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MODELLING AND SIMULATION OF PWM BASED Z-SOURCE INVERTER USING MATLAB/SIMULINK

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ABSTRACT

Voltage Source and Current Source Inverters have some common problems. The Z-Source Inverter is a novel power conversion topology that can buck and boost the input voltage using passive components. With its unique structure, Z-Source Inverter can utilize the shoot through states to boost the output voltage and provides an attractive single stage DC to AC conversion that is able to buck and boost the voltage. The shoot-through duty cycle is used for controlling the DC link voltage boost and hence the output voltage boost of the inverter. In this paper MATLAB/SIMULINK model of Z-Source Inverter has been developed and harmonics analysis is carried out. Simulation results and harmonics analysis are compared with traditional inverters. It is found that for 0.1 pulse width the Total Harmonics Distortion (THD) and Weighted Total Harmonics Distortion (WTHD) are 0.22% and 0.08% respectively.

Keywords*: *Z-Source Inverter. Shoot Through State, Harmonics.

I. INTRODUCTION

Power electronics has been widely used in various applications since it was introduced. The three phase inverter, which converts DC voltage/current into three phase AC voltage/current, is one of its most important and popular converters. It has been widely used in motor drives, AC uninterruptible power supplies, induction heating, AC power supplies, active power filters and static VAR generators or compensators etc.

There are mainly two types of traditional inverters: Voltage Source (fed) Inverters and Current Source (fed) Inverters However, above both types of inverters have some conceptual barriers.

In Voltage Source Inverter [1] the output voltage range is limited; the inverter cannot output a higher voltage than the DC bus voltage. For many applications, when the input DC voltage is not always constant, like a fuel cell, photovoltaic array, and during voltage sag etc, a DC/DC boost converter is often needed to boost the DC voltage to meet the required output voltage. This increases the system complexity and the cost and reduces the system reliability. The two switches on the same phase leg cannot be gated on the same time, otherwise a short-circuit will occur and destroy the inverter.

For safety reasons, there is always a dead time to make sure that the two switches will not be turned on simultaneously. However, the dead time can cause output voltage distortion and harmonic problems. The harmonic problem can be solved by implementing a current/voltage feedback control. However, this increases the system complexity.

Current Source Inverter [1] is basically a boost converter. For applications where a wide voltage range is required, extra circuitry has to be used to obtain the required voltage. However, this increases the circuit complexity and reduces the efficiency as well as the reliability. At least one switch in the upper three devices and one in the lower three devices has to be turned on at the same time, or an open circuit will occur and destroy the inverter. To make sure that there will be no open circuit, overlap time is often needed, which will cause output waveform distortion and low frequency harmonic problem. The switches of the Current Source Converter have to block reverse voltage that requires a series diode to be used in combination with high-speed and high-performance transistors such as Insulated Gate Bipolar Transistors (IGBTs).

The newly presented Z-Source Inverter has some unique features and it can overcome most of these limitations. The purpose of this work is to simulate Z-Source Inverter and compare with the above both types of inverters along with harmonics study of Z-Source Inverter.

II. Z-SOURCE INVERTER

Z-Source Inverters are used to overcome the limitations of conventional Voltage Source and Current Source Inverters.

