Abstract

Renewable energy sources (RESs) are the sustainable solution to the present energy crisis and environmental pollution issues, which produces energy from natural sources like sunlight, wind, tides and geothermal. Among the RESs, solar photovoltaic (PV) technology is more popular and widely accepted due to lack of moving mechanical parts, and lower maintenance. According to the recent PV technology developments, solar PV-based renewable power generation has experienced swift growth among the commercial and residential sectors. Therefore, more and more PV systems are being installed and integrated into the distribution grid in the form of grid-tied PV system. However, there are some challenges in the power quality in the grid-tied PV systems due to various issues such as grid voltage harmonics, voltage sags, voltage swells and frequency deviation. The increased use of nonlinear loads such as compact fluorescent lamps, variable speed drives and power electronics interfaced converters increases the harmonic pollution and consequently deteriorates the power quality of the grid-tied PV systems. The increased harmonics in the injected current of the grid-tied PV system minimizes the life span and raises the malfunction of the equipment connected to the distribution network. The other issues of power qualities are active and reactive power oscillations during grid voltage sags/faults the grid-tied PV system. These power oscillations lead to ripples in DC-link voltage, which degrades the performance of the grid-tied PV system by increasing losses in the system and reducing the life span of PV sources. Further, during the grid fault conditions, the PV sources must achieve low voltage ride-through (LVRT) capability for keeping it connected with the grid for better reliability. Another issue in the grid-tied PV system is the weak grid (large grid impedance). The problem of power quality increases under weak grid conditions. Also, under this condition, the wide variation of the grid impedance leads to voltage fluctuations at the point of common coupling. As a consequence, the system cannot achieve the desired control performance. These issues are the driving force for the researchers to orient their research work to suppress grid current harmonics, eliminate power oscillations and enhance the LVRT capability of the grid-tied PV system.

Various control techniques have been used to handle the power quality issues in the grid-tied PV system. However, the existing control techniques face several challenges such as 1) unable to identify the active and reactive power limits of a PV system at MPP conditions;

2) lesser stability of the controllers at grid frequency; 3) complexity in the controller for design and implementation; 4) the simultaneous mitigation of grid currents harmonic and power oscillations; 5) simultaneous mitigations of current harmonics and enhancement of LVRT of the grid-tied PV systems and 6) the performance of the existing control strategies are not satisfactory under distorted and weak grid conditions.

To take care of the above issues, an improved mathematical methodology for deriving the active and reactive power limit for MPP operation and three advanced control strategies for mitigating power quality issues are proposed in this thesis. The improved mathematical methodology is used to obtain the *P-Q* capability curve of the grid-tied PV system under MPP conditions defining the active and reactive power limits. The first advanced phase-locked loop (PLL)-based control strategy proposed in this work simultaneously reduces the grid current harmonics and power oscillations under distorted grid voltage conditions. The second control strategy reduces the grid current harmonics and eliminates the active and reactive power oscillations without PLL under distorted grid voltage conditions. The third control strategy is the PLL-less strategy that enhances the LVRT capability with reduced grid current harmonics in grid-tied PV system under distorted and weak grid conditions.

The improved methodology is presented to derive the *P-Q* capability curve of the grid-tied PV system to find real and reactive power limits at MPP under various environmental conditions. The reactive power is managed by selecting all the possible sets of working points within the stable region of operation. The reactive power reference for the current controller of a grid-tied PV system is obtained by utilizing the capability curve.The first advanced PLL-based control strategy proposed in this thesis is used to simultaneously reduce grid current harmonics and eliminate power oscillations under distorted grid voltages. The proposed control strategy comprises an advanced proportional multi-resonant (APMR) controller integrated with a compensator for grid voltage sag (CGVS). The proposed APMR controller achieves wider bandwidth than the conventional PMR (CPMR) controller and finite gain at the resonant frequency. The CGVS and APMR controllers operate co-ordinately to eliminate the active and reactive power oscillations under unbalanced grid voltage conditions. Further, an adaptive step size incremental conductance (ASINC) maximum power point tracking (MPPT) controller in integration with the proposed control strategy is used for faster tracking of MPP under different environmental conditions. The effectiveness of the proposed control strategy is verified on a laboratory prototype of 3.8 kW PV power using a real-time digital simulator OPAL-RT OP4510. The experimental results show that the proposed control strategy achieves reduced current harmonics, low total harmonic distortion (THD), negligible power oscillations and faster frequency adaptability as compared to the CPMR control strategy.

The proposed APMR control strategy reduces the grid current harmonics effectively. However it requires a PLL block to synchronize the PV inverter to the grid. The PLL-based control strategy has poor frequency adaptability under grid frequency variations. To address these issues, the second, advanced control strategy based on PLL-less scheme is proposed for the simultaneous reduction of grid current harmonics and power oscillations under distorted grid voltage conditions. The proposed PLL-less APMR controller is integrated with a phase compensated reference current generator (PCRCG) to simultaneously reduce the grid current harmonics and power oscillations. The proposed PLL-less control strategy is implemented in the $\alpha\beta$ stationary reference frame, thus reducing the associated computational requirement and complexity. The experiments are carried out on a 3.65 kW PV power module. The experimental results show satisfactory performance of the proposed PLL-less control strategy with reduced grid current harmonics and power oscillations than the conventional PLL-based control strategy.

In the case of grid fault, the PV system must remain connected with the grid for reliable operation. For that purpose, the PV system should have LVRT capability. The performance of the proposed PLL-less APMR strategy integrated with PCRCG deteriorates under fault and weak grid conditions. The third proposed control strategy is a modified form of the PLL-less APMR control strategy, which successfully achieves enhanced LVRT operation, reduced grid current harmonics and negligible power oscillations simultaneously under weak and distorted grid voltages. This proposed modified PLL-less control strategy consists of an active power regulator (APR) with dynamic reactive power support (DRPS) controller, which enhances the LVRT capability of the grid-tied PV system during unbalanced grid faults. Further, an advanced phase compensated multi resonant (APCMR) controller integrated with APR and DRPS controller reduces grid the current harmonics under distorted and weak grid conditions. The proposed PLL-less control strategy is validated by conducting detailed experimental studies on a 4.3 kW laboratory prototype. A comparison among the proposed and different existing control strategies are also discussed to bring out the effectiveness of the proposed PLL-less control strategy in terms of various features such as LVRT capability enhancement, harmonic current mitigation, power oscillations reduction and frequency adaptability improvement.