SINGLE PHASE GRID CONNECTED MPPT WITH PHOTOVOLTAIC BASED Z-SOURCE INVERTER

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Abstract An alternative Power conversion topology that can buck or boost the input voltage/current with linear load depending upon duty ratio and modulation Index in a single stage conversion with the help of Impedance source passive Network(L and C), Which is usually known as Z-source. The buck and boost capabilities of inverters are operated in the shoot through state. The Objective of this paper demonstrate a low-cost, efficient, and reliable inverter for linear load. This paper verified the simulation result for Z-source PWM inverter with MATLAB and implementation to any linear single phase load AND synchronies with grid. The unique feature of Z-Source network is shoot-through duty cycle and it acts as a filter which reduces the line harmonics, Improve power-factor, reliability and extends the output AC Voltage range of inverter. The System has application on water pumping in remote area, home power supply, swimming-pool heating systems etc.

Keywords: Photovoltaic Module, Pulse width modulation(PWM), Z-source Inverter, Harmonic Analysis(THD) etc.

I. INTRODUCTION

The traditional Stand-alone photovoltaic systems contain voltage source inverter and the current source inverter. They are either a boost or a buck converter but not a buck–boost converter. Their obtainable output voltage range is also limited. The common problem of this topology is that the two switches of any phase leg can never be turned on at the same time otherwise a short circuit (shoot through) will occur and it may damage the inverter. The Z-source inverter overcomes the theoretical barriers and limitations of the traditional converter and presents a novel power conversion concept. the basic circuit of a Z-source inverter. It is a two port network that consists of a split inductors L1 and L2, C1 and C2 connected in x shape to provide an impedance source**.**

The Z-source concept can be applied to all dc-ac, ac-dc, ac-ac and dc-dc power conversions. The boost control strategy is quite similar to the traditional carried-based pulse width modulation (PWM) control method . The basic idea ofcontrol is to turn null states into shoot through states and keep the active switching states unchanged .

The reliability of the inverter is greatly improved because miss- gating can no longer destroy the circuit. This develops A MATLAB/simulink model of an PV system with z-source inverter and starts with an introduction of the stand-alone photovoltaic system for the proposed one. After that, an analysis of the basic operating principle of Z-source inverter with its PWM strategy. The main advantage of a Z-source converter is its shoot-through and voltage-buck or boost capabilities . In addition, power loss is reduced due to a lower number of switching devices.

II. Modeling of PV Panel

The PV cells are usually represented by a simplified equivalent circuit model as shown in the fig. 2. The series resistance R_S represents internal resistance to current flow. The shunt resistance is inversely related to the leakage current to ground. In ideal $R_S = 0$ and R_{Sh} = infinite.

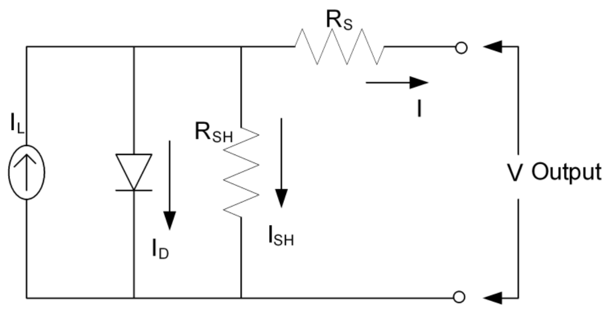


Fig. 1 Equivalent Circuit of PV Cell

The PV cell output voltage is a function of photocurrent. The photocurrent depends upon the temperature and solar irradiation level. The PV cell output voltage can be expressed as:

$$V = \frac{AkT}{e}\ln\left(\frac{I_{Ph} + I_0 - I}{I_0}\right) - R_s I \qquad (1)$$

Where, e = Electronic charge.
k = Boltzmann constant.
I = Cell output current, in A.
IPh = Photocurrent depends on temperature and solar irradiance (5 A).
I0 = Reverse Saturation Current of diode (0.0002 A)
Rs =Series resistance of cell (0.001 Ω).
T = Reference cell operating temperature (200 C).

