Energy Conversion and Management 88 (2014) 854–862

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

An improved transformerless grid connected photovoltaic inverter with reduced leakage current

Monirul Islam *, Saad Mekhilef *

Power Electronics and Renewable Energy Research Laboratory (PEARL), Department of Electrical Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia

ARTICLE INFO

Article history:
Received 7 May 2014
Accepted 4 September 2014
Available online 29 September 2014

Keywords:
Common mode voltage
Converter
Grid connected
Leakage current
Photovoltaic
Transformerless inverter

ABSTRACT

Transformerless inverters are most preferred for grid connected photovoltaic (PV) generation system due to higher efficiency and lower cost. However, to meet the safety regulations, the leakage current which deteriorates the power quality and generates electro-magnetic interference in transformerless PV inverter, has to be addressed carefully. In order to eliminate the leakage current, an improved H5 topology is proposed in this paper. The operating principle, common mode (CM) characteristics, and the impact of junction capacitance of the switches on the CM voltage are investigated in details. The desired relationship among the junction capacitances is proposed to eliminate the CM leakage current. Three-level output voltage is achieved in the improved inverter employing unipolar sinusoidal pulse width modulation (SPWM). Furthermore, the European efficiency is improved by replacing the high frequency IGBT switches with MOSFETs. The proposed topology is compared with other transformerless topologies in terms of leakage current, different mode (DM) characteristics, and efficiency. The improved inverter topology is simulated in MATLAB/Simulink software to validate the accuracy of the theoretical explanations. Finally, a 1 kW laboratory prototype has been built and tested. The experimental results show that the proposed inverter has a maximum efficiency of 98.0% and 97.45% European efficiency with 16 kHz switching frequency.

1. Introduction

The energy crisis is one of the most crucial problems in recent time and renewable-energy sources play an important role to address these problems. Among a variety of renewable-energy sources, the photovoltaic generation system has rapidly increased during recent years. Based on the newest report on installed PV power, the milestone of 100GW PV system was achieved at the end of 2012, and the majority of these were grid-connected [1–3]. A single-phase converter is used in low power (less than 5 kW) single phase grid-connected applications, but its design embeds generally a line-frequency transformer or a high-frequency transformer that adjusts the converter DC voltage and separates the PV arrays from the grid [4,5]. Because of size, weight and price in favor of high-frequency transformers, the tendency is to remove the line frequency transformers when designing the new converter. Furthermore, the existence of high-frequency transformer desires several power stages, as a result, reducing cost and increasing efficiency will be a challenging task [6,7]. In contrast, the transformerless grid connected PV inverters are manifested to offer the benefits of lower cost, higher efficiency, smaller size, and weight. However, a galvanic connection is formed between the power grid and the PV module when the transformer is omitted. Therefore, a varying CM voltage is generated; as a result, leakage current flows through the loop consisting of the parasitic capacitors, the filter inductors, the bridge, and the utility grid [8–10]. This CM leakage current increases the grid current harmonics and system losses and creates a strong conducted and radiated electromagnetic interference and more specifically, leads to a safety threat [11–13].

Many topologies have been investigated to minimize the CM leakage current and improve the efficiency of the transformerless grid-connected PV inverters, which can be classified into two groups: (1) half-bridge inverter topology, (2) full-bridge (FB) inverter topology. The half-bridge inverter topology eliminates the fluctuating CM voltage and produces almost zero leakage current. The main drawback of the half-bridge topology is the necessity of high input voltage (700VDC) corresponds to 230VAC application [14]. On the other hand, in the full-bridge inverter, this required input voltage is only 350 VDC for the same application. Nevertheless, the main disadvantage of the full-bridge inverter is that it can employ only bipolar-SPWM with two-level output voltage. Consequently, high ripples in the output current are produced and thus, the efficiency of the entire system is reduced. To overcome these problems, many advanced topologies have been proposed in the

* Corresponding authors.
E-mail addresses: monir04eee@yahoo.com (M. Islam), saad@um.edu.my (S. Mekhilef).

http://dx.doi.org/10.1016/j.enconman.2014.09.014
0196-8904/

literature [15–23] as shown in Fig. 1, which are based on the full-bridge topology. These topologies can achieve three-level output voltage by employing unipolar SPWM and also can keep the CM voltage constant during all operational modes.

The main two issues for the transformerless PV inverters are; (1) the inverter should not have any leakage current and (2) achieve high efficiency over a wide load range. In order to obtain these advantages, an improved single-phase transformerless grid-tied PV inverter topology is proposed in this paper. The main features of the proposed improved inverter are: (1) the efficiency of the inverter is improved by replacing the high frequency IGBT switches with MOSFETs because the supper MOSFETs has low conduction and switching losses, (2) proposed relationship among the switches' junction capacitance and disconnection of PV module from the grid at the freewheeling mode ensure not to produce ground leakage current, (3) dead time is not required at both high-frequency switching commutation and grid zero-crossing instant which improves the output power quality and increases the efficiency. Detail operation principle, unipolar SPWM scheme and CM leakage current characteristics of the proposed inverter are illustrated in this paper. The efficiency of the improved inverter, H5 inverter and FB bipolar inverter are measured and a comparison among these topologies has been summarized to ensure the effectiveness of the proposed topology.

