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A Quasi Z -Source Matrix Microinverter for Grid Connected PV Applications

Sindhu A, K P Shobha
Post Graduate Research Scholar, Associate Professor
Department of Electrical Engineering,
University Visvesvaraya College of Engineering, Bengaluru, Karnataka, India.

Abstract : Distributed Generation (DG) has been widely adopted in recent years because of the dramatic increasing of energy consumption. Researches show that DG provides more varied energy options to the customers, increases efficiency of generation and transmission, and improves power quality and system stability. Among different types of DG, photovoltaic (PV) solar power generation, along with fuel cell and wind turbine has attracted great attention as "green power" or renewable energy sources because they are pollution free. Over the past few years, Microinverters have gained interest in the area of PV power conversion, this since the direct connection of modules to the grid can increase overall harvested energy in comparison with other power conditioning approaches. Moreover, microinverters which are essentially modular, allow the system to grow over time and result in a more reliable solar plant. In the implementation of a microinverter system important features are its overall voltage gain, to allow interfacing the low voltage PV module to the grid and its power conversion efficiency. The traditional approach to achieve these two aspects is to use a two-stage system where a fly-back converter is cascaded with a single-phase inverter, which has drawbacks such as a discontinuous input current with high second harmonic ripple, high EM noise, high semiconductor stress, and reduced efficiency. In this paper, a single-stage quasi-Z source push-pull matrix microinverter system is presented to deal with some of these drawbacks. Resulting in a high-performance microinverter topology which produces the required voltage gain, while having continuous input current and a high-quality output.

***IndexTerms* - PV, microinverters, quasi-Z source converters.**

I. INTRODUCTION

Topologically, microinverters are commonly implemented using a two-stage approach, where a DC-DC converter is cascaded with a single-phase inverter, having at its interconnection point a bulky DC capacitor to decouple both stages. Usually, the input side DC-DC converter of choice is a fly-back type, whose function is to follow the maximum power point of the module and boost its low input voltage to a high enough level to supply the inverter on the second stage. On the other hand, the output side inverter in most cases is a single-phase H-bridge inverter controlled to operate in current mode to interface with the AC grid. This microinverter architecture has several drawbacks such as the highly discontinuous current of the input side flyback converter, which also is related to high EM noise and semiconductor stress. Also, the need for a bulky DC capacitor to interconnect both stages burdens power density and reduces system lifetime. Further, this two-stage approach also negatively impacts overall power conversion efficiency. Besides, due to the use of the H-bridge single-phase inverter, a large second harmonic current is present on the current drawn from the module, thus degrading maximum power point tracking and power generation.

To cope with some of these issues, a quasi-Z source matrix microinverter is presented in this paper. The proposed microinverter combines a quasi-Z source network integrated with a push-pull DC-DC converter, and a single-phase matrix inverter to produce a single-stage system. In this system the qZ-source network provides a high impedance path for the second harmonic current components, making current drawn from the module continuous and mostly DC and producing an initial voltage boost. Further, the use of a matrix single-phase inverter, allows for the microinverter to produce a high quality, low distortion output..

