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A Comparison of Multilevel Inverter Methodology for Single Phase Transformer less PV Systems

G.Dhivya[1] M.tech, G.Santoshamma[2] Assoc.Professor
Electrical and Electronics Engineering[1, 2], Sri Venkateswara College Of Engineering & Technology
Email:bendalamdivya@gmail.com[1]

Abstract: This paper presents comparison between advanced multilevel inverters like nine and eleven level. The multi level inverters are used in high power and medium voltage applications, because of pros like common mode voltage operation at both basic fundamental and high switching frequency, drawing input current with low distortion, less harmonic distortion. The common mode leakage current is detract by using a transient circuit and efficiency is enhanced, by regulating flying capacitor voltage with suitable switching frequency. The multilevel output deteriorates harmonic distortion and electromagnetic interference .simulations and experiments gives the viability and fine performance and projected converter.

Index Terms - Leakage current, multilevel systems, photovoltaic (PV) systems, pulse width modulation (PWM) inverters.

1. INTRODUCTION:

The demand of electricity is ever growing ,fast depletion of fossil fuels ,skyrocketing prices of oil ,environmental impact greenhouse effect had led to an alternative source power generation from the renewable energy sources like solar ,wind, tidal ,fuel cell overcomes the above mentioned draw backs.

Mainly this paper is dealing with pv systems, Photovoltaic's (PV) is the name of a method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. Though, sunlight is not available continuously, solar energy is used due to its vast availability. PV systems are accepted to be in top position among all renewable electric power generation as it generates direct current electricity without many environmental effects and pollution.

When transformer is not used in a grid-connected photovoltaic (PV) system, a galvanic connection between the grid and the PV array exists. In these conditions, dangerous leakage currents (common-mode currents) can appear through the stray capacitance between the PV array and the ground. In order to avoid these leakage currents, different inverter topologies that generate no varying common-mode voltages, such as the half-bridge and the bipolar pulse width modulation (PWM) full-bridge topologies, have been proposed. The bipolar PWM full bridge requires a lower input voltage but exhibits a low efficiency. This paper proposes a new high-efficiency topology that generates no varying common-mode voltage and requires the same low-input voltage as the bipolar PWM full bridge.

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 transformer less 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] to clean the output voltage and current from high frequency switching components. Further reduction in cost and weight and improvement in efficiency can be achieved by reducing the filter size, and this is the goal of multilevel converters. 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 [9]–[13]. Recently, they have found their way to residential-scale single-phase PV converters, where they currently represent a hot research topic [14]–[29]. Single-phase multilevel converters can be roughly divided into three categories based Single-phase multilevel converters can be roughly divided into three categories based on design: neutral point clamped (NPC), cascaded full bridge (CFB), and custom.

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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 multistring PV fields [17]. 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 [17]–[20]. As an alternative, only one power supply can be used if the output voltage is obtained through a transformer [21], [31]. CFB converters have also been proposed for stand-alone applications [17], [22]. 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 [23] and predictive control [24] have been proposed to minimize harmonic distortion and achieve maximum power point tracking (MPPT). A CFB made up of n full bridges (and at least $4n$ power switches) can synthesize $2n + 1$ voltage levels when the supply voltage is the same for each full bridge. Custom architectures can generally provide more output levels with a given number of active devices, and custom converters generally need custom pulse width modulation (PWM) and control schemes [25]–[27], although unified control schemes for different types of multi-level converters have been proposed [28]. In addition to using less switches, custom architectures can be devised so that some of the switches commutate at the grid frequency, thus improving the efficiency [29]. Reduction in the switches-per-output-voltage-level ratio can be achieved in CFB structures if different supply voltages are chosen for each full asymmetrical CFB, generating nine output voltage levels. In the proposed converter, the dc voltage source supplies one of the full bridges, whereas a flying capacitor supplies the other one. By suitably controlling the ratio between the two voltages, different sets of output levels can be obtained. Moreover, the flying capacitor used as a secondary bridge (asymmetrical CFBs) [32], [33]. The topology proposed in this paper consists of two

