Transformer-less Inverter for Photovoltaic Grid Connected Power System

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Abstract—This paper presents newly developed transformer-less single phase inverter for photovoltaic (PV) power system. When grid connected photovoltaic system is transformer-less, a galvanic connection between the grid and PV array exists. In these conditions, common mode leakage currents can appear through the stray capacitance in between PV array and the ground. In order to avoid these leakage current, different inverter topologies are used which generate constant common mode voltages. The two different control techniques are used to eliminate common mode leakage current. These current increase harmonics injected in the utility grid and losses.

Key words: Total Harmonics Distortion (THD), Photovoltaic (PV), sinusoidal pulse width modulation (SPWM)

I. INTRODUCTION

Grid connected photovoltaic (PV) system include a line transformer in between conversion stage and grid. The transformer create galvanic isolation between grid and PV system, thus there is no safety issue. However, because of its use a system becomes bulky and expensive. More to the point, it reduces the overall efficiency of conversion stage. Because of cost and size reduction and overall efficiency improvement, the interest on transformer less topologies is growing. If the system is transformer-less the inverter must cover purpose of transformer [1]. The galvanic connection between the grid and PV Array result in common mode leakage current flows through the parasitic capacitor appear between the PV array and ground. As shown in fig 1. These common mode leakage current cause severe electromagnetic interferences, grid current distortion, and additional losses in the system. To avoid these common mode leakage current, it is necessary to use conversion topologies which do not generate variable common mode voltages [4]. There is several conversion topologies used to like half bridge topology, Full bridge inverter topology with unipolar or bipolar sinusoidal pulse width modulation (SPWM). Half bridge topology requires a high input voltage which is greater than 700V for 220V-ac applications. As a result, large number of PV modules in series involved which increase the cost of system. Full bridge inverter just need half of the input voltage demanded by the half bridge topology, which is about 350V for 220-application [3]. But full-bridge inverter can only employ for the bipolar SPWM strategy which induces high current ripple, low system efficiency.

Fig. 1: Leakage current in transformer less Inverter.

Furthermore, many advanced inverter topologies developed for transformer-less PV application such as H5 inverter, HERIC inverter etc. as shown in fig2. This system used for the unipolar SPWM and bipolar SPWM with three level output can be obtained in the presented inverter. Unipolar have higher efficiency same as bipolar technique but bipolar strategy have higher efficiency and lower current ripple. A smaller filter inductor can be employed to reduce harmonic and THD of the output current are reduced greatly, and grid current quality is improved accordingly. In this paper an improved grid connected inverter topology for transformer-less PV system is presented, which can sustain the same low input voltage as the full bridge inverter and it also have guarantee not to generate the common mode leakage current.

(a) Half bridge inverter

(b) Full bridge inverter
A. Analysis of Common Mode Leakage Current

In order to derive common mode leakage current consider N be the reference point of solar panel. How to eliminate a leakage current derived below in stepwise,

1) Step1.
Consider equivalent Circuit as below.

2) Step 2.
Equivalent circuit simplified as,

3) Step3.
The switching frequency of IGBT is much higher than that of grid hence effect of grid on variation of common mode voltage is ignored[5].

4) Step4.
Under balance condition, if $L_A = L_B$

II. IMPROVED INVERTER Topology

Fig. 6. shows an improved grid connected inverter topology, which eliminate common mode leakage current by keeping common mode voltage constant. There are two strategy used to keep common mode voltage constant, 1) Unipolar SPWM, 2) Bipolar SPWM sinusoidal pulse width modulation. This technique is used to achieve a three level output and lower current ripple [6]. The improved inverter
topology is same as to full bridge inverter but one difference is that, two additional switches are connected towards dc side for decoupling purpose.

A. Unipolar SPWM Technique

There are four operation mode in unipolar SPWM which generate the voltage stages as \(+V_{dc}\), \(0\), \(-V_{dc}\) as below,

1) **Mode 1:**
When \(S_4\) and \(S_5\) are ON, \(V_{AB}=+V_{dc}\) and the inductor current increases through the switches \(S_5\), \(S_1\), \(S_4\), and \(S_6\). Common mode voltage,
\[V_{cm} = \frac{(V_{AN}+V_{BN})}{2} = \frac{(V_{dc}+0)}{2} = \frac{V_{dc}}{2}\]

2) **Mode 2:**
When \(S_4\) and \(S_5\) are turned OFF, the voltage \(V_{AN}\) falls and \(V_{BN}\) rises until their values are equal, and the antiparallel diode of \(S_3\) conducts. Therefore, \(V_{AB}=0\) and the inductor current decreases through the switch \(S_1\) and the antiparallel diode of \(S_3\)
The common-mode voltage is \(V_{cm}\),
\[V_{cm} = \frac{(V_{dc}/2+V_{dc}/2)}{2} = \frac{V_{dc}}{2}\]