II. PROPOSED MICROINVERTER SYSTEM

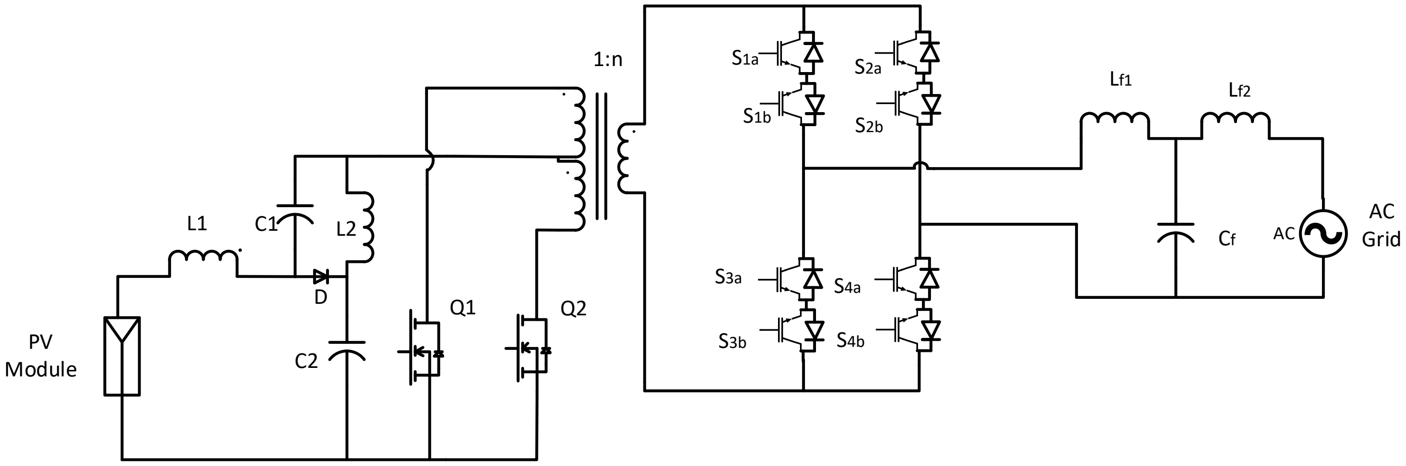

Figure 1. Proposed microinverter

The microinverter system shown in fig. 1 is proposed. This microinverter is composed of a quasi-Z source network integrated at the input side of a push-pull converter and coupled with a single-phase matrix converter at its output. This structure has as advantages single-stage power conversion, as it has no DC-link and thus there is no need for a bulky DC capacitor, and a reduced input current ripple. In this converter, the input side is composed of a quasi-Z source push-pull structure that has the main function providing the voltage gain required to interface directly to the grid, and to reduce the second harmonic current component from the input current. On the other hand, the single-phase matrix inverter at the output of the microinverter transforms the high-frequency quasi square-wave voltage generated at the secondary of the transformer into a line frequency sinewave voltage. Further, to interface the output terminals of the microinverter with the grid an LCL type filter is used to provide good filtering characteristics and to allow for controlling the current injected to the utility.

2.1 Quasi-Z Source Push-Pull operation

The input side of the proposed microinverter is implemented using a quasi-z source push-pull topology. In this topology, the qZ-source network is excited by shorting through both switches for a time given by the converter duty cycle, which produces the equivalent circuit shown in fig. 2 storing energy in both inductors L1 and L2. This energy is then released to the transformer secondary winding once one of the switches is opened, producing a positive or negative voltage across its terminals depending on which of the two switching states.

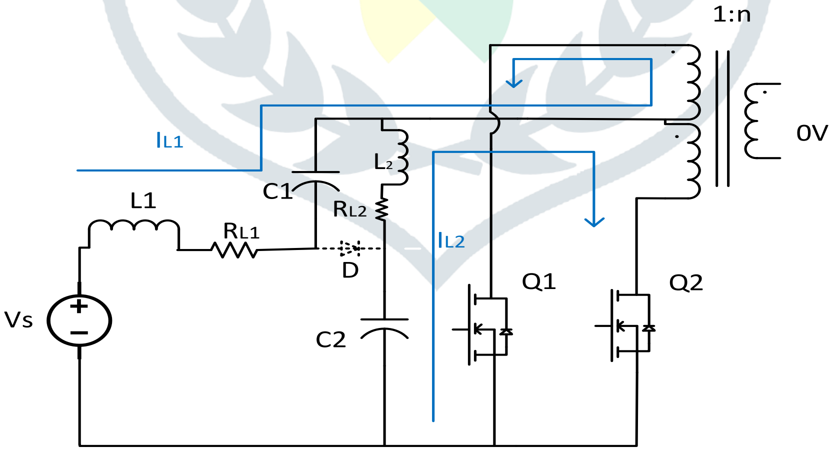

Figure 2. Switching states of the qZ-Source push-pull input.

The qZSI has two general types of operational states at the DC side: the non-shoot-through state (i.e., the six active states and two conventional zero states), and the shoot-through state (i.e., both switches in at least one phase conduct simultaneously).

