EAI Endorsed Transactions
on Energy Web Short Communication EAI.EU

Simulation Analysis and Realization of Z-H Converters for Standalone PV Applications

N. Kalaiarasi[1*], D. Anitha[1] and S. Usha[1]

[1] Department of Electrical and Electronics Engineering, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu, Tamil Nadu, India.

Abstract

INTRODUCTION: Power converter plays the major role of a power conditioning unit in solar photovoltaic (PV) system and acquiring the maximum power from the photovoltaic array. ZH converters are known for their ability to perform both buck and boost operations. This dual capability is crucial in solar energy systems where the output voltage from the PV array can vary due to factors like sunlight intensity and temperature. ZH converters are well suited for such applications due to their ability to operate in both buck and boost modes.
OBJECTIVES: To design and validate the performance of a ZH converter that provides a wide range of flexible voltage regulation, thereby enhancing system adaptability and reliability by mitigating ripple and inrush currents.
METHODS: In boost mode, the operating principles of both the ZH converter and ZSI (Z-source inverter) have the same characteristics. ZH converter has the same impedance network which is in the ZSI but with a different connection due to which the ZH converter has different features compared to that of ZSI.
RESULTS: The simulation has been performed using MATLAB/Simulink software and prototype hardware is designed to verify the simulation results.
CONCLUSION: The front-end diode and ST (shoot-through) switching state are removed in the ZH converter. Also, there is no requirement for an additional filter in the circuit because it generates a low ripple waveform. Therefore, the ZH converter can be put into effect various forms of power conversions like DC-DC, DC-AC, AC-DC, and AC-AC power conversion and can be used in photovoltaic applications.

Keywords: ZH converter, Z-source inverter, DC-DC converter, DC-AC converter, Photovoltaic array, Shoot-through, In-rush currents

Received on 05 February 2024, accepted on 27 November 2025, published on 26 January 2026

doi: 10.4108/ew.5024

1. Introduction

The conventional voltage source inverter and current source inverter, irrespective of their simple topology and control, have some disadvantages like unable to boost voltage and unprotected against shoot-through switching state [1]. In order to overcome these disadvantages, ZSI (Z-source inverter) is utilized. For buck and boost the output voltage a single- stage converter is designed that utilizes a unique impedance network. The special operating mode in ZSI is ST (Shoot-Through) state. Based on the shoot-through period, the output voltage is boosted during the ST state. There will be a limitation in the shoot through duty cycle.
Figure 1 shows the block diagram representation of the PV system with the DC-DC Converter. This diode must maintain a high voltage in the shoot-through switching

