A New Multi Level Grid-Connected Converter Topology for Single-Phase Transformerless PV System

1. K.SWATHI, 2. A.PANDU RANGA RAO

1. PG Scholar, swathi219@gmail.com, Sri Sunflower College of Engineering And Technology, Lankapalli

2. Assistant Professor, panduranga.adapala@gmail.com, Sri Sunflower College of Engineering And Technology, Lankapalli

ABSTRACT

The ever-increasing energy consumption, fossil fuels soaring costs and exhaustible nature, and worsening global environment have created a booming interest in renewable energy generation systems, one of which is photovoltaic. Such a system generates electricity by converting the Sun's energy directly into electricity. Photovoltaic-generated energy can be delivered to power system networks through grid-connected converters. A single-phase seven-level converter for grid-connected photovoltaic systems, with a novel pulse width-modulated (PWM) control scheme is proposed. Three reference signals that are identical to each other with an offset that is equivalent to the amplitude of the triangular carrier signal were used to generate the PWM signals. Eliminating the leakage current is one of the most important issues for transformer less converters in grid-connected photovoltaic system applications, where the technical challenge is how to keep the system common-mode voltage constant to reduce the leakage current. A novel single-phase three-level topology for transformer less photovoltaic systems is presented in this paper. Compared with the conventional H-bridge topology, it only needs two additional asymmetrically distributed switches, and the system common-mode voltage can be kept constant with a simple modulation scheme. Test results verify the theoretical analysis and the feasibility of the proposed topology and further extension can be done using Eleven Level Converters

Key Words: Transformer Less, Asymmetrically Distributed Switches, Eleven Level Converters, Pulse Width-Modulated, Conventional H-Bridge, Leakage Current, Common-Mode Voltage, Photovoltaic-Generated Energy.

I. Introduction

Grid-Connected photovoltaic (PV) converters represent the most widespread solution for residential renewable energy generation. While classical designs of PV converters feature a grid frequency transformer, which is a typically heavy and costly component, at the interface between the converter and the electrical grid, researchers are now considering transformerless architectures in order to reduce costs and weight and improve efficiency. Removing the grid frequency transformer entails all the benefits above but worsens the output power quality, allowing the injection of dc current into the grid [1], [2] and giving rise to the problem of ground leakage current [3], [4]. Although the active parts of PV modules might be electrically insulated from the ground-connected mounting frame, a path for ac ground leakage currents generally exists due to a parasitic capacitance between the modules and the frame and to the connection between the neutral wire and the ground, usually realized at the low-voltage/medium-voltage (LV/MV) transformer [3]. In addition to deteriorating power quality, the ground leakage current increases the generation of electromagnetic interference and can represent a safety hazard, so that international regulations pose strict limits to its magnitude. This issue must be confronted in all transformerless PV converters, regardless of architecture. In particular, in full-bridge-based topologies, the ground leakage current is mainly due to high frequency variations of the common-mode voltage at the output of the power converter [4]. Several solutions can be found in literature aiming at the reduction of the common-mode voltage harmonic content [5]–[7].

II. Concept of Multilevel Converter

The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three-level converter. Subsequently, several multilevel converter topologies have been developed. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Capacitors, batteries, and renewable energy voltage sources can be used as the multiple dc voltage sources. The commutation of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output; however, the rated voltage of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected.

Multilevel converters have been investigated for years [8], but only recently have the results of such researches found their way to commercial PV converters. Since they can synthesize the output voltages using more levels, multilevel converters outperform conventional two- and three-level converters in terms of harmonic distortion. Moreover, multilevel converters subdivide the input voltage among several power devices, allowing for the use of more efficient devices. Multilevel converters were initially employed in high-voltage industrial and power train applications. They were first introduced in renewable energy converters inside utility-scale plants, in which they are still largely employed. Recently, they have found their way to residential-scale single-phase PV converters, where they currently represent a hot research topic [14]. Single-phase multilevel converters can be roughly divided into three categories based on design: neutral point clamped (NPC), cascaded full bridge (CFB), and custom. In NPC topologies, the electrical potential between the PV cells and the ground is fixed by connecting the neutral wire of the grid to a constant potential, resulting from a dc-link capacitive divider [15]. A huge advantage is that single-phase NPC converters are virtually immune from ground leakage currents, although the same is not true for three-phase NPC converters [12], [30]. A recent paper has proposed an interesting NPC design for exploiting next-generation devices such as super junction or SiC MOSFETs [16]. The main drawback of NPC designs, with respect to full bridge, is that they need twice the dc-link voltage.

