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A Modified High Efficiency Microinverter Topology for Grid Connected PV System

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ABSTRACT:In this paper a microinverter for a grid connected single phase photovoltaic system with high efficiency is proposed. The microinverter topology for solar inverter offers high efficiency of MPPT due to the property of its individual module control and performs the energy conversion efficiently. The conventional microinverters have low efficiency and high total harmonic distortion (THD). A topology with galvanic isolation is preferred in the proposed system in order to have the required gain to boost the output from the PV panel. There are two stages in the proposed system. The DC-DC converter stage and the inverter stage. The clamp circuit at the DC-DC converter provides zero voltage switching (ZVS) for the high frequency switches. At the inverter stage, only one switch is modulated at a time. This avoid the problems of shoot through in the system and improves efficiency. The performance of the system is evaluated for varying input voltages in MATLAB/Simulink.

KEYWORDS:Microinverter, Individual module control, THD, MPPT, PV panel.

I.INTRODUCTION

The ever increasing demand for electrical energy and the alarmingly decreasing energy resources has always been a threat to mankind. This is the reason why we constantly search for alternate energy sources, especially the renewable energy sources. Of the renewable energy sources, the most popular one is the solar energy. But the cost of PV panels is always an issue. Therefore it is important that according to the cost, the power extracted from the PV panels and the efficiency must be improved [1]. At present, based on the connection method of PV modules, inverters have been broadly classified into three namely, the centralized system, the string system, and the microinverter. The most commonly used type of inverter is the string inverter. This is due to its low cost. When it comes to efficiency, the most efficient type of inverter system is the microinverter system.

Implementation of a single stage flyback PV-microinverter is discussed in [1]. The circuit employs soft switching and the dc-dc stage of the circuit is provided with galvanic isolation so as to obtain the required voltage gain. The inverter here uses boundary conduction mode so as to maximise the power that can be transferred by eliminating the dead time. Although galvanic isolation is used in order to obtain high voltage gain, the leakage inductance is also becoming high. Another factor is that the flyback topology apart from being simple and easy to control, it has issues of high switching losses and reverse recovery problem of the diode.

Micro-inverters are installed on the roof under or next to a module and usually serve one single module at a time. Therefore each module is individually controlled whichbrings higher efficiency. Shading of one of the modules does not affect the rest of the system unlike the string inverters [2]. Another advantage of microinverters is that the power performance and the overall health of each module can be tracked and monitored in real time. Many experiments are being carried out on microinverters in order to reduce its cost and also to improve the efficiency [3].

A family of new transformerless topologies for single-phase grid-tied PV system is proposedin [4] based on two asymmetric phase legs. The topology reduces current distortion at the output and the conduction losses. Also, the system does not use galvanic isolation and thus has advantages such as less weight and low cost. The main drawback of transformerless inverter being the leakage current issues becomes the drawback of [4].The topology chosen in the proposed microinverter system uses galvanic isolation.

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Also when it comes to the efficiency in boosting the input voltage to the PV panel, the topologies without galvanic isolation is having very low voltage gain. One problem with increasing the transformer turns ratio in order to increase the voltage gain is that it also increases the leakage inductance of the transformer and this large inductance decreases the efficiency of the system [5].

In this paper a modified high efficiency microinverter topology for single phase grid connected PV system is introduced. The dc-dc converter and the inverter is designed and simulated in MATLAB/Simulink platform to validate the design.There are two stages in the proposed system. The first stage involves the DC-DC converter which releases the maximum solar power from the PV panel and thus provides a high voltage DC bus for the second stage. The voltage doubler circuit in the first stage eliminates the need for a high turns ratio for the transformer. This improves the transformer utilization and efficiency of the system. Also, the doubler circuit avoids the reverse recovery problem of the rectifier diodes on the secondary of the transformer. This stage provides a regulated DC input voltage output as the input to the next stage. The second stage is the inverter stage. In this stage, each of the two switches are modulated individually so that no problem of shoot through happens. Thus, the proposed system can achieve high efficiency and reliability.
The organization of the paper is as follows. Section IIdeals with the proposed solar microinverter. Simulation results and analysis of the proposed solar microinverter is given in section III. Section IV concludes the paper.

II.PROPOSED SOLAR MICROINVERTER

Fig. 1 represents the circuit topology of the proposed solar microinverter. The DC-DC boost converter stage and the inverter stage are shown. The primary of the transformer T1 consists of two switches S1 and S2 which are operated at high frequency and a clamp capacitor Cc. This forms the voltage clamp circuit of the system.

