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High Efficiency Transformer less Inverter for Single-Phase Photovoltaic Systems using Switching Converter

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***Abstract*— There is a strong trend in the photovoltaic inverter technology to use transformer less topologies in order to acquire higher efficiencies combining with very low ground leakage current. When no transformer is used in a grid/Load 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 need of a high-input voltage represents an important drawback of the half-bridge. The bipolar PWM full bridge requires a lower input voltage but exhibits a low efficiency. This paper proposes a new topology with eight switches and two diodes that generates no varying common-mode voltage and exhibits high efficiency.**

***Index Terms*—About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

The importance of renewable energy sources is recognized by both the general public and the power industries. Some researchers believe the concern for environmental damage is now an even greater priority than the need to preserve the finite natural resources for future generations. PHOTOVOLTAIC (PV) inverters become more and more widespread within both private and commercial circles.

These grid/load-connected inverters convert the available direct current supplied by the PV panels and feed it into the utility grid/load. There are two main topology groups used in the case of grid/load-connected PV systems, namely, with and without galvanic isolation. Galvanic isolation can be on the dc side in the form of a high-frequency dc–dc transformer or on the grid/load side in the form of a big bulky ac transformer. Both of these solutions offer the safety and advantage of galvanic isolation, but the efficiency of the whole system is decreased due to power Losses in these extra components.

An improvement in inverter efficiency and a reduction in cost have been achieved by omitting the 50 Hz power transformer (transformer less) and by optimizing the Inverter current control strategies. The inverter described in this project is specifically for grid/Load-connected PV Systems, it can be used for other traditional applications such as in uninterruptible Power supplies (UPS), motor controls and voltage regulation systems. The main aim of this project was to develop a new design procedure for a single-phase, transformer less PV inverter system suitable for grid/Load connection, which would lead to higher inverter efficiencies, improved output power quality and reduced cost. Detailed performance analyses of both the unipolar and the bipolar switched inverters will be carried out before a final choice is made.

Techniques to remove DC offset current will be investigated to ensure that the DC current injected into the grid/Load system is maintained within the legal limits irrespective of its source. To improve the quality of inverter output current, a suitable efficient and cost effective ripple current filter design will also be developed. The specific objectives of the project are summarized

- High efficiency
- Constant High Frequency Common Mode Voltage
- Very Small Leakage Current
- Low Total Harmonic Distortion

Inverter or power inverter is a device that converts the DC sources to AC sources. Inverters are used in a wide range of applications, from small switched power supplies for a computer to large electric utility applications to transport bulk power. This makes them very suitable for when you need to use AC power tools or appliances Control of the switches for the sinusoidal PWM output requires a reference signal (modulating or control signal) which is a sinusoidal wave and a carrier signal which a triangular wave that control the switching frequency.

The benefit of choosing the PWM over analog control is increased noise immunity which the PWM is sometimes used for communication. Switching from an analog signal to PWM can increase the length of a communications channel dramatically. At the receiving end, a suitable RC (resistor-capacitor) or LC (inductor capacitor) network can remove the modulating high frequency square wave and return the signal to analog form. So, the filter requirement can be reduced and the overall inverter size can be reduced.

II. PROPOSED TOPOLOGY

A. Proposed Circuit Diagram

Transformer less inverters with the single-phase bridge, using the pulse width modulation (PWM) scheme, the

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electronic switches can be switched using either the bipolar or the unipolar mode. In the bipolar mode, the diagonally opposite switches of the two legs of the inverter bridge are switched as pairs. In the unipolar mode, the two legs of the bridge are not switched simultaneously but are controlled separately. In the unipolar mode, the output voltage swing is half of that in the bipolar mode for the same input DC voltage. Bipolar PWM generates a constant common-mode voltage. But, by using unipolar PWM modulation, the output of the converter will have three levels, but in this case, the generated common-mode voltage will have high-frequency components, which will lead to very high ground leakage currents.

To reduce the losses, cost and size of the inverter system, it was decided not to use current loop configurations in which a power transformer is essential. Other types of inverters such as single-phase half bridge inverters with two capacitors connected across the input DC source were considered not suitable. Without the use of a step-up transformer, Half-bridge would need to be supplied with twice the DC voltage from the boost converter compared to the full bridge configuration. This method was therefore considered unsuitable and hence, the Single-phase full bridge inverter was chosen.