*Corresponding author. Email: kalaiarn@srmist.edu.in

state and will generate an undesired operation mode during the nonshoot-through switching state due to current discontinuity [2]. This study proposes a novel power converter (dubbed the Z-H converter) inspired on the concept of the Z-source converter. The Z-H converter is symmetrical in design [3]. It utilises an impedance network similar to that of the Z-source inverter, but with a different connection. The impedance network's input has two ports connected to the power supply, while the output has four ports connected to an H-bridge [4].
The unique architecture differs from the Z-source inverter in several ways. The Z-H converter has no shoot-through condition, and the front-end diode is removed. Without modifying the construction, the Z-H converter may be used for direct dc-dc, dc-ac, ac-dc, and ac-ac power conversion [5]. The study will use a Z-H dc-dc converter as an example to demonstrate the working concept, and it will also introduce expansions to dc-ac power conversion. The modelling and experimental findings validated the study and revealed the Z-H converter's enormous potential [6].
To solve the difficulties of the Z source converter, new structures, and control approaches have been developed in the literature. Among these are methods for managing DC and AC output voltage [7] as well as continuous boost.
Control to minimize inductor current ripple was discussed in [8], as well as modelling and control of quasi-Z-Source networks for distributed generating applications [9]. Some of the architectures are discussed in [10], with the primary notion being the incorporation of diodes, capacitors, and inductors.
The Z-source converter has been used in fuel cell-based systems [11], motor drive applications [12], and high-frequency systems. Half-bridge inverters are used in electrochemistry [13, 14], distributed generation [15], solar systems [16], and electric vehicles [17]. The Z-H structure, which employs the Z-source converter, was described in [18] in order to alleviate the issues of the front-end diode in traditional Z-source converters. One of the key advantages of the Z-H converter is that it may be used for ac-dc, dc-dc, dc-ac, and ac-ac conversions without requiring any structural changes.
Therefore, ZH converter is introduced to eradicate all the limitations of ZSI [19]. It implicates a blend of H-bridge network with a ZSI which reduces a lot of complexities. However, ZH converter has the same impedance network which is in the ZSI but with a different connection [20]. The two ports of power source are connected to the input of the impedance network while the four ports of an H-bridge are connected to the output. Figure 1 shows the block diagram of a solar PV system with ZH DC-to-DC converter. Maximum Power Point Tracking (MPPT) is a technique used to extract the maximum possible power from a solar panel. MPPT algorithms continuously measure the output voltage and current from the solar panel and adjust the operating point to match the maximum power point (MPP). The voltage and current from the PV panel is measured using voltage sensor and current sensor respectively. A controller in the ZH converter monitors the input voltage and current. It then adjusts the duty cycle of the DC-DC converter to maintain operation at or near the MPP of the source. Commonly used Perturb and Observe (P&O) algorithm is implemented in this system.

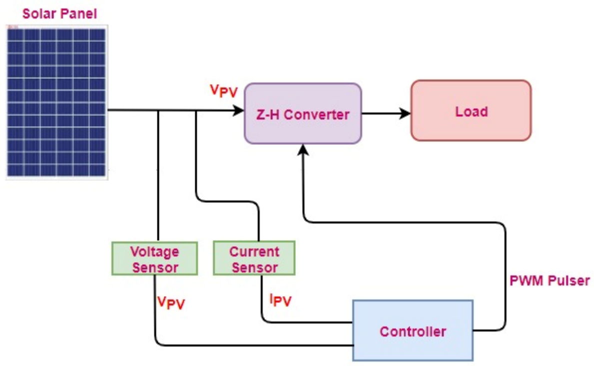

Figure 1. Block Diagram of PV System with ZH DC-DC Converter

A lot of advantages are there of using ZH Converter over using ZSI like, it dismisses in-rush currents and reduces ripples. They have a greater range of output voltage and are highly reliable as compared to ZSI. It has a greater range of voltage gain and the front-end diode and ST switching state are removed from the converter so that an additional filter is not required.

2. Design and Analysis of Z-H Converter

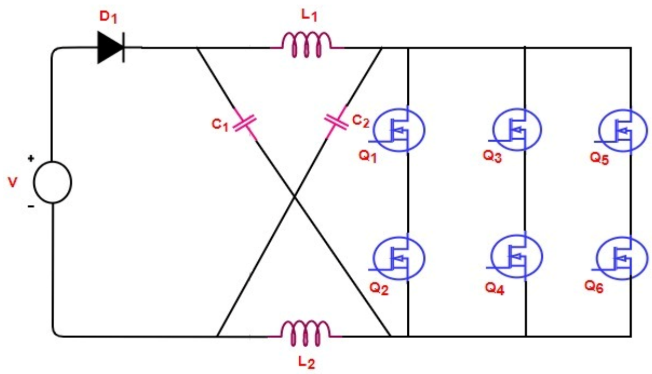

Figure 2. Z-source inverter circuit

Figure 2 represents the circuit of the Z-source inverter. The thought of ZH converter is a modernized idea that is generated from ZSI. The voltage transfer ratio reaches a maximum as the duty cycle of the converter is close to 0.5. The control variable of the duty cycle of ZH converter is not D but 2D. Therefore, by the usage of the duty cycle for ST, the peak DC voltage across the inverter bridge of ZSI can be boosted higher than the input voltage.
Figure 3 represents the equivalent circuit diagram of the ZH converter. All four switches i.e. Q1, Q2, Q3, and Q4

are bidirectional and are complemented respectively. To reduce the voltage ripples, switch Q2 and switch Q3 can be in phase, or have 180° phase shift. ZH converter consists of two operating zones: The first operating zone is D= [0, 0.5] where the output voltage is positive, and the second operating zone is D= [0.5, 1] where the output voltage is negative.

