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Maximum Power Point Tracking (MPPT) for a PV Powered Z-Source Inverter

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Abstract

Objectives: A constant voltage maximum power point tracking algorithm based PV powered z-source inverter was examined for varying irradiation and temperature to maximize power output. **Method:** Maximum power point tracking algorithm applied to photo voltaic system keep the boost converter output constant. The constant output from boost converter is taken to three phase z-source inverter with load arrangements. Three phase z-source inverter is operated in closed loop control for voltage and frequency synchronization. Eventually three phase z-source inverter output with LC filters will produce sinusoidal output fed to the three phase asynchronous machine. **Findings:** Simulations are provided to validate the presentation of the proposed algorithm. Perturb and Observation Algorithm (P&O) used for maximum power point tracking may accomplish fast maximum power point for rapid change of environmental conditions such as irradiance and temperature. The usual means to work with lesser MPP voltages is to have a supplementary DC-DC boost converter with conventional inverters like current source inverter or voltage source inverter (CSI or VSI). However, proposed z-source inverter can either buck or boost AC output voltage without any supplementary DC-DC boost converter which is not possible in the conventional CSI or VSI. Moreover, the z-network of three phase z-source inverter comprising of pair of capacitors and inductors forms a second order filter and filters unwanted voltage sags of the DC voltage source thereby improving the quality of power and total harmonic distortion. Consequently enhanced power quality without sag and lesser total harmonic distortion is given to three phase asynchronous machine. Thus a MPPT based PV powered z-source inverter is effective in comparison with conventional inverters. **Applications:** Proposed system finds its applications in renewable energy sources like solar, wind and combined solar- wind systems, electric vehicles and AC motor drives.

Keywords: Asynchronous Machine, Maximum Power Point Tracking (MPPT), PV Power, Perturb and Observation Algorithm, Z-Source Inverter

1. Introduction

Renewable energy sources obtain their energy from sunshine, wind, flowing water and geothermal heat flow. As the PV energy from sunshine are gaining popularity more than other renewable energy sources due to ease of installation and less maintenance, it is the most feasible alternative energy source with a disadvantage of high unpredictability. However, PV power, changes in insolation on the panels due to cloudy weather and increase in ambient temperature will result in wastage of power. Hence, Maximum Power Point Tracking (MPPT) algorithm[1] is applied to PV system so as to keep boost converter output constant. Two different MPPT algorithms such as perturb and observe (P&O) algorithm and incremental conductance (Inc Cond) algorithm[2] have been considered to gain maximum power for any given environmental conditions. The arrangement was integrated with different configurations of controllers and converters. Owing to the modernizations of Power Electronics and Embedded System Technologies, control and implementation of renewable energy schemes are made promising[3,4].

2. Photovoltaic System

Photovoltaic power generation has a vital part to perform owing to the point that it is a green basis. The only radiations connected to PV output are from the fabrication of its modules. Once PV panel installed, they produce electrical energy

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from the PV irradiation without radiating greenhouse gases like carbon dioxide. Due to the requirement of equipment, PV power output is more costly than other renewable energy resources. However, raising the efficiency of PV plants will reduce the cost of power generated. Improving the tracking of maximum power point with control algorithms called maximum power point tracking algorithm might result in rise of PV plant efficiency and consequently a fall in its price.

An equivalent circuit of PV cell[5,6] shown in Figure 1 is developed for understanding the electronic behaviour of a PV cell. The circuit comprises of a constant current source, series and parallel resistances along with a diode and a load. A parallel and series resistances are connected to the model. From figure 1 it is obvious that the output current is formed by photo generated current, minus diode current, minus current through the parallel resistance.

$I = I_{PV} - I_D - I_P$ (Ampere) (1)

Where I is output current, I_{PV} is photo generated current, I_D is diode current and I_p is current through parallel resistance.

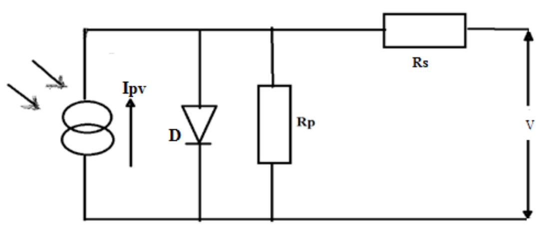

Figure 1. Equivalent circuit of PV Cell.

