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Design and Performance Evaluation of Z-Source Inverter with Maximum Boost Control Method in PV Applications

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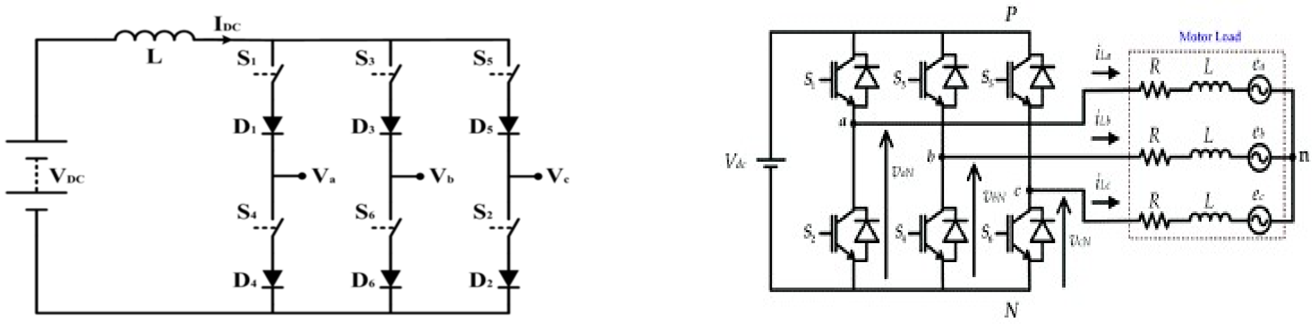
Abstract--This paper represents the robust control methods and utilization of Z-source inverter in the field of power conversion that Buck/Boost the output voltage and its applications in photo-voltaic cells (Renewable Energy Systems). The topology of Z-source inverter can easily be merge with the Renewable resources like PV, Fuel cell, wind and motor drives. The Advanced techniques like SPWM (Sinusoidal Pulse Width Modulation) and SVM (Space Vector Modulation) enhance its boost capacity and modulation index. To understand the vast applications of ZSI, a maximum boost control model along with MATLAB simulations is presented that verify the concept and theoretical model.

Keywords: Z-source Inverter; Pulse-width modulation; Maximum Boost Control Method; Shoot-through state

I. INTRODUCTION

In Power Electronics, we have two traditional power inverters namely Current source inverter (CSI) and Voltage source inverter (VSI) as shown in Fig .1. The CSI can boost (step-up) and VSI can Buck (step-down) the input voltage so we cannot get the desired voltages from these two inverters without transformer or booster. Furthermore, the upper and lower switches cannot be triggered simultaneously, that's why the output voltage is distorted. [1]



(a) (b)

Fig. 1 Topologies of (a) CSI and (b) VSI

To overcome these limitations of traditional CSI and VSI, the Z-source inverter as shown in Fig.2 is introduced with unique impedance network topology having (six switches S_1 to S_6) that can buck/boost the input voltage to desired level. It has unique impedance network of capacitors and inductors that allowing both switches to be turned on simultaneously (Shoot-through state). ZSI has significant benefits such as low cost, high efficiency, unique network topology and low volume. We can increase the voltage by Shoot-through operation and transformer is not required. By using ZSI, the output waveform distortion is reduced, total harmonic distortion is less and PWM dead time also absent. [2]

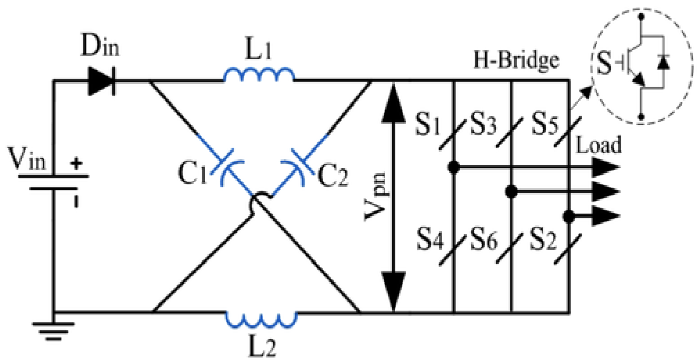


Fig. 2 Topology of Z-source inverter

Turning on the both switches of Z-source inverter at the same time is called "**Shoot-Through state**" that's how we can boost up the voltage without any booster.