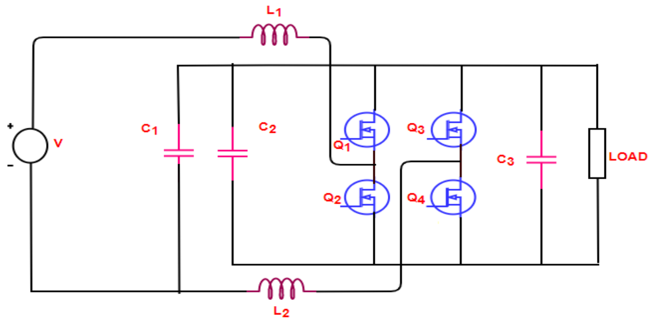

Figure 3. ZH converter circuit

The operating modes of ZH converter are Current Charging Mode (T0) and Current Discharging Mode (T1) as shown in Figure 4(a) and 4(b) respectively. From Figure 4(a) it is observed for the duration T0 the capacitor C2 is charging the inductor L1 and the capacitor C1 is charging the inductor L2. Similarly, from Figure 4(b), for duration T1 the inductor L1 is discharging through capacitor C1, and inductor L2 is discharging through capacitor C2.
Based on the assumption, the values of inductors and capacitors L1, L2, C1, and C2 respectively are taken as equal, so

$$V_{L1} = V_{L2} = V_L$$
(1)

$$V_{C1} = V_{C2} = V_C$$
(2)

Now, during the current charging mode

$$V_L = V_C \tag{3}$$

And during the current discharging mode

$$V_L = V_{in} - V_C \tag{4}$$

For both operating modes, the output voltage is same and is given as

$$V_O = 2V_C - V_{in} \tag{5}$$

During steady state condition, the average value of the inductor voltage is zero for one switching interval. Equation (6) is obtained by deducing equation (3) and equation (4)

$$V_C T_0 + (V_{in} - V_C)\, T_1 \tag{6}$$

From equation (5), the obtained capacitor voltage expression is

$$V_C = \left(\frac{1-D}{1-2D}\right) V_{in}$$
(7)

Where, D is the duty cycle and is defined as:

$$D = \frac{T_0}{T_0 + T_1}$$

Now, the output voltage expression can be derived from equation (5) and equation (7) and is given as:

