Leakage Current Analysis of Single Phase Photovoltaic Grid Tied Inverters

1Murli j.Antani, 2Sridhar Makkapati
1PG Scholar, 2Assistant Professor

1,2Department of Electrical Engineering, Marwadi Education Foundation Group of Institutions

1murliantani2@yahoo.co.in, 2sridhar.makkapati@marwadieducation.edu.in

Abstract - In domestic single phase grid connected PV applications; single phase converters are usually employed. In low power applications converter topologies without galvanic isolation can be adopted between PV panel and grid. On the other side in the presence of galvanic connection, ground leakage current could arise due to parasitic PV panel capacitance. In order to avoid these leakage current inverter topology with no varying common mode is required. This paper presents the converter topology to minimize the leakage current/common mode currents using unipolar sinusoidal pulse width modulation technique using MATLAB/SIMULINK.

Keywords— Leakage current, common mode current, Photovoltaic system, unipolar sinusoidal PWM (UPSPWM)

I. INTRODUCTION

This Renewable energy sources play an important role in electric power generation. Variable renewable sources such as solar energy, wind energy, geo thermal and bio-mass can be used for generation of electricity and for meeting our daily energy needs. Wind and biomass system requires suitable electric generator for producing electrical power. However solar panels give electrical energy directly from sun radiation.

Quite often, the grid connected system includes a transformer, which is heavier in size and much costly though it provides a galvanic isolation and providing personnel protection. Furthermore it strongly reduces the leakage current and also increases the inverter output voltage. Technological development has made possible implementation of effective conversion topologies without impacting any system characteristics related to safety and grid integration [13].

The use of PV array which produces a maximum voltage can limit the boosting voltages in the conversion stage. This conversion stage can consists of a simple Buck or Boost topology without having a transformer which is more efficient. The absence of Boost dc-dc converter resulting in power fluctuation causes the voltage ripple in the PV side. However when no transformer is used, a dangerous leakage current(common mode current) can flow through the large stray capacitance between the PV array and ground if inverter generates a varying common mode voltage.[11]

In present days leakage current is big issue in the transformerless grid connected inverters. Grid connected Photovoltaic systems particularly the low power single phase systems are becoming more important. Issues such as reliability, high efficiency, small size and weight and low cost are of great importance for conversion stage of Photovoltaic system [12].

This paper proposes a new topology that generates the no varying common mode voltages with low input voltage using sinusoidal pulse width modulation, which can achieve the higher efficiency. This topology consists of six switches and two diodes which are advantages during power conversion stage. Transformerless Grid connected photovoltaic systems

II. SYSTEM DESCRIPTION

Block diagram of PV grid tied inverter is shown in Figure 1 and it consists of PV array, Boost converter, Inverter unit, filter circuit, and Grid. The capacitor shown in above diagram is parasitic capacitor which is cause for leakage current.

A. P V ARRAY

Photovoltaic array is used for transfer the solar energy in the electric al energy. PV cell is the basic unit of the Photovoltaic generator. Combination of solar cells makes a module and modules together become PV array.[4]

\[
I = I_{ps} - I_{d}
\]  

Figure 1 shows circuit model of PV cell. Basically photovoltaic cell is a semiconductor diode whose PN junction is exposed to light and generates the charge carriers when the incidence of light on the cell that originate an electric current. This Diagram consists of a current source which is connected in parallel with a Diode, series and parallel Resistances are represent by \( R_{s} \) and \( R_{p} \) respectively. Total current \( I \) is composed of the light generated current \( I_{ps} \) and the diode current \( I_{d} \).
Common mode voltage must be eliminated due to the radiation, temperature effect, and so many reasons, so it needs to step up the voltage output. By the use of Boost converter we can get the constant output DC voltage. It is able to control and maintain the same voltage [5]. Duty cycle of the Boost converter is controlled by the MPPT algorithm. Design of Boost converter is carried out by using the following equations:

\[ I_p = I_v \cdot \exp^{q/(kT)} \]  
\[ V_i = N_c kT/q \]  
\[ I = I_{pv} - [\exp (V + (R_s I/V_a)) - 1] - (V + R_s I)/R_p \]