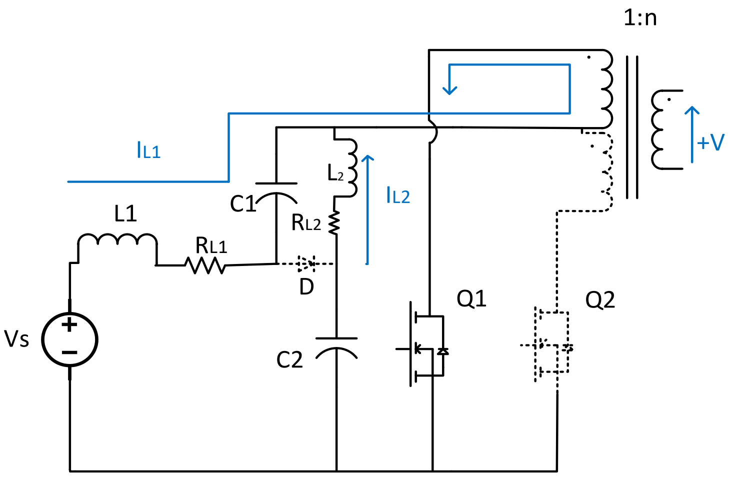

Figure 2a. Switching state of the qZ-Source push-pull positive output voltage

Assuming that during one switching cycle T, the interval of the shoot-through state is T0, then the interval of non-shoot-through state is T1; thus, T=T0 +T1 and the shoot-through duty ratio D =T0/T. From Figure 2(a), during the interval of the non-shoot-through state T1, there are

$$v_{L1} = V_{in} - V_{C1}\text{........}(1)$$
$$v_{L2} = -V_{C2}\text{............}(2)$$
$$v_{PN} = V_{C1} - v_{L2}\text{........}(3)$$
$$= V_{C1} + V_{C2}\text{......}(4)$$
$$V_{diode} = 0\text{...............}(5)$$

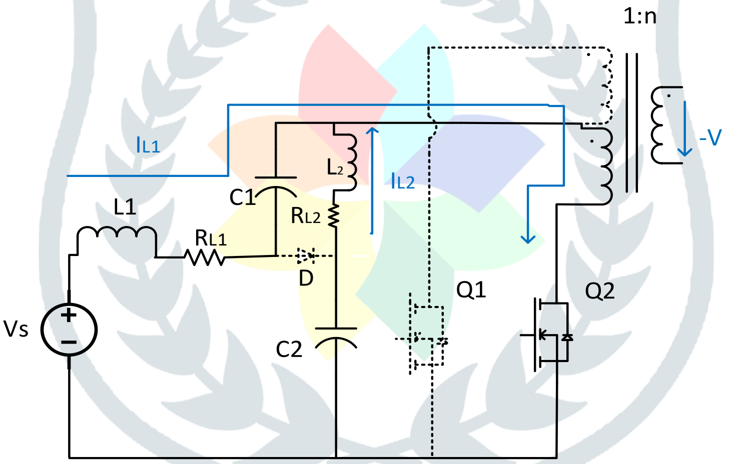

Figure 2b. Switching state of the qZ-Source push-pull negative output voltage

From Figure 2(b), during the interval of the shoot-through state T_0, one can get

$$v_{L1} = V_{C2} + V_{in}\text{......}(6)$$
$$v_{L2} = V_{C1}\text{............}(7)$$
$$v_{PN} = 0\text{...............}(8)$$
$$V_{diode} = -(V_{C1} + V_{C2})\text{..}(9)$$

2.2 Microinverter

A device used with solar arrays to convert the energy that is generated (Direct Current) to usable electricity for a home (Alternating Current). Each micro-inverter is connected to a single solar panel for maximum control and reliability. The big difference between string inverter and microinverter is that solar panel installation with microinverter will typically have the same number microinverter as there are solar panels.

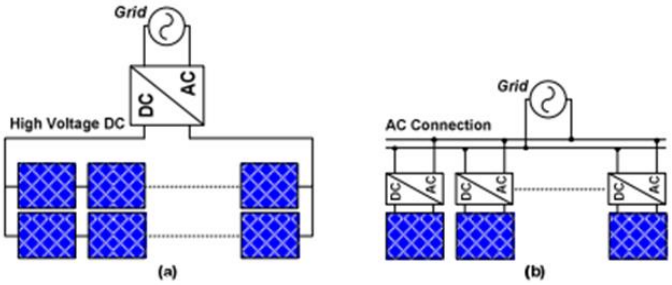

Fig. 3:Comparison of electrical wiring for photovoltaic systems: (a) series dc connection for the string inverter (b) parallel ac connection for the microinverter.

