A Nine-Level Converter Topology for Transformerless Grid Connected PV Systems

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Abstract— In this paper we present a single phase transformer less grid connected PV System having two cascaded full bridge converters which will maintain different voltage levels at the dc-link. With a single DC bus the converter can synthesize up to nine voltage levels as one of the bridge is supplied by a flying capacitor. Due to the increase in the number of levels will reduce the harmonic distortion and interference. To improve the efficiency most of them are switched at grid frequency. A suitable switching strategy is proposed for controlling the voltage across the flying capacitor. Simulation is done and the performance of the system is observed.

Key words: Photo Voltaic (PV) Systems, Pulse Width Modulated Inverters, Multilevel Systems, Grid Frequency

I. Introduction

Now-a-days due to increase in the demand of electricity and also conventional energy sources are going to exhaust in some years the demand for the non-conventional sources is increasing day by day. In the non conventional sources the main methods are wind and solar. To improve the efficiency of the system we are proposing some strategies that will makes the system more reliable. The traditional method PV converter uses a grid frequency transformer, which are having more weight and the cost of the system will also increases. In order to reduce the cost and weight and to increase the efficiency transformerless architectures are used at the interference between grid and converter. But removing the transformer will raise the problem of ground leakage current. The power quality of the system will also gets deteriorate. In addition to this ground leakage current increases the generation of electromagnetic interference which causes safety hazard. In full wave bridge converters the leakage current is due to high frequency variations of the common mode voltage at the output of the power converter. To reduce the common mode voltage harmonic content many methods are proposed in literature.

Due to the above reasons if the grid frequency transformer is removed and replaced by a multi level converters then the cost of the bulk windings and the output filters which are used to clean the output voltage and current can be reduced. By reducing the size of the filters the efficiency can also be improved.

Initially the multi level inverters are used in high voltage industrial and power train applications. Recently, multi level inverters have found their application in residential-scale single-phase PV converters. Based on their design 1-Φ multilevel converters are mainly divided into three types, they are neutral point clamped (NPC), cascaded full bridge (CFB), and custom.

In neutral point clamped topologies, the voltage between the PV cell and ground is maintained constant by connecting the neutral wire of the grid to the constant potential. The main advantage of the neutral point clamped converter is it is immune from ground leakage current. The main drawback is it requires twice the dc link voltage.

Cascaded full bridge converters are used for highly modular design. In this case to share power among the different parts and to minimize effect of partial shading sequential permutations of the full bridge is used. In case if the output voltage is obtained through a transformer only one power supply can be used. Also to minimize harmonic distortion and to achieve maximum power artificial neural networks are used.

In custom architectures with a given number of active devices it can produce more output levels. These custom architectures requires PWM converters and control schemes. Less number of switches are used in this architecture so that the efficiency of the system increases with some of the switches working at grid frequency.

The number of switches per output voltage can be reduced in CFB structure if we use different voltage levels for different bridges. In this paper our proposed topology uses two different CFB's which has the capability of generating nine output voltage levels. Out of the two full bridges one of the bridges is supplied with the dc voltage source and the other is supplied from flying capacitor. By controlling the ratio between the voltages of two bridges the different output levels can be obtained.

The number of output levels is equal to the number of switches plus one. In order to reduce the ground leakage current very low power switches and a line frequency switching devices were included in the final topology. In PV applications the dc output is not constant due to variation in the solar irradiation so MPPT algorithm is used to track the maximum power supply.

The paper is organized as follows: In section II power converter topology and PWM control strategy is used to improve the performance by using digital signal processor. Section III the regulation of flying capacitor is described. Section IV represents the simulation results. Section V will conclude the paper.