II. Switching States Of ZSI

There are three switching states of ZSI with this topology, null state or zero voltage state, shoot through state and non-shoot through or active state. [4]

In null state, the switches $S_{1,}$ $S_{3,}$ S_5 or $S_{4,}$ S_6 and S_2 are closed or turn on. In this mode the inverter will act as Open circuit as show in Fig. 3.

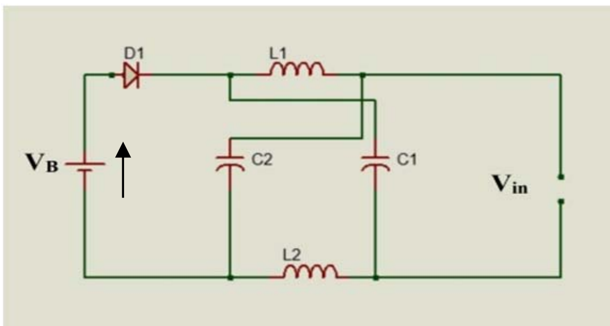


Fig.3 Null state of ZSI

In shoot-through state, either switch S_1 and $S_{4,}$ S_3 and S_6 or S_5 and S_2 are turn on/close. In this mode the inverter will act as closed circuit and diode is reverse bias because of high voltage at that point as shown in Fig.4.

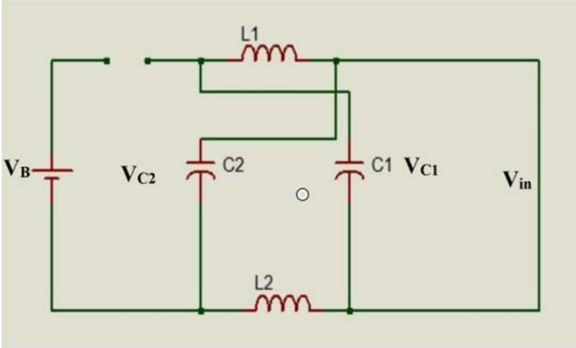


Fig. 4 Shoot through state of ZSI

ZSI work in shoot through state for short interval of time and this state is called $T_{shoot\ through.}$ Now, the sum of capacitor voltage V_{C1} and V_{C2} is greater than the input battery voltage **(V_{C1+} V_{C2} >V_B)** and energy stored in capacitor is transferred to inductor. In this way ZSI gain **"**High voltage boost capability**"**.

In Active state, the inverter will act as high impedance voltage source as shown in Fig.5. Now energy stored in inductor is delivered to the inverter. The switching time period is;

$$\mathbf{T_S = T_{active} + T_{shoot\text{-}through.}}$$

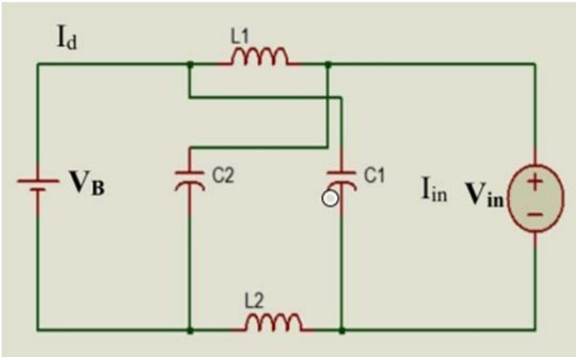


Fig.5 Active state of ZSI

III. CIRCUIT ANALYSIS OF ZSI

During shoot through:

L_1 and C_1 are parallel so, V_L=V_C and inverter V_{in} =0.