2.3 Matrix inverter modulation scheme

The output side of the proposed microinverter system is implemented using a single-phase matrix inverter connected to the secondary winding of the high-frequency transformer as shown in fig. 4.

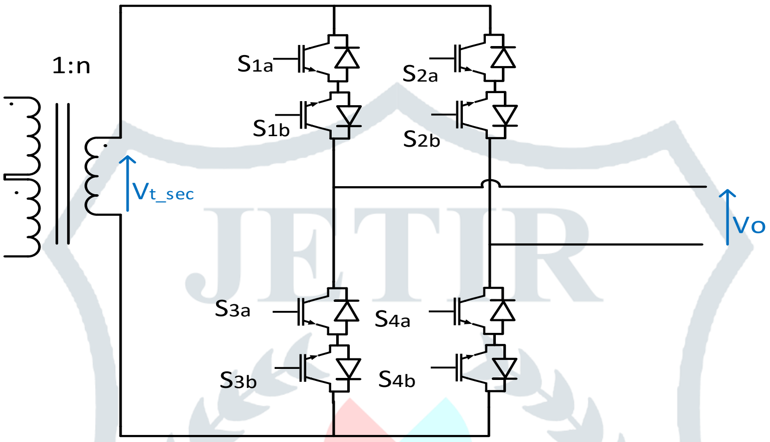

Figure 4. Single-phase matrix inverter output

The function of the matrix converter side is to generate a sinusoidal output voltage operating as a voltage unfolder. For this, it is required to properly select which of the switches in the inverter needs to be closed at any given instant. This selection can be done in terms of the required output voltage and the polarity of the voltage available at the transformer secondary, resulting in the switching table shown below.

SEM+	SEM-	V+	V-	PWM	Active Switches
1		1		1	S_{1a} and S_{4a}
1			1	1	S_{3b} and S_{2b}
	1		1	1	S_{2a} and S_{3b}
	1	1		1	S_{4b} and S_{1b}

Table 1 Switching state selection for the matrix inverter

In this table signals SEM+, SEM- and PWM are generated as shown in fig 5 by comparing the sinusoidal reference waveform with a high-frequency triangular carrier and by calculating its negative and positive semi cycles. Further V+ and V- depend on whether the transformer secondary voltage is positive or negative. Which in turn is a function of which of the push-pull switches is closed ad any given time. As can be observed from Table I, if the output voltage is in its positive semi cycle (SEM+), and the voltage available at the transformer secondary is positive (V+), and the PWM signal modulating the output sinewave is high, then Switches S1a and S4a need to be closed. Conversely, if the output voltage is in its negative semi-cycle (SEM-), the voltage at the transformer secondary is positive (V+), and the PWM is high, then switches S4b and S1b need to be closed.

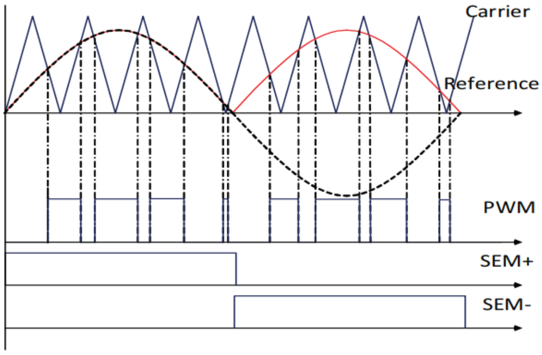

Figure 5. Matrix inverter PWM scheme

The proposed switching strategy for the matrix output of the microinverter can be implemented by a set of combinational rules in a microcontroller or DSP, or by a combinational circuit as shown in fig. 6.