The full-bridge inverter is a single stage dc–ac conversion topology that is used quite often in PV inverters. By using bipolar PWM in the proposed topology, there is a constant common mode voltage which leads to very small leakage current.

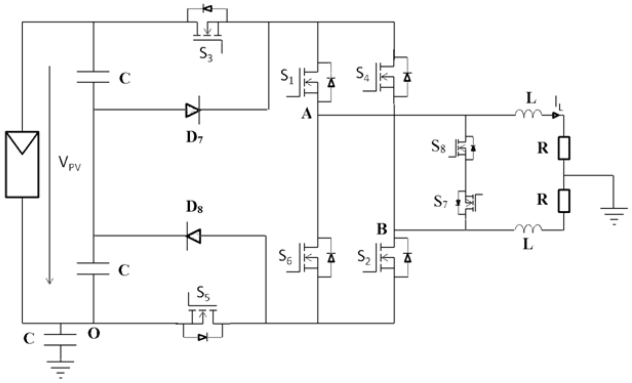

Figure.1. Proposed Circuit Diagram

As shown in figure.1 the proposed circuit diagram, which consists of eight switches and two diodes. In this topology, diodes D_7 & D_8 and the capacitive divisor limit the blocking voltage of S_5 & S_6 and to half of the input voltage V_{pv}.

B. Positive Half Cycle: Active Vector

As shown in figure.2 in the positive half cycle, S_1 & S_2 are on. In order to modulate the input voltage, S_5 and S_6 commutate at the switching frequency with the same commutation orders.S_3 and S_4 commute at the switching frequency together and complementarily to S_5 and S_6.

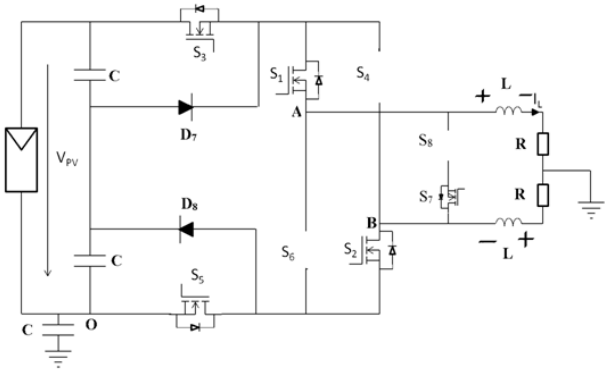

Figure.2 Positive Half Cycle: Active Vector

In this situation, when S_5 and S_6 are on, $V_{AB} = V_{PV}$ and the inductor current, which flows through, S_5, S_1, S_2 & S_6 and increases. The common-mode voltage is

$$V_{cm} = (V_{AO}+V_{BO})/2 = (V_{PV}+0)/2 = V_{PV}/2$$

C. Positive Half Cycle: Zero Vectors

As shown in figure.3.When S_5 and S_6 are turned off and S_3 and S_4 are turned on, the current splits into three paths: S_2 and the freewheeling diode of S_4, the freewheeling diode of S_3 and S_1 and S_8 and the freewheeling diode of S_7. Thus, S_4 and S_3 are turned on with no current and therefore no switching losses appear. The authors of the accepted manuscripts will be given a copyright form and the form should accompany your final submission.

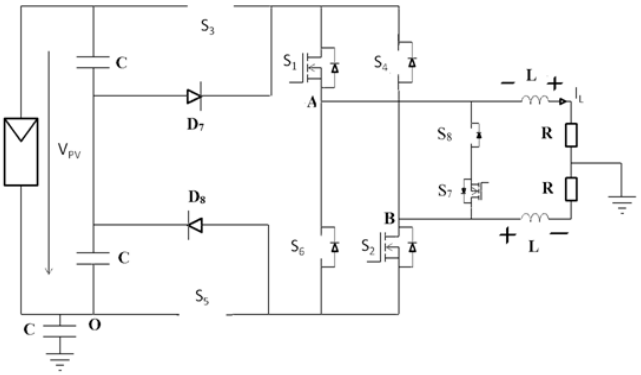

Figure.3. Positive Half Cycle: Zero Vectors

In this situation, voltages V_{AB} and V_{CD} tend to zero and diodes D_7 & D_8 fix the voltages V_{AO} and V_{BO} to $V_{PV}/2$. Since V_{AB} is clamped to zero the current decreases. Now, the common-mode voltage is

$$V_{AO} = V_{BO} = V_{PV}/2 = V_{cm} = V_{PV}/2$$

D. Negative Half Cycle: Active Vector

As shown in figure 4 in the negative half cycle, S_3 and S_4 are on.