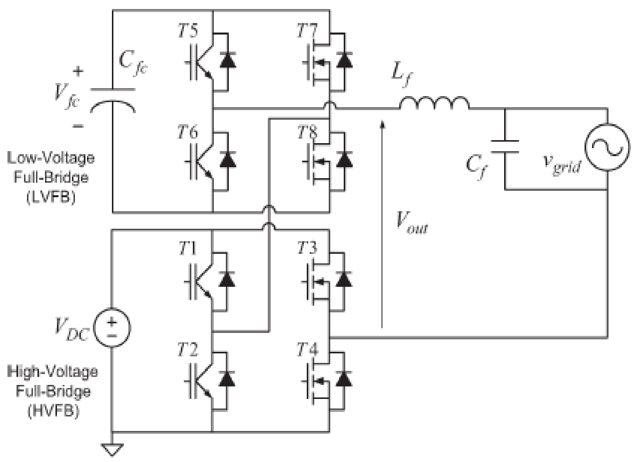


Fig. 1: Model of Cascaded Full Bridge with flying capacitor

II. CONTROL STRATEGY

In this paper the controller consists of two full bridges cascaded one of the bridge is supplied by a flying capacitor and other with dc voltage source which are connected with grid without the transformer. The proposed PWM strategy increases the efficiency the proposed PWM strategy for the two legs where PWM frequency switching is not occurring, devices with low voltage drop, MOSFETs are used. In fact, the low commutation frequency of those two legs allows, even in a reverse conduction state, the conduction in the channel instead of the body diode. Insulated-gate bipolar transistors (IGBTs) with fast anti-parallel diodes are required in the legs where high-frequency hard switching commutations occur. In grid-connected operation, one full-bridge leg is directly connected to the grid neutral wire, whereas the phase wire is connected to the converter through an LC filter.

In this Cascaded Full Bridge topology different PWM schemes can be chosen. However the chosen solution needs to satisfy the following requirements such as:

1) To limit the switching losses most commutations must be done in the low voltage full bridge side
2) To reduce the ground leakage current the neutral connected leg of high voltage full bridge should be switched at grid frequency
3) The driving signal should get from a single carrier for a low cost DSP.

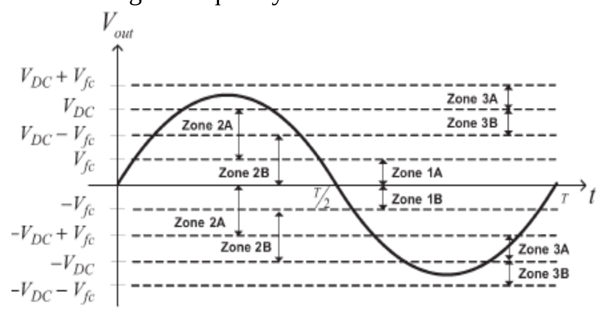
Zone	Output Voltage	On Devices	Off Devices	Switching Devices
Zone 3B	$-V_{DC}-V_{fc} \leftrightarrow -V_{DC}$	T2, T3, T7	T1, T4, T8	T5, T6
Zone 3A	$-V_{DC} \leftrightarrow -V_{DC}+V_{fc}$	T2, T3, T8	T1, T4, T7	T5, T6
Zone 2A	$-V_{DC}+V_{fc} \leftrightarrow 0$	T3, T7	T4, T8	T1, T2, T5, T6
Zone 2B	$-V_{DC} \leftrightarrow -V_{fc}$	T3, T7	T4, T8	T1, T2, T5, T6
Zone 1B	$-V_{fc} \leftrightarrow 0$	T1, T3, T7	T2, T4, T8	T5, T6
Zone 1A	$0 \leftrightarrow V_{fc}$	T2, T4, T8	T1, T3, T7	T5, T6
Zone 2A	$V_{fc} \leftrightarrow V_{DC}$	T4, T8	T3, T7	T1, T2, T5, T6
Zone 2B	$0 \leftrightarrow V_{DC}-V_{fc}$	T4, T7	T3, T8	T1, T2, T5, T6
Zone 3B	$V_{DC}-V_{fc} \leftrightarrow V_{DC}$	T1, T4, T7	T2, T3, T8	T5, T6
Zone 3A	$V_{DC} \leftrightarrow V_{DC}+V_{fc}$	T1, T4, T8	T2, T3, T7	T5, T6

