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A comprehensive review on CHB MLI based PV inverter and feasibility study of CHB MLI based PV-STATCOM

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ABSTRACT

A conventional grid-connected solar Photovoltaic (PV) inverter consists of Two-Level or Three-Level configuration is not suitable for very high power ratings and the size of AC side filter required is high to maintain the power quality as per the grid codes. It is inefficient in extracting maximum power as the tracking of Maximum power point is carried out for entire PV arrays connected together instead of independent MPPT of each PV array. With a conventional PV inverter, the utilization factor is also very less, since the system will be in idle state during night times or when the irradiation is weak. Hence a conventional solar inverter consists of Two-Level or Three-Level inverter suffers from the following drawbacks (a) Not suitable for very high Power Ratings (b) High filter size (c) Inefficient in harvesting maximum power (d) Less utilization factor. In this study, the need for the multilevel inverter (MLI) to minimize the drawbacks of the conventional inverter is discussed. Cascaded H-Bridge (CHB) configuration which is more preferred for solar power applications where isolated input DC sources are available and for STATCOM applications where there is no requirement of DC Sources is discussed in detail. The basic operation of CHB inverter, PWM techniques, and fault tolerant operations are explained through simulation results. The Independent MPPT control of each PV array using CHB inverter is reviewed. CHB inverter controls for PV applications and STATCOM applications are also reviewed. The concept of a PV-STATCOM which is required for improving the utilization factor of PV inverter is reviewed. The operation of PV-STATCOM is explained through simulation studies. Real and reactive power flow through a 11-Level, CHB MLI is verified through experimental results. Feasibility study for multilevel PV-STATCOM for High power applications using CHB configuration is carried out in this paper.

1. Introduction to PV inverters and PV-STATCOM

A typical grid-connected solar power conditioning system comprises of an inverter, sine filter, isolation Transformer, AC and DC breakers connected across PV array and the grid is as shown in Fig. 1. An output transformer is required to match voltages of the grid and the inverter output and for providing galvanic isolation. Conventionally a Two or Three level inverter is used for PV applications and a digital controller controls the power flow through PV inverter. For tracking of MPP, controller monitors the PV array voltage and currents. Controller monitors grid voltage for synchronizing the inverter output with grid through Phase-locked Loop (PLL). Direct Current reference (Id_Ref) is obtained based on MPP and the quadrature current reference (Iq_Ref) is obtained form the reactive power reference. In a conventional PV inverter, Iq_Ref is Zero. Power control is carried out through PI controllers by comparing the dq components of reference grid current with dq components of actual grid current. The output of PI controllers generated the reference output voltage required for the inverter gate pulse generator.

A review on PV inverter topologies for grid applications is presented in Ref. [1]. Single phase Inverter configurations based on commutation of devices i.e. self-commutated and line-commutated inverters are explained briefly. Centralized inverters, string, and multi-string inverters are reviewed in this paper. PV systems based on the power conversion stages i.e. single stage or multiple stage PV systems are explained and a brief review on multi-level PV inverters are also presented. In Ref. [2], a review on Grid connected micro inverters is presented. Authors presented standards and requirements of grid connected PV inverters in this work. A brief review on central inverters, string inverters, and micro inverters is also presented.

Utilization factor of a conventional PV inverter is a major concern as the conventional PV inverter feeds only active power to the grid during daytime and the system will be in the idle state when solar energy is not available. This problem can be mitigated through the concept known as PV-STATCOM which can regulate the real and reactive power through the converter. In such system, Id_Ref is obtained from MPP and Iq_Ref is generated as per Reactive power requirement.

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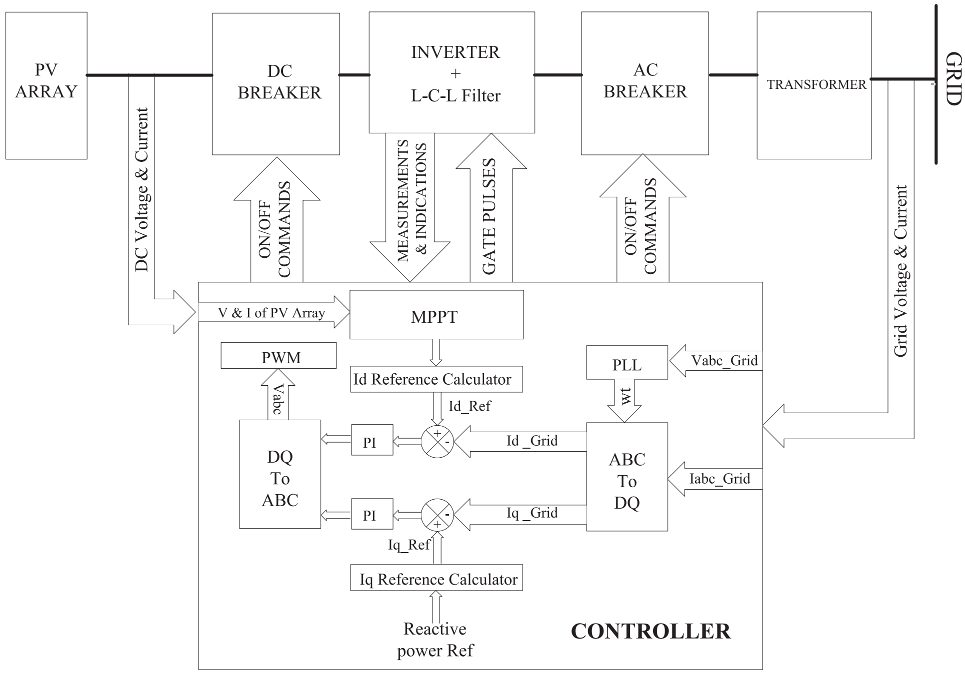

