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Modeling and control strategy of three phase neutral point clamped multilevel PV inverter connected to the grid

Arulkumar K*, Vijayakumar D, Palanisamy K

School of Electrical Engineering, VIT University, Vellore, India

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ABSTRACT

This paper focuses on control design of three phase neutral point clamped multilevel inverters (NPC-MLI) interconnected with PV array to the existing grid together equipped with boost converter. To achieve synchronized pulse width modulation and nominal harmonic performance space vector modulation (SVM) is adopted. The controller method of feed forward as well as integrator anti-windup is adopted for the proportional integral (PI) controllers to minimize the degradation problem. The synchronization and stability of the tracking performance of the controllers are verified by the bode diagram. In the proposed method harmonic current from filter capacitance is tracked and transformed to dq controller to reduce the total harmonic distortion (THD). Different three phase transformer-less inverter topologies with the proposed controller are compared with the traditional method. The reliability of the converters is determined by the thermal behavior of the semiconductor devices which equally affects the robustness and cost of the converters. Therefore a simulation platform is developed in a Matlab/Simulink and PLECS simulation environment to analyze the dynamics of the system. The controllers examine feasible option for three phase grid connected PV inverters.

1. Introduction

Renewable energy is an emerging sector in which meeting the energy needs of perennial natural energy resources like solar, wind, hydro, biomass, etc. Particularly solar energy based photo voltaic (SPV) has gained more importance based on availability and feasibility in off-grid industrial applications [1]. The surplus amount of power produced, apart from giving to the consumer load can be fed to the grid utility with IEEE standards and policy. Due to the variation of renewable energy supply, the voltage source converter (VSC) needs to change the harvested energy into regulated AC waveform. The generated power from the PV is supplied to the utility grid with various topologies of transformer connected as an isolation purpose that decreases its efficiency and increases cost. In order to achieve high efficiency, transformerless inverter have made keen interest in it.

Selection of appropriate topology is most considered in PV generation with transformer-less low leakage current and less total harmonic distortion (THD) [2]. The most widely used grid connected PV configurations are heric topology [3], H5 topology [4] and neutral point clamped (NPC) [5] due to their high efficiency and reduced leakage current. This paper examines the analysis and implementation of transformer-less three phase grid connected PV inverter. The PV system uses an PV string connected series and parallel array to get the desired output power. To extract maximum possible power from the solar PV array, perturb and observe (P&O) MPPT technique is used [6]. In order to increase the voltage from the solar panel boost converter is used. The modulation index used in three phase inverter is based on space vector modulation (SVM) technique discussed in literature [7–9], depicts minimization of switching frequency. In the event of reducing harmonics and high dc-link voltage, three level inverter plays a prominent role [10]. The filters are fundamental components that reduce the harmonics generated by the switching. Before connecting to the grid, harmonics are eliminated with the help of LCL filters [11]. The controllers are able to provide satisfactory sinusoidal reference tracking with low injected harmonics. The most attracting control technique is implemented in synchronous reference frame (SRF) based on proportional resonant (PR) controller [12] with a simple infinite impulse response. The proposed algorithm uses a space vector modulation

Abbreviations: PV, Photovoltaic; SPV, Solar photovoltaic; NPC-MLI, Neutral point clamped multilevel inverters; PWM, Pulse width modulation; SVM, Space vector modulation; THD, Total harmonic distortion; MPPT, Maximum power point tracking; P&O, Perturb and observe; VSC, Voltage source converter; SRF, Synchronous reference frame; PI, Proportional integral; PR, Proportional resonant; IGBT, Insulated gate bipolar transistor; PLL, Phase locked loop; PCC, Point of common coupling; 3-FB, Three phase full bridge; 5L M^2DCC, 5 level multiple pole multilevel diode clamped converter

* Corresponding author.
E-mail addresses: karuleee@gmail.com (K. Arulkumar), vijayakumar.d@vit.ac.in (D. Vijayakumar), kpalanisamy@vit.ac.in (K. Palanisamy).

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Nomenclature

V_{dc}	DC voltage
V_{dc}^{*}	Reference DC voltage
I_g	Grid current
V_g	Grid voltage
$I_{c,g}$	Capacitor grid current
ω_g	Grid frequency
θ_g	Grid synchronizing angle
dq	Synchronous frame
αβ	Stationary frame
I_d	Direct current axis controller
I_q	Quadrature current axis controller

(SVM), in order to obtain low switching ripple in the output currents, at a fixed switching frequency. The harmonic current from the filter is tracked and transformed to dq controller to reduce current disturbances [13]. This control scheme helps to improve the stability margins of previous approaches and reduce the harmonic currents [14–16]. In order to achieve a quick steady state, feed forward and anti-wind up scheme [17] is introduced in the controller and improves the performance of grid connected PV inverter. Modeling of grid connected PV inverter is performed using Matlab/Simulink and PLECS simulation environment.