$$V_O = \left(\frac{1}{1-2D}\right) V_{in} \tag{8}$$

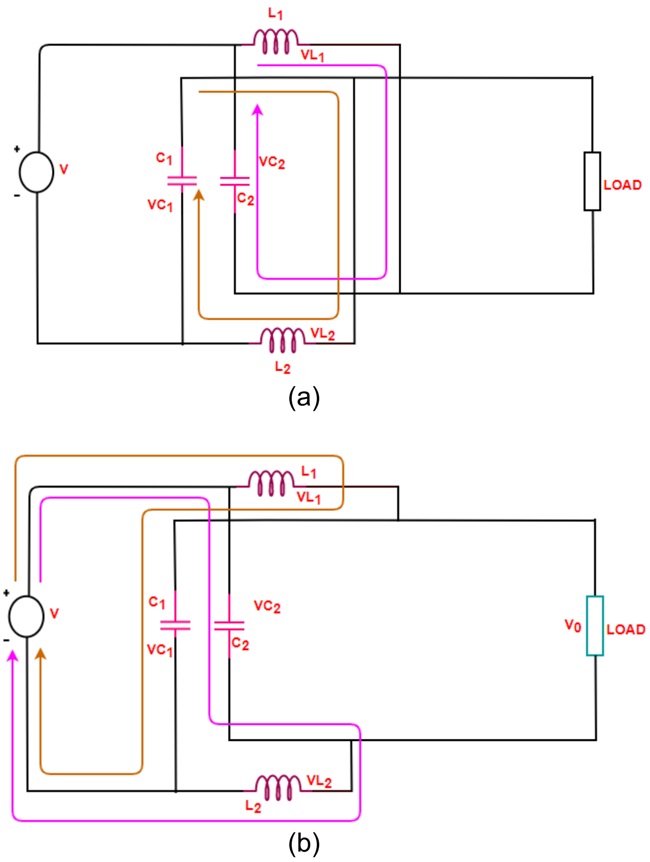

Figure 4. Equivalent circuit diagram for (a) Current charging mode (T0), (b) Current discharging mode (T1)

Figure 5 represents the graph of the practical and theoretical voltage gain against duty cycle in boost mode. The output voltage changes its polarity at 0.5 duty cycle, which represents that the converter can provide both positive and negative voltage. This characteristic can be utilized to design a ZH converter. Table 1 shows the voltage gain obtained for given different duty cycle keeping V_{in}=12V.

Table 1 Voltage gain with duty cycle

Duty Cycle	Voltage gain (Theoretical)	Voltage gain (Practical)
0.05	1.11	3.62
0.1	1.25	4.03
0.15	1.43	4.48
0.2	1.66	5.01
0.25	2	5.54
0.3	2.5	6.16
0.35	3.33	6.85
0.4	5	7.61
0.45	10	9.02

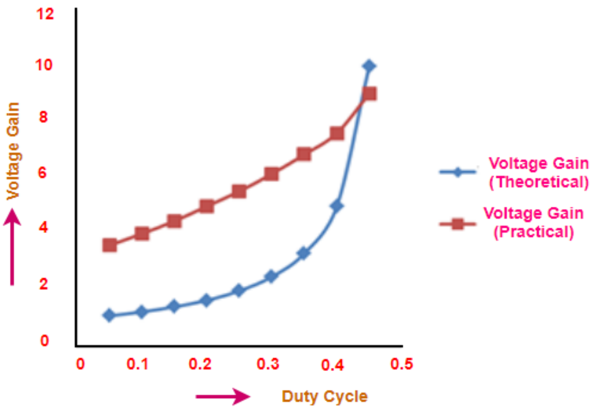

Figure 5. Graph of Voltage gain vs. duty cycle

Table 2 Voltage stress on the capacitor with duty cycle

Duty Cycle	Capacitor voltage stress (theoretical) (V)	Capacitor voltage stress (Practical) (V)
0.05	12.66	27.77
0.1	13.5	30.2
0.15	14.5	32.9
0.2	16	35.9
0.25	18	39.3
0.3	21	43
0.35	26	47.1
0.4	36	51.7
0.45	66	56.8