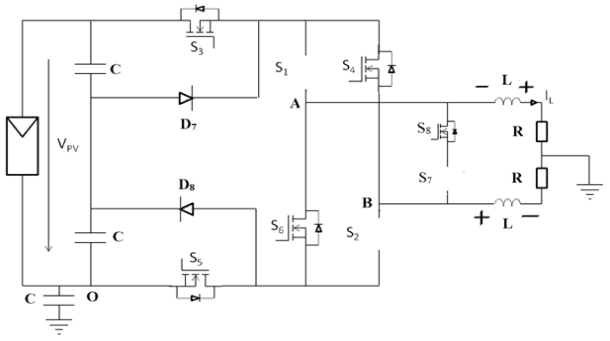

Figure.4. Negative Half Cycle: Active Vector

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Again, S_5 and S_6 commutate at the switching frequency in order to modulate the input voltage. S_1 and S_2 commute at the switching frequency together and complementarily to S_5 and S_6. In this situation, when S_5 and S_6 are on, V_{AB} equals $-V_{PV}$, and the inductor current, which now flows through, S_5, S_3, S_4 and S_6 , decreases. The common-mode voltage is

$$V_{cm} = (V_{AO}+V_{BO})/2 = (0+V_{PV})/2 = V_{PV}/2$$

E. Negative Half Cycle: Zero Vectors

As shown in figure 5 when S_5 and S_6 are turned off and S_1 and S_2 are turned on, the current splits into three paths. The first path consists of S_4 and the freewheeling diode of S_2, and the second of freewheeling diode of S_1 and S_3 and S_7 and the freewheeling diode of S_8.

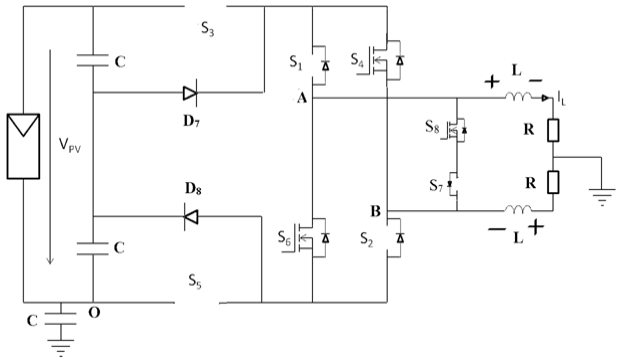

Figure.5 Negative Half Cycle: Zero Vectors

Then Consequently, S_1 and S_2 are turned on with no current, so no switching losses appear. In this situation, voltages V_{AB} and V_{CD} tend to zero and diodes D_7 & D_8 fix the voltages and to V_{AO} and V_{BO} to $V_{PV}/2$. The current decreases because V_{AB} is clamped to zero. Now, the common-mode voltage

$$V_{AO}=V_{BO}=V_{PV}/2=V_{cm}=V_{PV}/2$$

III. SIMULATION

Simulated diagram of Proposed Transformer Less HERIC is shown in figure 6, where PWM technique applied for this topology is bipolar switching.