Fig. 1. Block diagram and control structure for a PV-inverter.

The concept of using PV Inverter as STATCOM has been proposed for optimal utilization of the system in Ref. [3]. PV inverter acts as active power provider when the solar energy is available and provides reactive power when the irradiation is low. The concept is validated through simulation studies. In Ref. [4], a PV-STATCOM which can operate as a STATCOM throughout the day is presented. Reactive power flowing through the converter depends on the inverter rated capacity and the MPP at that instant of time. Operation of a PV-Inverter as STATCOM for 24-h for reactive power compensation and to control the DC link voltage in a distribution utility network is discussed in Refs. [5] and [6]. A PV-Active Filter -STATCOM for Harmonic compensation and for the regulation of reactive power for grid applications is proposed in Ref. [7]. Voltage flickering, transient voltages and harmonics are the main issues with the power quality of PV generation system. A comparison on power quality issues in a conventional PV inverter and in a PV-STATCOM is presented in Ref. [8]. Operation of PV inverter as PV-STATCOM for short duration to improve the stability of voltage sensitive loads during grid faults is presented in Ref. [9],

In Ref. [10], Authors presented the PV-STATCOM testing in three stages. In the first stage of testing, RSCAD software is used to test the controller. In stage two, to test the controller and control algorithm, an hardware-in-loop simulation is carried out by interfacing the DSP based controller with Real time digital simulator. System operation is tested on the 10 kW laboratory model in stage three. Presented results explain that the system can be used for voltage control and for correcting the power factor. Steady state response and dynamic response of a PV-STATCOM controller are explained through the hardware-in-loop (HIL) simulation results in Ref. [11]. In Ref. [12], a PV-STATCOM without a DC-DC converter is proposed. DC link voltage is controlled through STATCOM operation in this system. Eliminating the DC-DC converter resulted in the reduction of cost and size of this system. The impact of Distributed generation systems on the grid and the technical challenges on power quality, protection and stability are discussed [13]. Negative impacts of PV systems on the grid network and a comprehensive review of the power quality improvement i.e. voltage regulation controls and static compensation techniques are presented in Ref. [14]. In Ref. [15], Authors presented the effects of power quality issues and the issues related to islanding are discussed and presented a brief review of anti-islanding techniques.

A PV-STATCOM is simulated to understand the power flow through PV-STATCOM. A load equal to the capacity of PV-STATCOM is connected at the at the AC terminals of the inverter. Power flow through PV-STATCOM is controlled by adjusting the real power reference (Pref) and reactive power reference (Qref). When Power Reference for PV-STATCOM is Zero, then the total current supplied from the PV-STATCOM is Zero and the complete Load Current is fed from Grid as shown in Fig. 2(a). When the Pref is adjusted to 1 P.U. and Qref is adjusted to 0 P.U., then complete real power required for Load is fed from PV-STATCOM and reactive Power for Load is fed from the Grid. Since the PV-STATCOM is feeding only the Active Power, PV-STATCOM phase voltage and currents are in phase with each other as shown in Fig. 2(b). Grid current is lagging the phase voltage by 90 degree, since the grid is supplying only reactive power. When Qref is also increased to 1 P.U. for PV-STATCOM, then the Grid current becomes Zero and the total power requirement is drawn from inverter as shown in Fig. 2(c). From above discussion, it is evident that a PV Inverter can also be used for Reactive Power Compensation, by varying Reactive Power reference in the range of 0–1 P.U. With this concept called PV-STATCOM, the Utilization factor can be improved and the issues related to power quality can be reduced without any additional cost.

In Ref. [16], a Sliding mode control based on an extended state observer for the grid-connected converter is presented. DC-link capacitor voltage is regulated by the external control loop. It gives the current references to inner control loop based on the desired power factor. Inner current control loop maintains the actual currents equal to their reference currents. Concepts of extended state observer (ESO), Super-twisting algorithm (STA) are explained briefly. Instead of using a general PI Controller for outer voltage control loop, STA + ESO based control is adopted in this work to reject disturbances and uncertainties. Inner current control loop is based on Super twisting algorithm. From presented results, it is observed that this control is an alternative solution for grid connected inverter controls.

Some of the PV-Inverter products based on Two-Level or three-Level inverter configuration available in the market are listed in Table 1. Some of these products are available with reactive power compensation feature. In large scale systems, number of such systems