Active state:

$$VL=VB-VC$$

$$\text{And } V_{in}=V_C-V_L=2V_C-V_B$$

The average voltage of inductor L_1 or L_2 over one switching period in steady state operation is zero, so

$$V_L= (V_B-V_C)\, T_{active} +V_C\, T_{shoot}=0$$

The capacitor voltage V_C is

$$V_C=\frac{T_{active}}{T_{active}-T_{shoot}}V_B$$

Inverter input voltage or DC link voltage is

$$V_{in}=\frac{T_s}{T_{active}-T_{shoot}}V_B$$

Or $V_{in}=B.V_B$

where **B=Boost Factor**= $\frac{T_s}{T_{active}-T_{shoot}}$

By dividing by T_s, we get B= $\frac{1}{1-2\frac{T_{shoot}}{T_s}}$

And B=$\frac{1}{1-2d}$

Where, d=Duty Ratio= $\frac{T_{shoot}}{T_s}$

IV. Output Voltage Of ZSI

Output peak voltage is

$V_{ac}=M\frac{V_{in}}{2}$

And $V_{ac}= M\frac{BV_B}{2}$

$V_{ac}=MB\frac{V_B}{2}$

Where M= Modulation Index

Voltage gain G is G= $\frac{V_{ac}}{\frac{V_B}{2}}$

Or G=MB [5]

V. Maximum Boost Technique Of ZSI

Different techniques are used to boost up the output voltage with low switching loss. The two mostly used is simple boost control technique and maximum boost control technique. In maximum boost control technique the ripple factor is decreased in low frequency ranges. The Simulink model of maximum boost control method is as under; [6]