Energy source allows for limited voltage boosting, as it will result clear in the following section. The number of output levels per switch (eight switches, nine levels) is comparable to what can be achieved using custom architectures. In fairness, it should be noted that two additional very low power switches and a line frequency switching device [transient circuit (TC)] were included in the final topology in order to reduce the ground leakage current. The custom converter proposed in [29] gen-erates five levels with six switches but has no intrinsic boosting capability. In [25], Rahim *et al.* used three dc-bus capacitors in series together with two bidirectional switches (diode bridge + unidirectional switch) and an H-bridge to generate seven output levels; however, they give no explanations on how they keep the capacitor voltages balanced. In [27], five switches, four diodes, and two dc-bus capacitors in series are used to generate five levels with boosting capability. Again, no mention is made about how the capacitors are kept balanced.

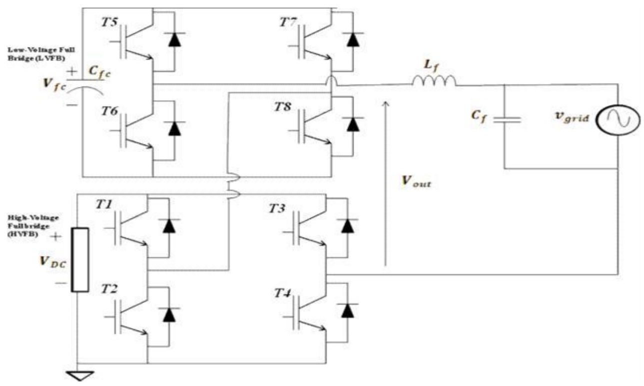
In PV applications, the PV field dc voltage is constantly changing due to variations of solar radiation and to the MPPT algorithm, but the output voltage has to be controlled regardless of the voltage ratio. This problem was studied in [34]–[36], measuring the separate full-bridge voltages and computing on line the duty cycles needed to balance the different voltages, and analyzing also the power balance between the separate cells. A similar approach is followed in this paper. Moreover, the developed PWM strategy, in addition to controlling the flying-capacitor voltage, with the help of the specific TC illustrated in Section IV, minimizes the ground leakage current. Finally is important to put in evidence that the proposed converter can work at any power factor as reported in Section III, while not all the alternative proposals can continuously supply reactive power [37], [38]

The proposed topology was presented by the authors in a previous paper [39]. With respect to the previous work, this paper was rewritten and presents a better organization and a new set of simulation and experimental results with different setups. This paper is organized as follows: Section II presents the power converter topology and the PWM control strategy chosen in order to maximize the performance with the use of a low-cost digital signal processor (DSP). Section III describes the regulation of the flying capacitor used to supply the second full bridge of the CFB topology. Section IV describes the principle of operation of the additional components able to reduce the ground leakage current. Sections V and VI show the simulation and experimental results, whereas Section VII reports the concluding remarks.