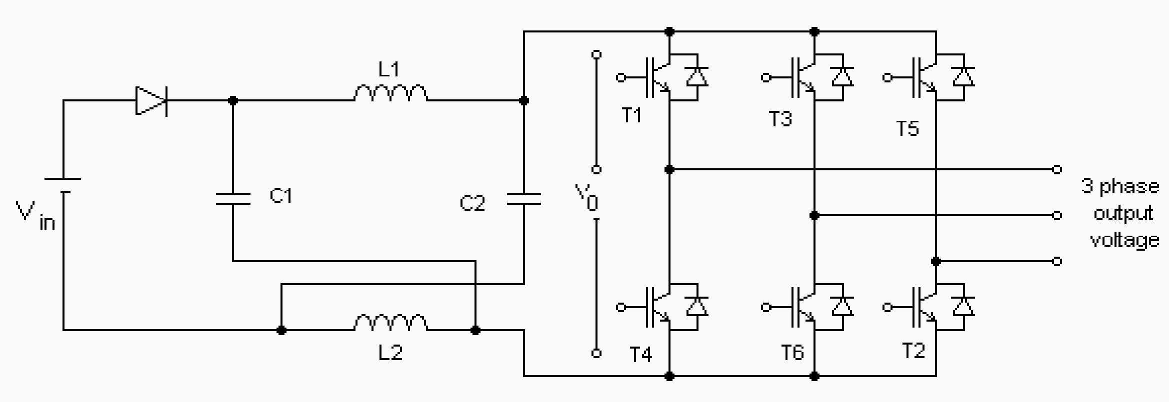


Fig.1 Z-Source Converter Structure

Fig.1 [2] shows the general Z-Source Converter structure proposed. It employs a unique impedance network 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 Voltage and Current Source Converters where a capacitor and inductor are used respectively. A split-inductor L_1 and L_2 and capacitors C_1 and C_2 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/or load can be either a voltage or a current source/or load. Therefore, the DC source can be a battery, diode rectifier, thyristor converter, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the antiparallel combination or the series combination etc. The inductance L_1 and L_2 can be provided through a split inductor or two separate inductors.

III. ANALYSIS OF IMPEDENCE NETWORK OF Z-SOURCE INVERTER

The Z-Source Inverter is a buck–boost inverter that has a wide range of obtainable voltage. The equivalent circuit of Z-Source Inverter is shown in Fig.2 [2].

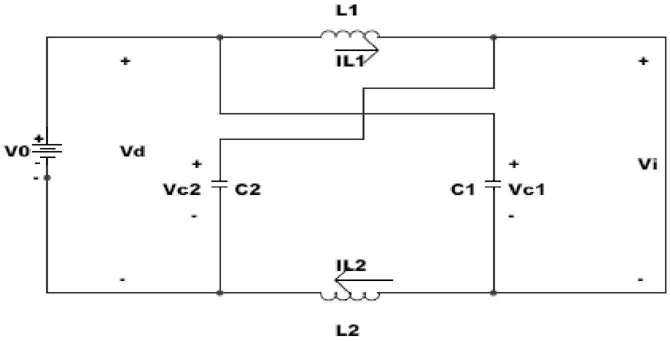


Fig. 2: Equivalent Circuit Of Impedance Network

Assuming that the inductors L_1 and L_2 and capacitors C_1 and C_2 have the same inductance and capacitance respectively, the Z-Source network becomes symmetrical. From the symmetry and the equivalent circuit as shown in Fig. 2, we have

$V_{C1}=V_{C2}=V_C$ and $V_{L1}=V_{L2}=V_L$ (1)

Given that the inverter bridge is in the shoot-through zero state for an interval of T_0, during a switching cycle T, and equivalent circuit during shoot through mode is shown in Fig.3[2]. We have

$V_L = V_C$; $V_d = 2 V_C$; $V_i = 0$; (2)

Now consider that the inverter bridge is in one of the eight non shoot through states i.e. during active state, as shown in Fig. 4 [2].

During active state, inverter bridge acts as an equivalent current source as in Fig 4. for an interval of T_1, during the switching cycle T. From the equivalent circuit, one has

$V_L = V_0 - V_C$;

$V_d = V_0$;

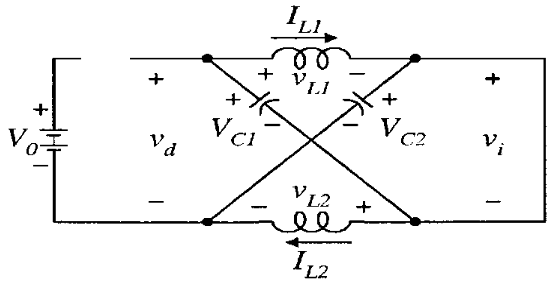
$V_i = V_C - V_L = 2V_C - V$ (3)

Where V_0 is the DC source voltage and T = (T0 + T_1.)