Where,
- \( I_p \) = Leakage current of the diode
- \( q \) = Electron charge
- \( k \) = Boltzmann constant
- \( T \) = Temperature of PN junction
- \( a \) = Diode ideality constant
- \( V_i \) = Thermal voltage
- \( N_c \) = Number of cells

**B. BOOST CONVERTER**

\[ D = 1 - (V_s / V_o) \]  
\[ L = V_s D / \Delta I (I) f \]
\[ L = (D (1-D)) R / (2*f) \]  
\[ C = D/2*f^2 R \]

Where,
- \( D \) = Duty cycle
- \( V_s \) = Supply voltage
- \( V_o \) = Output voltage
- \( \Delta I \) = Change in inductor current

Above equation represents the equation of PV cell but it does not represent the I-V characteristic of a practical PV array. Practically array consists of several connected PV cells and the characteristic of the PV array requires additional parameters to the basic equation is of as follow. [8]

**III CONDITION OF ELIMINATING COMMON-MODE LEAKAGE CURRENT**

Absence of transformer in PV grid connected system, galvanic connection presents between the grid and the PV array. So its form common mode resonant circuit and leakage current is flow through the circuit. Due to the leakage current additional losses appears in the damping elements, thus decreasing the conversion stage efficiency. This leakage current can cause severe electromagnetic interferences, distortion in the grid current, hence it requires to eliminate the leakage current. The leakage current is excited by the common mode voltage. So the condition for reducing or eliminating leakage current is drawn that common mode voltage must be kept constant. [13]

\[ V_{cm} = (V_{Ao} + V_{Bo}) / 2 \] = Constant

Where \( V_{cm} \) is the common mode voltage.

**IV INVERTER TOPOLOGY AND ITS OPERATING MODES**

**A. FULL BRIDGE DC BYPASS TOPOLOGY (FBDCBP)**

Figure 4 indicates the existing topology, which consist of the six switches (S1-S6) and two diodes (D7-D8). Diodes D7-D8 and the capacitive divisor limiting the blocking voltages of S5 and S6 to half of the input voltage. In these topology, the operations will be occurs similar for all power factors. Operation of this topology is as follow.[11]

**MODE 1**

During MODE 1, the positive half cycle, switch S1 and S4 are ON. S5 and S6 commutate at switching frequency with same commutation orders. S2 and S3 commutate at switching frequency together and complementarily to S5 and S6 to half of the input voltage.
S6. When S5 and S6 are ON, $V_{AB} = V_{PV}$ through the switches S5, S1, S4 and S6 is increases the inductor current.

So,

$$V_{CM} = \frac{(V_{AO} + V_{BO})}{2}$$ \hspace{1cm} (9)

$$V_{CM} = \frac{(V_{PV})}{2}$$ \hspace{1cm} (10)

$$V_{CM} = \frac{(V_{PV})}{2}$$ \hspace{1cm} (11)

**MODE 2**

In MODE 2 current splits in to two paths when S5 and S6 are turned off and S2 and S3 are turned ON. S1, freewheeling diode of S3 and S4, freewheeling diode of S2. Thus S2 and S3 are turned on with no current. $V_{AB}$ and $V_{CD}$ voltage tend to zero and D7 and D8 diodes fix $V_{AO}$ and $V_{BO}$ voltage to $V_{PV}/2$. Now, the common mode voltage is,

$$V_{AO} = V_{BO} = \frac{V_{PV}}{2}$$ \hspace{1cm} (12)

So, $V_{CM} = V_{PV}/2$ \hspace{1cm} (13)