Table 1: Operating zones of converter

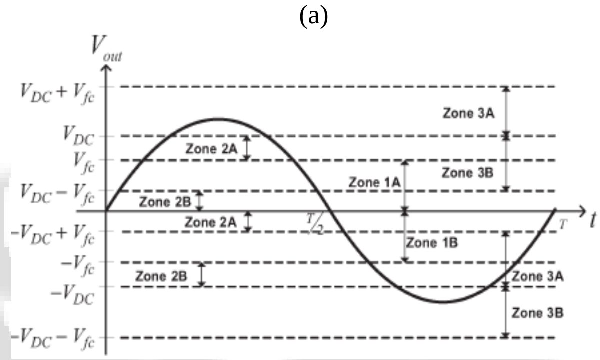
The above table shows the different operating zones of the converters and which devices are in ON state at that zone and which devices are in OFF state and which devices are in switching state. The converter can operate at different output voltage zones, where the output voltage switches between two specific levels. The operating zone boundaries vary according to the dc-link and flying-capacitor voltages, and adjacent zones can overlap.

There are two different zones zone A and zone B. in zone A the major contribution of the converter voltage is due to the flying capacitor and is positive, where as in zone B it is negative. Depending upon the ratio of V_{fc} and V_{DC} the output can either like (a) or (b) as shown in the below figure 2

If Vfc = VDC/3, the converter can synthesize nine equally spaced output voltage levels where one leg of the high voltage full bridge operates at the grid frequency while the low voltage full bridge will operates at a frequency five times that of grid frequency.



(a)



(b)

Fig. 2: operating zones of converter for different Vfc values (a) Vfc/VDC <0.5 (b) Vfc/VDC >0.5

III. FLYING CAPACITOR

The main function of the grid connected PV converter is the transfer of electric power to the grid but the control of flying capacitor is difficult. Flying-capacitor voltage Vfc is regulated by suitably choosing the operating zone of the converter depending on the instantaneous output voltage request. In particular, if a positive value of current is injected into the grid, in A zones flying capacitor will discharge and while in B zones flying capacitor will discharge. Since a number of redundant switch configurations can be used to synthesize the same output voltage waveform, it is possible to control the voltage of the flying capacitor which will force the converter to operate in zone A if the capacitor voltage is greater is greater than that of reference value and will operate in zone B if it is less than the reference value.

Figure below shows the regulation of flying capacitor voltage

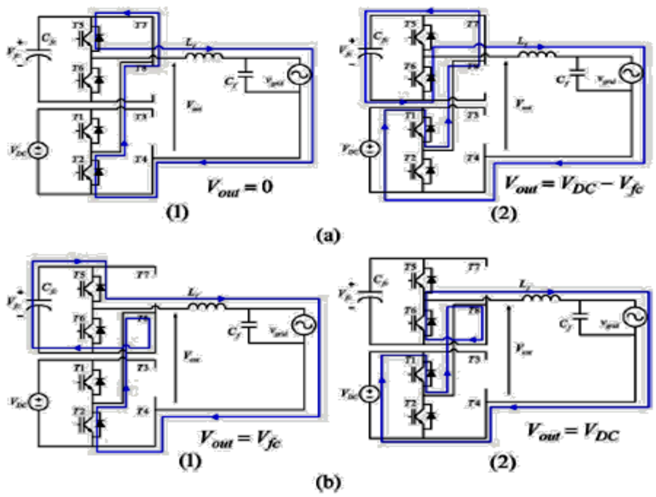


Fig. 4: (a) Flying capacitor charge (b) Flying capacitor discharge

From the above figure suppose the positive grid current is injected with the output voltage greater than zero and flying capacitor voltage is less than 0.5Vdc and if the flying capacitor voltage is too low, output voltage can be replaced by Vdc-Vfc.. So the switching occurs between 0 and Vdc-Vfc as shown in figure (a). while when the Vfc is too high then Vdc-Vfc can be replaced with Vfc causing converter switching action between Vdc & Vfc as shown in figure (b)

If Vfc < 0.5VDC, in order to minimize the current ripple, zone 2 is chosen only when Vfc < V*out < VDC − Vfc limiting level skipping. That means Level skipping always occurs if and only if Vfc > 0.5VDC; hence, according to the voltage regulation algorithm either A or B zone can be chosen. As the dc-link voltage can undergo sudden changes due to the MPPT technique, it is important to ensure that the converter can work in any [VDC, Vfc] condition. The distortion in the output voltage can be minimized by on-line duty cycle computation. It is very much important to assess the capability of the converter to regulate the voltage across the flying-capacitor under different operating conditions.