CFBs make for highly modular designs. Usually, each full bridge inside a CFB converter needs an insulated power supply, matching well with multi string PV fields. In this case, sequential permutation of the full bridges can be used to evenly share power among the parts and to mitigate the effects of partial shading. CFBs give developers many degrees of freedom for the control strategy. Together with the aforementioned sequential permutation and with phase shifting [19], artificial neural networks and predictive control have been proposed to minimize harmonic distortion and achieve maximum power point tracking (MPPT)

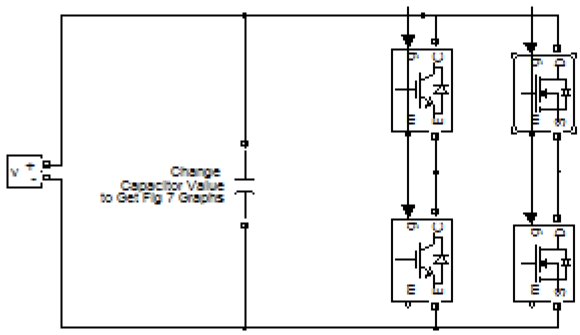


Fig 1: Basic Multi Level Circuit

Types of Multilevel Converter

The general structure of the multilevel converter is to synthesize a near sinusoidal voltage from several levels of dc voltage. As the number of levels increases, the synthesized output waveform has more steps, which produce staircase wave that approaches a desired waveform. Also, as more steps are added to the waveform, the harmonic distortion of the output wave distortion of the output wave decrease. As the number of levels increases, the voltage that can be spanned by summing multiple voltages.

The multilevel converters can be classified into three types

- Diode-Clamped Multilevel Converter
- Flying Capacitor Multilevel Converter
- Cascaded Multilevel Converter

3. PROPOSED TECHNIQUE.

3.1. CASCADED MULTILEVEL CONVERTERS

Introduction

Among various configurations of multilevel converters, cascaded multilevel converter is important. An eleven level multilevel converter consists of five H-bridge cascaded in single-phase. One H-bridge consisting of 4 IGBTs as shown in fig. A multilevel converter synthesize a desired voltage from several separate dc sources (SDCS's), which may be obtained from batteries, fuel cells, or solar cells. Each SDCS is connected to a single-phase full- bridge converter. Each H-bridge can generate three different voltage outputs (+vdc, 0 and -vdc) by the different combinations of the four switches (s1, s2, s3 and s4). The fig. shows the switching pattern of four switches in a single H-bridge. One more alternative for a multilevel converter is the cascaded multilevel converter or series H-bridge converter. Since then, the CMI has been utilized in a wide range of applications. With its modularity and flexibility, the CMI shows superiority in high-power applications, especially shunt and series connected FACTS controllers. The CMI synthesizes its output nearly sinusoidal voltage waveforms by combining many isolated voltage levels. By adding more H-bridge converters, the amount of Var can simply increased without redesign the power stage, and build-in redundancy against individual H-bridge converter failure can be realized. A series of single-phase full bridges makes up a phase for the converter.

3.2.MODULATION TECHNIQUES

Definition of Modulation

Mainly the power electronic converters are operated in the “switched mode” which means the switches within the converter are always in either one of the two states - turned off (no current flows), or turned on (saturated with only a small voltage drop across the switch). Any operation in the linear region, other than for the unavoidable transition from conducting to non-conducting, incurs an undesirable loss of efficiency and an unbearable rise in switch power dissipation. To control the flow of power in the converter, the switches alternate between these two states (i.e. on and off). This happens rapidly enough that the inductors and capacitors at the input and output nodes of the converter average or filter the switched signal. The switched component is attenuated and the desired DC or low frequency AC component is retained. This process is called Pulse Width Modulation (PWM), since the desired average value is controlled by modulating the width of the pulses.

PWM And Level Shifted Modulation

The main aim of the modulation strategy of the multilevel converter is to synthesize the output voltage as close as possible to the sinusoidal waveform. Many modulation techniques have been developed for harmonic reduction and switching loss minimization. The modulation methods used in multilevel converters can be classified according to switching frequency, as shown in Figure Methods that work with high switching frequencies have many commutations for the power semiconductors in one period of the fundamental output voltage. A very popular method in industrial application is the classic carrier-based sinusoidal PWM (SPWM) that uses the phase shifting technique to reduce the harmonics in the load voltage.