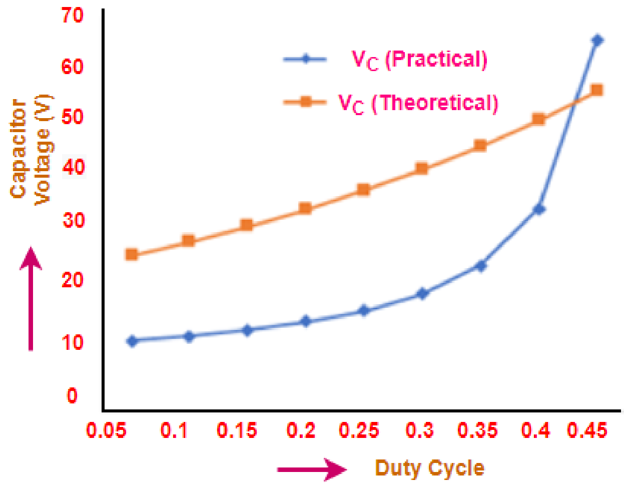

Figure 6. Graph of Voltage stress on the capacitor vs. duty cycle

Table 2 represents the voltage stress on the capacitor for various values of duty cycle. Figure 6 shows the plot of voltage stress obtained for different duty cycles. Figure 7 represents the ZH DC-DC converter in boost mode. It boosts the DC voltage by changing the duty cycle. Figure 8 represents the ZH DC-AC converter. It converts dc voltage into ac voltage and can boost the given dc voltage to any desired magnitude. As the voltage across the load of the ZH DC-AC converter is sinusoidal waveform which implies that no additional filter is required. Hence, the ZH DC-AC converter has less complexity and is easy to design.

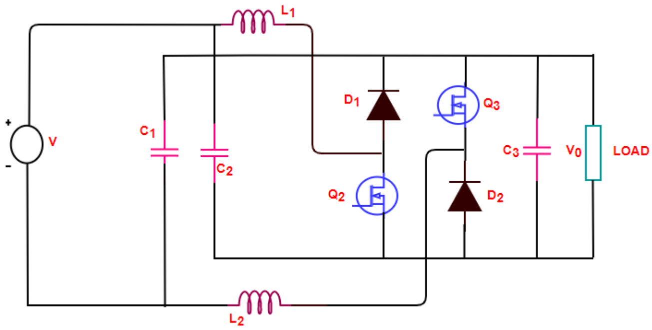

Figure 7. Z-H DC-DC converter

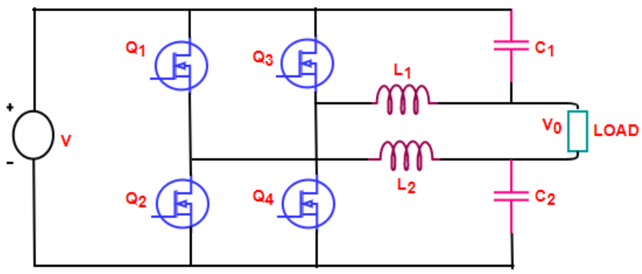

Figure 8. Z-H DC-AC converter

3. Results and Discussion

The Z-H DC-DC converter and ZH DC-AC converter are analyzed using MATLAB Simulink tool. The input voltage is 12V and the duty cycle for the DC-DC converter is 0.3. For DC-AC converter the modulation index is 0.75. The output voltage waveform for dc-dc converter and DC-AC converter is shown in Figures 9 and 10 respectively. The hardware module of ZH DC-DC converter is designed, and the simulation results are verified through it.

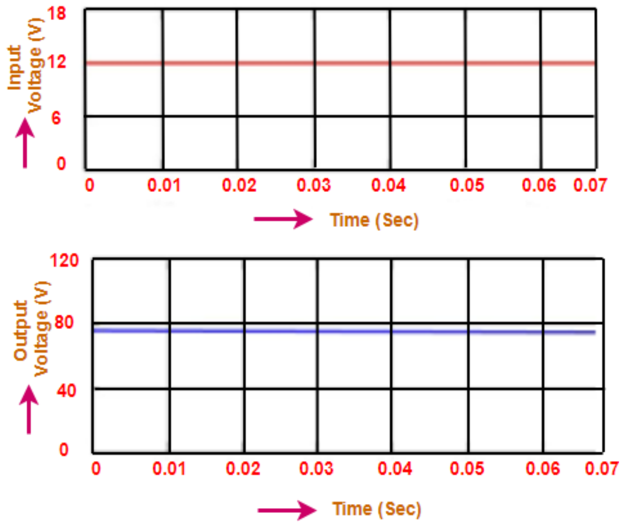

Figure 9. Input and output voltage of Z-H DC-DC converter.