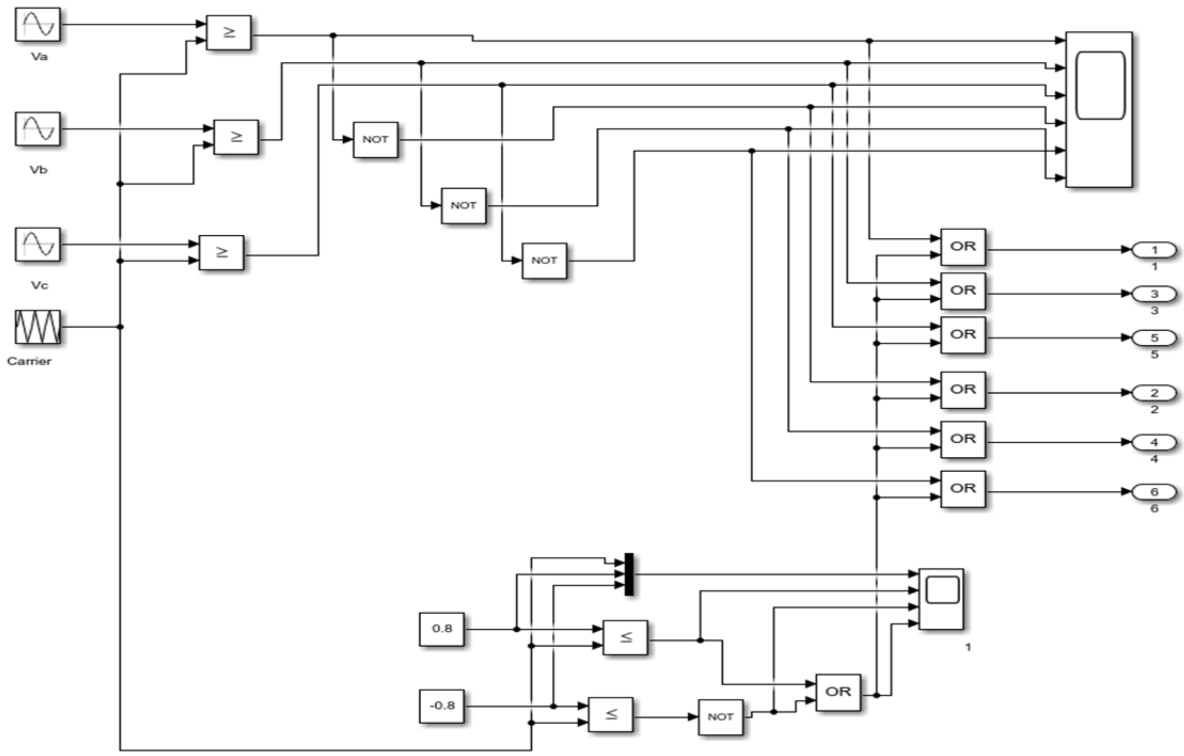


Fig.6. Gate driver circuit of Maximum Boost control method

Figure shows the circuit diagram of gate driver circuit for switches of ZSI. The upper part in the diagram is for the switching in Null State of ZSI, and lower part of the diagram is for the Shoot through state. As, in the traditional inverter there is no shoot through state the switching is done between Null state and Active State, in case of ZSI because of Z-network Zero shoot through state during switching, for this state the lower part of the diagram worked. The output of OR gate in the lower part is 1, this will turn on the all six switches. The parameters for the simulation is as under in table. [7], [8], [9]

Table1; Parameters of ZSI

Parameters	**Values**
Input DC voltage	220V
L_1 & L_2	6.8mH
C_1 & C_2	550uF
Modulation Index	0.8

VI. Simulation Results

DC voltage coming from the PV cells cannot be directly store in the batteries, this DC voltage first boosted up by DC-DC converters than this boosted DC voltage converted into AC voltage for use in home appliances. To convert the DC voltage into AC an inverter with Z network is used, this Z network has the capability to Buck Boost the voltage and reduce the the ripple content in output. Also, for minimizing the ripple content and switching loss a specified maximum boost control PWM technique is used.

Simulation has been performed with maximum boost control method in Simulink with the specified values of inductor and capacitor given in Table 1 with modulation index of 0.8 which gives us the output shown in the figure below.

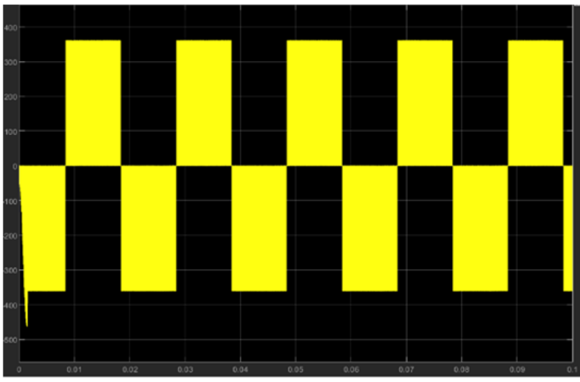


Fig 7. Output Line Voltage

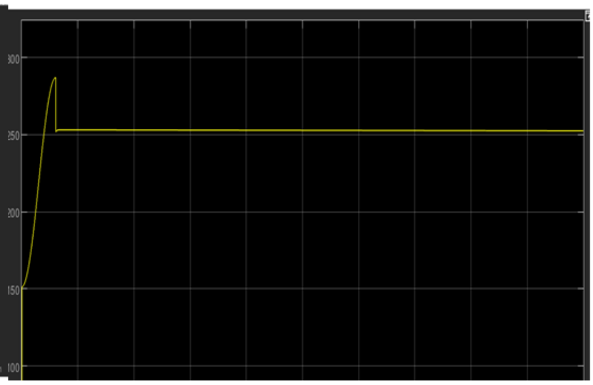


Fig 8. Voltage across Z network

Figure 7 is showing the line voltage coming as the output at modulation index of 0.8 and figure 8 showing the voltage across Z network of ZSI. If we pass the output line voltage through 2nd order Low Pass filter we get the output as given below.