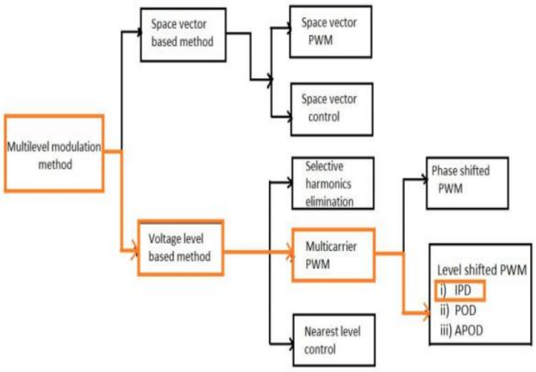


Fig 2: Classification of Multilevel Modulation Methods.

PWM (Pulse Width Modulation):

Pulse width modulation control is the most widely used method of controlling depth of converter, including the multilevel family. A significant amount of research has been published on the various ways of implementing PWM control. The focus here is level shifting carrier based sinusoidal PWM schemes for controlling a flying-capacitor multilevel three-phase converter. The main aim of this investigation is to ascertain which of the large number of possible implementations of multilevel sine-triangle PWM is the optimum for a cascaded multilevel converter, using models of a practical implementation to help simulate as accurately as possible the complete system's performance. The aim is also to develop a balancing control scheme applicable to all forms of PWM control. Pulse width modulation (PWM) is the basis for control in power electronics. The theoretically zero rise and fall time of an ideal PWM waveform represents a preferred way of driving modern semiconductors power devices.

PWM Methods Of Carrier Based Techniques:

Carrier based methods are simplest for the realization, yet not always straight forward to understand. The switching state of the converter leg is determined by comparison of the modulating signal providing information on the voltage reference, and carrier signal providing information of the switching period Multilevel converters are aimed at higher power applications and the semiconductor switch technology has inherent operating speed limitations due to higher switching losses. Therefore, the converter switching frequencies must be relatively low, so that it is preferable to synchronize the triangular carrier to the reference sinusoid to optimize performance. The following analysis focuses predominantly on synchronous mode operation. The carrier-based PWM methods are traditionally used in analogy implementation of modulators, where the advantage of the continuous reference can be explained in full when switching instants are determined with a certain carrier frequency, the average voltage will be as close to the reference as possible. Nowadays, the control systems are digitally implemented, and therefore the references are not continuous but sampled. The same reference remains in force for a sampling period, which is now determined as Tsw .

Level Shifted PWM Method:

Another major aim is to identify the maximum energy factor for a PWM controlled cascaded multilevel converter. In this case, it explores the different forms of multilevel sine-triangle PWM and bench-marks their performance under ideal system conditions. There are three alternative PWM strategies with different phase relationships for the level-shifted multicarrier modulation:

- In-phase disposition (IPD), where all carrier waveforms are in phase.
- Phase opposition disposition (POD), where all carrier waveforms above zero reference are in phase and are 180 degree out of phase with those below zero.
- Alternate phase disposition (APOD), where every carrier waveform is in out of phase with its neighbour carrier by 180 degree.

3.3.Controlling Circuit

A prototype nine-level converter was designed and built in order to test the performance of the proposed solution. The prototype is based on the Texas Instruments TMS320F28335 microcontroller and features the two full bridges, the TC, the sensors, and the output filter. Infineon IKW30N60H3 IGBTs and ST Microelectronics STW55NM60ND MOSFETs were employed as active devices.

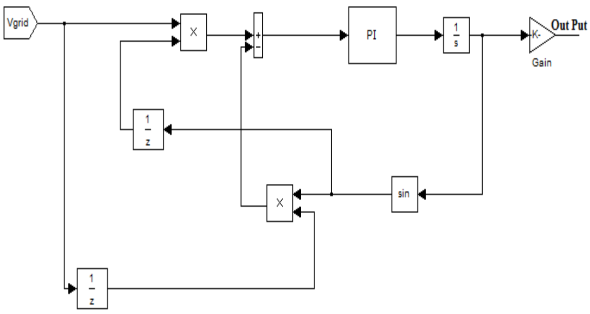
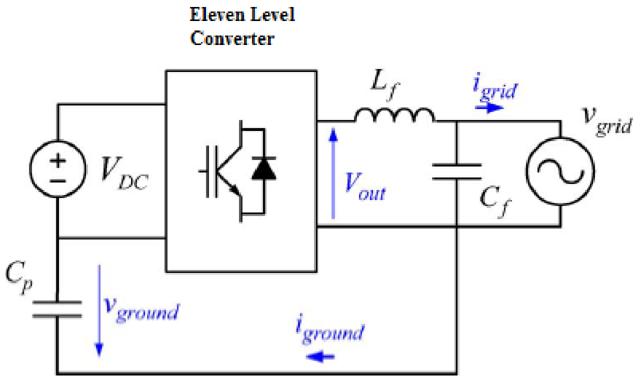


Fig.3 Block scheme of the delay-based PLL.