The paper is organized as follows. The Section 2 illustrates model of two stage three phase grid connected PV inverter. Section 3 describes model PV string and the importance of MPPT algorithm. Section 4 reports the significance of three phase NPC-MLI topology and space vector modulation technique with the proposed design of integrator anti-windup scheme in current and voltage controllers. Section 5 narrates the thermal model analysis of boost converter and multi level inverter with power loss accordance with junction temperature. Section 6 interprets simulated results and comparative analysis of different topologies. Section 7 ends with conclusions.

2. Proposed two stage three phase PV inverter

As shown in Fig. 1 a two-stage three-phase PV system contains the PV array, the DC–DC converter, NPC-MLI, LCL filters and control parameters connected to the distribution line. The PV configuration consists of 4*20 modules connected together for the requirement. The bypass diodes are connected across in order to protect from hotspot destruction. The DC–DC converter controls the output of the PV array and increases the voltage with MPPT technique to an appropriate level so that grid inverter could work regularly. Stable voltage is given to the DC-link to the good performance of the inverter. Through the NPC-MLI and LCL filter, solar power generated is fed into the grid with the control strategy.

3. Model of PV string and MPPT algorithm

PV strings are connected in series and parallel according to the requirement. The shade on one module affects the other module and creates hot spot problem. In order to avoid partial shading several techniques like series–parallel, total cross-tied, Bridge linked, Honey comb are evaluated in [18]. By pass diodes are also connected for the effective performance of large energy yield production by avoiding partial shading. MPPT algorithm [19] known as dP/dV control is used with the values of PV voltage and PV current. The PV voltage control is achieved by PI controller and to regulate the PV current injected in to the DC–DC converter. It increases the voltage somewhere from 700 V to constant 800 V DC-link. The grid-side converter transfers the power from the DC-link into the grid through an NPC-MLI and LCL filter, with the proposed control structure.

4. Significance of neutral point clamped-MLI topology

Nabae, Takahashi, and Akagi in 1981 successfully proposed the neutral point converter [20] for many applications. Three phase transformerless grid connected topologies [21] are three phase full bridge (3-FB) [22], H7 [23], 5 level multiple pole multilevel diode clamped converter (5L M^2DCC) [24]. Among all three phase NPC-MLI has attracted due to its high efficiency with low leakage current and THD. The output phase voltage has more than two levels that reduce the harmonic content. Further, it has compact structure that is clear to implement digital signal.

NPC inverters, as shown in Fig. 2 are shaped of twelve switches with its freewheeling diode, and six power diodes. The AC output is connected to middle of supply voltage ($V_{dc}/2$). At any time instant, the two switches of each phase (either upper two or lower two) are closed, while the other two are opened. The gating signals of 1, 0, −1 connect the phase output of positive, neutral, and negative. The common mode voltage (V_{cm}) of the system defined as (1), should be kept constant as $V_{pn}/2$ to eliminate leakage current.

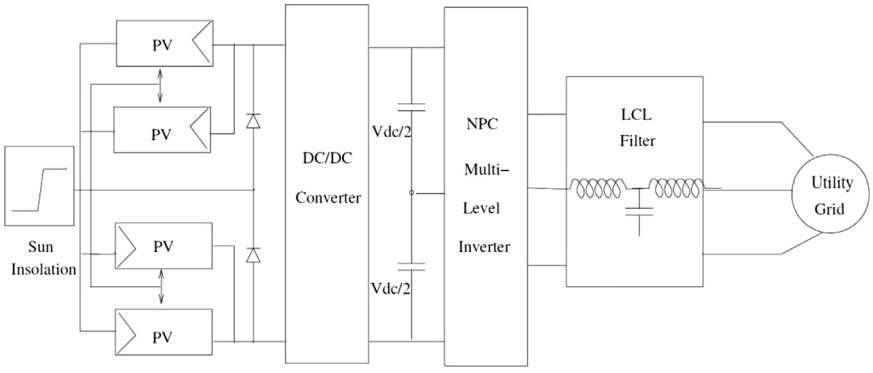

Fig. 1. Architecture of proposed PV three phase inverter connected to the grid.