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Eliminating Ground Leakage Current in Single Phase Transformerless Grid Connected Power System

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ABSTRACT: Leakage current elimination is most important issue produced in the transformerless inverters in grid connected photovoltaic(PV)system. Improved single phase transformerless inverter topology used to avoid the commom mode leakage current and keep the common mode voltage constant.It has two additional switches decoupled in dc side gives higher efficiency and convenient thermal design. The common mode voltage remain constant during all operation modes of improved inverter. The unipolar SPWM strategy achieved three level output voltage and reduction of leakage current. Simulation done in MATLAB.

KEYWORDS: Improved transformerless inverter, Common mode leakage current, Photovoltaic(PV) system, Sinusoidal pulse width modulation(SPWM) strategy.

I.INTRODUCTION

Now-days,renewable energy sources become more important because increasing demand of world's energy.In renewable energy sources solar energy is considered to be better because of its availability and reliability.It is pollution free and abundant in nature.The PV(photovoltaic) system is either island or grid connected system[11].The grid connected PV system is mostly used.Grid tied inverters is the main component of distributed generation system because it act as interface between renewable energy sources and grid.Depending on galvanic isolation between PV panel and grid, the grid connected PV inverters can be classified as isolated or non-isolated. Most of PV inverters used the transformer with galvanic isolation.The galvanic isolation observed by using high frequency transformer at the grid side or low frequency transformer on the dc side of inverter[11].Low frequency transformer are large and increases the size, weight and cost of the system.High frequency transformer consist of several power stages which makes the system compact and reduces the efficiency.

To overcome these problems transformerless PV grid connected inverters used[1].They have advantages of high efficiency, high power density,low cost and less complexity.When transformerless inverter directly connected to grid then galvanic isolation exists between PV system and grid and they may cause the fluctuation of the potential between PV panel and ground which is also known as parasitic capacitance or stray capacitance.Due to fluctuating potential common mode leakage current flows through the parasitic capacitor between PV panel to ground.The common mode leakage current will cause system losses,current harmonics,safety problems and Electro Magnetic Interference(EMI) issues.To eliminate common mode leakage current and improve the efficiency of the converter system,transformerless PV inverters employing unipolar SPWM control have been presented.

II.CONDITION OF ELIMINATING THE COMMON MODE LEAKAGE CURRENT

When transformer is not used in the PV grid connected system then ground leakage current arise on parasitic capacitor between PV panels and ground because galvanic connection exists[1].The presence of common mode current increases grid current distortion,reduces power conversion efficiency and give rise to safety risk.The common mode current path in the grid connected transformer less PV inverter is represented in figure1..It is arranged by power switches,filters

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ground impedance ZG and parasitic capacitance between PV panel and ground.It forms the resonant circuit and produce common mode leakage current.

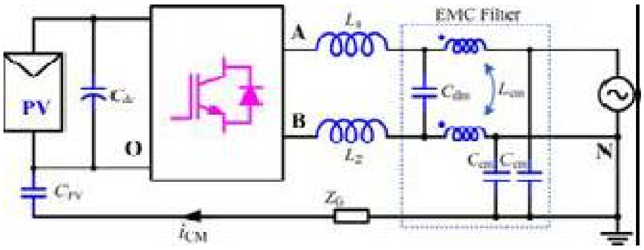

Figure.1Common mode leakage current path

The simplified equivalent model of common mode resonant circuit has been derived in as shown in Figure.2[1],Where Cpv is the parasitic capacitor,LA and LB are the filter inductors and icm is the common mode leakage current.

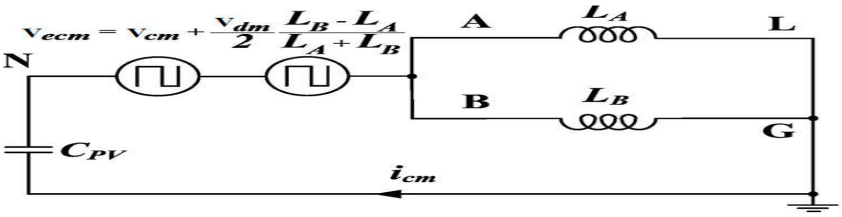

Figure.2 Equivalent circuit

An equivalent common mode voltage Vecm is defined by,

$$\text{Vecm} = \text{Vcm} + \frac{\text{Vdm}}{2}\frac{\text{LB}-\text{LA}}{\text{LA}+\text{LB}} \quad (1)$$