The important points in characteristic curves of a PV cell [7] such as maximum power point (MPP), short circuit current (I_{sc}) and open circuit voltage (V_{oc}) are shown in Figure 2

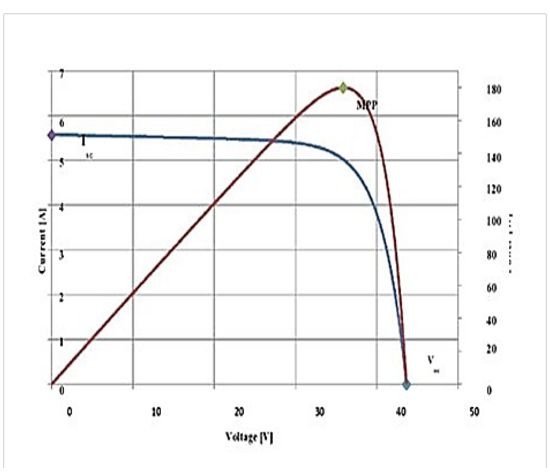

Figure 2. Important points in the characteristic curves of PV panel.

As the open circuit voltage (V_{oc}) and short circuit (I_{sc}) points, no power is produced. V_{oc} can be obtained without current output in the PV cell and parallel resistance R_p is discarded. The current at V=0 is the short circuit current and approximately equal to light generated current. The maximum power is acquired by the PV cell at a point where the product VI is maximized. This point is identified as the maximum power point and is unique as in Figure 2.

3. MPPT Algorithms

Many algorithms have been developed for tracking the maximum power point as the MPP of a PV panel varies with the irradiation and temperature. A maximum power point tracker (MPPT) tracks the maximum power from the PV module and transfer tracked power to the load connected to the system. Different power converters serve the intention of transmitting maximum power from the PV panel to the load. The developed algorithms diverge in many features such as necessary sensors, convergence speed, proper tracking when irradiation and/or temperature variations, the hardware required for functioning etc. Among these algorithms, perturb and observation (P&O) and Incremental Conductance (Inc Cond) is the most common.

3.1 Perturb and Observation Algorithm

Perturb and Observation Algorithm[8, 9] is commonly used algorithms for maximum power point tracking. This includes introducing perturbation in PV panel operating voltage. Changing the operating voltage is achieved through changing the duty cycle of converter. In case of a rise in operating voltage, the algorithm relates existing reading of power with the preceding and if it has improved, it retains the same direction, else it changes direction[10]. This procedure is repetitive at each maximum power point tracking step until the maximum power point is attained. Once attaining the maximum power point, the algorithm obviously fluctuates about accurate value. As the algorithm is a comparatively an accurate method, it is very popular and most commonly used.

3.2 Incremental Conductance Algorithm

The incremental conductance algorithm[11] utilizes the point that the panel power curve derivative is 0 at maximum power point, positive on the left side and negative on the right side of the maximum power point. This can be given by,

$P' = 0$ at MPP (2)

$P' > 0$ left of MPP (3)

$P' < 0$ right of MPP where $P' = d(P)/dV$ (4)

The power derivative can be written as:

$d(P)/dV = d(IV)/dV = I\,d(V)/dV + Vd(I)/dV = I + Vd(I)/dV = I + V\Delta I/\Delta V$ (5)

Combining above equations, we get

$\Delta I/\Delta V = -I/V$, at MPP (6)

$\Delta I/\Delta V > -I/V$, left of MPP (7)

$\Delta I/\Delta V < -I/V$, right of MPP (8)

The core idea is to link the incremental conductance $\Delta I/\Delta V$ to the instantaneous conductance I/V. Depending on the output; the PV operating voltage is either increased or diminished to the maximum power point. Under steady state the output power does not oscillate around the MPP unlike the previous algorithm. Hence this algorithm is beneficial.

