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Z SOURCE INVERTER FOR FUEL CELL VEHICLES

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ABSTRACT

Inverters are one of the most emerging topologies in field of power electronics. Z source inverters can obtain higher voltage gain with lower voltage stress and they can operate with wide range load and hence their demand is high in the industry. The Z – source inverter provides unique features that overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter (abbreviated as V-source converter) and current-source converter (abbreviated as I-source converter) and provides a novel power conversion concept. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. Z –Source inverters have been recently proposed as an alternative power conversion concept as they have both voltage buck and boost capabilities. These inverters use a unique impedance network, coupled between the power source and converter circuit, to provide both voltage buck and boost operation, which cannot be achieved with conventional voltage source and current source inverters. To facilitate understanding of Z – source inverter, this paper presents a detailed analysis, showing design of impedance network, implementation of Simple Boost PWM Control method, simulation of Z-source inverter and harmonic analysis in comparison with traditional VSI.

Index Terms *- Z source inverter, V- Source converter, C- Source converter, Impedance network, PWM control*

1. INTRODUCTION

A power inverter is a power electronic circuit that converts direct current (DC) to alternating current (AC). Power inverters are primarily used in electrical power applications where high currents and voltages occur. There exist two traditional inverters: voltage-source (or voltage-fed) and current-source (or current-fed) inverter. The V- source inverter is widely used. However, both V-source and I-sources has limitations like – lower efficiency, protection to be given to avoid shoot through. Z source converter overcomes the limitations of the traditional V-source and I-source converters. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter.

1.1 Limitations and problems in VSI and CSI

Obtainable output voltage is limited quite below the input line voltage. Inrush and harmonic current from the diode rectifier can pollute the line. Miss-gating from EMI can cause short circuit through that leads to destruction of the inverter. A Z-source Inverter System can produce any desired output ac voltage, even greater than the line voltage, regardless of the input voltage, thus reducing motor ratings. Provide ride-through during voltage sags without any additional circuits. Reduce the harmonic current and common-mode voltage. The control method has been verified by simulation and experiment

1.2 Traditional inverter

Fig.1.1 shows the traditional three-phase voltage-source inverter (abbreviated as V-source converter) structure. A dc voltage source supported by a relatively large capacitor feeds the main converter circuit, a three-phase bridge.

The dc voltage source can be a battery, fuel-cell stack, diode rectifier, and capacitor. Six switches are used in the main circuit; each is traditionally composed of a power transistor and an anti-parallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability. The V-source inverter is widely used. It, however, has the following conceptual and theoretical barriers and limitations.

The ac output voltage is limited below and cannot exceed the dc-rail voltage or the dc-rail voltage has to be greater than the ac input voltage. Therefore, the V-source inverter is a buck (step-down) inverter for dc-to-ac power conversion and the V-source inverter is a boost (step-up) rectifier (or boost converter) for ac-to-dc power conversion. For applications where over drive is desirable and the available dc voltage is limited, an additional dc-dc boost converter is needed to obtain a desired ac output. The additional power converter stage increases system cost and lowers efficiency.

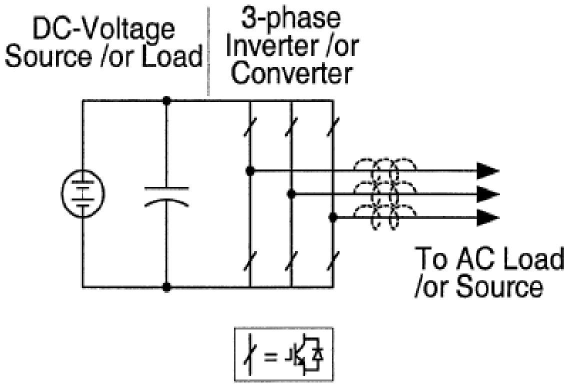

Figure 1.1 Traditional Voltage Source Inverter

1.3 Z source Inverters

The switching circuit and boosting circuit is eliminated in Z-source inverter, that reduces the space taken by the components, also most importantly the cost of total circuit reduces. Boosting is done only by the capacitors and Inductors connected in 'Z' shape. The Z-source converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional VSI and CSI provides an over power conversion concept. Fig. 1.2 shows the general Z-source converter structure proposed. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively. The Z- source converter overcomes the above-mentioned conceptual and theoretical barriers and limitations of the traditional V-source converter and I-source converter and provides a novel power conversion concept.