The average voltage of the inductors over one switching period (T) should be zero in steady state, from (1) and (2), thus, we have

$V_L = \frac{T_0 . V_C + T_1 .(V_0 - V_C)}{T} = 0$ (4)

Or, $\frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0}$ (5)



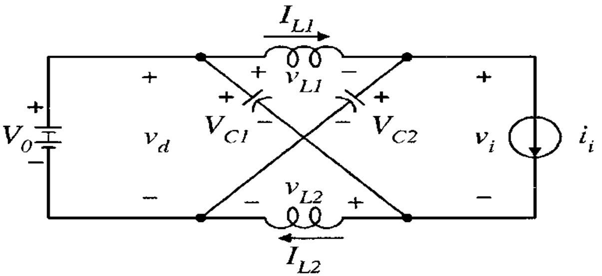


Fig.3 Shoot through switching states **Fig.4 Non shoot through switching states**

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

$V_i = \frac{T_0.0 + T_1(2V_C - V_0)}{T}$ (6)

The peak DC link voltage across the inverter bridge is expressed in (3) and can be rewritten as

$V_i = V_C - V_L = 2V_C - V_o = \frac{T}{T_1 - T_0} V_0 = B.V_0$ (7)

Where, B is the boost factor resulting from the shoot-through zero state.

The peak DC link voltage $\hat{V}i$ is the equivalent DC link voltage of the inverter. On the other side, the output peak phase voltage from the inverter can be expressed as

$\hat{V}ac = M.\frac{\hat{V}i}{2}$ (8)

Where, M is the modulation index.

$\hat{V}ac = B.\,M.\frac{V_0}{2}$ (9)

For the traditional Voltage Source PWM Inverter, we have the well-known relationship:

$\hat{V}ac = M.\frac{V_0}{2}$ (10)

The output voltage spectrum shows that the output contains single component at 50 Hz frequency. The performance of the scheme has been evaluated on the basis of THD & WTHD and found that the output voltage quality is good and pure sinusoidal.

Eq. (9) shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor B_B,

$B_B = M.\,B$ (11)

From (1), (5) and (7), the capacitor voltage can expressed as

$V_{C1} = V_{C2} = V_C$ (12)

The buck–boost factor is determined by the modulation index and boost factor. The boost factor as expressed in (7) can be controlled by duty cycle (i.e., interval ratio) of the shoot through zero state over the non shoot through states of the PWM inverter.

Note that the shoot-through zero state does not affect the PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal. The available shoot through period is limited by the zero-state period that is determined by the modulation index.

IV. DESIGN OF IMPEDENCE NETWORK

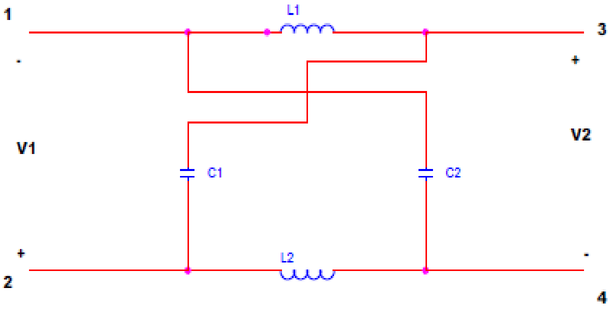


Fig.5: Impedance Network

The impedance network is shown in Fig.5 [3] shows the equivalent circuit of the Z-source inverter for the calculation of the impedance parameter.

Where L_1 and L_2 - series arm inductors

C_1 and C_2 - parallel arm capacitors

V_1 is input voltage

V_2 is output voltage

The network can be redrawn this way shown in Fig.6 [3].