If the temperature and solar irradiation levels change, the output voltage and current of the PV array will follow this change. The variable ambient temperature Ta affects the cell output voltage and cell photocurrent. These effects are represented in the model by the temperature coefficients C TV and CTI for the cell output voltage and cell photo current respectively as:

$$C_{TV} = 1 + \beta_T (T_a - T_x) \qquad (2)$$
$$C_{TI} = 1 + \frac{\alpha_T}{S_C}(T_x - T_a) \qquad (3)$$

Where, βT = 0.004 and αT=0.06 for the cell used. The ambient temperature (Ta) during the cell testing is equals to 200C. The change in the temperature is represented by T_x. This will be responsible for the change in the voltage generated by the PV Panel.

A change in solar irradiation level causes a change in the cell photocurrent and operating temperature, which affects the cell output voltage. The change in the operating temperature and in the photocurrent due to variation in the solar irradiation level can be expressed by the correction factors i.e.CRV and CRI for changes in cell output voltage V and photocurrent, respectively;

$$C_{RV} = 1 + \beta_T \alpha_s (S_x - S_R) \qquad (4)$$
$$C_{RI} = 1 + \frac{1}{S_C}(S_x - S_R) \qquad (5)$$

Where, SR is the reference solar irradiation level during the cell testing. Sx is the new level of solar irradiation. The newvalues of the cell output voltage VCX and photocurrent IPhx for the new temperature Tx and solar irradiation Sx can be given as:

$$V_{Cx} = C_{TV} C_{RV} V_c \qquad (6)$$
$$I_{Phx} = C_{TI} C_{RI} I_{Ph} \qquad (7)$$

III. **Modeling of Z-Source Inverter**

The Z-Source inverter is used to overcome the problems in the traditional voltage source inverters. This Z-Source Inverter employs a unique impedance network coupled with the inverter main circuit to the power source. This inverter has unique features compared with traditional sources. The equivalent circuit arrangement is shown in the fig. 2. The PV Panel generates DC voltage. This DC voltage is feto the Z- Source network consisting of two equal valued inductors (L1 and L2) and capacitors (C1 and C2). The network inductors are connected in series arms and capacitors are connected in diagonal arms. The impedance network bucks or boosts the input voltage depending upon the boosting factor. This network also acts as a second order filter. This network requires less number of inductors and capacitors, hence size of components is small. The inverter main circuit consists of four switches. Gating signals are generated from the Pulse Width Modulation (PWM) operation.

Assume the inductors (L1 and L2) and capacitors (C1 andC2) have the same inductance and capacitance values respectively. From the fig. 3.

$$V_{C1} = V_{C2} = V_C \qquad (8)$$
$$V_{L1} = V_{L2} = V_L \qquad (9)$$
$$V_L = V_C,\ V_{pv} = 2V_C,\ V_0 = 0$$

During the switching cycle T,

$$V_L = V_{pv} - V_C \qquad (10)$$
$$V_0 = V_C - V_L = V_C - (V_{pv} - V_C); \qquad (11)$$
$$V_0 = 2V_C - V_{pv}$$

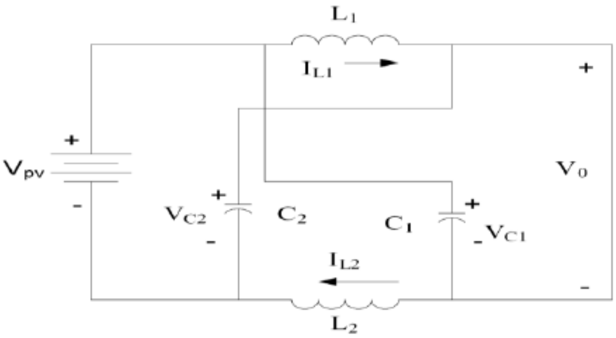


Fig. 2 Equivalent circuit of the Z-Source Inverter

Where, Vpv is the output DC voltage of the PV panel and *T*= T0+T1. The T0 and T1 are the ON and OFF periods of the Switching cycle respectively. The average voltage of the inductors over one switching period (T) should be zero in steady state.