Where Vcm is the common mode voltage,Vdm is the differential mode voltage,VAN and VBN are the output voltages of the inverter relative to negative terminal N of the dc bus as the common reference.

$$V_{cm} = \frac{\text{VAN}+\text{VBN}}{2} \quad (2)$$

$$V_{dm} = V_{AB} = V_{AN} - V_{BN}$$

It is clear that common mode leakage current icm is excited by defined equivalent common mode voltage Vecm.Hence condition of removing common mode leakage current is drawn that equivalent common mode voltage Vecm must be kept constant as follows:

$$\text{Vecm} = \text{Vcm} + \frac{\text{Vdm}}{2}\frac{\text{LB}-\text{LA}}{\text{LA}+\text{LB}}$$

$$= \frac{V_{AN}+V_{BN}}{2} + \frac{V_{AN}-V_{BN}}{2}\frac{\text{LB}-\text{LA}}{\text{LA}+\text{LB}} = \text{Constant} \quad (3)$$

In half bridge inverter family,one of the filter inductors LA and LB is commonly zero. Therefore, the condition of eliminating common-mode leakage current is accordingly met that

$$\text{Vecm} = \frac{V_{AN}+V_{BN}}{2} + \frac{V_{AN}-V_{BN}}{2} = V_{AN} \quad (4)$$

$$= \text{Constant } (L_A = 0)$$

$$\text{Vecm} = \frac{V_{AN}+V_{BN}}{2} - \frac{V_{AN}-V_{BN}}{2} = V_{BN} \quad (5)$$

$$= \text{Constant } (L_{B=0})$$

In the full-bridge inverter family, the filter inductors LA and LB are commonly selected with the same value.As a result,the condition of eliminating common-mode leakage current is met that,

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$$Vecm = Vcm = \frac{V_{AN+V_{BN}}}{2}$$

= Constant (L_A=L_B) (6)

III.THE PROPOSED SYSTEM

The improved transformerless inverter consist of two additional switches connected symmetrically in conventional full bridge inverter[1] shown in fig 3.In this topology meet the condition of eliminating common-mode leakage current.The PWM pulses to those switches are given in a such way that the common mode leakage current elimination condition is completely met.Unipolar SPWM strategy adopted and three-level output can be achieved.

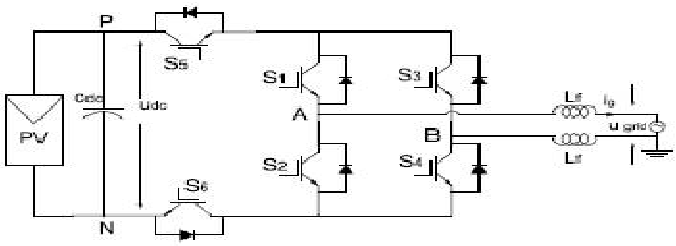

Figure.3 Improved inverter topology

A] UNIPOLAR SPWM STRATEGY

As similar to full-bridge inverter with unipolar SPWM,improved inverter switches in one phase leg operating in grid frequency and switches in another phase leg operating in switching frequency[1].The additional switches are commutate alternately at the grid frequency and switching frequency to obtain dc-decoupling state.There are four operation modes that generate three level output.In the positive half cycle switches S1 and S6 are always ON and the switches S4 and S5 commutates at switching frequency. In the negative half cycle switches S2 and S5 are always ON and S3 and S6 commutates at switching frequency.

Mode1:During positive half cycle switches S4 and S5 are ON,$V_{AB=}+V_{dc}$and the inductor current increases through the switches S5 ,S1 , S4 , and S6 . The common-mode voltage,

$$V_{cm=\frac{1}{2}}(V_{AN+V_{BN}}) = \frac{1}{2}(V_{dc+0}) = \frac{V_{dc}}{2} \qquad (7)$$

Mode2: During mode 2 switches S4 and S5 are turned OFF, the voltageV_{AN}falls and the voltage V_{BN}rises until their values are equal. $V_{AB=0V}$and the anti -parallel diode D3 across the switch S3 conducts. The current decreases through the path S1, D3.The common mode voltage changes to,

$$V_{cm=\frac{1}{2}}(V_{AN+V_{BN}}) = \frac{1}{2}\left(\frac{V_{dc}}{2} + \frac{V_{dc}}{2}\right) = \frac{V_{dc}}{2} \qquad (8)$$