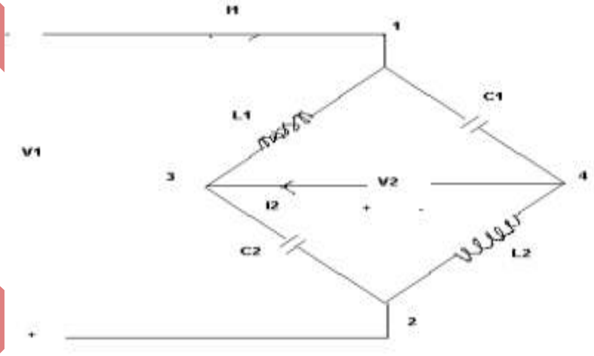


Fig.6: Impedance Network Circuit –Redrawn

Now assume I_2 =0, the current I_1 enters the bridge at point 1 and divides equally between the two arms of the bridge.

Using Kirchhoff's law

$I_1.L/2+V_2 = I_1/2C$

$V_2 = I_1/2C - I_1.L/2$

$V_2 = I_1/2\ [1/C - L]$

Assume c=5.5 mF

440 = 5/2 [1/5.5*10-3- L]

L = 5.8 H

V. SIMULINK MODEL OF Z-SOURCE INVERTER

The simulink model of Z-Source Inverter is shown in Fig.7, Fig.8 shows the switching signals which are applied to all the six switches so that the output of the Z-Source Inverter is according to the requirement. For the simulation purpose we have keep the modulation index 0.907 due to the limitation in under modulation region. More than this would go in the over modulation region.

We keep the input voltage 100 V DC and the sampling time is 1e-06 and the carrier frequency is 2 KHz. The frequency of the output voltage is kept 50 Hz. Fig.9 shows that the time calculation for the application of shoot through states in Z-Source Inverter. The Fig.9 shows the coparison of the DC signal which has the magnitude if 0.9 with carrier signal which has the magnitude of 1. The resultant signals which shown at the below a pulse time duration for which the shoot through states has applied in Z-Source Inverter. Pulse width can be defined as below

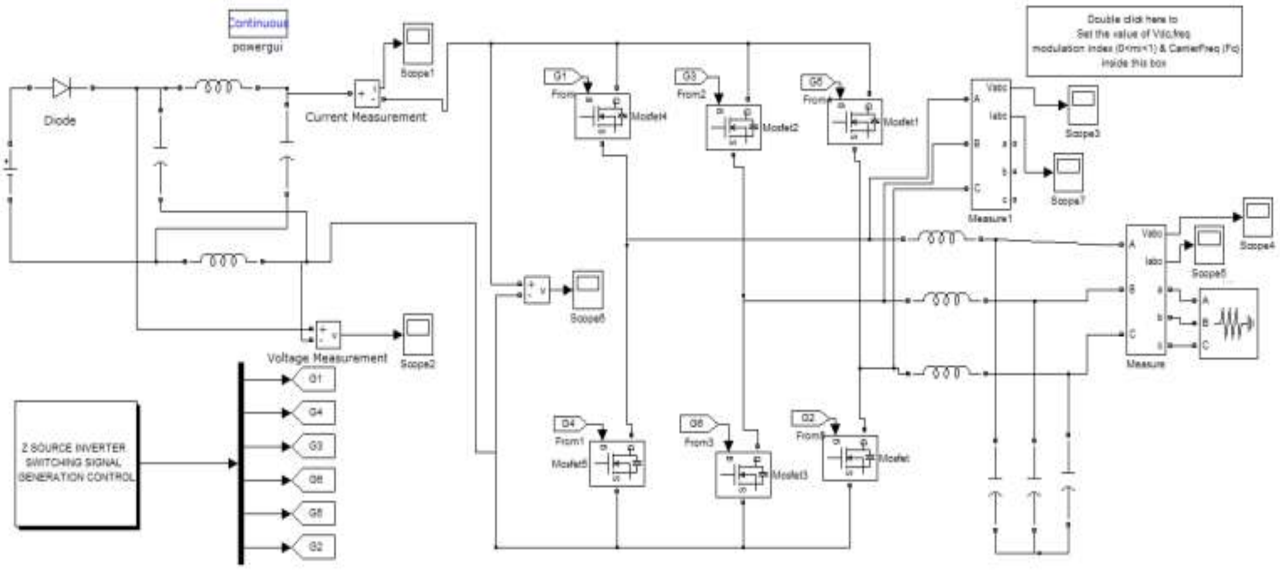
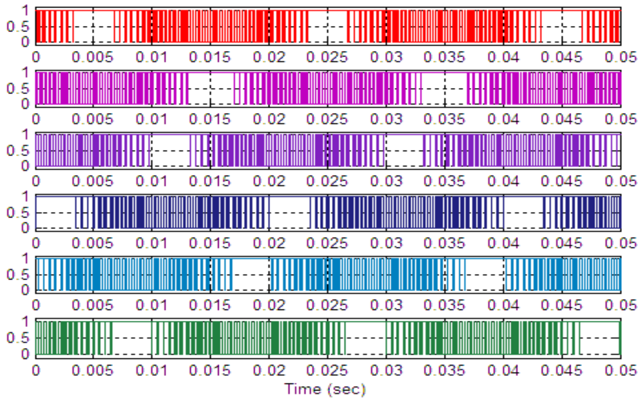