$$V_L = T_0 . V_C + T_1 \frac{(V_{pv} - V_C)}{T}$$

$$V_L = \frac{1}{T}\left(T_0 . V_c + V_{pv} . T_1 - V_C . T_1\right) = 0$$

$$V_L = \frac{(T_0 - T_1)}{T} V_C + \frac{T_1 V_{pv}}{T} \qquad (12)$$

$$\frac{V_C}{V_{pv}} = \frac{T_1}{(T_1 - T_0)} \qquad (13)$$

Similarly the average DC link voltage across the inverter bridge can be found as follows:

$$V_0 = \frac{1}{T}\left(T_0 . 0 + T_1 (2 . V_c - V_{pv})\right) \qquad (14)$$

$$= \left(\frac{2 . V_C . T_1}{T}\right) - \left(\frac{T_1 V_{pv}}{T}\right)$$

$$2V_C = V_{pv}$$

From eq.12

$$V_C = \frac{V_{pv} T_1}{(T_1 - T_0)}$$

The peak DC link voltage across the inverter bridge is

$$V_0 = V_C - V_L = 2 . V_C - V_{pv} = \frac{T}{T_1 - T_0} . V_{pv} = B . V_{pv} \qquad (15)$$

Where,

$$B = \text{Boost Factor} = \frac{T}{(T_1 - T_0)} \geq 1$$

The output peak phase voltage from the inverter:

$$V_{ac} = M . \frac{V_0}{2}$$

Where, M is the modulation index. Substituting the value of in eq. 16, the expression of the output peak phase voltage from the inverter will be:

$$V_{ac} = M . \frac{B . V_{pv}}{2}$$

The output voltage can be stepped up and down by choosing an appropriate Buck-Boost factor (BB):
BB = B*M (it varies from 0 to α)

The capacitor voltage can be expressed as:

$$V_{C1} = V_{C2} = V_C = \left(1 - \frac{T_0}{T}\right) \cdot \frac{V_{pv}}{\left(1 - 2 \cdot \frac{T_0}{T}\right)} \qquad (18)$$

The Buck-Boost Factor (BB) is determined by the modulation index (M) and the Boost Factor (B). The Boost Factor B can be controlled by the duty cycle of the shoot through zero state over the non-shoot through states of the PWM inverter. The shoot through state does not affect PWM control of the inverter, because it equivalently produces the same zero voltage to the load terminal. The available shoot through period is limited by the zero.

IV. Pulse-Width Modulated (PWM) :

Inverters that use PWM switching techniques have a DC input voltage that is usually constant in magnitude. The inverters job is to take this input voltage and output ac where the magnitude and frequency can be controlled. There are many different ways that pulse-width modulation can be implemented to shape the output to be AC power. A common technique called sinusoidal-PWM will be explained. In order to output a sinusoidal waveform at a specific frequency a sinusoidal control signal at the specific frequency is compared with a triangular waveform (See Figure 7a). The inverter then uses the frequency of the triangle wave as the switching frequency. This is usually kept constant output. Since the output of the inverter is affected by the switching frequency it will contain harmonics at the switching frequency. The duty cycle of the one of the inverter switches is called the amplitude modulation ratio, m_a.

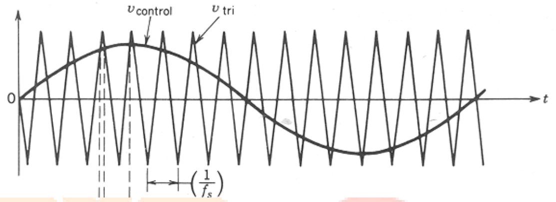
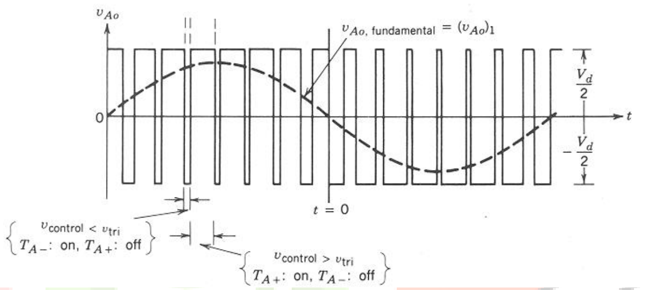


