Leakage Current Analysis of Single Phase Photovoltaic Grid Tied Inverters

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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 Photo voltaic 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

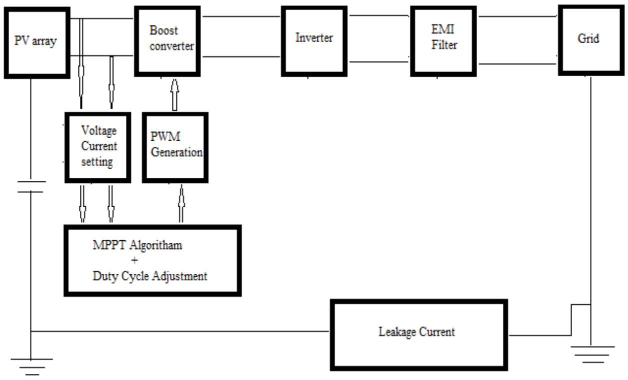

Figure.1 Block diagram of PV grid tied inverter.

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]

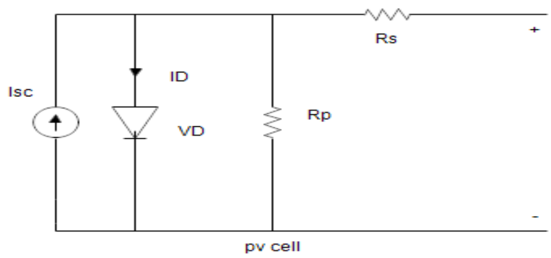

Figure.2 Circuit model of PV cell

Figure2. 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 represents by R_s and R_p respectively. Total current I is composed of the light generated current I_{pv} and the diode current I_d.

$$I = I_{pv} - I_d \quad (1)$$

$$I_d = I_0 * \exp^{qv/akt} \quad (2)$$

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]

$$I = I_{pv} - [\exp (V + (R_s I / V_t a)) - 1] - (V + R_s I)/R_p \quad (3)$$

$$V_t = N_s kT/q \quad (4)$$

Where,

I_0= Leakage current of the diode

q=Electron charge

k=Boltzmann constant

T=Temperature of PN junction

a=Diode ideality constant

V_t= Thermal voltage

N_s=Number of cells

B. BOOST CONVERTER

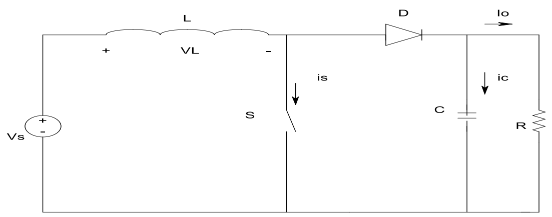

Figure.3 Boost converter

The output of the PV array is low level unregulated Dc voltage due 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 the value of inductor and capacitor by using the following equations:

$$D=1-(Vs/Vo) \quad (5)$$

$$L=Vs\ D/\Delta (I)\ f \quad (6)$$

$$L= (D (1-D) R)/ (2*f) \quad (7)$$

$$C=D/2*f*R \quad (8)$$

Where,

D= Duty cycle

V_s= Supply voltage

V_{O}=Output voltage

ΔI= Change in inductor current

f=Switching frequency, H_z

L=Value of the inductor

R=Equivalent load, Ω

C=Value of the capacitor

Boost Converter with high output voltage was connect to the inverter topology which will gives AC and fed to the grid.[5]

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]

$$V_{cm} = (V_{Ao} + V_{Bo}) / 2 = \text{Constant}$$

Where V_{cm} is the common mode voltage.

IV INVERTER TOPOLOGY AND ITS OPERATING MODES

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

Full bridge DC bypass topology is shown in Figure.4. This is used to satisfy the condition of eliminating common-mode leakage current. This topology consists of six switches and two diodes, where Unipolar switching method is employed.