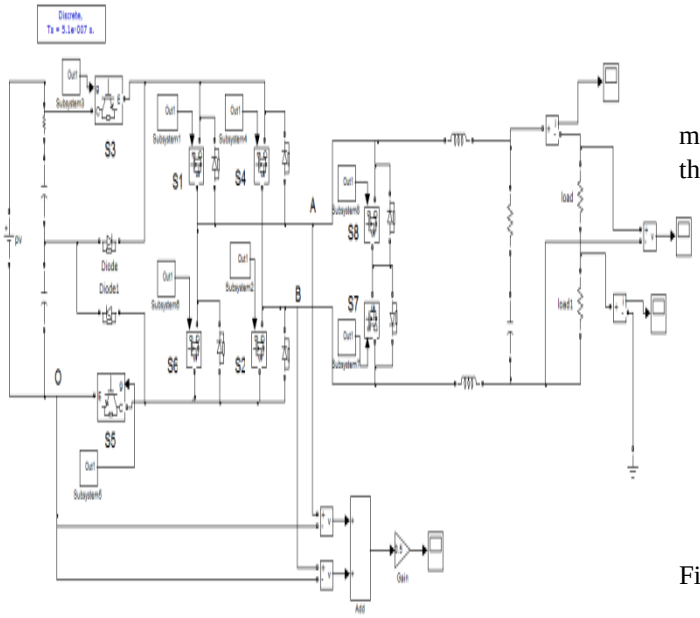

Figure.6 Simulation Diagram of Proposed Transformer Less HERIC

It consists of single phase full bridge inverter with four switches, two bidirectional switches at the output of inverter, two switches and two diodes at the input side. Two diodes and capacitive divisor limit the blocking voltages of two switches at the input side. The input was dc source and the output has two resistive loads and there is a filter element between the bidirectional switches and output.

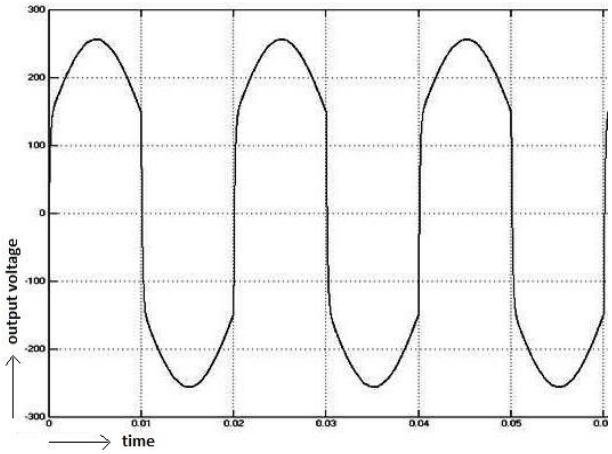

Figure.7 Simulated Output Voltage

Figure.7 shows the simulated output voltage, which is measured across the output of two resistive loads by connecting a voltage measurement with scope.

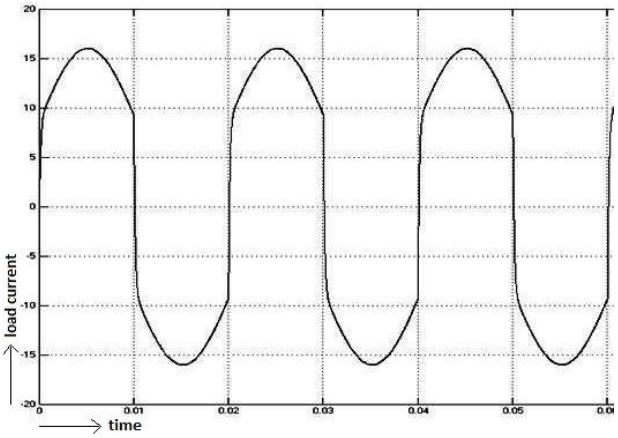

Figure.8 Simulated Load Current

Figure.8 shows the simulated Load Current, which is measured by connecting a current measurement with scope at the output inductance in series connection.

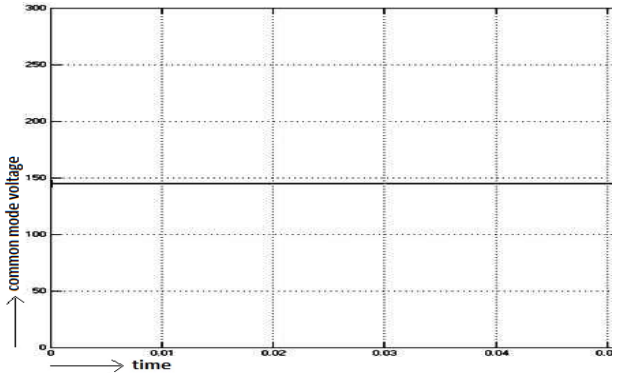

Figure.9 Simulated High Frequency Common Mode Voltage

Figure.9 shows the simulated High Frequency Common Mode Voltage, which is measured by connecting two voltage measurements with scope between the output of first leg

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inverter 'A' and negative terminal 'O' in one measurement and in another measurement between the output of second leg inverter 'B' and negative terminal 'O'.

The measured voltage is half of the input voltage and constant. So the leakage current is very small and also there is no small pulse in the voltages compared to conventional topology with bipolar switching.