Figure 3 – Desired frequency is compared with a triangular waveform



EQUATION 1

$$m_a = \frac{V_{control}}{V_{tri}}$$

where, $V_{control}$ is the peak amplitude of the control signa

EQUATION 2

$$m_f = \frac{f_s}{f_1}$$

$$v_{control} > v_{tri} \quad \text{Ta\_pos is on,} \quad v_A = \frac{V_d}{2}$$

EQUATION 3

$$v_{control} < v_{tri} \quad \text{Ta\_neg is on,} \quad v_A = \frac{-V_d}{2}.$$

V. RESULT AND ANALYSIS:

The proposed topology of Photovoltaic based Z-source Inverter consists of various models.
They are:

1. Photovoltaic Generation Model.
2. PWM Generation Model and Logic.
3. THD Analysis.
4. Low Pass filter
5. Grid Syncronisation Logic and Implimantation.

VI. PHOTOVOLTAIC GENERATION MODEL

The Simulation diagram for the PV Generation by a single stand-alone 12V PV module is shown in Figure 5.

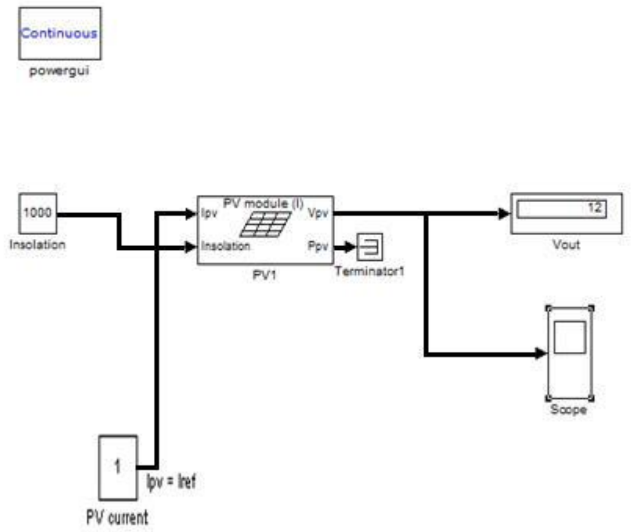


Figure 4.MATLAB Model of Photovoltaic Generation.

It consists of Insolation block, Single PV module block for DC voltage generation and display & scope blocks for displaying the output in numerical and graphical form respectively. The technical specifications of the PV module used in the proposed system are listed in the TABLE I.

Table I : Technical Specifications of PV Module.

S. No	Parameters	Specifications	Units
1	Short Circuit Current (Isc)	5.45A	Amperes
2	Open Circuit Voltage (Voc)	12V	Voltage
3	Current at Pmax	4.95A	Amperes
4	Voltage at Pmax	17.2V	Voltage
5	Insolation	1000 W/m^2 (Constant)	Watts / $metre^2$

The Simulated output is taken for 1000 $watts/m^2$ of Insolation and $25^{o}C$ of Temperature under Standard Test Condition (STC).

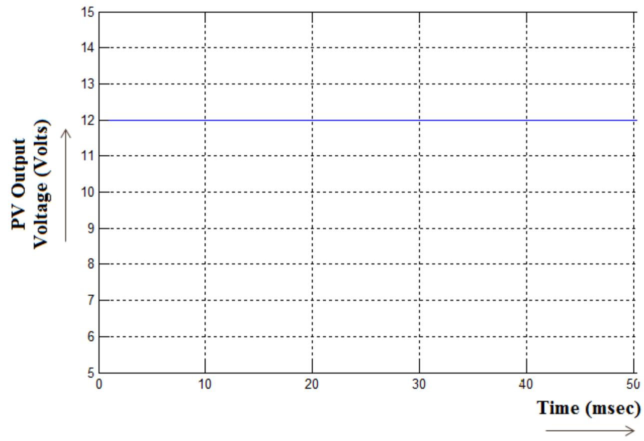


Figure 5: Output Voltage Waveform of PV Module

Thus from the PV Panel, a 12V DC of Unidirectional Voltage is produced. Then this low value of DC voltage is given to the Boost converter for achieving desired DC voltage for giving input to the Multilevel Inverter.