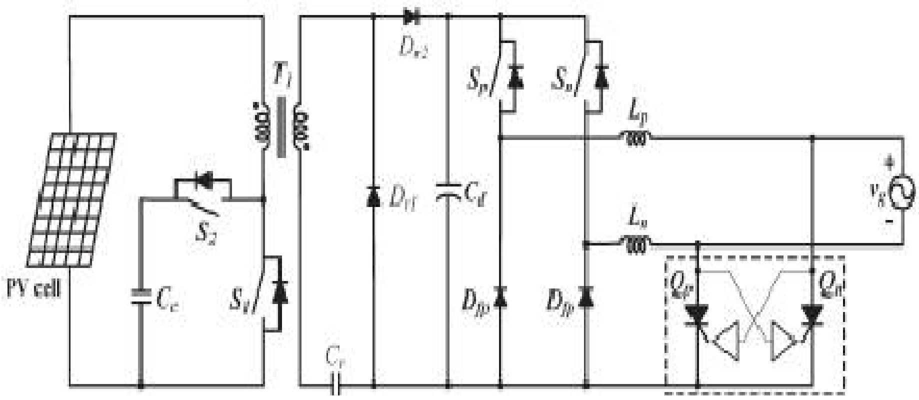

Fig1.Proposed solar microinverter

Equivalent circuit of the proposed dc–dc stage is shown in Fig 2. The circuit consisting of the secondary of the transformer, the resonant capacitor Cr and the diodes D_{r1} and D_{r2} forms the voltage doubler circuit.

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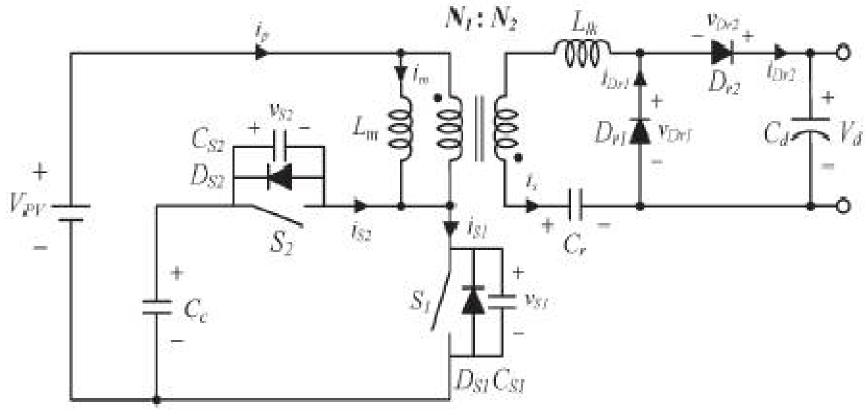

Fig. 2. Equivalent circuit of the dc–dc stage

The clamp circuit reduces the voltage across the switches S_1 and S_2 and thus reduces the voltage stress. Also, both the switches S_1 and S_2 are operated complementarily so that the switches will be operating in zero voltage switchingturn on. The voltage doubler on the secondary side forms a resonant circuit. Thus the circuit can provide resonant current paths for power transfer independent of the main switching state. The Fig 3. Represents the equivalent circuit of the different stages of operation of the microinverter during one switching period, Ts. There are 6 operating modes as shown.

