distribution networks. Various configurations of grid interfaced multifunctional PV units are presented, and associated control algorithms are developed. Grid voltages in distribution network are prone to being unbalanced and distorted. An accurate phase angle of grid voltages is necessary for grid synchronized operation, otherwise stability and power quality (PQ) issues arise. In this work, multiple new filters are developed, analyzed and compared with reported filters, and provide better removal of defects in sensed grid voltages such as harmonics components, unbalance and DC offset. Using developed control mechanisms, system has a capability of grid interconnection at weak grid conditions, and continues feeding balanced, and sinusoidal currents to the grid.

Local loads present at point of common coupling (PCC) are nonlinear, which draw reactive power, neutral current, harmonics currents, and unbalanced power from grid. The system is suitably controlled by advanced control algorithms, to mitigate the impact of such loads on the grid. Conventionally, the regulation of the DC link voltage of the voltage source converter (VSC) interfacing the PV array with the PCC, is used to achieve power balance, and control grid currents. However, the dynamic performance at changing PV array power or varying local loads, is not satisfactory. The response in grid currents, to changes on the PV side and grid voltage variations, is expedited using a PV feed forward term. Similarly, an estimate of the load current is made, and used to hasten system response to load changes. In the reported methods to estimate load, a vulnerability is found, which is the poor performance in the presence of impulsive noise. In this work, the significance of local load current weight estimation is underlined, in conditions where the DC link voltage is liable to have ripples due to unbalanced VSC currents, and a mechanism is implemented to make the estimation robust against impulsive environment or sensor noise.

A single stage PV system involves direct coupling of PV array with the DC link of the grid interfaced VSC. While an intermediate stage is avoided, the control of DC link voltage is constrained to track the maximum power point (MPP) voltage of the PV array. In conventional single stage system, this causes PQ issues at conditions such as low irradiance and grid overvoltage, when the DC link voltage is less than required to properly control grid currents. A flexible mechanism for the control of DC link voltage for a single stage system is presented in this work, which rectifies the PQ issues, maintains desired modulation index of VSC, and reduces operating losses. The presented control also enables deliberate de-rating of PV array power during voltage dips to limit grid currents and mitigate overcurrent tripping issues, ensuring continued current injection to support the grid. During voltage rises, the de-rated PVA power helps prevent further deterioration of utility network conditions, by lessening or eliminating the power outflow to the grid.

The challenges faced by utilities in accommodating significant amounts of intermittent power from local distributed PV generation units are also addressed. The lack of control over the PV array power production makes it difficult to match the real time supply against demand, which causes voltage regulation problems of undervoltage (UV) and overvoltage (OV) as well. Moreover, the time of availability of PV power causes large variations between the amount of power the utility is required to supply throughout the day, causing increased reliance on peak power plants which are often diesel run. Hence, buffering energy storage is required for easing such issues, and to allow for further penetration of PV units. However, it is seen that the utilization of battery energy storage (BES) is limited in the reported PV-BES systems.

The developed control strategy leverages the BES to achieve several operational benefits. It eliminates grid power fluctuations caused by variations in PV array output and local load demand. The injected grid power is dynamically adjusted based on prevailing feed-in tariffs, maximizing economic benefits and contributing to demand-side power curve flattening. There is a provision to import and store power from the grid at lower rates. Unlike conventional systems, it prevents tripping during significant voltage drops, ensuring continued support to the utility even when PV power production is absent. Additionally, no de-rating of PV array is required. During overvoltage conditions, the system aids the utility by halting power export while allowing power import as needed. Furthermore, the BES health is preserved by transitioning to a recovery mode upon detecting over-charge or over-discharge conditions.

Proposed solutions are developed for three phase three wire and three phase four wire system configurations, with two stage and single stage implementations. The system and associated developed control strategies are modelled and simulated using MATLAB SIMULINK platform and evaluated using tests performed on a developed hardware prototype at various challenging use cases. The PQ compliance with IEEE 519 and IEEE 1547 standards is verified.