Mode3: During negative half cycle when S3 and S6 are ON,$V_{AB=}-V_{dc}$ and the inductor current increases reversely through the switches S5, S3, S2 and S6.Then common mode voltage becomes,

$$V_{cm=\frac{1}{2}}(V_{AN+V_{BN}}) = \frac{1}{2}(0 + V_{dc}) = \frac{V_{dc}}{2} \qquad (9)$$

Mode4: When S3 and S6 are OFF, The voltage V_{AN}rises and the voltage falls until$V_{AN} = V_{BN}$.The antiparallel diode of S4, D4 conducts and the inductor current decreases through switch S2 and diode D4. The common-mode voltage Vcm also keeps Vdc/2

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$$V_{cm} = \frac{1}{2}(V_{AN}+V_{BN}) = \frac{1}{2}\left(\frac{V_{dc}}{2}+\frac{V_{dc}}{2}\right) = \frac{V_{dc}}{2} \qquad (10)$$

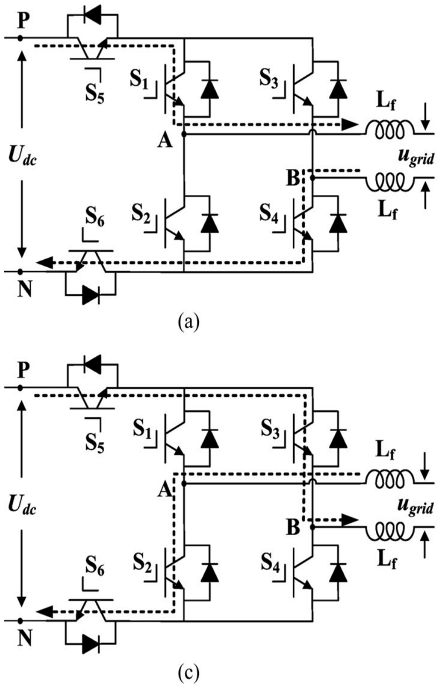

Figure.4 Four operation modes of the improved inverter with unipolar SPWM (a) Mode 1 (b) Mode 2(c) Mode3 (d) Mode 4.

Mode 1 and Mode 2 continuously rotate to generate +Vdc and zero states and modulate the output voltage. Likewise, in the negative half cycle, Mode 3 and Mode 4 continuously rotate to generate –Vdc and zero states as a result of the symmetrical modulation [1]. In Unipolar SPWM strategy the common mode voltage remain constant as Vdc/2 during all four modes of operation.The switching voltages of all commutating switches are half the input voltage so compared with full bridge inverter the switching losses are reduced.

IV. SIMULATION RESULT

1.Unipolar SPWM strategy:

In simulation by using simple resistance as load the generated voltage of the inverter and modulation strategy can be shown because utility grid has no impact on common mode performance of the system.The detailed components and parameters used are as follows:

Dc source voltage Vdc= 380 V,The parasitic capacitance Cpv=75nf,Load resistance R=40ohms,Filter inductoLf=4mH, Switch frequency fs= 2kHz,Grid frequency=50Hz,Power switches MOSFET S1-S6=IRF840

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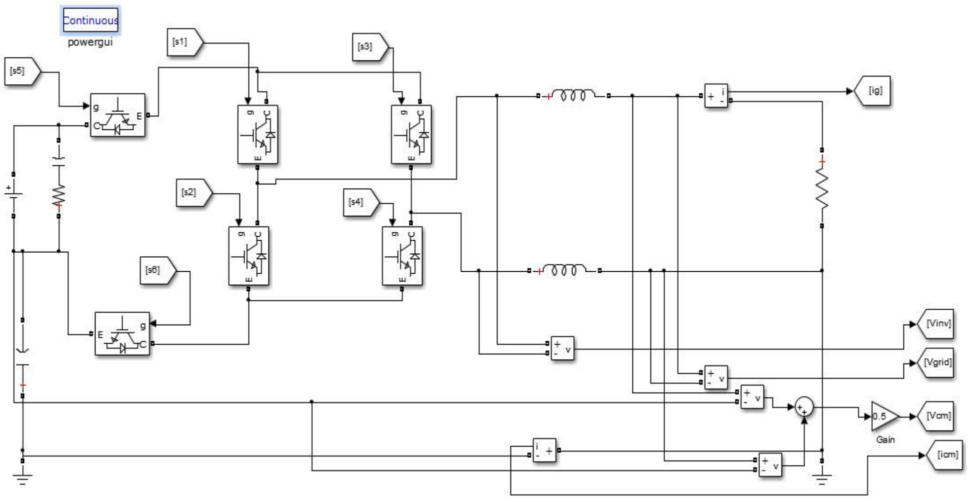

