DC-link voltage control of a Grid-connected solar photovoltaic system

The high penetration level of solar photovoltaic (SPV) generation systems imposes a major challenge to the secure operation of power systems. SPV generation systems are connected to the power grid via power converters. During a fault on the grid side, overvoltage can occur at the direct current link (DCL) due to the power imbalance between the SPV and the grid sides. Subsequently, the SPV inverter is disconnected; which reduces the grid reliability. DC-link voltage control is an important task during low voltage ride-through (LVRT) for SPV generation systems. By properly controlling the power converters, we can enhance the LVRT capability of a grid-connected SPV system according to the grid code (GC) requirements. This study proposes a novel DCL voltage control scheme for a DC-DC converter to enhance the LVRT capability of the two-stage grid-connected SPV system. The control scheme includes a “control without maximum power point tracking (MPPT)” controller; which is activated when the DCL voltage exceeds its nominal value; otherwise, the MPPT control is activated. Compared to the existing LVRT schemes the proposed method is economical as it is achieved by connecting the proposed controller to the existing MPPT controller without additional hardware or changes in the software. In this approach, although the SPV system will not operate at the maximum power point and the inverter will not face any over current challenge it can still provide reactive power support in response to a grid fault. A comprehensive simulation was carried out to verify the effectiveness of the proposed control scheme for enhancing the LVRT capability and stability margin of an interconnected SPV generation system under symmetrical and asymmetrical grid faults.

2. Grid Connected solar PV system

Figure 1 illustrates the schematic diagrams of the grid connected PV system. Two-stage energy conversation systems are used in this work. The first stage of the energy conversion system consists of a PV array and a DC-DC converter, which boosts the relatively low SPV system voltage to match with the inverter input voltage rating. The next stage consists of a voltage source converter (VSC) connected to the grid via an L-filter and a step-up transformer to increase the inverter voltage to match with the grid voltage, respectively [26]. The incremental conductance (IC) maximum power point tracker (MPPT) for the PV is implemented on the boost converter for extracting maximum power under the normal condition. Moreover, “control without MPPT” controller is adopted under the fault condition. The inverter control scheme is modified to inject the required reactive current to the grid under the fault condition by using the developed reactive power injection strategy.

![Figure 1. Schematic diagram of grid-connected PV system.](image)

3. Proposed Low voltage ride-through (LVRT) Enhancement Strategies:
3.1 DC-Link (DCL) voltage control scheme

The simple PI controller selected for this study provides immediate changes in the control signal according to the respective set value. The proposed control strategy controls the injected active power to the grid during voltage sag while avoiding the over-voltage in the DCL. When we use the PI controller under “control without MPPT” mode, a problem may occur because the system works at a different point than the MPP under the fault condition. Therefore, the DCL voltage takes a long time to reach the nominal value after the fault is cleared, because the error in the DCL voltage promotes the accumulation of control action to an integral part of the PI controller at the end of voltage sag, which should be compensated by an input error in the opposite direction. Therefore, the actual DCL voltage is reduced below the reference value, which may cause the inverter to lose control and be disconnected. To solve this issue, anti-wind-up technique is applied to the PI controller to accumulate excessive control action when it exceeds a specified value. Thus, when the voltage sag ends, the DCL voltage recovers to the nominal value without perceptible overcompensation.

Figure 3. Proposed DC-link voltage control.

The operational flowchart as shown in Figure 5. Under the fault condition, initially the DC-link voltage is measured and compared with set DCL voltage. If it exceeds the reference value, the “control without MPPT” mode is enabled; otherwise, the MPPT control is enabled. The “control without MPPT” controller is enabled in the system until the DCL voltage is equal to the reference voltage. If V_DCL_meas>V_DCL_actual condition MPPT control is enabled until the VDCL_MEA is drop below the open circuit voltage of the PV system.
**Algorithm - 1**: Proposed LVRT method based on reactive power injection

1: Measuring $V_g_{\text{rms}}$ value in per unit (pu);

2: Nominal $V_g_{\text{rms}} = 1.01$;

3: If ($V_g_{\text{rms}} < 0.9$)

4: $P = P^*$ && $Q = Q^*$; % $P^*$ and $Q^*$ are the post-fault active and reactive powers

5: else if ($0.5 < V_g_{\text{rms}} < 0.9$)

6: $P = P^*$ && $Q = Q_{\text{LVRT}}$; % $P$ is the pre-fault active power and $Q_{\text{LVRT}}$ is the Q at LVRT period

7: else if ($V_g_{\text{rms}} < 0.5$)

8: $P = 0$ && $Q = Q_{\text{max}}$; % $Q_{\text{max}}$ is the maximum reactive power injection into the grid

9: else

detecting $V_g_{\text{rms}}$ value in per unit (pu);

10: return step
4. Simulation result analysis and discussion

4.1. Simulation details

The given power system model (Figure 7), is simulated using MATLAB / Simulink software to evaluate the performance of the proposed control scheme. The PV array is used to deliver the maximum value of 100 kW at 1000 W/m² irradiance; a boost converter is used to increase the PV voltage to 500 V DC; the I-V and P-V characteristics of SPV system is shown in Figure.8; switching duty cycle is optimized by the MPPT controller under normal condition; the VSC converts 500 V DC to 260 V AC and retains unity power factor and its connected with single machine-infinite bus system (SMIB) via step-up transformer. To validate the performance of the proposed LVRT control scheme for the grid connected PV system, the German E.ON grid code (GCC) shown in Figure. 3 is taken as a reference.

Keywords

DC-link voltage control; low voltage ride-through; maximum power point tracking; voltage sag; grid code; grid-connected solar photovoltaic system

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