3.3 Comparison of Perturb and Observation and Incremental Conductance Algorithms

An MPPT control for a PV powered Z-Source Inverter[12] with both algorithms retains the system power operating point at its maximum. Perturb and Observation algorithm may reach first the maximum power point than Incremental Conductance Algorithm for rapid change of irradiance and temperature.

4. Basics and Configurations of Boost Converter and Z-source Inverter

4.1 Boost Converter:

Boost converter[13,14] is also known as a step-up chopper, as its average output voltage is higher than the input voltage. When the chopper is ON, current through the load would rise. Hence input voltage is applied to inductor. When the chopper is OFF, current would fall and the energy is released by inductor to the load. Here the boost converter operates in closed loop control so as to maintain PV panel voltage as constant.

4.2 Z -Source Inverter

A current source or voltage source inverter (CSI or VSI) if directly connected to PV panel would require a higher maximum power point voltage. The conventional way to work with lower MPP voltages is to have an extra DC-DC converter with CSI or VSI. However, z-source Inverter shown in Figure 3 can buck or boost AC output voltage which is not possible in the conventional method. Thus an inverter can provide buck-boost operation. Impedance source inverter deploys an impedance network coupled with the inverter main circuit. With a distinctive z-network comprising of capacitors and inductors, the z-source inverter utilizes the shoot through state by turning ON upper and lower switches in the same legs to regulate the DC voltage without DC/DC converter. The z-network also form a II order filter that handles unwanted voltage sags of the DC voltage source. The inductors and capacitors can be practically designed to reduce the cost and size of inverter circuitry.

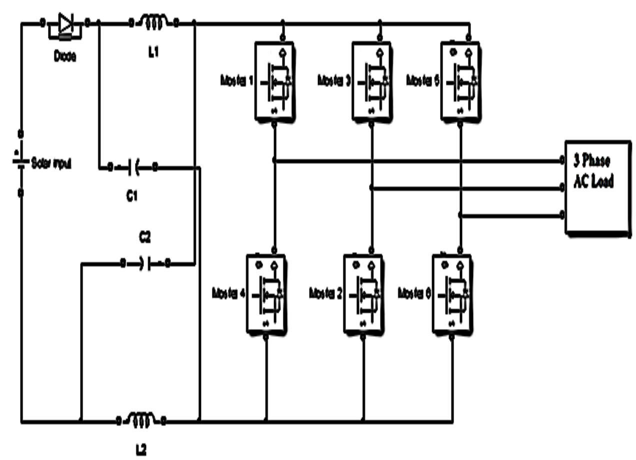

Figure 3. Z- Source Inverter.

The z-source inverter system does not require transformers or DC-DC converters to control the voltage as in case of conventional inverters. Improved control accuracy and reduced harmonics of inverter system is established as no dead time isrequired. The z-source inverter has the minimum amount KVA requirement for utmost renewable energy sources[15]. In addition, the z-source inverter scheme is able to track the maximum power and voltage boost simultaneously and individually by a single inverter[16].

5. Simulation Results

The simulation circuit of Maximum Power Point Tracking for a PV powered z-source inverter is shown in Figures 4 and 5 and it consists of the following blocks:

i) PV Panel
ii) Boost converter
iii) MPPT Controller
iv) Z-Source Inverter and
v) Asynchronous motor

The Table 1 gives the specifications of various passive elements used in boost converter, z-network/filter and universal bridge or a three phase z-source inverter. These passive elements aids, to simulate the various blocks of the system and the outputs are obtained to validate the performance of projected algorithms.

DC output voltage of 80W PV panel (V_{PV}), feeding z-source inverter through MOSFET based boost converter is shown in Figure 6. Its value is more than 20V. It is boosted nearly to 40V using a boost converter operated in closed loop operation as shown in Figure 9. Output current of PV panel (I_{PV}) and input power, a product of V_{PV} and I_{PV} is given to MPPT controller and they are shown in Figures 7 and 8. Similarly the product of output voltage of the boost converter (V_{dc}) and output current of the boost converter (I_{dc}) has shown in Figure 10 gives the output power as in Figure 11. The regulated output of boost converter is converted into three phase AC using z-source inverter. The output contains three voltages as shown in Figures 12, 13 and 14 displaced by certain degrees. The output voltage of z-source inverter shown in Figure 15 is given to three-phase asynchronous machine[17].