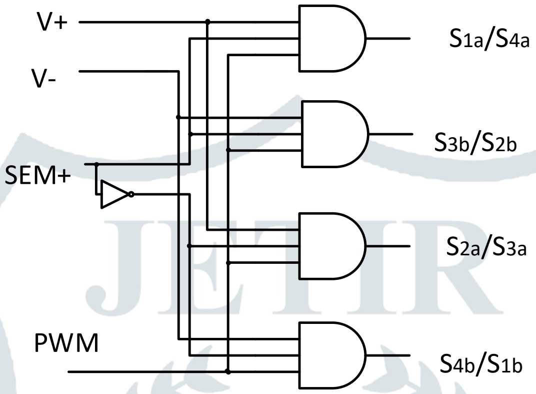

Figure 6. Matrix inverter switching scheme

2.4 LCL filter design

To interface the proposed microinverter to the grid the use of a filter is required. In single-phase grid connected inverters usually the filter topology of choice is the LCL, this mainly due to its good harmonic suppression capabilities, and performance in terms of output current regulation. Filter configuration is shown in fig. 7 and its transfer function given in (1).

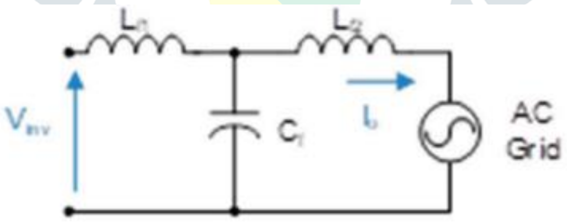

Figure 7. LCL filter

$$H_{LCL}(s) = \frac{I_o}{V_{inv}} = \frac{C_f R_f s + 1}{C_f L_1 L_2 s^3 + C_f R_f (L_1 + L_2) s^2 + (L_1 + L_2) s} \qquad (1)$$

2.5 Microinverter Control

The proposed microinverter operates as an on-grid system, therefore a current mode control scheme is required to regulate the injected power to the grid. the controller shown in fig. 8 In this structure, unity power factor is ensured by taking the grid voltage and properly scaling it to produce the reference signal for the output current (Io). The output power of the microinverter can be regulated by the magnitude of the current reference of the inverter, thus the signal is multiplied by the output of the MPPT regulator, which in turn produces the output current reference for the inverter (Iref). Further, the resulting signal is then used along with the measured output current of the microinverter (ILO) to produce the modulation signal needed to generate the PWM signal required for the operation of the combinational logic in fig. 6.

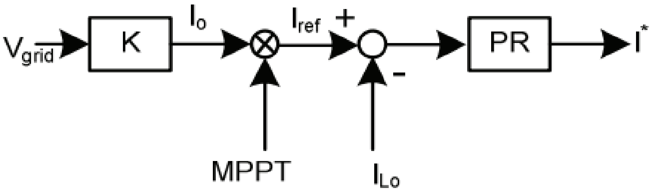

Figure 8.Control scheme

III. MICROINVERTER DESIGN

A design example for a 175W microinverter connected to a 220V, 50Hz grid is outlined in this section. For this, a 175 W module, with maximum power voltage and current of 36.63V and 4.78A is selected. The array data is parallel string of 5 and Series-connected modules per string 1 so current taken from PV module is 25.18A Starting from the required input and output voltages, the overall voltage gain of the microinverter can be calculated by (2) as follows.

$$G_{v\_microinverter} = \frac{\sqrt{2}*V_{grid}}{m_i V_{mp}} = 8.98 \approx 9p.u. \qquad (2)$$

where Vgrid and Vmp are gird and module maximum power voltage respectively, and mi the inverter modulation index. LCL filter components can be calculated according to the method outlined in [18] and result in the parameters shown in Table II

qZ-Source network		LCL filter	
Component	Value	Component	Value
L_1	500µH	L_{1f}	200µH
L_1	500µH	L_{2f}	950µH
R_L	0.15Ω	C_f	145µF
C_1	860µF	R_f	1Ω
C_2	860µF	$f_{carrie\_pushpull}$	20kHz
		$f_{carrier\_unfolder}$	3kHz

Table II Microinverter component values

IV. SIMULATIONS AND RESULTS

To verify the operation of the proposed microinverter system a prototype converter is designed, and computer simulations carried out. Converter design and simulation results are presented in the following sections. The proposed system is modeled and simulated in MATLAB using the parameters shown in Table II.