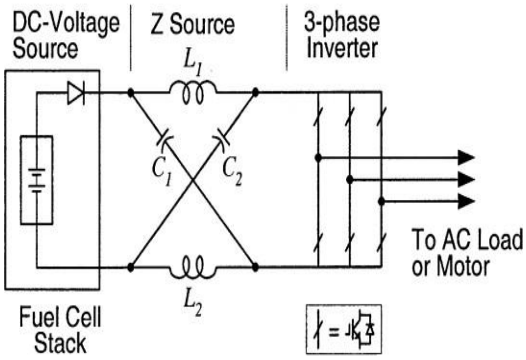

Fig 1.2 Z source inverter circuit

Z source inverter has a two-port network that consists of a split-inductor and capacitors and connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter. The dc source can be a battery, diode rectifier, thyristor converter, fuel cell, combination of an inductor and a capacitor. Switches used in the converter can be a combination of switching devices and diodes. The inductance can be provided through a split inductor or two separate inductors.

1.3.1 Operating principle and Control of Z-Source Inverter

The three-phase Z-source inverter bridge has nine permissible switching states (vectors) unlike the traditional three-phase V-source inverter that has eight. The three-phase Z-source inverter bridge has one extra zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one phase leg, any two phase legs, or all three phase legs. The shoot-through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. Fig 1.3 (a) shows the equivalent circuit of active state. Fig 1.3 (b) shows the equivalent circuit of zero state. Fig 1.3 (c) shows the equivalent circuit of shoot through state.

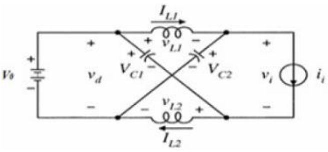

Fig 1 (a) Active State

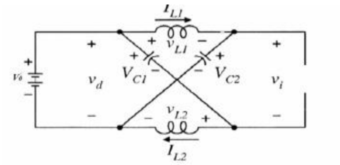

Fig 1 (b) Zero State

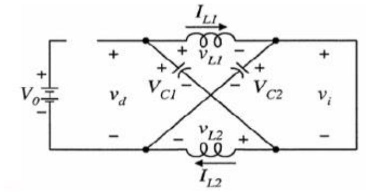

Fig 1 (c) Shoot Through State

2. LITERATURE SURVEY

The author F.Z. Peng [1] illustrates how to overcome the problems of the traditional V-source and I-source converters this paper presents an impedance-source (or impedance-fed) power converter (abbreviated as Z-source converter) and its control method for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The Z-source concept can be applied to the entire spectrum of power conversion. Based on the concept, it is apparent that many Z-source conversion circuits can be derived. As another example, the Z-source concept can be easily applied to adjustable speed drive (ASD) systems [1]. The Z-source rectifier/inverter system can produce an output voltage greater than the ac input voltage by controlling the boost factor, which is impossible for the traditional ASD systems.

The author Shen M [2] describes fuel cells, as one of the most promising energy sources and have attracted attention from automotive as engineers as well power electronics engineers have been used in a variety of areas, such as domestic applications, utility applications and traction applications. Unlike batteries that have fairly constant output voltage, the fuel cell has a unique V-I characteristic and wide voltage change range. The Z-source inverter can increase inverter conversion efficiency by 1% over the two existing systems and inverter motor system efficiency by 1% to 15% over the conventional PWM inverter [2]. The Z-source also reduces the total average SDP by 15%, which leads to cost reduction.

The author Li Yuan [3] the voltage-fed Z-source inverter/quasi-Z-source inverter (ZSI/qZSI) has been presented suitable for photovoltaic (PV) applications mainly because of its single stage buck and boost capability and improved reliability. The dynamical characteristics of the qZSI-network were investigated through small-signal analysis. Based on the dynamical model, the two-stage control method for qZSI operating in both output voltage control and current control mode was presented. MPPT in grid-connected qZSI based DG is implemented by the proposed controller. Experimental and simulation results confirm the effectiveness of the controller, exhibiting good reference tracking and disturbance rejection characteristics [3].

The author Tran-Quang Vinh Tae-Woo Chun [4] aims to achieve the good performances of both the dc boost control and ac output voltage control of the Z-source inverter. The dc–dc boost converter between the dc source and inverter is required to obtain the desired ac voltage. The additional dc–dc boost converter increases the cost and lowers the efficiency. The Z-source inverter (ZSI) was introduced in order to overcome limitations in the inverter. The transient responses of the dc capacitor voltage of the ZSI can be improved by controlling linearly the capacitor voltage.