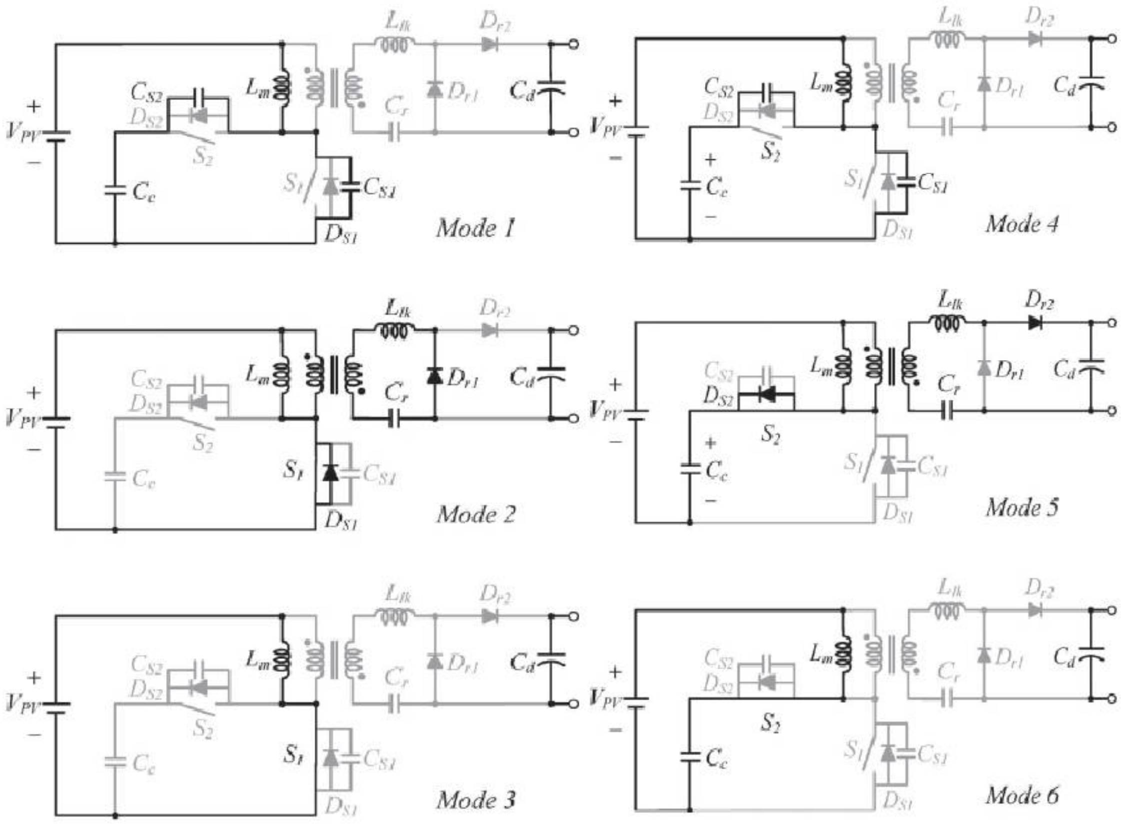

Fig. 3. Modes of operation of DC-DC converter

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A. Mode 1

The first mode occurs in the time period between t_0 and $t_{1.}$ Before t_0, the switch S_2 and the secondary side diodes D_{r1} and D_{r2} of the transformer are in the off-state. After the time t_0, the output capacitor C_{S1} of the switch S_1 and the output capacitor C_{S2} of the switch S_2 are discharged and charged, respectively.

B. Mode 2

The second mode is from t_1 to t_2. The voltage v_{S1} across the switch S_1 becomes zero, and the primary current ip of the transformer flows through the antiparallel diode of the switch S_1 before the switch S_1 is turned on. Thus, the ZVS operation of the switch S_1 is achieved. Then, the input voltage V_{PV} equals the voltage across magnetizing inductance $L_{m,}$ and the magnetizing current i_{Lm} increases linearly.

C. Mode 3

At the time t2, the secondary current is becomes zero. The primary current i_p is equal to the magnetizing current i_{Lm}. Therefore, the primary current i_p increases linearly till $t_{3.}$

D. Mode 4

This mode is from t_3 to t_4. The rectifier diode D_{r1} and the switch S_1 are turned off. Since the secondary current i_{Dr1} is already zero in Mode 3, the reverse-recovery loss of the rectifier diode D_{r1} is removed. At the same time, the output capacitor C_{S1} of the switch S_1 is charged, and the output capacitor C_{S2} of the switch S_2 is discharged.

E. Mode 5

Mode 5 spans from t_4 to t_5. At the end of Mode 4, the voltage v_{S2} across the switch S_2 is zero, and the primary current i_p flows through the antiparallel diode of the switch S_2. Thus, the ZVS turn-on of the switch S_2 is achieved.

F. Mode 6

This mode is from t_5 to t_6. Since the secondary current i_{Dr2} is already zero in Mode 5, the reverse-recovery loss of the rectifier diode D_{r2} is removed. Similar to Mode 4, the rectifier diode D_{r2} achieves the zero-current switching (ZCS) turn-off. As the secondary current is becomes zero, the primary current i_p and the magnetizing current i_{Lm} are linearly decreased.

Fig.4. represents the operating stages of the inverter stage. In conventional full bridge inverters, four switches are used. Unlike such a topology, in this system, only two switches are used. Both these switches are operated at high frequency. There are two thyristors, Q_p and Q_n. These thyristors are switched at grid frequency, according to grid voltage polarity. The dc-dc stage provides a regulated dc output voltage V_d as the input to the inverter stage.