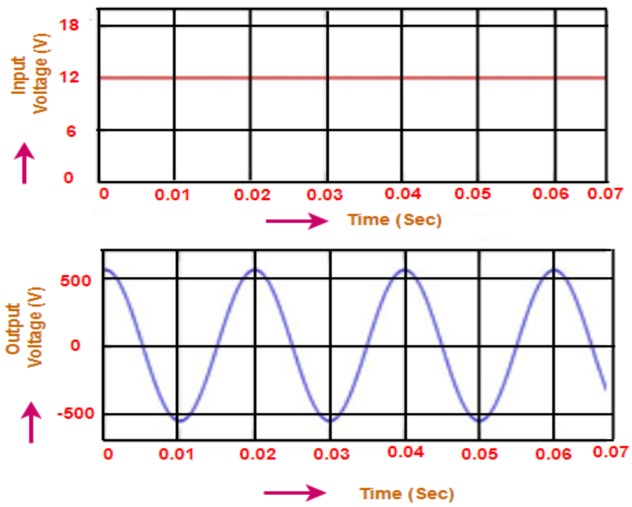

Figure 10. Output voltage of Z-H DC-AC converter

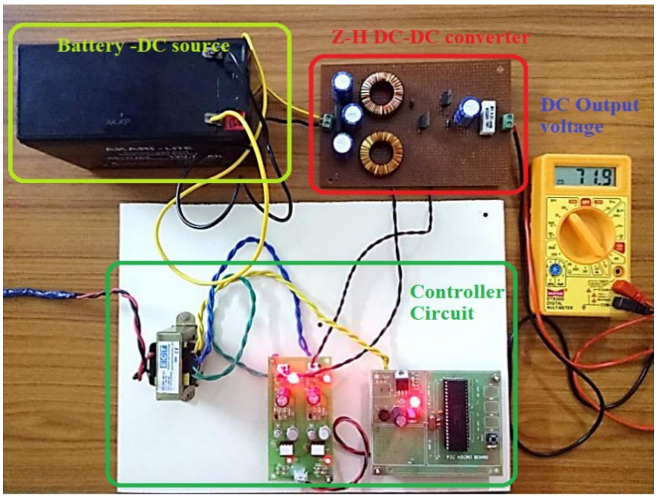

Figure 11. Z-H DC-DC converter hardware module

The designed Z-H DC-DC hardware model is shown in Figure 11. The control signals are generated from the PIC16F877A microcontroller. The controller circuit generates the switching pulses with an amplitude of 5 V which is insufficient to drive the MOSFET switches. The amplitude of the pulses is increased to 12 V with the help of the gate driver circuit which is sufficient to turn on the switches. The generated PWM pulses for the switches are shown in Figure 12. In this prototype model 10 kΩ, 5 W, load resistor is considered as a load. The input supply is given through a 12V rechargeable battery. The obtained output voltage across the load is 71.9 V, which is measured using the multi-meter. The boost factor is 6 for the given duty cycle of 0.3. The input and output voltages are shown in Figures 13 and 14 respectively.