Figure.5 Simulated circuit diagram of Unipolar SPWM strategy

In the fig.5 simulated circuit diagram of Unipolar SPWM control strategy,the improved inverter consist of two additional switches S5 and S6. In this strategy, the devices in one leg are turned on or off based on the comparison of the reference signal with a high frequency triangular wave. The devices in the other leg are turned on or off by the comparison of the reference signal with the same high frequency triangular wave. Transformer is replaced by inductor coils.

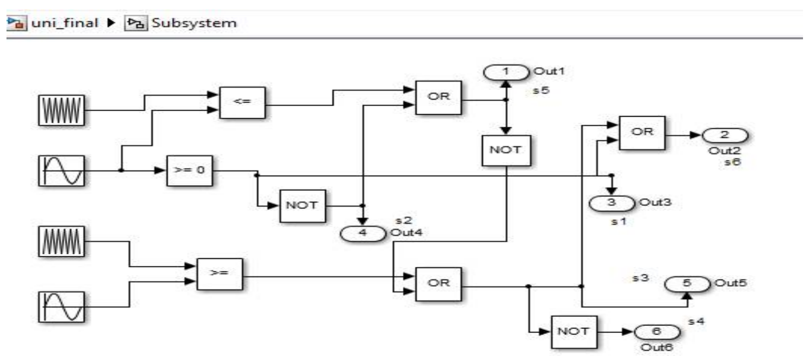

Figure.6 Subsystem of generating switching pulses

In the fig.6 switching pulses are generated by comparing high frequency triangular carrier wave with sinusoidal reference wave with desired frequency.

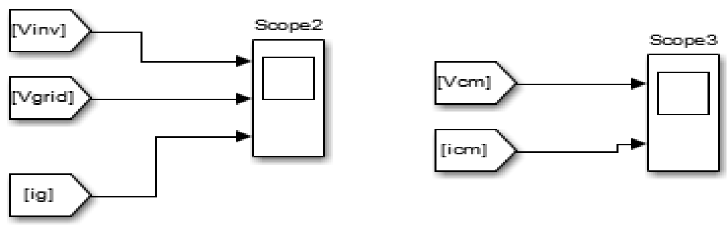

Figure.7 Results of Vinv,Vgrid, ig,Vcm and icm are shown on scope

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Fig.7 shows the results of inverter voltage(Vinv),grid voltage(Vgrid),grid current(ig),common mode leakage voltage(Vcm) and common mode leakage current(icm) are shoen on scope.

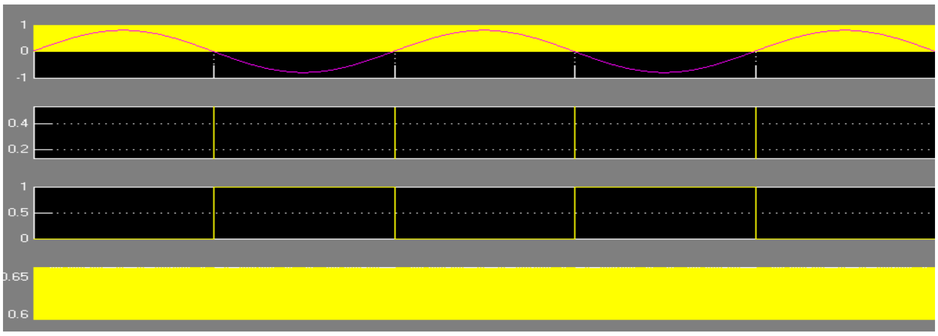

Figure.8 Switching pulses of switch S1,S2 andS3 respectively

In the fig.8 for positive half cycle switch S1 is always ON and S2 and S3 respectively, commutate complementarily to S1 and S4.