Fig.7: Simulink Model of Z-Source Inverter



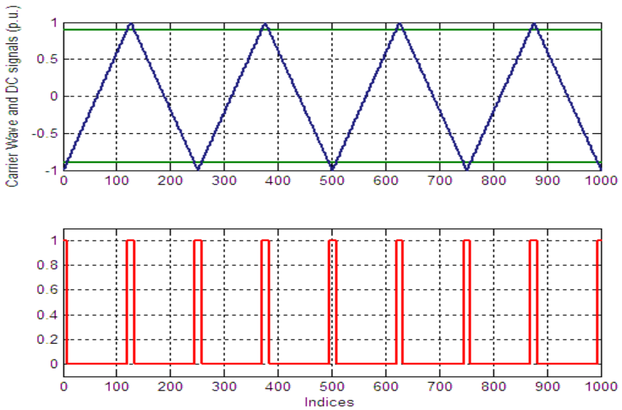
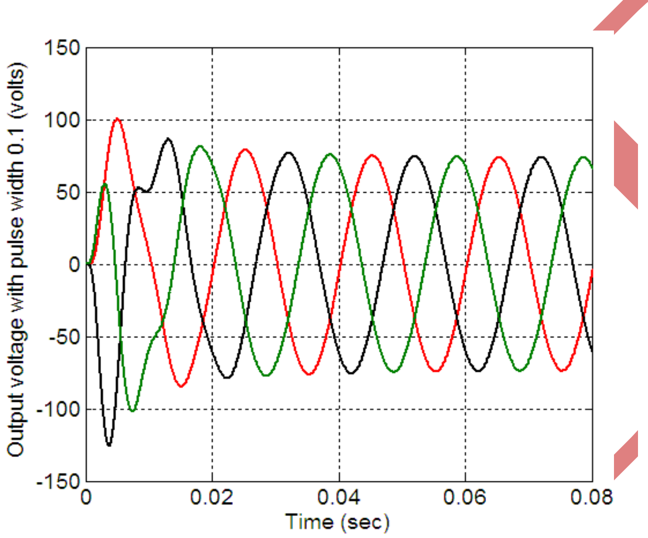


Fig.8: Switching signals **Fig.9 Switching signal time calculation for**
0.1 width

Pulse width = 1- magnitude of DC signal.