2. NINE-LEVEL CONVERTER AND PWM CONTROL STRATEGY:

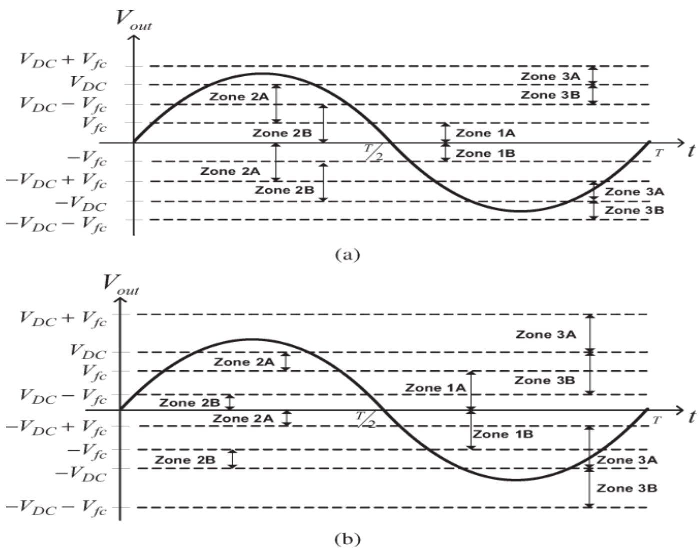
The proposed converter is composed of two CFBs, one of which is supplied by a flying capacitor (see Fig. 1). This basic topology was already presented in [34]. In this paper, a different PWM strategy was developed in order to allow grid-connected operation with no galvanic isolation (transformer less solution) for this basic topology. Since the PWM strategy alone is not sufficient to maintain a low ground leakage current, other components were added as will be shown in Section IV. As it will be described in the following, the proposed PWM strategy stretches the efficiency by using, for the two legs where PWM-frequency switching does not occur, devices with extremely low voltage drop, such as MOSFETs lacking a fast recovery diode. 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 (i.e., active rectification). 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 flying-capacitor voltage V_{fc} is kept lower, at steady state, than dc-link voltage V_{DC}. Accordingly, the full bridge supplied by the dc link is called the high-voltage full bridge (HVFB), whereas the one with the flying capacitor is the low-voltage full-bridge (LVFB).

The CFB topology allows certain degrees of freedom in the control, so that different PWM schemes can be considered; however, the chosen solution needs to satisfy the following requirements.



1) Most commutations must take place in the LVFB to limit the switching losses.
2) The neutral-connected leg of the HVFB needs to switch at grid frequency to reduce the ground leakage current.
3) The redundant states of the converter must be properly used to control the flying-capacitor voltage.
4) The driving signals must be obtained from a single carrier for a low-cost DSP to be used as a controller.

The switching pattern described in Table I was



(a)

(b)

A PV system is connected to the grid, interfaced by a CHBMLI. The block diagram of PV system connected to grid through CHBMLI is shown developed starting from the above requirements. Requirement in particular, is due to the aforementioned parasitic capacitive coupling between the PV panels and their frames, usually connected to the earth. Capacitive coupling renders the common-mode current inversely proportional to the switching frequency of the neutral-connected leg.The converter can operate in 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 (see Fig. 2).

In zones labeled A, the contribution of the flying-capacitor voltage to the converter output voltage is positive, whereas it is negative in B zones. Constructive cascading of the two full bridges can, therefore, result in limited output voltage boosting. Depending on the V_{fc}/V_{DC} ratio, one of the (a) or (b) situations in Fig. 2 can ensue; nevertheless, the operation of the converter does not differ much in the two cases. If two overlapping operating zones can supply the same output voltage, the operating zone to be used is determined taking into account the regulation of V_{fc}, as will be described in Section III.

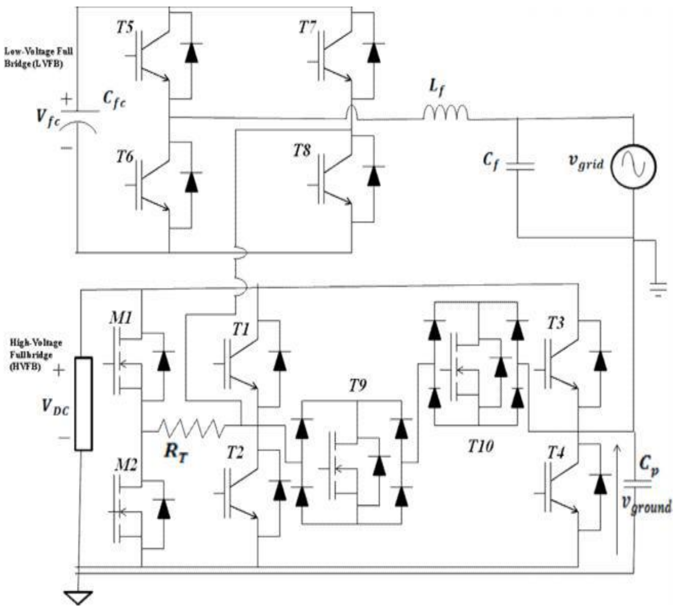
As mentioned in the introduction, the duty cycles are calculated on-line by a simple equation, similarly to the approach presented in [34]. The switching pattern depends on the instantaneous fundamental component of output voltage V_{out} and on the measured values of V_{fc} and V_{DC}.