The author Praveen Kumar [5] The design and simulation of three phase source inverter are implemented. The three-phase Z-source inverter consists of nine operating modes. Whereas the usual three-phase VSI has only eight modes. The three-phase Z-source inverter electrical circuit has an extra zero state when ends of the load are shorted by lower and upper switches of any phase leg or any two legs of phase, or on all three legs. These zero shoot-through modes is not present in the usual V-source inverter The zero shoot-through state is possible by Z-source concept which provides the buck and boost operation of input DC voltage.

3. DESIGN FOR TRADITIONAL VOLTAGE SOURCE INVERTER

VSI is mainly used to convert a constant DC voltage into AC voltage with the variable magnitude and frequency. Fig 4.1 is the voltage source inverter is composed of six switches with each phase output connected to the middle of eachinverter leg. it should be noted that the switches in each leg should be operated interchangeably, in order to avoid a dead short circuit of the dc supply. The different parameters and range are given in table 1.

Table 1 – Parameters and Range

Parameters	Range
Input voltage	245V
Output voltage	650V
Switchingfrequency	25kHz

Efficiency	98%
Power	113kW

3.1 Design

Vin = 245V Vo = 650 fs = 25kHz Efficiency = 98% P = 113 K

Duty Cycle:

$$D = (1 - \frac{Vi}{Vo}) * ▯ \quad \text{------------------ (3.1)}$$

D = 0.623

Load at rated power

$$P = \frac{V^2}{R} \quad \text{------------------ (3.2)}$$

R = 3.681Ω

Inductance

$$\tau - \frac{Vin*D}{fs*\Delta Il} \quad \text{------------------ (3.3)}$$

P = Is*Vin as ▯ is 98%

113kw= IL*245

$$Il = \frac{113*10^3}{245} = 461.22A$$

$$Io = \frac{113*10^3}{650} = 173.84A$$

$$L = \frac{245*0.623}{25000*0.3*461.22}$$

$$L = 4.412*10^{-5}\ H$$

Capacitance:

$$C = \frac{Io*D}{fs*\Delta Vc} \quad \text{------------------ (3.4)}$$

$$C = \frac{173-84*0.623}{25000*0.01*645}$$

$$C = 6.717*10^{-4}F$$

Boost circuit

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors)are normally added to such a converter's output (load-side filter) and input (supply-side filter).