The output voltage and harmonic spectrum for 0.1 width is shown in Fig.10 and Fig.11 respectively.



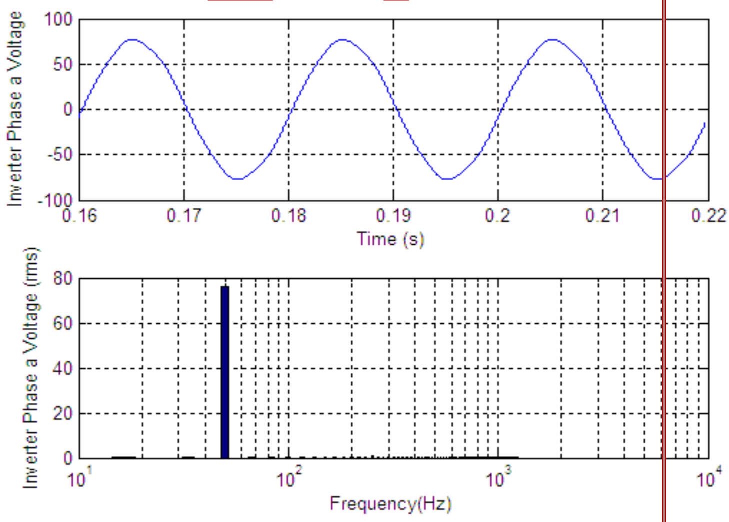


Fig.10 Output voltage for the 0.1 pulse width **Fig.11 Harmonic spectrum of output phase voltage ‘a’**
with 0.1 pulse width.

Table 1 represents the variation of the pulse width and corresponding output voltages of the inverter. It shows the highest harmonics available in the output voltage in % of the fundamental and THD and WTHD

The total harmonic distortion and weighted total harmonic distortion can be defined as

$$\text{THD} = \sqrt{\sum_{n=3,5,7..}^{\infty}\left(\frac{V_n}{V_1}\right)^2} \quad (13)$$

Table 1: Variation of Pulse Width

Pulse Width	***Magnitude of output voltage (peak)***	***Highest harmonics in the output voltage (% of fundamental)***	***THD***	***WTHD***
0.1	*76.884*	5^{th} – 1.46 %, 7^{th} – 0.2166%	*0.22%*	*0.08%*
0.15	*98.8858*	5^{th} – 2.104 %, 7^{th} – 0.135%	*0.17%*	*0.12%*
0.2	*128.931*	5^{th} – 2.22 %, 7^{th} – 0%	*0.15%*	*0.15%*
0.25	*165.636*	5^{th} – 1.749 %, 7^{th} – 0.166%	*0.19%*	*0.13%*
0.3	*207.098*	5^{th} – 0.895 %, 7^{th} – 0.229%	*0.29%*	*0.24%*
0.35	*245.441*	5^{th} – 0 %, 7^{th} – 0%	*0.74%*	*0.84%*
0.4	*304.549*	5^{th} – 0.683 %, 7^{th} – 0.418%	*0.48%*	*0.38%*
0.45	*365.986*	5^{th} – 1.316 %, 7^{th} – 0.486%	*0.52%*	*0.32%*
0.5	*107.102*	5^{th} – 2.31 %, 7^{th} – 0.334%	*0.35%*	*0.18%*
0.55	*84.967*	5^{th} – 3.43 %, 11^{th} – 0.116%	*0.17%*	*0.15%*
0.6	*72.639*	5^{th} – 4.59 %, 7^{th} – 0.323%	*0.44%*	*0.39%*
0.65	*61.061*	5^{th} – 5.714 %, 7^{th} – 0.754%	*0.79%*	*0.39%*
0.7	*49.858*	5^{th} – 6.75 %, 7^{th} – 1.20%	*1.23%*	*0.51%*
0.75	*39.141*	5^{th} – 7.7 %, 7^{th} – 1.65%	*1.69%*	*0.73%*
0.8	*29.0*	5^{th} – 8.57 %, 7^{th} – 2.09%	*2.14%*	*0.77%*
0.85	*19.693*	5^{th} – 9.22 %, 7^{th} – 2.412%	*2.50%*	*1.15%*
0.9	*11.3904*	5^{th} – 9.53 %, 7^{th} – 2.81%	*3.01%*	*1.72%*
0.95	*4.782*	5^{th} – 10.091 %, 7^{th} – 2.85%	*3.03%*	*1.48%*