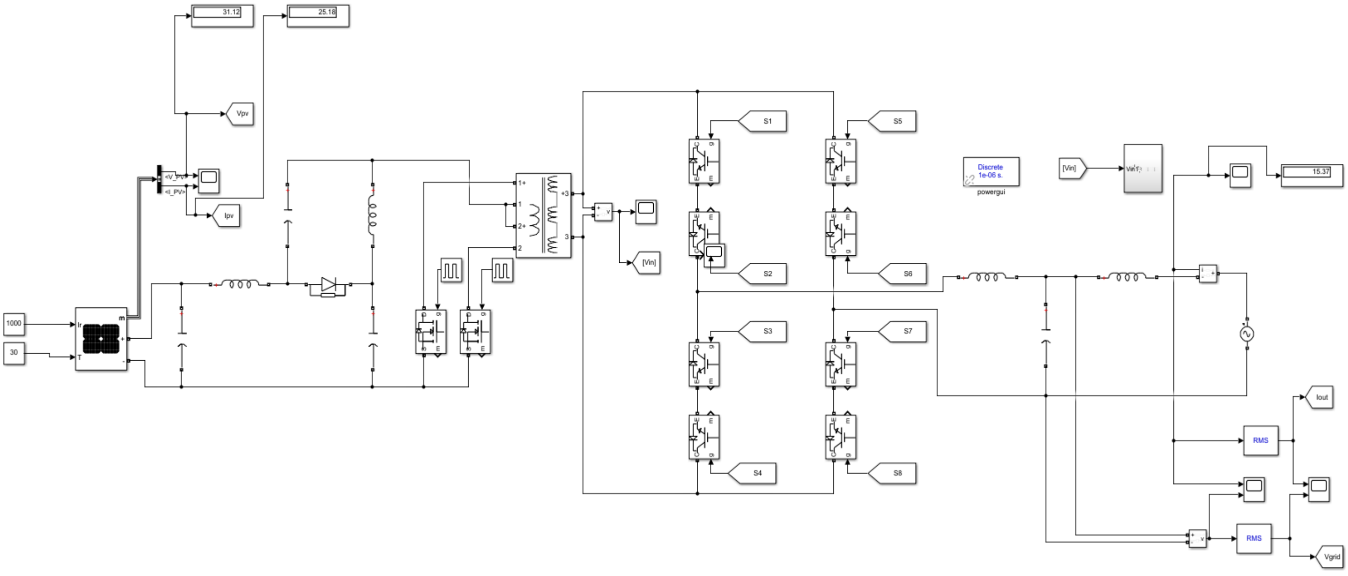

Figure 9.Simulink model of Quasi Z -Source Matrix Microinverter PV system connected to the grid