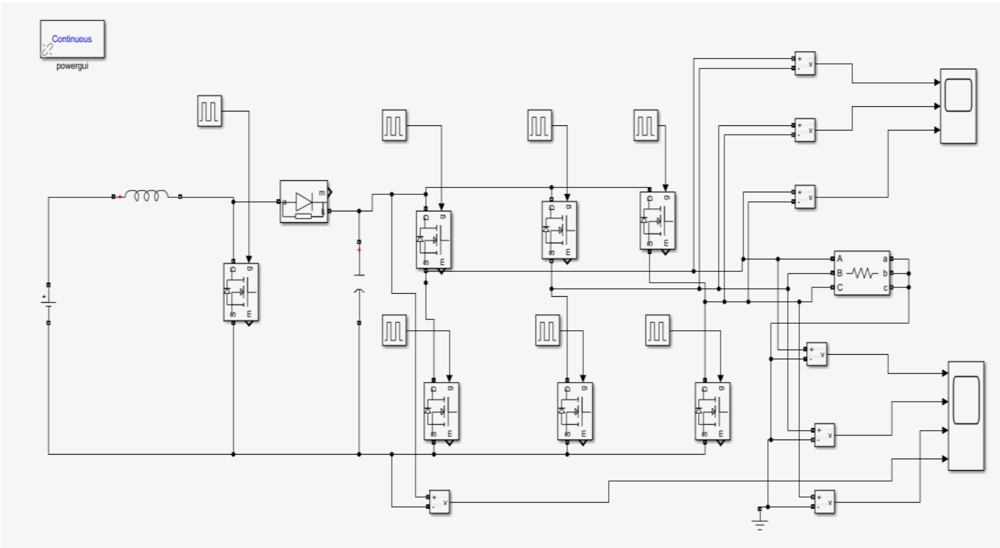

Fig 3.1 Simulation of Traditional Voltage Source Inverter

There are many different powers circuit topologies and control strategies used in inverter designs. Fig 3.1 shows the Simulation of Traditional Voltage Source Inverter. The simulation is done for both traditional and Z source inverters for a specified specification from the Toyota Mirai paper. In traditional inverter simulation, an extra boost circuit is present that is necessary for boosting the output voltage. Fig 3.2 shows the phase to phase output voltage with 120° phase shift of traditional voltage source inverter and it measures 410V RMS. The boost circuit consists of an Inductor and capacitor, where the calculation is shown above. Further, a MOSFET is used for switching circuit and according to the calculation, the duty cycle is 0.0623, pulse width is 62.80, and the switching frequency is 25kHZ. The time

period is $4*10^{-5}$ and with the help of MOSFET 120° mode is obtained. So, the output voltage is inverted. The pulses are given with the help of pulse generator.

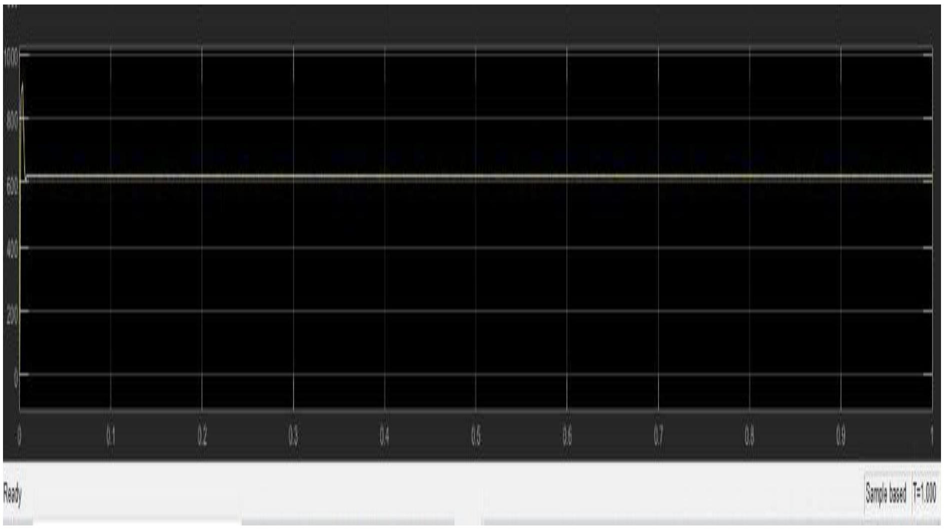

Fig 3.2 Output voltage waveform for boost circuit

4. DESIGN, SIMULATION AND OUTPUT OF Z SOURCE INVERTER

Z source inverter as shown in Fig 3.3 employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively.

4.1 Design

Vin = 245V Vo = 650 fs = 25kHz Efficiency = 98% P = 113 K

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D = 0.623

Load at rated power

$$P = \frac{V^2}{R} \quad \text{------------} (3.2)$$

R = 3.681Ω

Inductance

$$L = \frac{Vin*D}{fs*\Delta Il} \quad \text{------------} (3.3)$$

P = Is*Vin as □ is 98%

113kw = IL*245

$$Il = \frac{113*10^3}{245} = 461.22A$$

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Capacitance:

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The switching circuit and boosting circuit is eliminated in Z-source Inverter that reduces the space taken by the components, also most importantly the cost of total circuit reduces. Boosting is done only by the capacitors and Inductors connected in 'Z' shape. The Z-source converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional VSI and CSI provides a novel power conversion concept. The Z-source inverter bridge could boost the DC link capacitor (C1 and C2) voltage to any desired value that is above the average DC value of the rectifier, a desired output voltage is always obtainable regardless of the line voltage. For an input voltage of 245 V, the Z-source inverter voltage is boosted to 650V. The simulation results will be discussed in the following Fig. 3.2 shows the inverter's dc link voltage and the Z network's capacitor voltage. We observe from the figure that the inverter builds equal steady state dc link voltage (Vin) and capacitor voltage. However, there are variations in the value of voltage overshoot of the dc link voltage. As can be seen from Fig. 3.2, the lowest overshootoccurs when the modulation index and shoot-through duty ratio are high.