Table 1. Required Passive Elements

Boost Converter	Z-Network/Filter	Universal Bridge/Inverter
Resistor (R) =50Ω	A Pair of Inductors (L_1= L_2=L) =4.5 mH	Snubber Resistance (R_S) =3Ω
Inductor (L) = 3mH	Pair of Capacitors (C_1= C_2=C) =300μF	Snubber Capacitance (C_S) = ∞
Capacitor (C) = 1000μF	-	On-State Resistance (R_{on}) = 1Ω

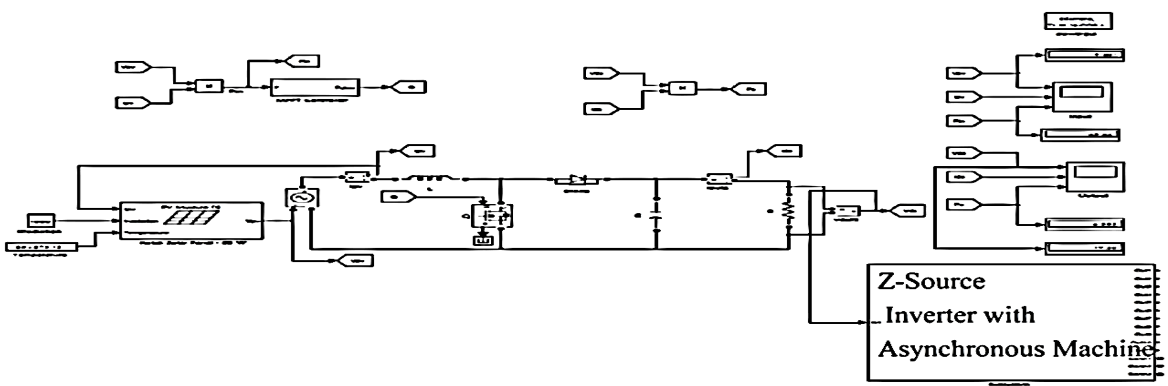

Figure 4. Simulink circuit of MPPT for a PV powered Z-Source inverter.

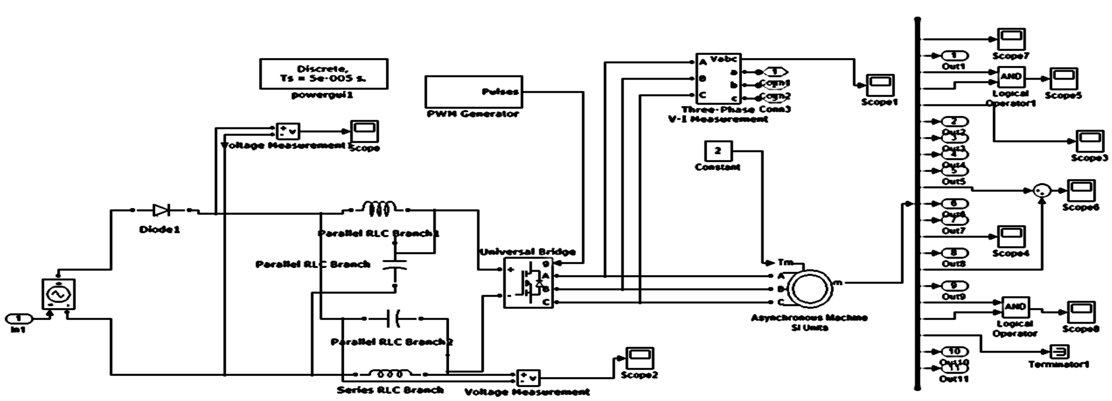

Figure 5. Sub System (ZSI and Asynchronous Machine) of MPPT for a PV powered Z-Source inverter.