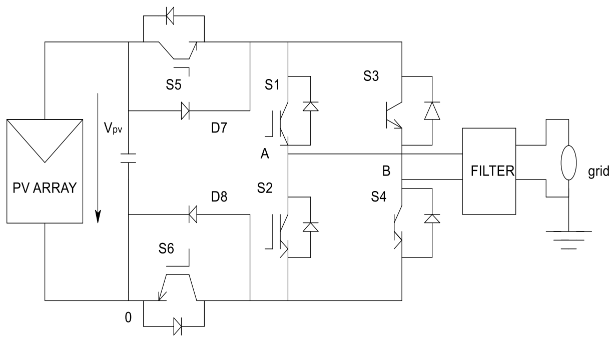

Figure.4 FBDCBP topology

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. When S5 and S6 are ON, $V_{AB} = V_{pv}$ through the switches S5, S1, S4 and S6 is increases the inductor current.
So,

$$V_{CM} = (V_{AO}+V_{BO})/2 \quad (9)$$

$$(V_{pv}+0)/2 \quad (10)$$

$$V_{CM} = (V_{pv})/2 \quad (11)$$

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,

$$V_{AO} = V_{BO} = V_{PV}/2 \quad (12)$$

$$\text{So, } V_{CM} = V_{PV/2} \quad (13)$$

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

$$V_{cm} = (0+V_{pv})/2 \quad (14)$$

$$= V_{pv}/2 \quad (15)$$

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 VBO to $V_{PV\ /2.}$ The current decreases and V_{AB} is clamped to zero.

$$V_{AO} = V_{BO} = V_{pv/2} \quad (16)$$

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

TABLE I
SWITCHING SCHEME

MODE	S1	S2	S3	S4	S5	S6
1	ON	OFF	OFF	ON	ON	ON
2	ON	F.D	F.D	ON	OFF	OFF
3	OFF	ON	ON	OFF	ON	ON
4	F.D	ON	ON	F.D	OFF	OFF

IV SIMULATION CIRCUITS OF PV AND INVERTER TOPOLOGY

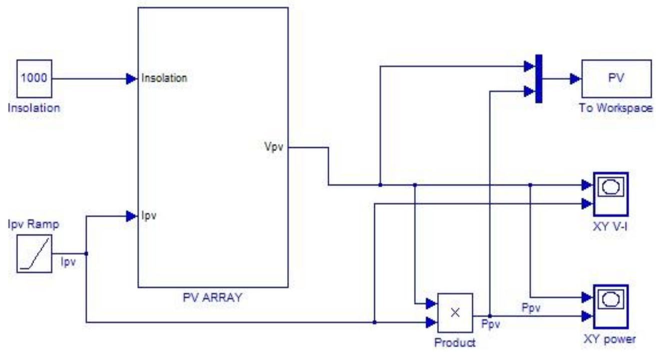

Figure. 5 PV Array

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.

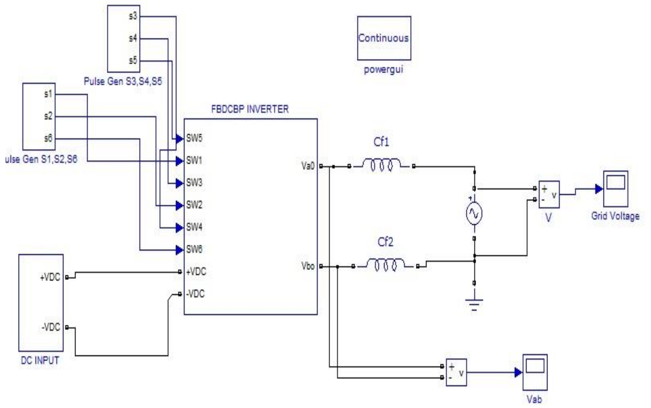

Figure.6 simulation circuit of FBDCBP

Figure 6. shows the simulation circuit of suggested full bridge dc by pass inverter topology. The constant boost output voltage is fed to inverter circuit with a input voltage of 380 volts.Unipolar Sinusoidal pulse width modulation technique is used to generate the pulse patterns and corresponding switching pattern is shown in Table 1. Switches S1 and S2 are operated at grid frequency and remaining switches are operated at switching frequency [14].The detailed parameters are used as follows. V_{dc} = 380V; input capacitor, C_{dc} = 940 μF V_g =220V_{ac}; 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/m^2.Figure 9 shows the FBDCBP inverter positive half cycle output voltage with an output voltage of +380 V. The negative half cycle output voltage 0f -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 of as follows.