This voltage is always maintained at a higher voltage compared to the grid voltage. During the positive half cycle of the grid voltage, the thyristorQ_p is turned on. During this time, when the switch S_p is on, the current flows through S_p and when S_p is off, the current freewheels through the diode D_{fp}. This is shown in Fig.4 (a). Similarly, during the negative half cycle of grid voltage, $Q_n$is turned on. Then, when the switch S_n is on, the current flows through S_n and when S_n is off, the current freewheels through the diode D_{fn}. This is shown in Fig.4 (b). During every half cycle of the grid voltage, only one switch is operating. Thus the problem of shoot through is avoided.

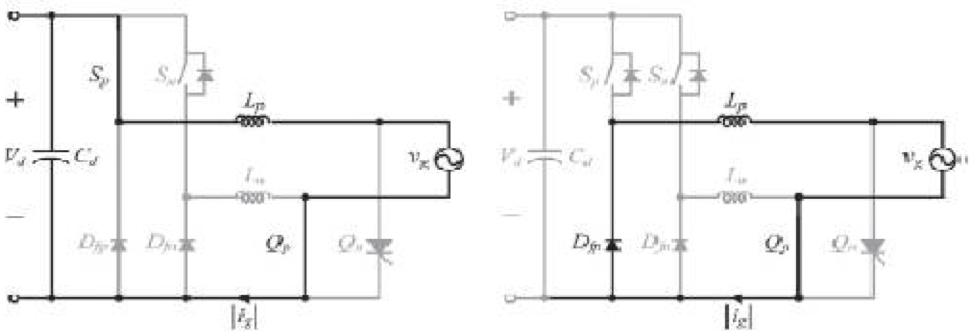

Fig. 4(a)

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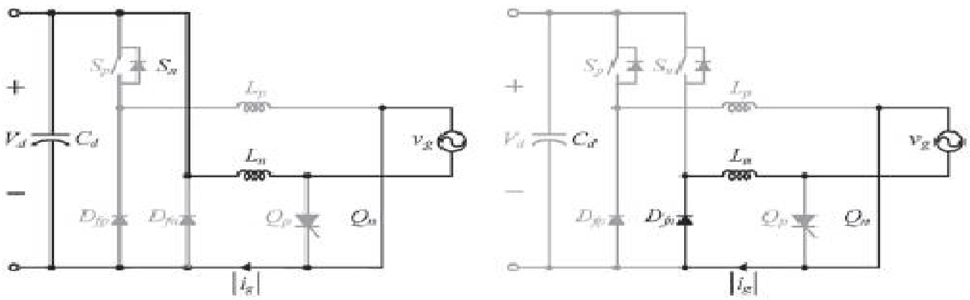

Fig.4(b)

Fig. 4. Operation of inverter during (a) Positive half cycle of grid voltage and (b) negative half cycle of grid voltage.

The control implemented is PI voltage controller based pulse width modulated (PWM) control. The output current from the inverter stage is controlled by comparing it with a sinusoidal reference waveform, where the angle is taken from the grid by using a phase locked loop and the MPPT control alogorithm. The MPPT alogorithm used is P and O algorithm. The input voltage to the inverter is controlled by using a voltage controller at the dc-dc stage. The output voltage from the dc-dc converter is sensed and is compared with the reference voltage. The error so produced is fed to a voltage controller which is then compared with a saw tooth waveform of high frequency. The frequency of the saw tooth wave determines the switching frequency. The resulting PWM pulses controls the duty ratio of the two switches. The two switches should conduct alternatively and it should be ensured that sufficient dead time is provided to avoid shoot through problem.

III.SIMULATION ANALYSIS

The proposed solar microinverter is simulated in MATLAB to check its performance and its simulink model is shown in Fig. 5. The PV voltage is taken within the range of 45V to 75V. With varying voltages in this range, the output of the dc-dc converter was obtained as 350V.