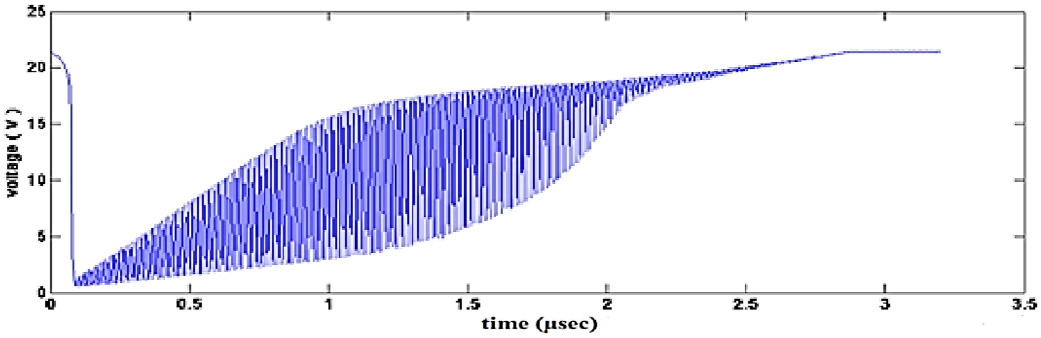

Figure 6. Output voltage of PV panel.

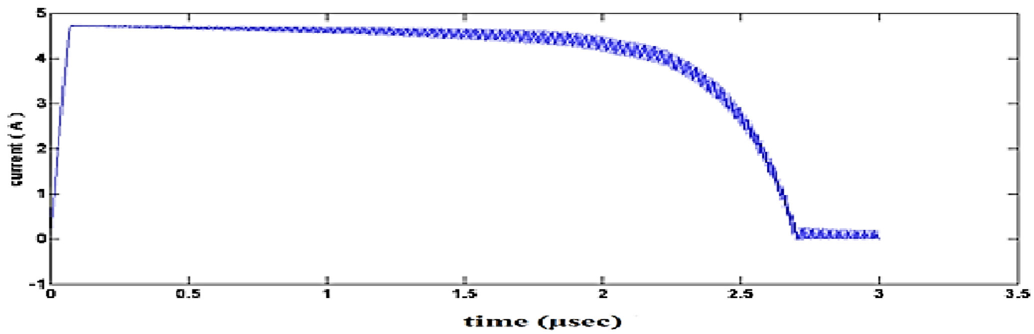

Figure 7. Output current of PV panel.

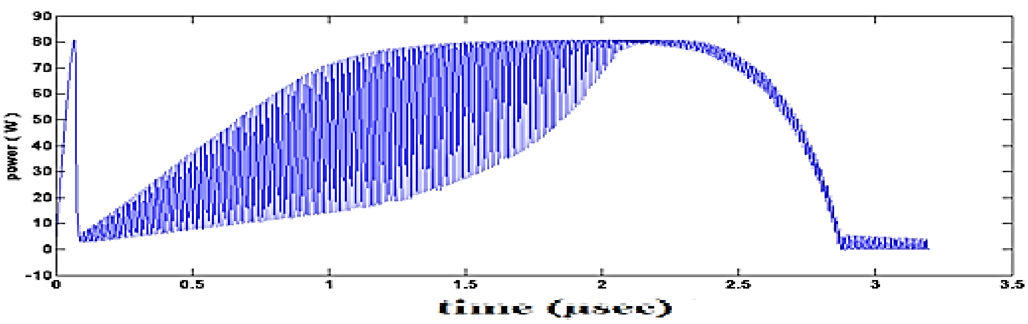

Figure 8. Input power of MPPT controller.

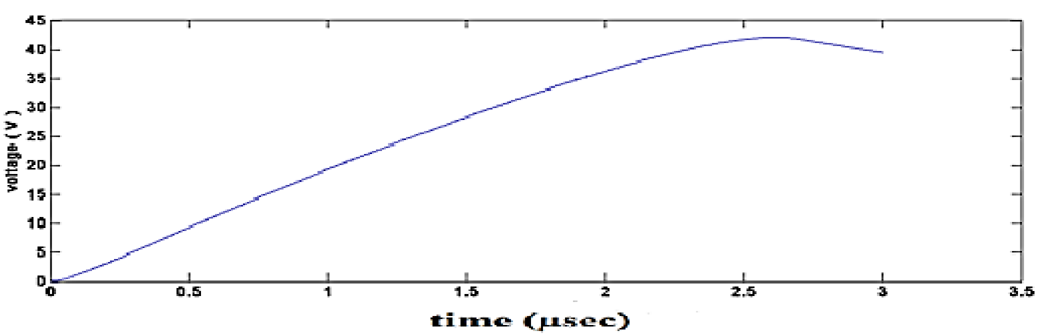

Figure 9. Output voltage of boost converter.