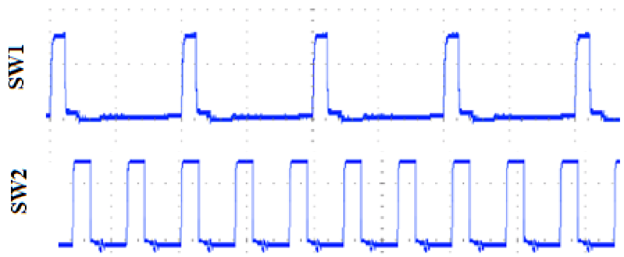

Figure 12. Obtained PWM Pulses

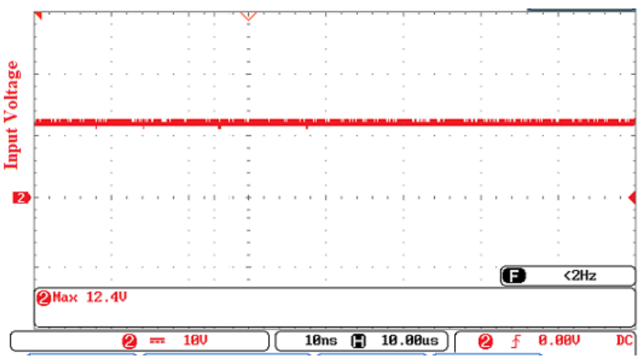

Figure 13. Input voltage

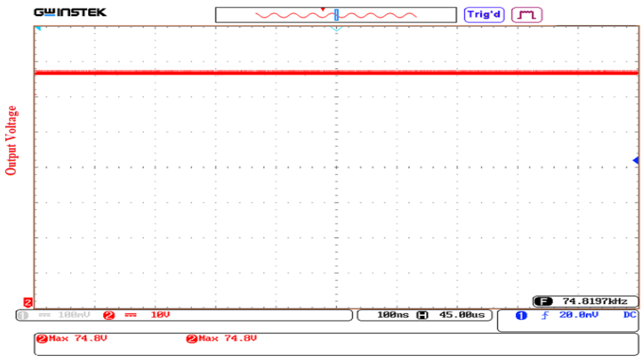

Figure 14. Output Voltage

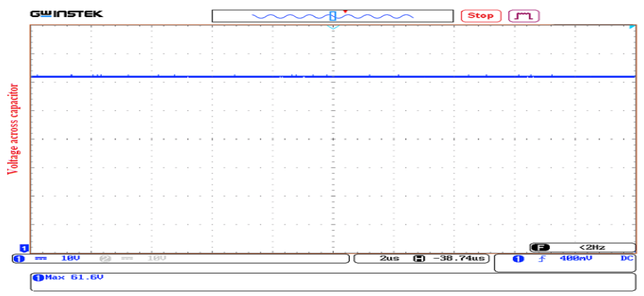

Figure 15. The voltage across the capacitor

The voltage stress across the capacitor is measured as 61.6 V which is shown in Figure 15. Aside from the uses mentioned above, the Z-H converter may be used for a variety of power conversions. A novel family of converters can be generated, but additional study is required to determine their potential values. The proposed method has improved performance in terms of boost factor. In [6] the boost factor is 3 for the duty cycle of 0.31 but in the proposed system the boost factor is 6 for the duty cycle of 0.3. The output voltage has been increased to six times compared to the existing method for the same input voltage. Also, the voltage ripple has been mitigated in the proposed method.

4. Conclusion

This paper deals with the novel power converter i.e. ZH converter which is introduced as a part derived from the ZSI which has a different structure but a similar operating concept, However, the new topology has a lot of new features compared to ZSI. The shoot-through switching state is removed due to the elimination of the front-end diode. This concept can be applied to all types of power conversion. Here, we have practically applied and successfully obtained the results for ZH DC-DC converter and ZH DC-AC converter. The analysis of ZH converter demonstrates its greatest potential amongst other power converters. Simulation of both the converters is done using MATLAB software and the experimental results are verified through the hardware module. The output voltage has been increased to 220 V and the voltage ripple has been reduced to 1.5 % for the proposed method as compared to the conventional method for the same input voltage.

References

[1] Fang Z. Peng; "Z-source inverter", IEEE Transactions on Industry Applications, vol, 39, no. 2, Mar/Apr 2003, pp. 504–510.

[2] Fang Zheng Peng, Miaosen Shen, and Zhaoming Qian, "Maximum Boost Control of the Z-Source Inverter", IEEE Transactions on Power Electronics., 20(4), pp. 833-838, 2005.

[3] Poh Chiang Loh, D. Mahinda Vilathgamuwa, Yue Sen Lai, Geok Tin Chua and Yunwei Li," Pulse-Width Modulation of Z-Source Inverters", IEEE Transactions on Power Electronics, 20 (6), pp.1346-1355, 2005.

[4] M. Hanif M. Basu K. Gaughan, "Understanding the operation of a Z-source inverter for photovoltaic application with a design example", IET Power Electronics., 4 (3), pp. 278–287, 2011. doi: 10.1049/iet-pel.2009.0176.