4.1 PWM Technique for ZSI

There are 3 PWM Techniques for ZSI

1. Simple boost PWM Control
2. Maximum boost PWM Control
3. Third harmonic injected maximum boost PWM Control

4.1.1 Simple boost PWM Control

Simple boost control uses two straight lines to control the shoot-through states. When the triangular carrier waveform is greater than the upper envelope, V1, or lower than the bottom envelope, V2, the circuit turns into shoot-through state. Otherwise it operates just as traditional carrier-based PWM. Fig 4.1 shows the pulse generation of the three phase leg switches (S1, S3 and S5-positive group/upper switch and S2, S4 and S6-negative group/lower switch). This method is uncomplicated; however, the resulting voltage stress across the device is relatively high because some traditional zero states are not utilized either partially or fully. For a complete switching period, Ts is total switching period, T0 is the zero state time period and D0 is the shoot-through duty ratio.

Fig 4.1 illustrates the simple control method that employs a straight line equal to or greater than the peak value of the three phase references to control shoot-through duty ratio in a traditional sinusoidal PWM for the modulation index m_a = 0.7. The Z source inverter maintains the six active states unchanged as the traditional carrier based PWM control. For this simple boost control, the obtainable shoot-through duty ratio decreases with the increase of m_a. Themaximum shoot-through duty ratio (Eq. 4.5) of the simple boost control is limited to

$$D_o = 1 - m_a \text{ -- } (4.5)$$

thus reaching zero at a modulation index of one. In order to produce an output voltage that requires a high voltage gain, a small modulation index (m_a) ma has to be used. However, small modulation indices result in greater voltage stress on the devices. Fig 4.3 is the output obtained for Z Source Inverter using Simple Boost PWM Technique. When the modulation index is increased, the switching frequency of the inverter also increases and hence the switchinglosses.