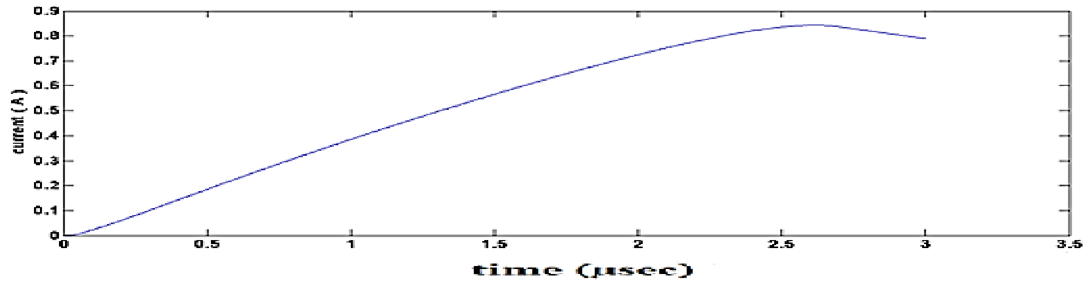

Figure 10. Output current of boost converter.

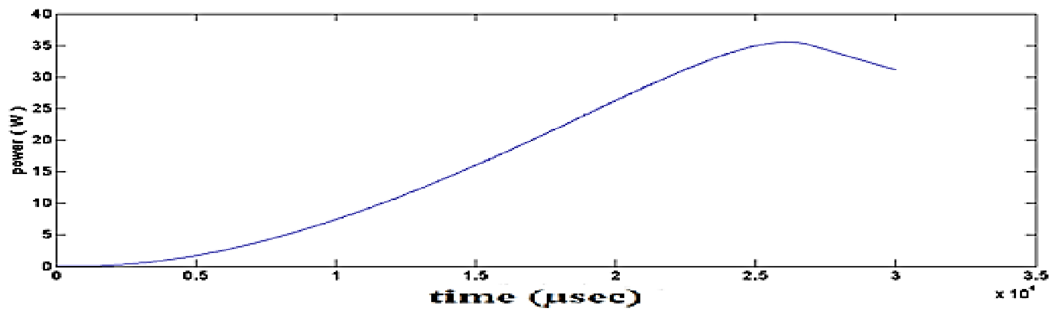

Figure 11. Output power of boost converter.

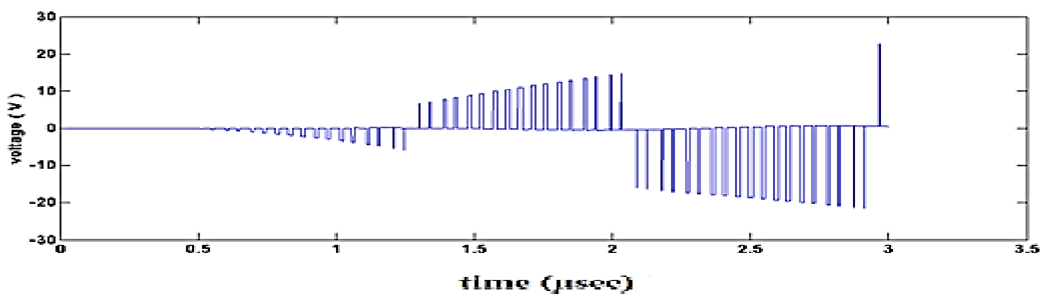

Figure 12. R- phase voltage of Z-Source Inverter.