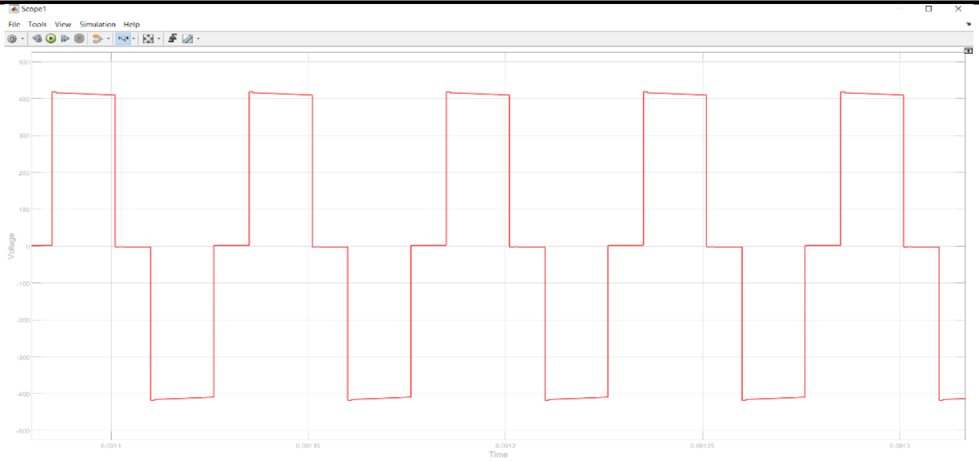

Figure 10. qZ-source push-pull characteristic waveform secondary winding voltage

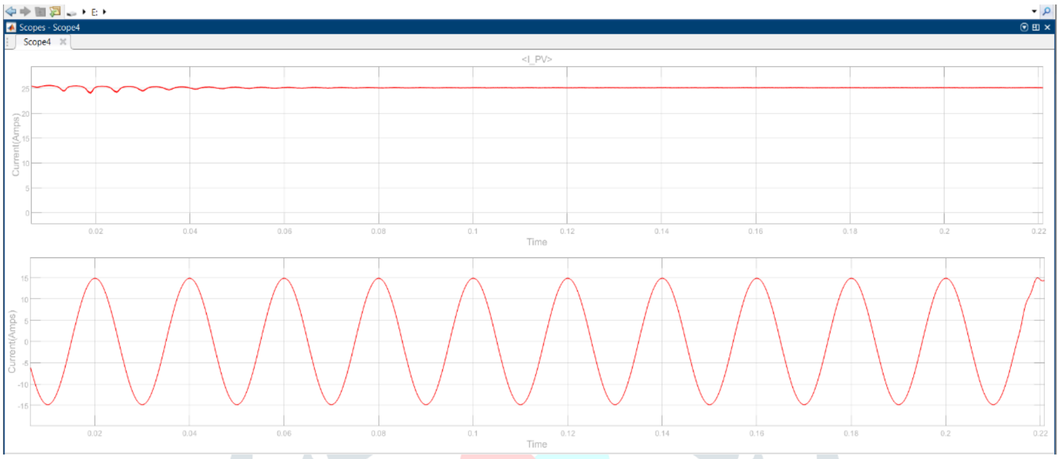

Figure 11.PV module output current and output current of the proposed microinverter.

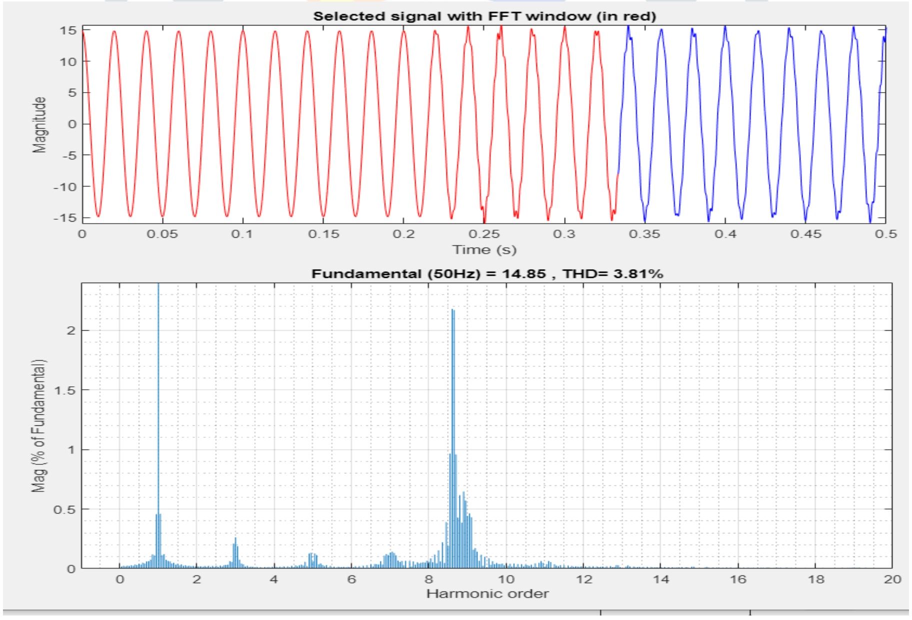

Figure 12 FFT of current of the proposed microinverter

V. CONCLUSIONS

A quasi-Z source matrix single-stage microinverter for on grid PV applications has been presented in this paper. The proposed power conditioner is formed by integrating a qZsource network to the input side of a push-pull DC-DC converter which produces a continuous input current with low harmonic distortion, and by replacing its output rectifier by a single-phase matrix inverter to unfold the high-frequency quasi-square wave voltage obtained on the transformer secondary winding into a line frequency voltage. Operation of the converter has been analysed, and appropriate modulation and switching schemes for the microinverter were conceived. Moreover, as the proposed microinverter is devised to operate tied to the AC grid a suitable current control scheme is proposed and designed. Lastly, the operation of the proposed microinverter was verified through computer simulations and it was shown that it can effectively interface a PV panel with the grid.

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