**MODE 3**

During the MODE 3, the negative half cycle S2 and S3 are ON. Switches S5 and S6 commutate at the switching frequency in order to modulate the input voltage. Switching S1 and S4 Commutate at the switching frequency together and complementarily S5 and S6. $V_{AB} = -V_{PV}$ when S5 and S6 are on. And inductor current flow through S5, S3, S2 and S6 is decreases. Voltage is

$$V_{CM} = \frac{(0 + V_{PV})}{2}$$ \hspace{1cm} (14)

$$V_{CM} = \frac{V_{PV}}{2}$$ \hspace{1cm} (15)

**MODE 4**

During MODE 4, When Switches S2 and S3 are turned on and switches S5 and S6 are off, the current splits in to two paths: S3 and freewheeling diode S1, and the second of S2 and the freewheeling diode of S4. Voltage across the $V_{AB}$ and $V_{CD}$ tend to zero and diodes D7 and D8 fix the Voltages $V_{AO}$ and $V_{BO}$ to $V_{PV}/2$. The current decreases and $V_{AB}$ is clamped to zero.

$$V_{AO} = V_{BO} = \frac{V_{PV}}{2}$$ \hspace{1cm} (16)

From the above equations, it is clear that common mode voltage remains constant for all the modes. So no leakage current appears.

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**IV SIMULATION CIRCUITS OF PV AND INVERTER TOPOLOGY**

The above figure 5 shows the simulation circuit diagram for PV array. It consists of 6 module PV panels each of 85 W. which are connected in series results the output power of 510 Watts.

The detailed parameters are used as follows. $V_{dc} = 380V$; input capacitor, $C_{dc} = 940 \mu F$; grid frequency, $f_g = 50$ Hz; Switching frequency, $f_s = 10$ kHz; filter inductor, $L_f = 4$ mH.

**VI. EXPERIMENTAL RESULTS**
I-V and P-V characteristics of PV array which consists of six PV panels each of 85W is shown in Figure 7 and Figure 8 respectively. The power output of PV array is of 510 Watts with a constant insolation of 1000 W/m². Figure 9 shows the FBDCBP inverter positive half cycle output voltage with an output voltage of +380 V. The negative half cycle output voltage of -380 V is shown in Figure 10. The inverter output voltage is filtered and fed to grid. Figure 11 shows the no varying common mode voltage of 190 V which will nullify the common mode leakage current. The corresponding results are as follows.

VII. CONCLUSION

In this paper, Full bridge DC bypass Inverter topology is simulated and got the no varying common mode voltage which eliminates the leakage current in solar photovoltaic grid tied inverters. The suggested inverter topology can achieve high efficiency, low cost, low leakage current to satisfy the requirements of photo voltaic grid tied systems. This system can be extended with Bipolar Pulse width modulation technique.

REFERENCES


[8] S. Daison Satallon, K. Vinoth Kumar, S. Suresh Kumar, “High efficient Module of Boost Converter in PV
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[13] V. Salas, M. Alonso-Abella, B., F. Cheno b, E. Olí, “as a “Analysis of the maximum power point tracking in the photovoltaic grid inverters of 5 kW” Electronic Technology Department, Universidad Carlos III de Madrid, Avda. de la Universidad, 30-28911 Leganes


Murli Antani1 received the B.E. degree in electrical engineering from the SVMIT, Bharuch in 2010. She has experience of one and half year as a lecturer in Veerayatan Institute of Technology at Mandvi – Kutch. Currently she is pursuing M.E. in power electronics and electrical drives from Marwadi Education Foundation Group of Institutions, Rajkot. Her research interests include Grid Tied photo voltaic systems and drives.

Sridhar Makkapati2 received the B.Tech degree in electrical and electronics engineering from the JNTU, Kakinada and the M.Tech degree in power electronics and drives from SRM University, Chennai India in 2012. Currently he is working as Assistant professor in Marwadi Education Foundation Group of Institutions, Rajkot. His research interests include power electronics, Grid Tied photo voltaic systems, Multilevel Inverters and Ac drives.