3. CASCADED H BRIDGE MULTI LEVEL INVERTER:

A conventional CHBMLI comprises of a number of H-bridge inverter cells (H-BIC) connected in series with separate dc source each. Three different ac voltage levels V_{dc} , 0 and □V_{dc} respectively can be produced by HBIC at the output terminals by different combination of four IGBT switches S-1, S-2, S-3 and S-4. These switches have low blocking voltage and have high switching frequency, the net ac voltage of CHBMLI is the sum of output of all individual H-bic's. Approximately sinusoidal output voltage can be produced by connecting adequate number of H-BICs and using a suitable modulation scheme.

4. PROPOSED 11 LEVEL INVERTER:

The proposed eleven level CHBMLI consist of two H-BIC 'S be former being supplied by apv generator and later fed by a flying capacitor ,this paper presents unique PWM strategy, that allows grid connected operation with transformer less converter for the proposed topology this strategy improves the efficiency by using two legs consisting of ,insulated –gate bipolar transistors with antBRIDGE ,a lc filter and the grid neutral wire is connected to other below full H-bridge leg .The full bridge is supplied by a dc link called, high voltage full bridge (HVFB), the other full bridge consisting of flying capacitor.The major task is the transfer of active power to the electrical grid while using a grid connected pv converter controlling the voltage of the flying capacitor is crucial. By choosing the operating zone of the converter depending on the instantaneous output voltage request flying capacitor vfc is regulated correctly. Described the following sections this proposed topology of PWM control strategy by using; IGBT 'S with fast anti parallel diodes are needed 4 legs.(High frequency hard switching commutation occur). The proposed 11 level inverter is shown in below figure.



Capacitive coupling extracts common mode current which is inversely proportional to switching frequency of the neutral connected leg .converter operates in different output voltage zones, output voltage switches between two definite voltage levels, Operating zone boundaries change as per dc-link and flying capacitor voltages, also the adjacent zones may overlap as shown in figure. Converter can be operated in different operating zones which depends upon the dc link and flying capacitor voltage, output voltage changes between two specific levels ,the flying capacitor voltage contribution to the converter output voltage is positive in zone A whereas it is negative in zone B
The switching pattern depends upon the instantaneous fundamental component of output

voltage v_{fc} and DC voltage v_{dc},The converter can produce 11-output voltage levels by choosing v_{fc}=V_{DC}/4.

Different operating zones of a 11 level inverter

The grid connected PV system has to transfer active power to grid and controlling the flying capacitor voltage ic crucial. As per the required output voltage level ,v_{fc} is controlled by selecting the operating zone ,depending on these zones v_{fc} can be added or substracted from the HVFB voltage during which the capacitor gets charged or discharged during injecting positive value of current to the grid ,the flying capacitor is charged in B zones and discharged in zones. With different switching configuration the same output voltages can be generated, controlling v_{fc} the converter can be made to operate more in a zone. when v_{fc} is more than a reference value ,more in B zone when v_{fc} is less than a reference value.The explanation would be similar to during injecting negative value of current to the grid .Zone A ,Zone B operation is determined by v_{fc} ,during changing and discharging of flying capacitor as shown in below figures.