3) **Mode 3:**
When \(S_3\) and \(S_6\) are ON, \(V_{AB}=-V_{dc}\) and the inductor current increases reversely through the switches \(S_5\), \(S_3\), \(S_2\), and \(S_6\).
The common-mode voltage \(V_{cm}\),
\[V_{cm} = \frac{(0+V_{dc})}{2} = \frac{V_{dc}}{2}\]

4) **Mode 4:**
When \(S_3\) and \(S_6\) are ON, \(V_{AB}=+V_{dc}\) and the inductor current increases reversely through the switches \(S_5\), \(S_3\), \(S_2\), and \(S_6\). The common mode voltage \(V_{cm}\),
\[V_{cm} = \frac{(V_{dc}/2+V_{dc}/2)}{2} = \frac{V_{dc}}{2}\]

From above we can see that common mode voltage remain constant during all mode of operation.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Switches</th>
<th>Voltage (V_{ab})</th>
<th>Voltage (V_{cm})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(S_4) and (S_5)</td>
<td>+(V_{dc})</td>
<td>(V_{dc}/2)</td>
</tr>
<tr>
<td>2</td>
<td>(S_4) and (S_5)</td>
<td>0</td>
<td>(V_{dc}/2)</td>
</tr>
<tr>
<td>3</td>
<td>(S_3) and (S_6)</td>
<td>-(V_{dc})</td>
<td>(V_{dc}/2)</td>
</tr>
<tr>
<td>4</td>
<td>(S_3) and (S_6)</td>
<td>0</td>
<td>(V_{dc}/2)</td>
</tr>
</tbody>
</table>

Table 1:
B. Bipolar SPWM Technique

The improved inverter can also operate with the Bipolar or double frequency SPWM strategy to achieve a lower ripple and higher frequency of the output current. In this situation, both phase legs of the inverter are modulated with 180° opposed reference waveform and the switches S1-S4 all acting the switching frequency. Two additional switches S5 and S6 also commutate at the switching frequency accordingly. In positive half cycle mode 1, mode2, mode5 continuously rotate to generate +Vdc and zero states. In negative half cycle mode3, mode4 and mode 6 continuously rotate to generate –Vdc and zero states. Thus there are six mode of operation continuously rotate with double frequency to generate +Vdc and zero states or –Vdc and zero states.

Modes 1 to Mode 4 are same as unipolar SPWM remaining two modes are as below,

Mode 5:

![Mode 5](image)

When S1 and S6 are turned OFF, the voltage VAN fall and VBN rises until their values are equal, and anti-parallel diode of S2 conducts. Therefore, VAB = 0V and the inductor current decreases through switch S4 and anti-parallel diode of S2. The common mode voltage Vcm,

\[ V_{cm} = \frac{(V_{AN} + V_{BN})}{2} = \frac{(V_{dc}/2 + V_{dc}/2)}{2} = V_{dc}/2 \]

Mode 6:

![Mode 6](image)

When S1 and S6 are turned OFF, voltage VAN falls and VBN rises until their values are equal, and the anti-parallel diode of S2 conducts. Therefore VAB=0V and inductor current decreases through switch S4 and the anti-parallel diode of S2. The common mode voltage Vcm,

\[ V_{cm} = \frac{(V_{dc}/2 + V_{dc}/2)}{2} = V_{dc}/2 \]

Thus, under bipolar SPWM strategy the common mode voltage can keep a constant Vdc/2 in the whole switching process of six operation modes. Furthermore, the lower current ripple, higher grid current quality and lower THD achieved.
From above, it is clear that grid connected current is highly sinusoidal and synchronized with grid voltage and common mode leakage current is eliminated. The harmonic profile for grid connected current with unipolar SPWM technique is shown which indicates that THD of grid connected current with unipolar SPWM technique is 2.48%.

IV. SIMULATED RESULT UNDER BIPOLAR SPWM

![Simulated results of (a) Output voltage (b) Grid voltage (c) Grid current](image1)

Fig. 17: Simulated results of (a) Output voltage (b) Grid voltage (c) Grid current

![Simulated results of (a) common mode voltage (b) Leakage current](image2)

Fig. 18: Simulated results of (a) common mode voltage (b) Leakage current

![Fig. 19: THD with bipolar SPWM](image3)

From above, it is clear that grid connected current is highly sinusoidal and synchronized with grid voltage and common mode leakage current is eliminated. The harmonic profile for grid connected current with bipolar SPWM technique is shown which indicates that THD of grid connected current with bipolar SPWM technique is 1.99%.

So it is clear that, THD of grid connected current under double frequency SPWM technique is lower than the unipolar SPWM technique.

V. CONCLUSION

This paper present the performance of transformer less inverter with different control strategy to achieve three level output. The bipolar technique achieves lower THD than unipolar technique. This paper also deals with analysis of common mode leakage current in transformer less inverter in PV application. The simulated result shows that as the common mode voltage is kept constant, the leakage current is completely eliminated.

REFERENCES