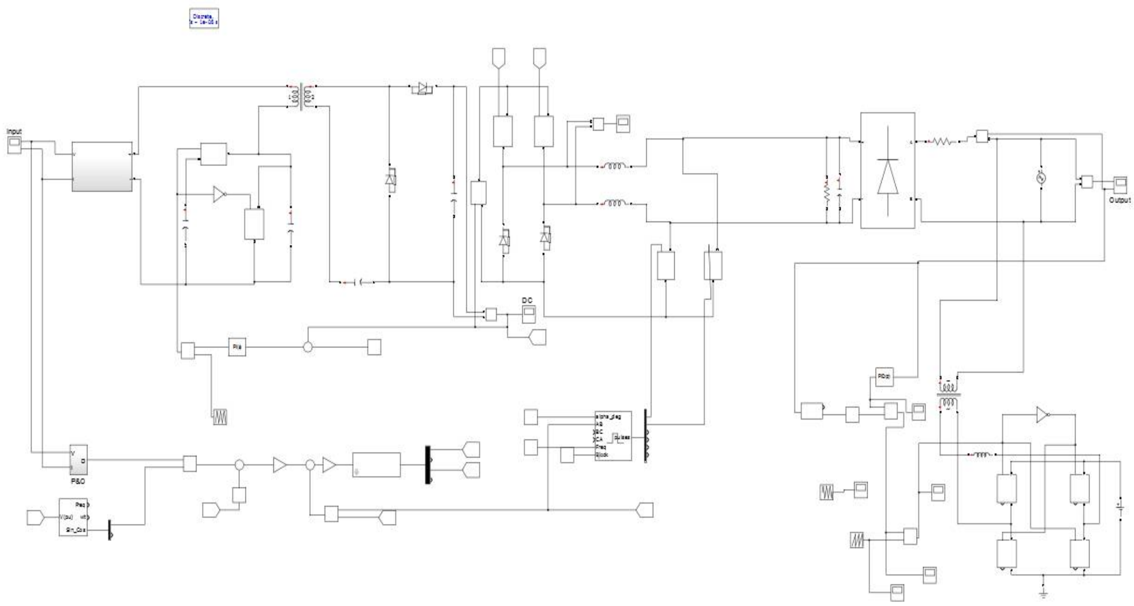

Fig. 5. Simulink model of the proposed solar microinverter.

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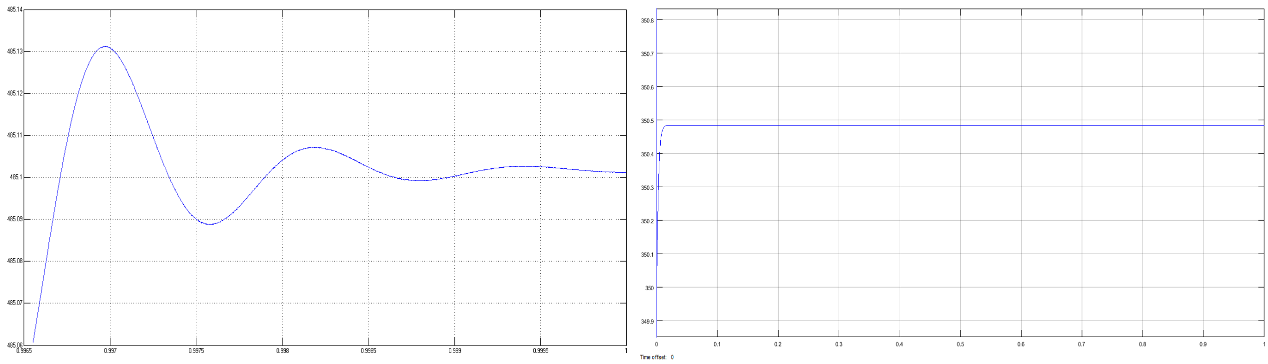
The output of the dc-dc converter with and without closed loop control is shown in Fig. 6. With closed loop control, a steady dc output voltage of 350V was obtained as shown in Fig. 6(b). The voltage maintained constant as shown in Fig. 6(b) is achieved by the voltage controller.



(a) (b)

Fig. 6. Output voltage of the DC-DC converter (a) without closed loop control (b) with closed loop control.

The Fig. 7. Shows the output voltage of the microinverter before grid current modulation. This waveform will be at high frequency due to the high frequency switching of the two inverter switches S_p and S_n.

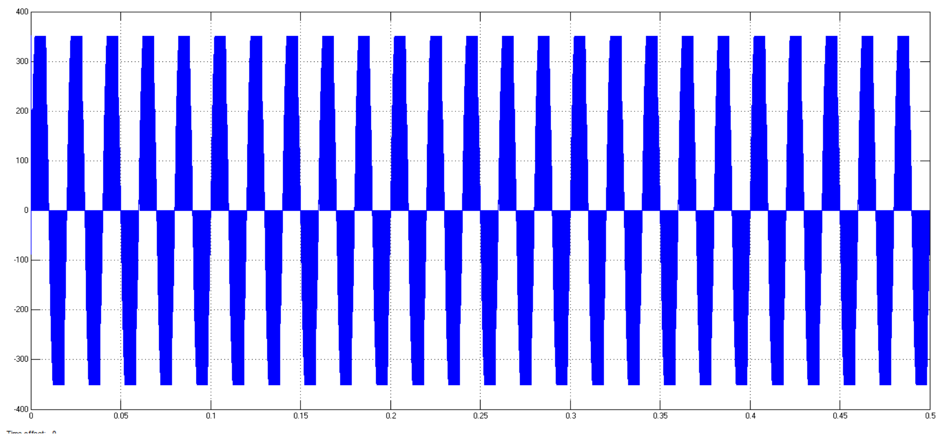


Fig. 7. Output voltage of the microinverter before grid current modulation.