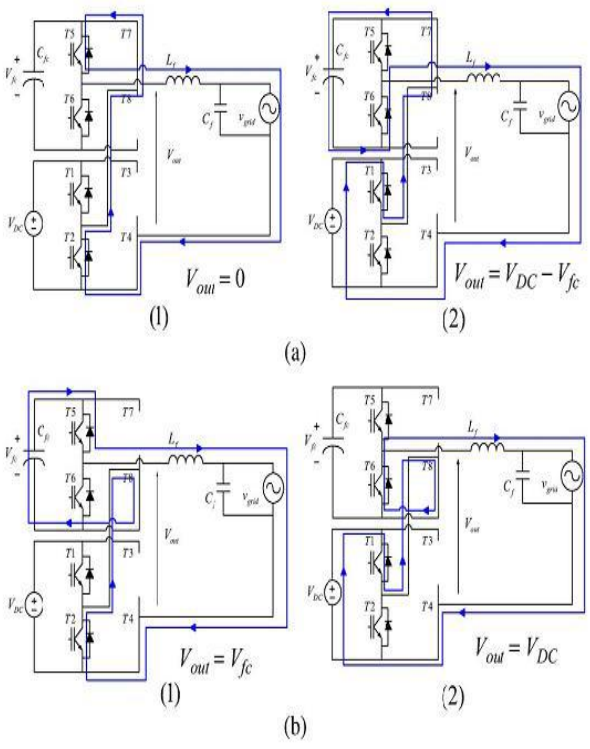
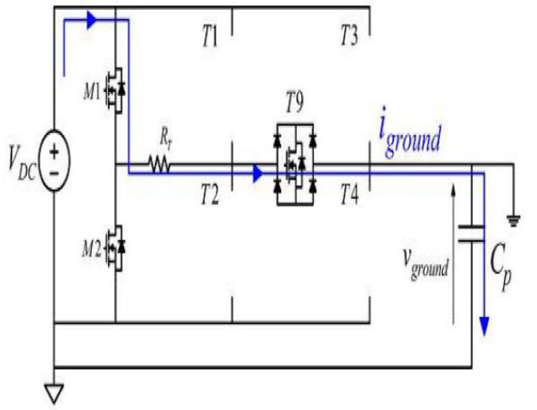


Fig. 3.4 illustrates the regulation off supposing a positive grid current without>0

and <0.5 .If is too low, output level can be replaced by – thus switching between the 0 and − output levels. Similarly, if is too high; can be replaced, causing the converter to switch between theft and

Zone	*Output Voltage*	Devices		
		On	Off	Switching
Zone-4A Zone-4B	(V_{DC}-V_{fc})to (V_{DC}+V_{fc}) (V_{DC}/2) to (V_{DC}-V_{fc})	T1,T4,T8 T1,T4,T7	T2,T3, T7 T2,T3, T8	T5,T6 T5, T6
Zone-3A Zone-3B	(V_{DC}-V_{fc})to(V_{DC}) (V_{DC}-V_{fc})to (V_{DC}/2)	T4,T8 T4, T7	T3,T7 T3,T8	T1,T2T5, T6 T1,T2 T5,T6
Zone-2A Zone-2B	(V_{fc}) to (V_{DC}-V_{fc})(0) to (V_{DC}/2)	T1,T8 T1,T	T2,T7 T2,T8	T4,T3,T5, T6 T4,T3, T5, T6
Zone-1A Zone-1B	(0) to (V_{fc}) (-V_{fc}) to (0)	T2,T4,T8 T1,T4,T7	T1,T3,T T2,T4,T	T5,T6 T5,T6
Zone-2A Zone-2B	(-V_{fc}) to (-V_{DC}+V_{fc}) (-V_{DC}/2) to (-V_{DC})	T2,T7 T2, T8	T1,T8 T1,T8	T3,T4,T5, T6 T3,T4; T5, T6
Zone-3A Zone-3B	(-V_{DC}/2) to (-V_{DC}+V_{fc})(-V_{DC}-V_{fc}) to (-V_{DC})	T3,T8 T3, T7	T4,T7 T4,T8	T1,T2,T5, T6T1,T2, T5,T6
Zone-4A Zone-4B	(-V_{DC}/2) to (-V_{DC}) (-V_{DC}+V_{fc})to(-V_{DC} V_{fc})	T2,T3,T8 T2,T3,T7	T1,T4,T T1,T4,T	T5,T6 T5,T6