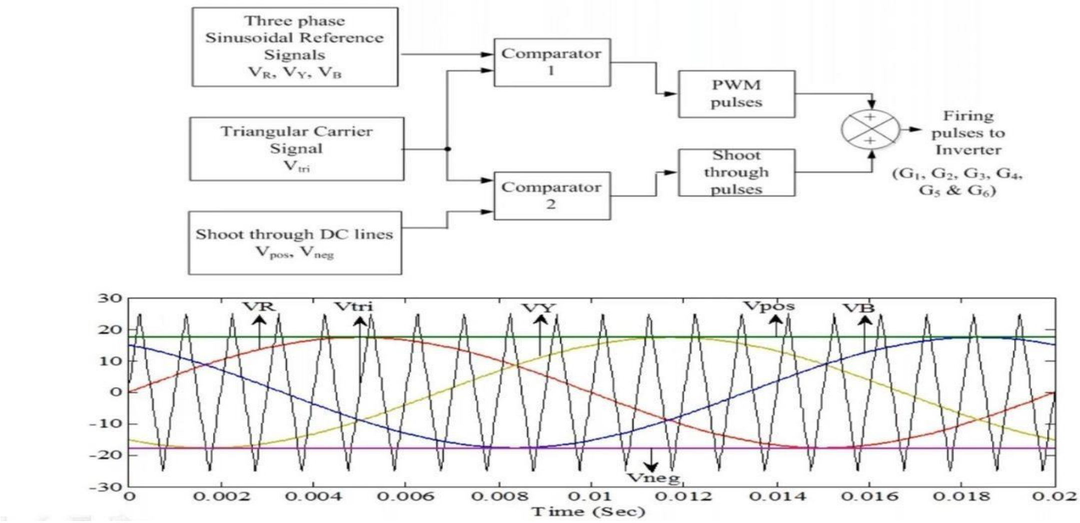

Fig 4.1 Modulation using Simple boost control

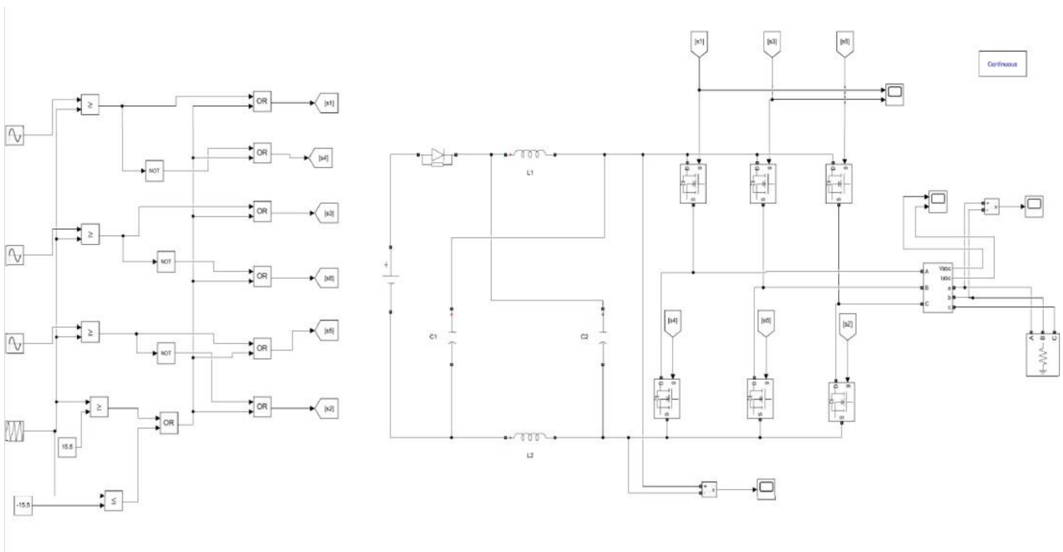

Fig 4.2 Z-Source Inverter with PWM control

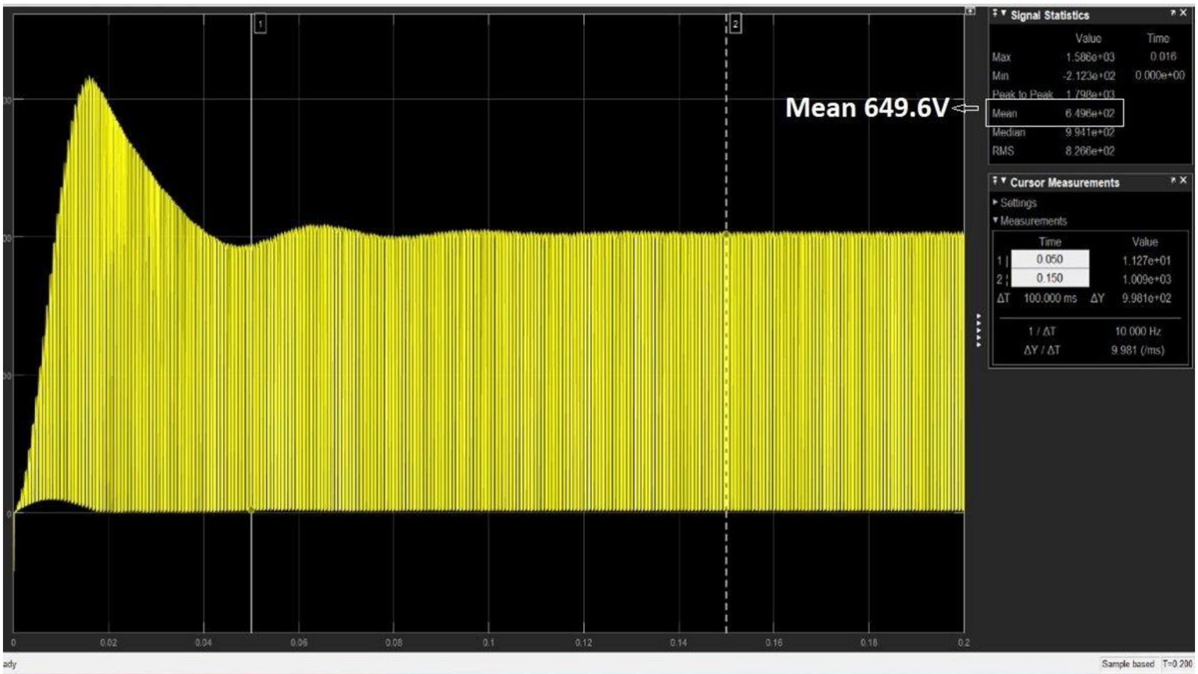

Fig 4.3 Z- Source voltage output with Simple Boost PWM Technique

5. CONCLUSION

From the simulation results obtained we can conclude that the construction of z source inverters are easier than the traditional inverters as we are able to successfully eliminate the switching circuits in the z source inverters. The switching components are costlier when compared with the capacitors and inductors and hence we were able to minimize the overall cost by a small margin. There is a special state called as shoot through state which can be only seen in the z source inverters and with the help of the shoot through state we can perform both buck and boost operations in z source inverters. The shoot through state is absent in the traditional inverters.

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