The microcontroller implements the PWM signal generation, the current controller, and the proposed modulation. Synchronization with the grid is realized with a transport delay-based PLL structure (see Fig. 3). The schematic is the same as that of the d–q PLL in a synchronous reference frame, except that the quadrature input signal and the cosine of the estimated angle are realized with a constant delay equal to 1/4 of the nominal grid voltage period T. This modification allows to obtain a zero steady-state error for small-frequency variations of the input signal with respect to the nominal grid voltage one. Fig. 4 shows a schematic of the test bed. The converter was powered by an Agilent Technologies dc power supply, and its output was directly connected to the grid. In order to simulate the parasitic capacitance of the PV field, a capacitor



was connected between the negative dc-link terminal and the neutral wire.

Fig. 4. Schematic of the test bed employed for the experiments.

Although in actual PV fields the parasitic capacitance is distributed between both the positive and negative sides of the dc link, for analysis purposes, it can be considered as concentrated only on the negative side.

4. RESULT

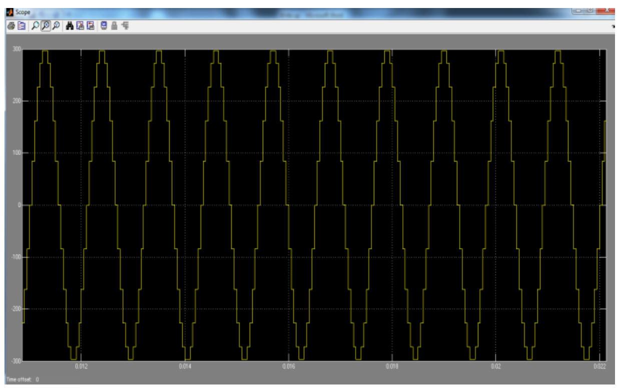


Fig5 : Output Voltage (Vout)

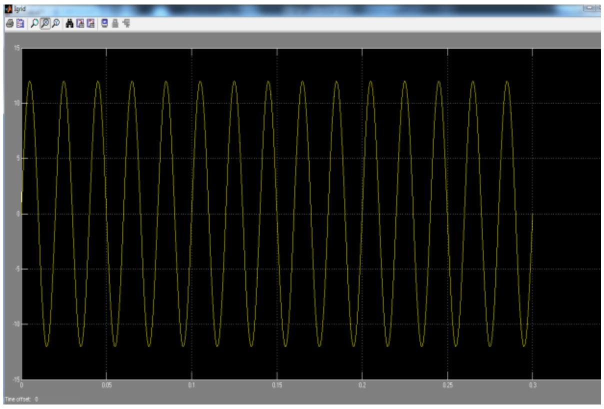


Fig 6 : Grid Current I_{grid}

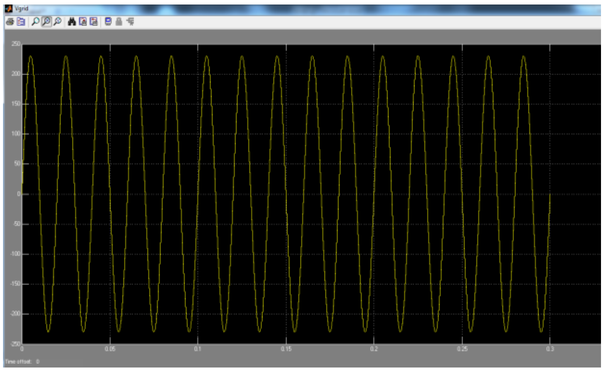


Fig7 : Grid Voltage V_{grid}

5. CONCLUSION

In this work , a Photovoltaic cell based eleven level Cascaded H-bridge Converter employing multicarrier pulse width modulation technique is developed which enhances the fundamental output voltage and hence reduces the total harmonic distortion to 19.605% compared to the conventional method .The operation and performance of the proposed multilevel converter is verified through MATLAB/SIMULINK. It can be also shown for any number of phases or levels.

6. FUTURE WORK

1. The proposed topology focused on the Converter Sine PWM method and this method can be applied to different voltage levels, other modulation techniques and similarly other PWM techniques can be applied.
2. Also if the comparison is done from an economical point of view, it gives a better picture in construction in reduction in circuit complexity, requiring a less number of power switches in industrial application.
3. Another interesting topic that can be studied in the modeling and control of multilevel converters in FACTS devices application, HVDC transmission lines and large wind turbine applications

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