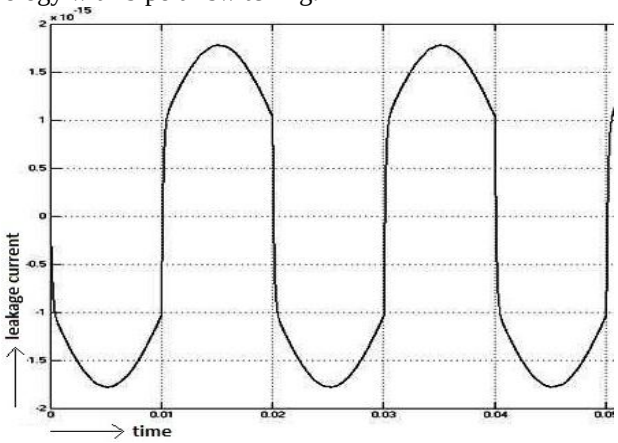

Figure.10 Simulated Leakage Current

Figure.10 shows the simulated Leakage Current, which is measured by connecting a current measurement with scope at the mid-point of two output resistances and ground.

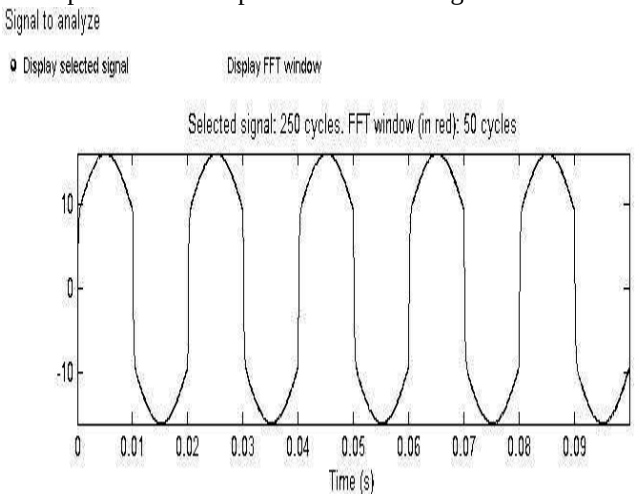

Figure.11 Fast Fourier Transform Analysis

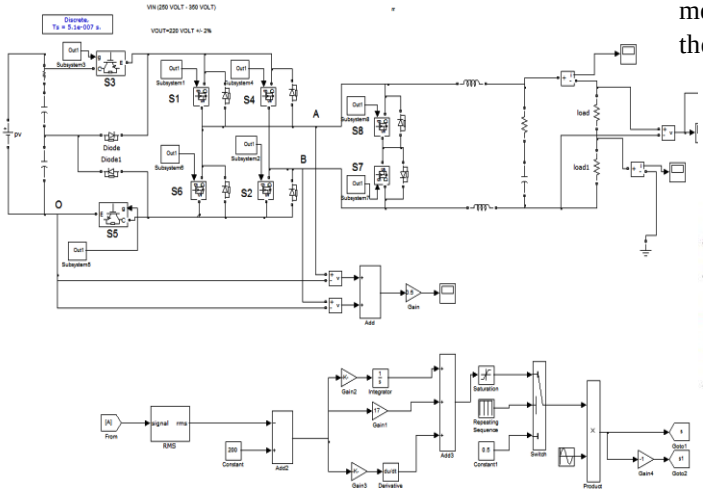

Figure.12 Simulation Diagram of Closed Loop of Proposed Transformer Less Heric

Figure.12 shows the simulated diagram of closed loop of Proposed Transformer Less HERIC, where PWM technique applied for this topology is bipolar switching. By using the closed loop, if there is change in input voltage between 250-350v, the output voltage is 220v with ±2%.

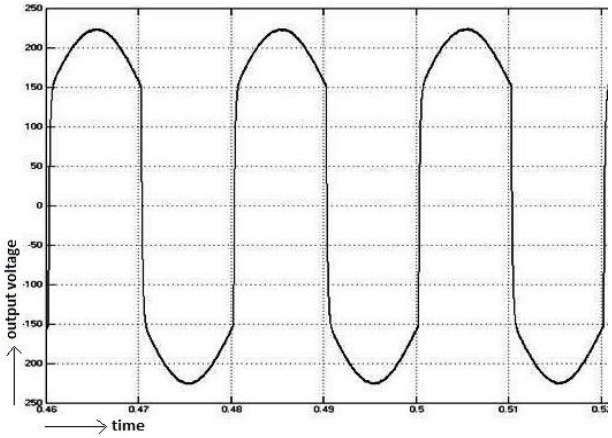

Figure.13 Simulated Output Voltage

Figure.13 shows the simulated output voltage, which is measured across the output of two resistive loads by connecting a voltage measurement with scope.