By the complementary operation of the two thyristorsQ_p and Q_n at a frequency which depends on the grid voltage polarity, the output voltage and current are obtained at grid frequency. The output voltage and current is shown in Fig. 8 (a) and (b) respectively.

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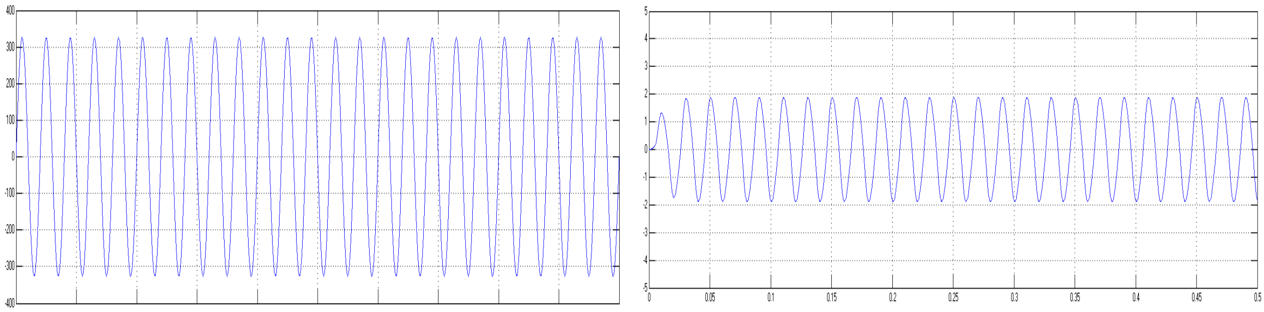

(a) (b)

Fig. 8. Microinverter output (a) Voltage (b) Current

From the simulation, the Total Harmonic Distortion (THD) of the microinverter was obtained as 1.24. This is shown in Fig. 9.

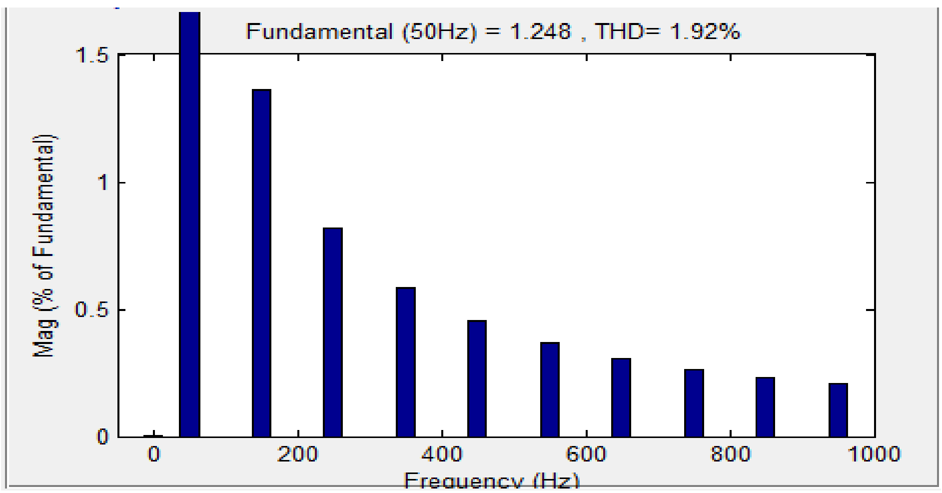

Fig. 9. THD of the microinverter output current waveform

IV. CONCLUSION

A microinverter for a grid connected PV system was proposed in this paper. The operational feasibility of the system was verified using MATLAB/ Simulink platform. The simulation results of the system showed a THD value below 5% in the input voltage range selected for analysis. The power factor obtained is 0.999.Hence the system conforms to standards set by IEEE and IEC. The system is capable to work at high efficiency in single phase grid connected PV systems.

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