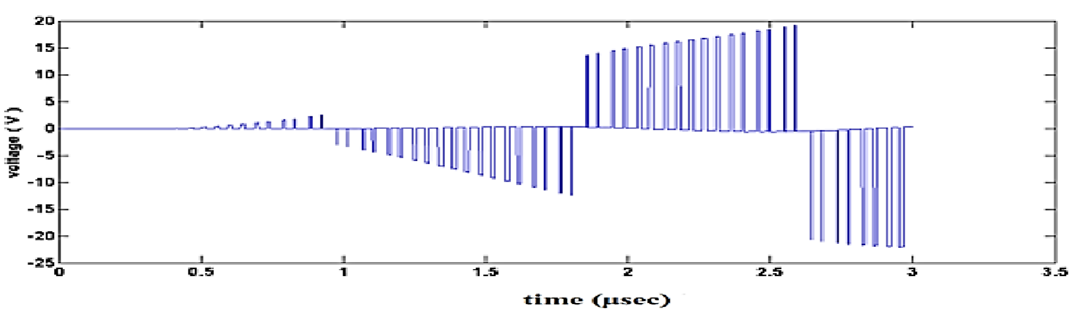

Figure 13. Y- phase voltage of Z-Source Inverter.

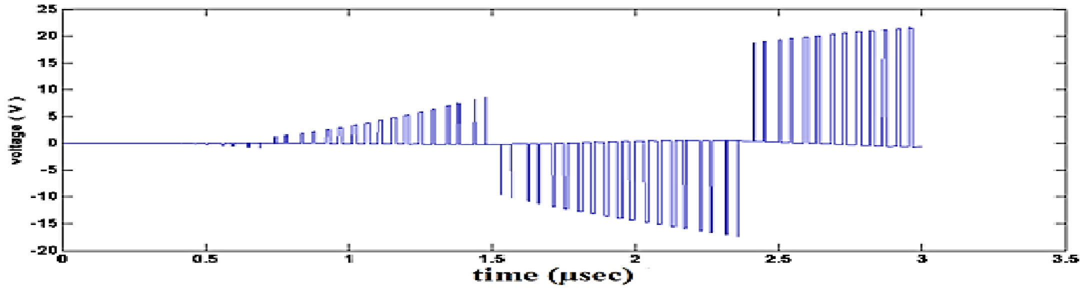

Figure 14. B-phase voltage of Z-Source Inverter.

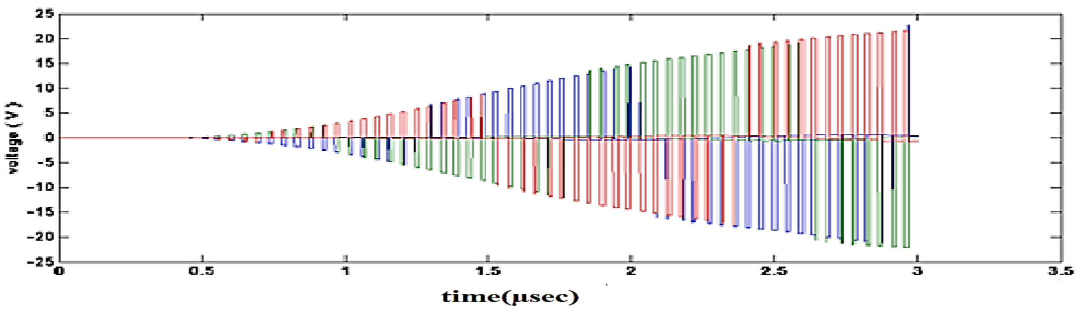

Figure 15. Output voltage of Z-Source Inverter.

6. Conclusions

A constant voltage maximum point power tracking for a PV powered z-source inverter has been executed for varying parameters. The execution shows that the z-source inverter power output is maximized. The results of z-source inverter have offered consistency since the shoot through cannot demolish the inverter. The traditional inverter suffers shoot through consistency crisis. In a nutshell, z-source inverter for Maximum Point Power Tracking is very promising in photovoltaic systems. The proposed system elucidates an arrangement realized on PV system with z-source inverter to obtain full energy from photovoltaic energy resources. Digital Simulink models of PV systems are established and the output power obtained under transient conditions. The future scope of this work is to simulate under steady state condition and to realize a hardware model of the system.

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