output levels [zone 2A,Fig. 4(b)]. In Fig. 4, the devices switching at low frequency are short circuited when on and not shown when off. Similar Vic regulation strategies can be likewise developed for the case when >0.5 . If <0.5 , in order to minimize the current ripple, zone2 is chosen only. When <V∗ out< − (zones 3 are otherwise chosen), limiting level skipping. Level skipping always occurs iffy >0.5 ; hence, any A or B zone can be chosen according to the voltage regulation algorithm. Since the dc-link voltage can go through sudden variations due to the MPPT strategy, it is important that the converter is able to work in any [,] condition. While the distortion of the output voltage is minimized through the on-line duty cycle computation, it is important to assess the capability of the converter to regulate the flying-capacitor voltage under different operating conditions. The ability to control the flying-capacitor voltage through the proposed PWM strategy has been studied in simulation by determining the average flying-capacitor current under a large span of and values. In the simulations, grid voltage grid is sinusoidal with amplitude of 230 √2V; however, the same results hold even for different voltages if the ratio Grid/ remains constant. The results in the case of unity power factor are summarized in Fig. 3.5 the white area covers the range over which is fully controllable, whereas it cannot be controlled in the gray and black regions. In particular, in the black region, cannot be decreased, whereas in the gray region, it cannot be increased. Therefore, the white region located between the gray and black ones is a stable and safe operating area for the converter. Even if was not actively controlled, it would be constrained inside the white region, ensuring that the flying capacitor cannot be over charged nor completely discharged. The results are not affected by the amplitude of the grid current. Nevertheless, the power factor affects the results: a lower power factor determines widening of the controllable area. When the converter supplies only reactive power is controllable in the entire domain



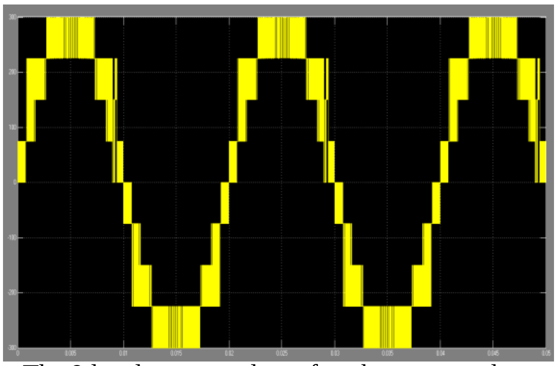
Proposed Transient Circuit operation

Magnitude of 230√2 . Consider a switching pattern of Table.1, where T3, T4 switch ON at grid frequency and switching OFF at zero crossing of V_{grid} . T4 opens and T3 closes when zero crossing with negative derivative is considered, hence the neutral wire voltage changes from zero to V_{DC} . Because of this, switching causes large surge of leakage current that damages the PV module and decreases the power quality. A transient circuit is designed to reduce the surge current. For better understanding the behavior of transient circuit, distributed capacitance of PV source is represented with a equivalent parasitic capacitance (C_P) connected between the dc link negative pole and ground. The transient circuit contains two MOSFET's M1, M2, bidirectional switch T9 and resistor R_T . During the operation of converter at Zone 1, the output voltage of HVFB is zero which is achieved by switching T1 and T3 or T2 and T4 are all switched off, only T9 is on which leads to neutral point floating, keeping the parasitic capacitance (Cp) is constant.