VII. PWM GENERATION(SHOOT THROUGH STATE) SYSTEM AND LOGIC:

The Simulation diagram for the PWM Generation And logic of PWM Generation is shown in Figure 6.

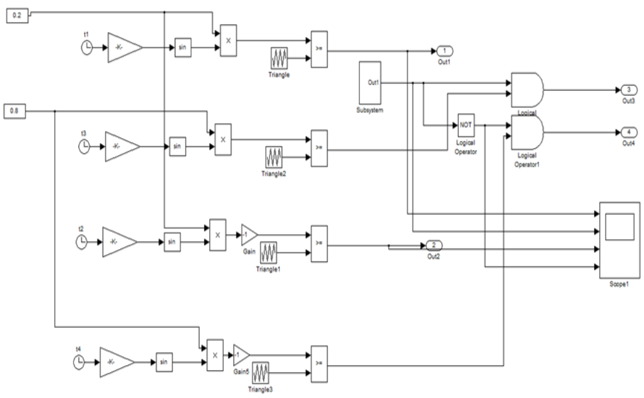


Figure 6. Logic of PWM Generation(Shoot through state).

Table: Logic PWM Generation

Switches	S1	S2	S3	S4
+ Cycle	PWM	OFF	Boost (PWM)	Continuous ON
- Cycle	OFF	PWM	Continuous ON	Boost (PWM)

VIII. Total Harmonic Distortion(THD) Analysis:

The Total Harmonic Distortion (THD) is used to characterize the linearity of audio systems and the power quality of electric power systems.

The formula below shows the calculation for THD on a voltage signal. The end result is a percentage comparing the harmonic components to the fundamental component of a signal. The higher the percentage, the more distortion that is present on the mains signal.

$$THD = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \ldots\ldots + V_n^2)}}{V_1} * 100\%$$

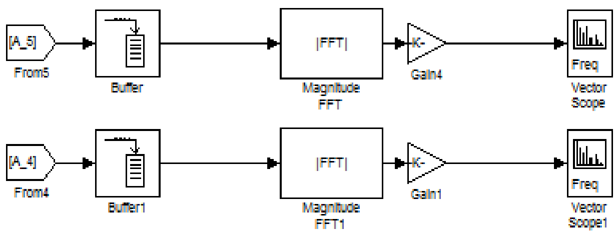


Figure 7: Basic Structure to Calculation of THD.

From the Figure 7, it is observed that THD value of 37.15% is obtained for Voltage Distortion. This value can be reduced using adding filter in ckt.

Total Harmonic Distortion of the voltage is calculated in the FFT analysis in the MATLAB software and the voltage before compensation is given as 40.33% which is abnormal THD under IEEE standards.

IX. Low pass filter:

For the series tuned low pass filter the impedance is:

$$Z_{sh(h)} = \left[R + j\left(hX_L - \frac{X_C}{h}\right)\right]$$

$$X_C = \frac{V_{ph}^2}{Q_{sh}\, h}$$

$$X_L = \frac{X_c}{h_n^2}$$

Where Qsh = reactive power provided by the passivefilter in VAR per phase, XL = reactance of inductor, XC= reactance of capacitor, h = harmonic order of the passive filter, Vph=Phase voltage Initially the reactive power requirement is assumed to be 25% of the rating of the load. It may be equally divided into different filter branches. The value of series tuned element can be calculated from equation. The quality factor of the low pass filter is:

$$QF = \frac{X_L}{R}$$

Here the quality factor is assumed to 30 to calculate the value of the resistive element. The resonant frequency is given by

$$f_0 = \frac{1}{2\pi\sqrt{(LC)}}$$

Where R = filter resistance
L = filter inductance
C = filter capacitance

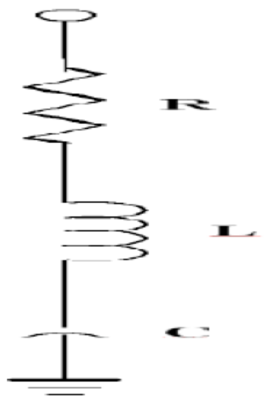


Figure 8: Low pass filter.