This paper is prepared as follows: The analysis of leakage current of the transformerless topology is described in Section 2. The proposed improved topology structure, operation principle with the unipolar SPWM control scheme, and the impact of junction capacitance on the CM voltage are investigated in Section 3. Design consideration for the improved topology is discussed in Section 4. The experimental and simulation results from a 1 kW/50 Hz rated prototype are presented in Section 5 and the conclusion is given in Section 6.

2. Leakage current analysis

When the transformer is removed from the PV inverter, a galvanic connection is formed between the PV module and the grid, which can create a CM resonant circuit. A fluctuating CM voltage

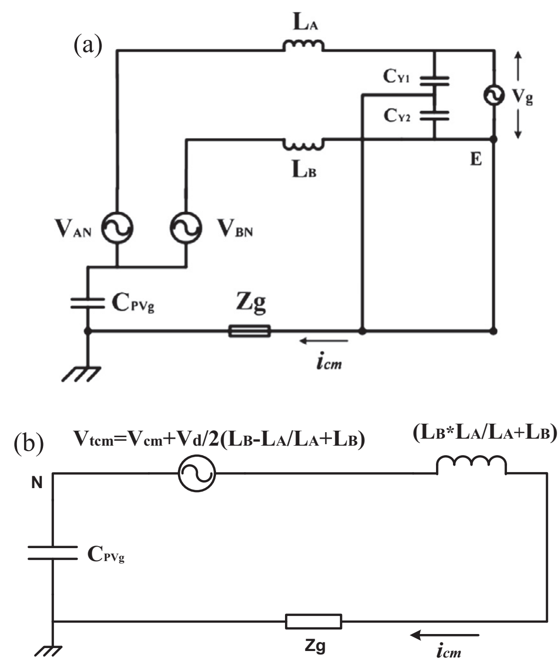

Fig. 2. Leakage current analysis: (a) equivalent model for full-bridge PV inverter (b) simplest form.

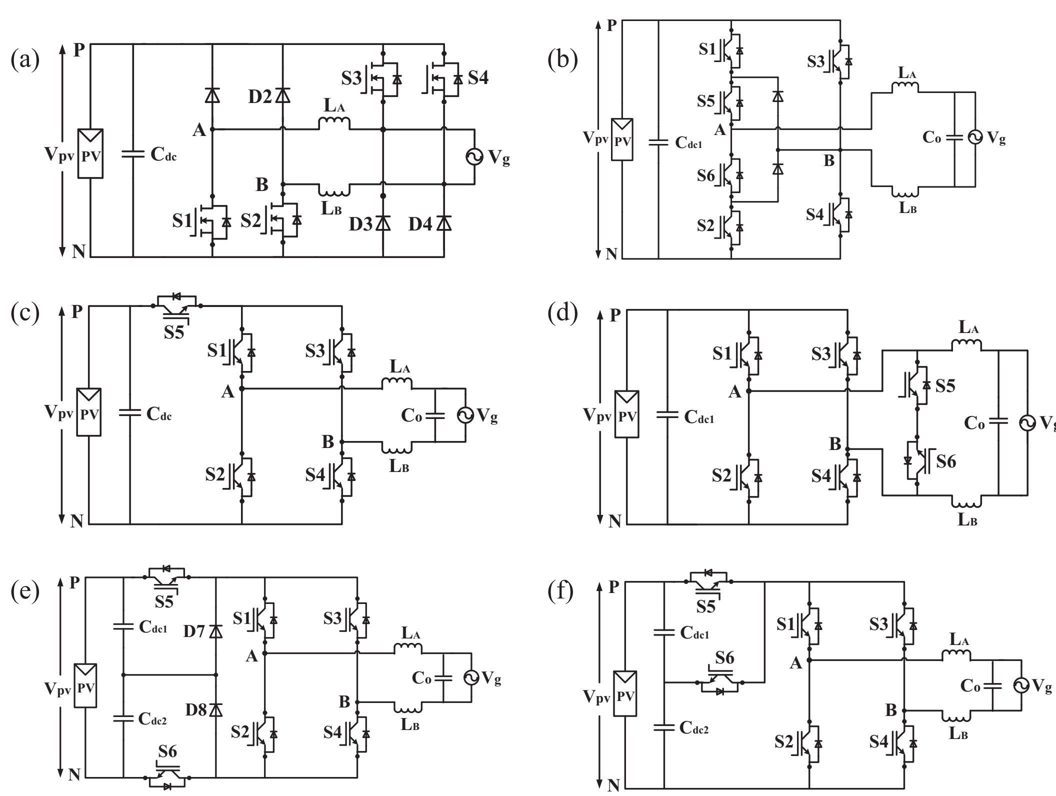

Fig. 1. Some existing transformerless topologies for grid-tied PV inverter (a) topology proposed in [17], (b) topology proposed in [22], (c) H5 topology proposed in [19], (d) HERIC topology proposed in [21], (e) H6 topology proposed in [20], and (f) oH5 topology proposed in [15].