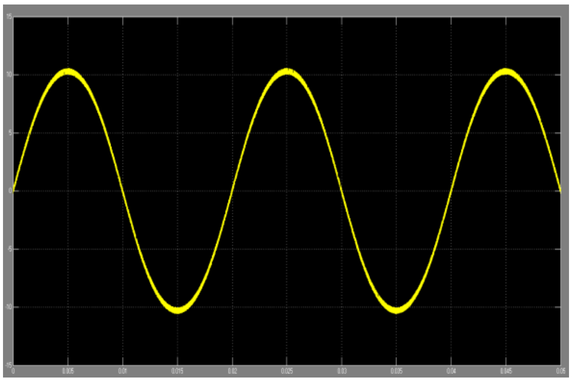
MOSFET, M1 is switched ON if slope of zero crossing is negative, M2 is switched ON if slope of zero crossing is positive, then the parasitic capacitance (C_P) gets charged through R_T , limiting the surge current. The power loss of the resistor in the transient circuit is negligible. The energy lost by charging and discharging the parasitic capacitance (C_P) to V_{DC} over a time period is given by $P_{tc} = (C_P V_{DC}^2)/T$, with C_P = 200nF and V_{DC} =300V. As the output voltage is close is close to grid voltage, the power factor does not influence the transient circuit operation, for correct operation, transient circuit requires grid voltage instantaneous angle which can be acquired by phase-locked loop (PLL) supplied by grid voltage.

5. SIMULATION RESULTS:

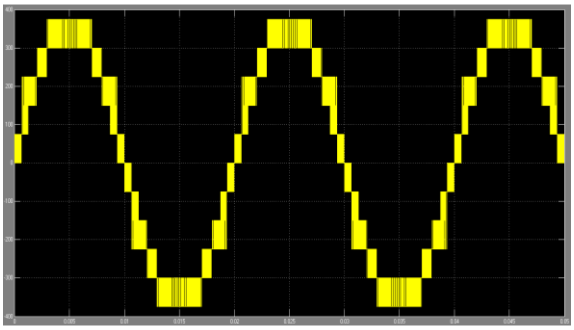
The proposed converter was simulated using MATLAB/Simulink, covering broad range of active and reactive power fed to the grid, dc link voltage, and PV parasitic capacitance (C_P) , the specifications of different parameters are as follows, dc link voltage V_{DC} =300V, grid sinusoidal voltage V_{grid} =230V, at a frequency 50Hz, Presents the output current for the proposed system.



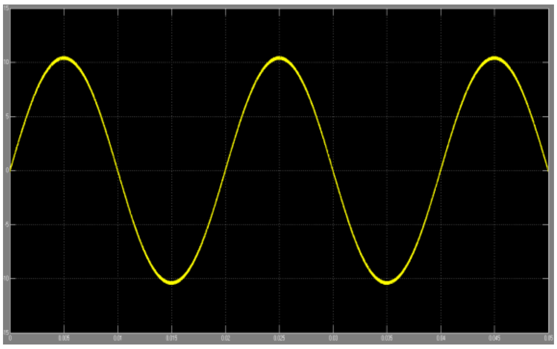
The 9 level output voltage for the proposed converter with respect to time



Grid voltage for 0.5 V_{fc}-9 level



The 11 level output voltage for the proposed converter with respect to time



Grid voltage for 0.5 V_{fc}- 11 level

6. CONCLUSION

This paper proposes a comparison between nine level and eleven level transformer less grid connected photovoltaic converter consisting of two H-BIC 's the efficiency is developed by a suitable PWM strategy and ground leakage current is minimized by using a definite transient circuit. Simulation results show the effectiveness of a proposed topology. To reduce ground leakage currents, two additional low power switches and a line frequency switching device (Transient circuit) is included in final topology. This paper is arranged in the following way: The proposed converter topology and PWM control strategy to maximize the performance, using a low-cost digital signal processor (DSP), is presented in Section II. Flying capacitor regulation, to feed the CFB's second full bridge is dealt in Section III. Section IV explains the Operating principle to reduce leakage current. Section V presents the simulation results, and finally section VI concludes the paper. compared to other two and so it weighs less and costs less [16]. This paper proposes an eleven level cascaded H-Bridge multi-level inverter consisting of only two cells. The DCMLI used in various applications like dynamic voltage restorers, unified power.

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