X. GRID SYNCRONISATION WITH Z-SOURCE INVERTER

10.1 (PLL) synchronization techniques

The most widely accepted synchronization solution to a time-varying signal can be described by the basic structure shown in block diagram form in Fig. 1, where the difference between phase angle of the input and that of the output signal is measured by the phase detection (PD) and passed through the loop filter (LF). The LF output signal drives the voltage-controlled oscillator (VCO) to generate the output signal, which could follow the input signal.

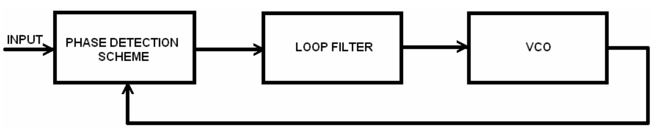


Fig.9 Closed-loop synchronization structure

Different types of phase locked loop (PLL) synchronization techniques are available to synchronies system with grid.

1. ***SF-PLL:*** Synchronous Frame PLL (SF-PLL)
2. ***PQ-PLL:*** instantaneous real and imaginary power
3. ***DSF-PLL:*** Double Synchronous Frame PLL
4. ***SSI-PLL :***Sinusoidal Signal Integrator PLL
5. ***DSOGI-PLL:*** Double second order generalized integrator PLL
6. ***EPLL:*** Enhanced phase-locked loop (EPLL)
7. ***3MPLL:*** Three-phase magnitude phase locked loop
8. ***QPLL :*** quadrature PLL
9. ***RPLL :*** robust single-phase PLL
10. ***ALC-PLL :*** adaptive linear combiner PLL
11. ***MR-PLL :***The multirate PLL

12. ***APLL:*** The adaptive PLL
13. ***Other synchronization methods***

The simplest synchronization solution is the zero crossing- detection (ZCD) method shown in Fig. 15, where the zero-crossing point is detected every one period and the sin-table pointer is reset from scratch. It can be only used where the input is a stable and sinusoidal signal due to its sensitivity to transient and noise .

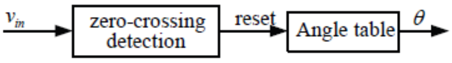


Fig.10. Zero-crossing-detection method

XI. THE COMPLETE SIMULATION MODEL

The figure given below shows the complete simulation model of system. The system consists of subsystem of photovoltaic array, z source network, THD Analysis , low pass filter.

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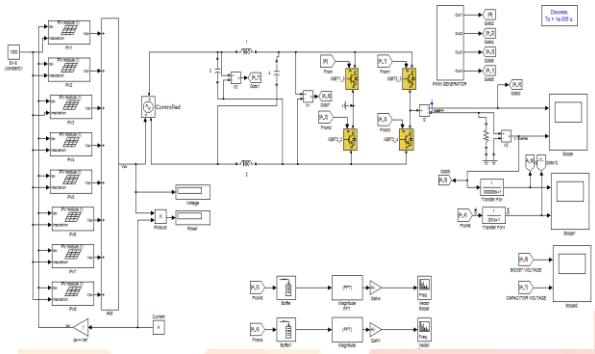

Figure 11 : MATLAB/SIMULINK model of photovoltaic stand-alone system.

Table : Simulation Parameters

PARAMETER	VALUE
Inductor L_1	$1e^{-3}$
Inductor L_2	$1e^{-3}$
Capacitor C_1	$8e^{-6}$
Capacitor C_2	$8e^{-6}$
Switching Frequency	10KHz
Load	10 OHM
Duty Cycle	0.25