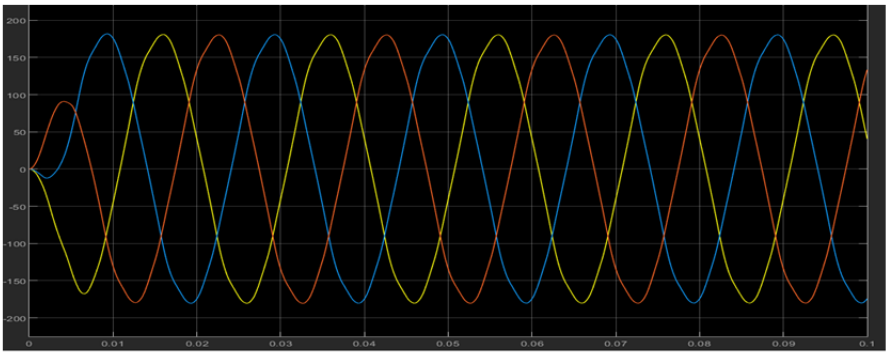


Fig 9. 3 phase output after LP 2nd order filter

VII. Conclusion

In this paper we represent a methodology of using Z source inverter with PWM technique of maximum boost control method which increase the output voltage and reduce the switching losses and cost in PV systems. We also implemented it and verify it through experimental results in Simulink. Maximum boost control method reduce the ripples in inductor current and capacitor voltage. So, the voltage is enhanced by Z source inverter without any additional stage. Hence the switching losses reduced and cost of the system also reduced.

Reference

[1] H. I. Yunus and R. M. Bass, "Comparison of VSI and CSI topologies for single-phase active power filters," PESC Record. 27th Annual IEEE Power Electronics Specialists Conference, 1996, pp. 1892-1898 vol.2, doi: 10.1109/PESC.1996.548839.

[2] F. Z. Peng, ”Z-source inverter”, IEEE Trans. Ind. Appl. vol. 39,no. 2,pp. 504-510, mar./ apr. 2003.

[3] N. Karthick1, Dr. V. Ramakrishnan, “Design and Implementation of Three Phase Γ-Z Source Inverter for Asynchronous Motor”, International Journal of Electrical Engineering. ISSN 0974-2158 Volume 7,Number 2 (2014), pp. 345-352

[4] Chitra, K., V. S. Prakash, and Kannan V. Kamatchi. "Design and Implementation Of Simple Boost Pwm Controlled T-Source Inverter For Solar PV Application." International Journal Of Scientific & Technology Research 8.11 (2019): 717-720.

[5] Chitra, K. and Jeevanandham, A. (2015), "Design and implementation of maximum constant boost switched inductor z-source inverter for three-phase on-line uninterrupted power supply", COMPEL - The international journal for computation and mathematics in electrical and electronic engineering, Vol. 34 No. 4, pp. 1101-1121

[6] Poh Chiang Loh, 2005. Mahintha Vilathgamuwa, Yue sen Lai, Geok Tin Chua & Yun wei Li, “Pulse width modulation of z-source inverters”, IEEE Transactions on Power Electronics, 20, pp: 6.

[7] Peng, F.Z., M. Shen, A. Joseph, L.M. Tolbert, D. J.Adams, 2004. "Maximum Constant Boost Control of the Z-Source Inverter" In proc. EEE IAS'04.

[8] P.C. Loh, F. Blaajerg,”Comparatively evaluation of pulse width modulation strategies for Z source neutral-point-changed inverter”, IEEE Trans, vol. 22, no. 3,pp. 1005-1013, May 2007.

[9] D. Gayathri; P. Thirumalai; T. Prashanth, “Design and performance Analysis of transformerless Z source Inverter in PV systems”, 2021 3rd International Conference on Signal Processing and Communication (ICPSC)