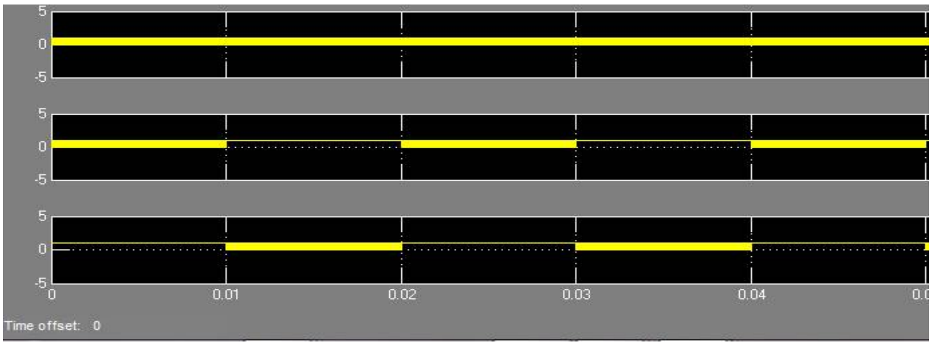

Figure.9 Switching pulses of switch S4,S5 and S6 respectively

In the fig.9 switch S6 in ON and switches S4,S5 commutate at the switching frequency with same commutation orders.

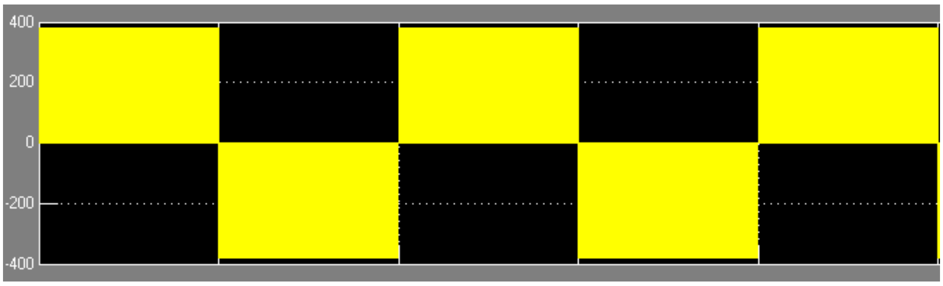

Figure.10 Inverter voltage (Vinv)

In the fig.10 Unipolar SPWM control strategy generate +Vdc,0 and –Vdc voltage states .In positive half cycle +Vdc and zero state generate and the negative half cycle generate –Vdc and zero state.

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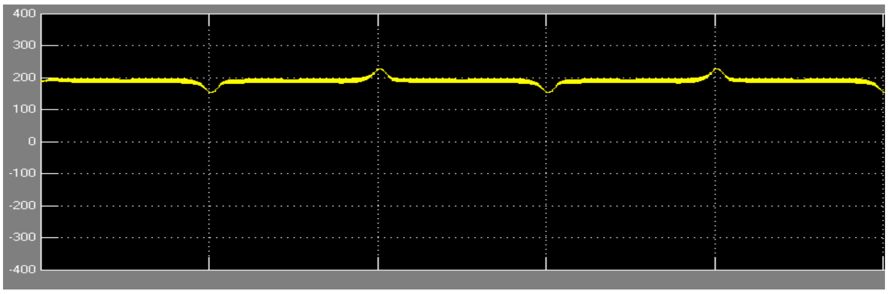

Figure11.Common mode voltage(Vcm)

In the fig.11 common mode voltage is 200 V i.e. Vdc/2 cam remain constant during Unipolar SPWM control strategy thus switching losses are reduced in improved transformerless inverter.

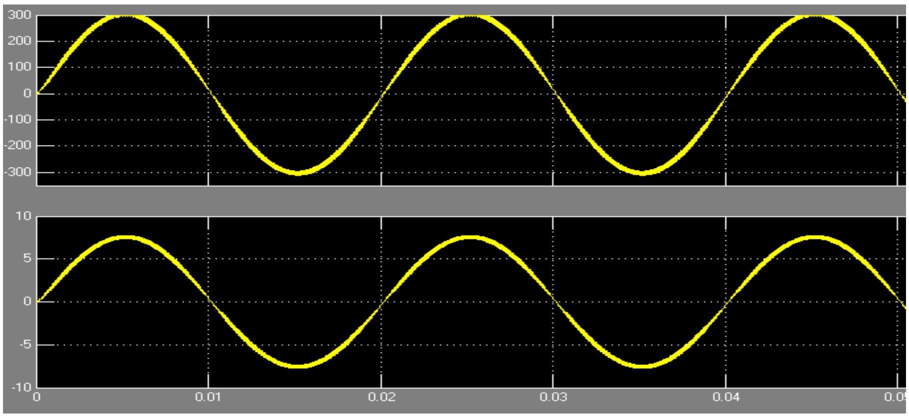

Figure.12 Grid voltage(Vgrid) and grid current(ig)