$$\text{WTHD} = \frac{THD}{(V_1 / \omega_1 L)} = \frac{\sqrt{\sum_{n=2}^{\infty}\left(\frac{Vn}{n}\right)^2}}{V_1} \quad (14)$$

Where V_n represents nth order harmonic component and V_1 represent fundamental output phase voltages. The Table 1 shows that the inverter works as in boost mode from 0.2 to 0.5 pulse width and the largest variation in the output voltage is for the 0.4 to 0.5 pulse width. The inverter works in buck mode for rest of the pulse width. The inverter output voltage variation again investigated between 0.4 to 0.5 pulse with and tabulated in Table

Table 2 shows that the output voltage maximum value goes up to 606.358 V at 0.49 pulse width then it starts decaying. It means the output voltage start increasing from 0.1 pulse width and keep on increasing up to 0.49 pulse width and then it start decreasing. The output voltage clearly represents the buck and boost mode of the inverter

Table 2: Output voltage variation against Pulse width

Pulse width	Magnitude of output voltage in volts (peak)	Pulse width	Magnitude of output voltage in volts (peak)
0.42	327.428	0.48	593.06
0.43	338.985	0.49	606.358
0.44	352.362	0.491	585.746
0.45	370.724	0.493	519.184
0.46	400.236	0.495	415.328
0.47	486.019	0.499	110.0

The variation of the output voltage with pulse width can be easily seen in the Fig.12. The output voltage clearly represents the buck and boost mode of the inverter.

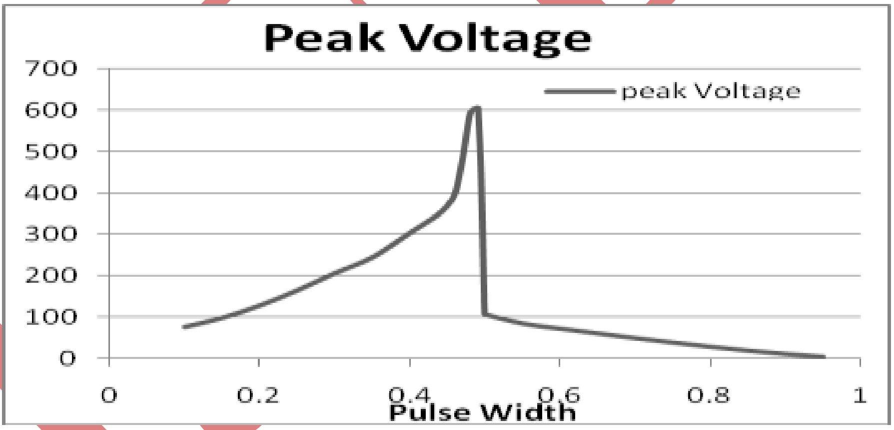


Fig.12: Variation of voltage at different pulse width

V. CONCLUSION

In this paper an impedance-source power converter for implementing DC-to-AC power conversion. The unique feature of Z-Source Inverter is that output AC voltage can be any value between zero and large value regardless of input voltage, Thus a Z-Source Inverter is a buck boost inverter that has a wide range of obtainable value at different pulse width, which is verified through MATLAB/SIMULINK model. The output voltage spectrum shows that the output contains single component at 50 Hz frequency. The performance of the scheme has been evaluated on the basis of THD & WTHD and found that the output voltage quality is good and pure sinusoidal.

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