[5] Yam P. Siwakoti, Fang Zheng Peng, Frede Blaabjerg, Poh Chiang Loh, and Graham E. Town, "Impedance Source Network for Electric Power Conversion Part-I: A Topological Review", IEEE Transactions on Power Electronics., 30(2), pp. 699-716, 2015.

[6] Fan Zhang, Fang Z. Peng, and Zhaoming Qian, "Z-H Converter", IEEE Power Electronics Specialists Conference.

[7] Hamideh Feyzi, Ebrahim Babaei, Reza Gholizadeh-Roshanagh, Vida Ranjbarizad, "Tapped Inductor Based Z-H Buck-Boost Converter", 10th International Conference on Electrical and Electronics Engineering (ELECO), Nov. /Dec. 2017.

[8] Taher Ahmadzadeh, Ebrahim Babaei, "Z-H Buck Converter: Analysis and Simulation", 6th Power Electronics, Drive Systems & Technologies Conference (PEDSTC2015), Feb. 2017.

[9] U. Shajith Ali, "Z-H converter with a new simple MPPT for Photovoltaic Power generation system", Journal of Electrical Engineering.

[10] W. Qian, F.Z. Peng, and H. Cha, "Trans-Z-source inverters," IEEE Trans. Power Electron., vol. 26, no. 12, pp. 3453–3463,Dec. 2017.

[11] M.K. Nguyen, Y.C. Lim, and G.B. Cho, "Switched inductor Quasi-Z-Source inverter," IEEE Trans. Power Electron., Vol. 26, No. 1, pp. 3183–3191, Nov. 2019.

[12] B. Axelrod, Y. Berkovich, and A. Ioinovici, "Switched-capacitor/switched inductor structures for getting transformerless hybrid dc-dc PWM converters," IEEE Trans. Circ Sys., Vol. 55, No. 2, pp. 687–696, Mar. 2018.

[13] E. Babaei, M. Hasan Babayi, E. Shokati Asl, S. Laali, "A new topology for Z-source inverter based on switched-inductor and boost Z-source inverter," J. Oper. Autom. Power Eng., Vol. 2, No. 2, pp. 167- 184, 2018.

[14] D. Vinnikov and I. Roasto, "Quasi-Z-source-based isolated DC/DC converters for distributed power generation," IEEE Trans. Ind. Electron., Vol. 58, No. 1, pp. 192–201, Jan. 2019.

[15] F. Bradaschia, M.C. Cavalcanti, P.E.P. Ferraz, F.A.S. Neves, E.C.D Santos, and J.H.G.M. da Silva, "Modulation for three-phase transformerless Z source inverter to reduce leakage currents in photovoltaic systems," IEEE Trans. Ind. Electron., Vol. 58, No. 12, pp. 5385-5395, Dec. 2019.

[16] F.Z. Peng, M.S. Shen, and K. Holland, "Application of Z-source inverter for traction drive of fuel cell-battery hybrid electric vehicles," IEEE Trans. Power Electron., Vol. 22, No. 3, pp. 1054– 1061, May 2020.
[17] T. Ahmadzadeh, and E. Babaei, "Z-H buck converter: Analysis and simulation," Proceedings of the 6th Annual International Power Electronics, Drives Systems & Technologies Conference (PEDSTC), pp. 436-441, 2015.
[18] E. Babaei, and T. Ahmadzadeh, "A New Structure of Buck-Boost Z-Source Converter Based on ZH Converter," Journal of Operation and Automation in Power Engineering, Vol. 4, No.2, 2016, pp. 117- 131.
[19] F.Z. Peng, "Z-source inverter," IEEE Trans. Ind. Appl., Vol. 39, No. 2, pp. 504–510, Mar./Apr. 2020.
[20] F. Z. Peng, "Z-source inverter," in Proc. Industry Applications Conference, 2019, Vol. 2, pp. 775-781.