Fig.12 shows the waveforms of grid voltage and grid current.The grid voltage is sinusoidal waveform.The grid current contain harmonics so current waveform distorted.In Unipolar SPWM strategy lower total harmonic distortion (THD) achieved.

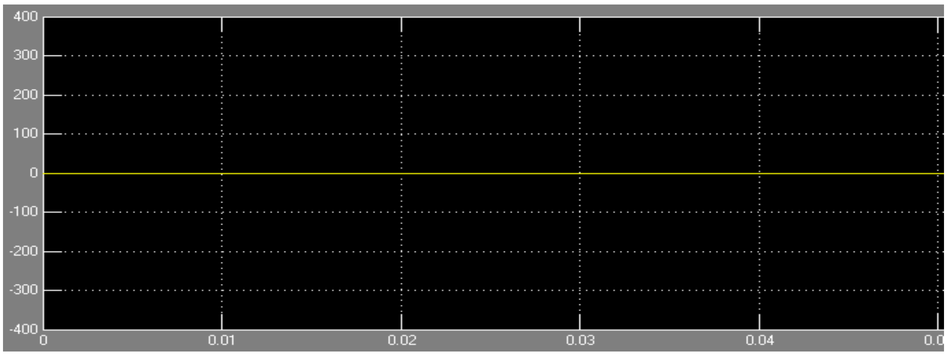

Figure13.Common mode leakage current(icm)

The fig.13 shows the common mode leakage current is eliminated in the improved transformerless inverter when Unipolar SPWM control strategy implemented with three level output voltage.

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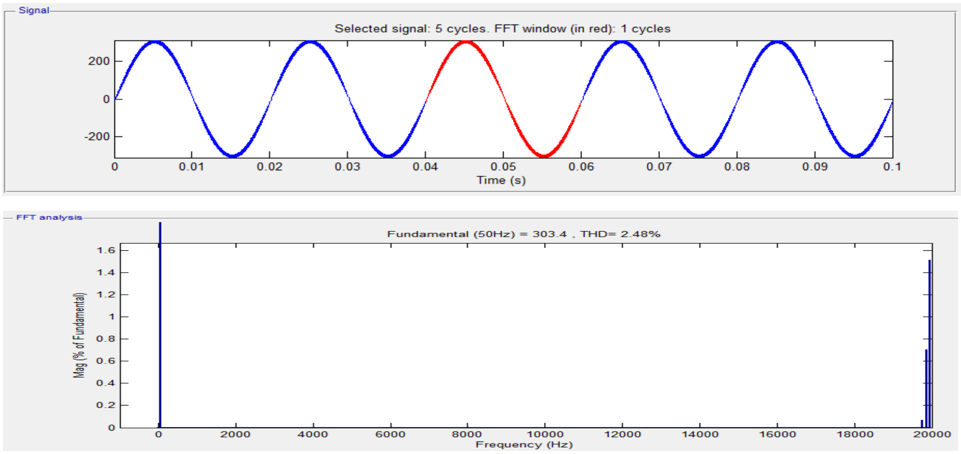

Figure14.Load current THD

In the fig.14 Total harmonic distortion(THD) of load connected current reduced.Lower THD i.e.2.48% is obtained in the Unipolar SPWM control strategy which reduces the switching losses and increases the efficiency.

VI.CONCLUSION

The paper presented an improved single-phase grid connected inverter topology for transformerless PV system.The common mode leakage current removed in the improved transformerless inverter and presents the high efficiency.The unipolar control strategy achieved three level output in inverter and common mode leakage current elimination condition.The additional switches decoupled in dc side of inverter accomplish the higher efficiency and convenient thermal design.The switching voltages of all commutating switches are half the input dc voltage hence switching losses are reduced.In improved unipolar SPWM strategy leakage current reduced with output current THD=2.48%.Simulation results are obtained by using MATLAB Simulink.

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