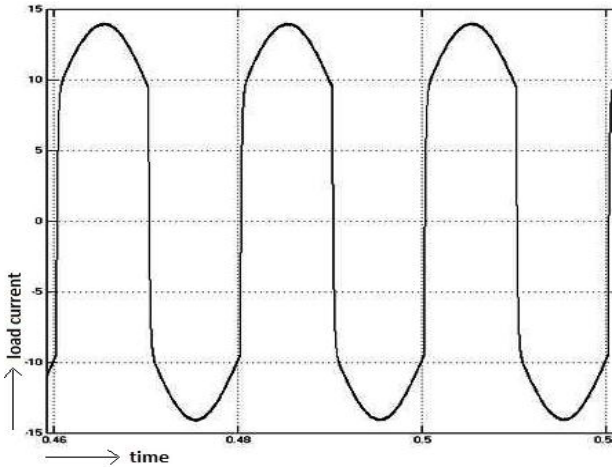

Figure.14 Simulated Load Current

Figure.14 shows the simulated Load Current, which is measured by connecting a current measurement with scope at the output inductance in series connection.

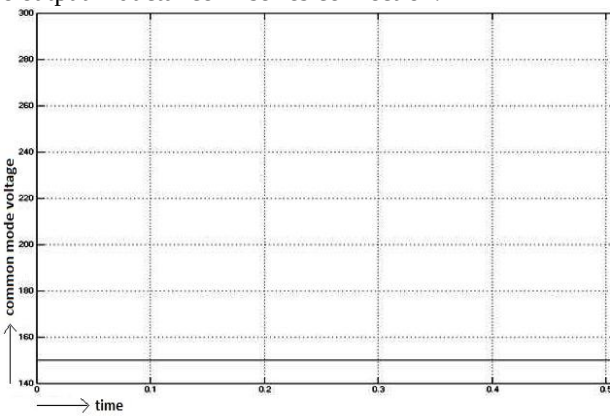

Figure.15 Simulated High Frequency Common Mode Voltage

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Figure.15 shows the simulated High Frequency Common Mode Voltage, which is measured by connecting two voltage measurements with scope between the output of first leg inverter 'A' and negative terminal 'O' in one measurement and in another measurement between the output of second leg inverter 'B' and negative terminal 'O'.

The measured voltage is half of the input voltage and constant. So the leakage current is also very small.

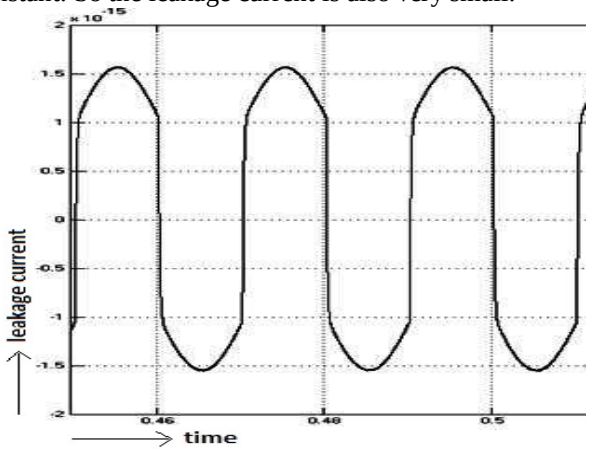

Figure.16 Simulated Leakage Current

Figure.16 shows the simulated Leakage Current, which is measured by connecting a current measurement with scope at the mid-point of two output resistances and ground.

IV. Conclusion

Transformer less inverters offers a better efficiency, compared to those inverters that have a galvanic isolation. On the other hand, in case the transformer is omitted, the generated common-mode behavior of the inverter topology greatly influences the ground leakage current through the parasitic capacitance of the PV. This project proposes a new transformer less, single-phase PV inverter with eight switches and two diodes. The proposed topology generates constant common-mode voltage, exhibits a high efficiency and this topology can be an advantageous power-conversion stage for transformer less, grid/Load-connected PV systems. In future the prototype model of a proposed transformer less HERIC is implemented in hardware and the results are analyzed.

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