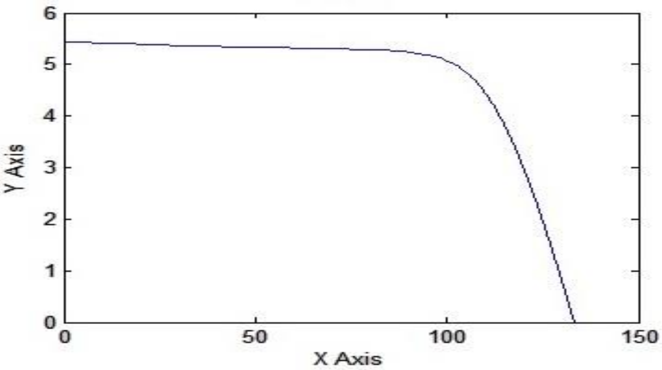

Figure.7 I-V Characteristics of PV Array

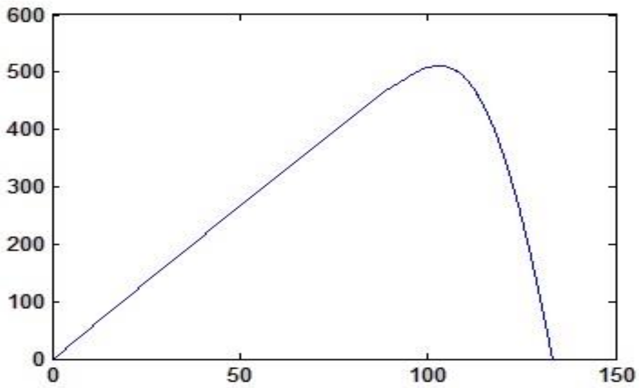

Figure.8 P-V Characteristics of PV Array

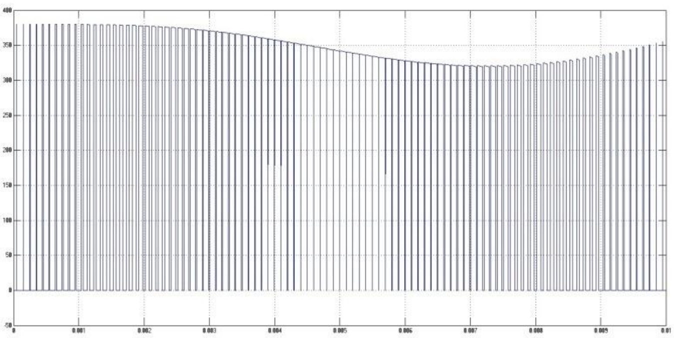
Figure9 Positive half output voltage of FBDCBP topology

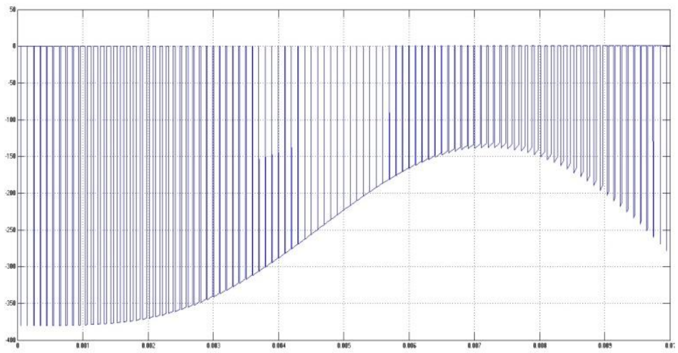
Figure10 Negative half output voltage of FBDCBP topology

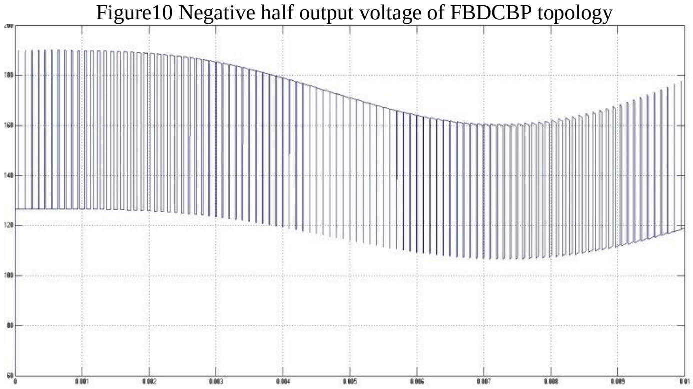
Figure.11 common mode voltage of FBDCBP topology

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 photo voltaic 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.

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