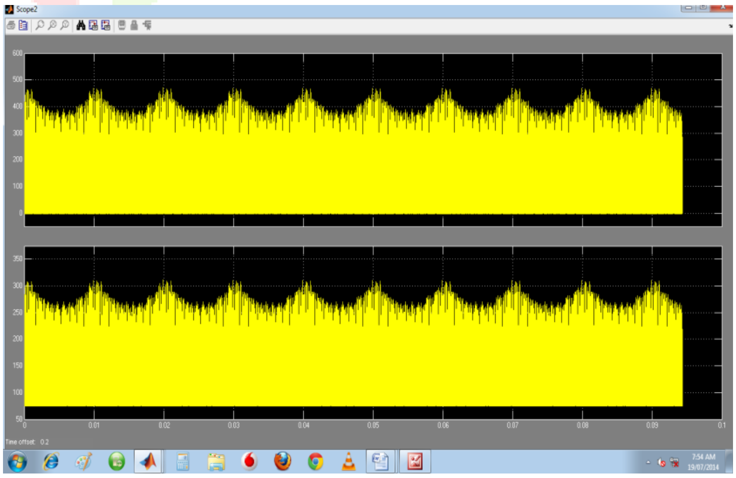

Figure 12: Z-source link voltage across Inverter and capacitor voltage connected to Impedance Network (C_1 and C_2).

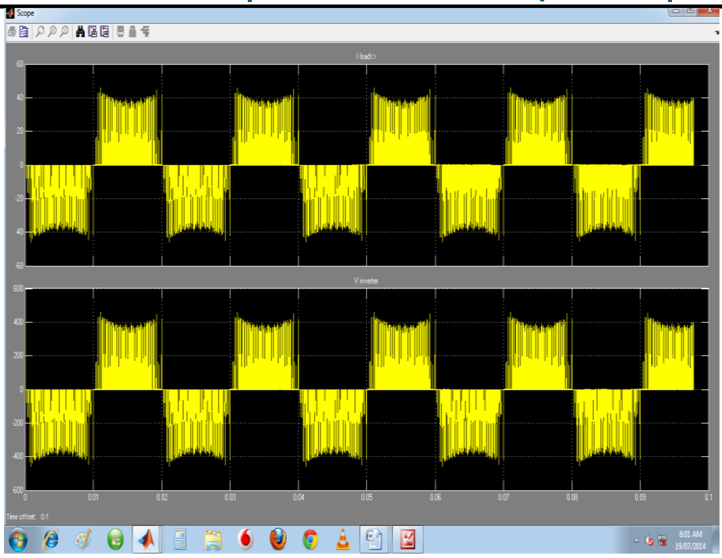

Figure 13: Output of Z source inverter, Current and Voltage without connected filter.

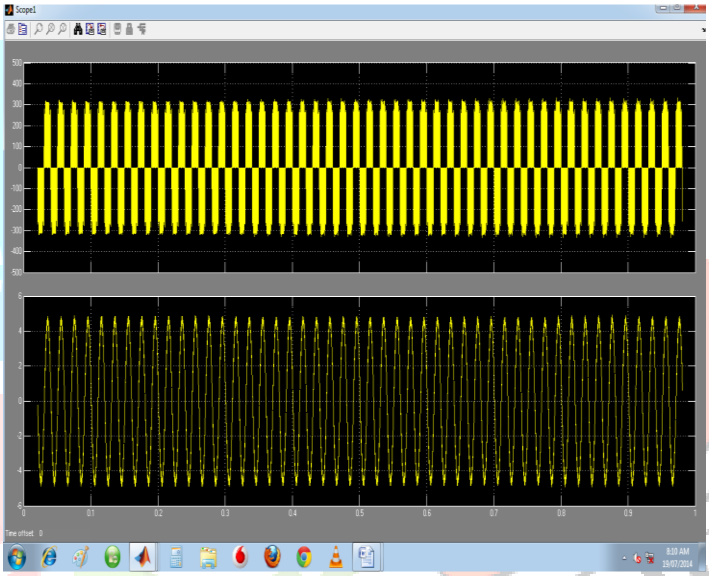

Figure 14: Output of Z source inverter, Current and Voltage connected with filter.

XII. CONCLUSION

The cost of energy is rising and therefore photovoltaic system is a promising alternative. They are abundant, pollution free, distributed throughout the earth and recyclable. The PV array has been designed in MATLAB environment. The coupling of the photovoltaic array with the z source inverter has been described. Also done the calculation of THD Using FFT analysis to calculate voltage distortion of inverter system. Reducing voltage distortion use addition low pass filter, this is also described in paper. The Inverter System has application on home power supply, water pumping in remote area, Swimming pool heating system etc.

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