IV. SIMULATION RESULTS

The commutation process that is given in table1 causes change in neutral wire voltage from zero to Vdc when T4 is opened and T3 is closed. So the commutation can cause large surge of leakage current which will decreases the power quality and has the possibility of damage of PV module. So a transient circuit is designed to increase the power quality and to decrease the surges. The proposed converter topology as shown in figure 5 below

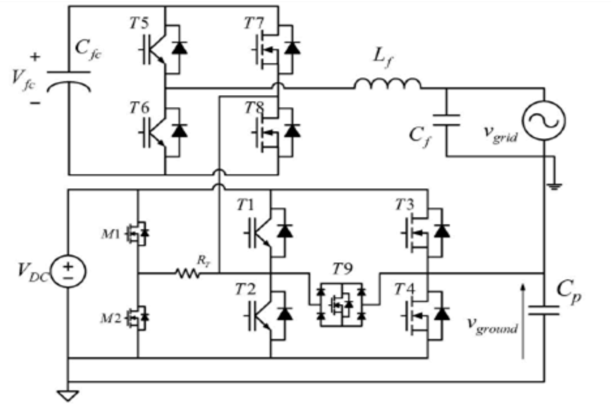


Fig. 5: Proposed transient circuit

The transient circuit consists of two low power MOSFETS M1 and M2, bidirectional switch T9, and resistor RT. During the transients to reduce the surge one of two mosfet's either M1 or M2 is turned on and the capacitor Cp is charged through the resistor Rt reducing the current surge as shown in figure6 below.

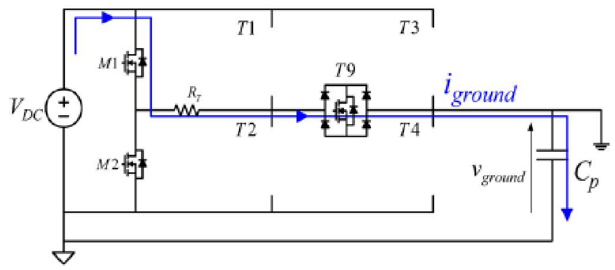


Fig. 6: Operation during switching

The value of the parasitic capacitor is taken as Cp=200nF and the DC voltage is taken as Vdc=300V. The Simulink model is developed and the outputs are obtained as shown in the below figure7 at different values of flying capacitor voltage.

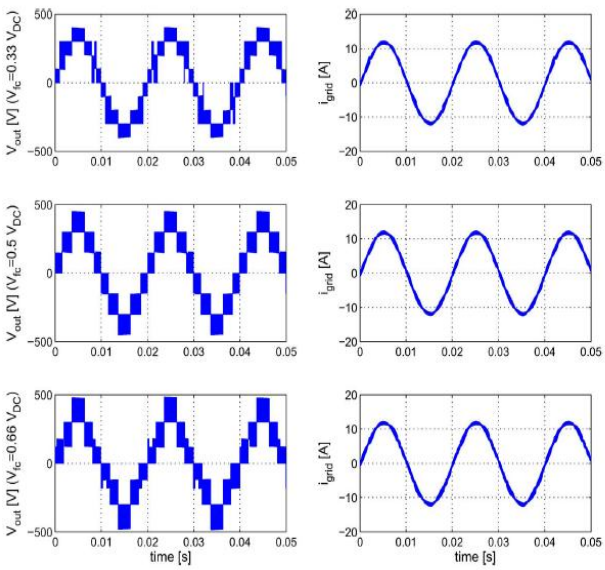


Fig. 7: Output Voltage and grid currents for different Vfc and Vdc=300V

V. CONCLUSION

In this paper a new nine level transformer less grid connected converter based PV panel has been proposed by using a low frequency converters with two full bridge converters. By using this proposed PWM topology the efficiency of the system is increased and by using a special transient circuit the ground leakage current and the surges can be reduced.

The simulation results are obtained by regulating the flying capacitor voltage in a very wide range of operating conditions. As the transformer is not used the size and the cost of the system will also reduced and will makes more reliable. Nine levels can be obtained by using 11 switches out of which three are low frequency switches used in transient circuit and PWM needs to control only four switches.

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