DESIGN AND IMPLEMENTATION OF TRANS-Z-SOURCE INVERTER

[1]O.B.Heddurshetti, [2]Jyotsna Chavan, [3]Santosh Sanadi, [4]Vijaykumar Patil, [5]Kartik Magadum
[1,2,3,4,5]Department of Electrical & Electronics Engineering
[1,2,3,4,5]Hirasugar Institute of Technology
[1,2,3,4,5]Nidasoshi-591236, India

ABSTRACT: This paper presents the impedance-source (Z-source) inverters concept to the transformer-based Z-source (trans-Z- source) inverters. The original Z-source inverter (ZSI) contains an impedance network of two inductors and two capacitors connected in a unique arrangement to interface the dc source and the inverter. It has buck and boost function that cannot be achieved by traditional voltage-source inverters and current- source inverters. In the proposed trans-Z-source inverter, the impedance network consist of a transformer and one capacitor. While retaining the main features of the previously presented Z-source network, the new networks exhibit some unique advantages, such as the increased voltage gain and reduced voltage stress in the voltage-fed trans-ZSIs .when the turns ratio of the transformer windings is over 1. Simulation and experimental results of the voltage-fed trans-ZSIs are provided to verify the analysis.

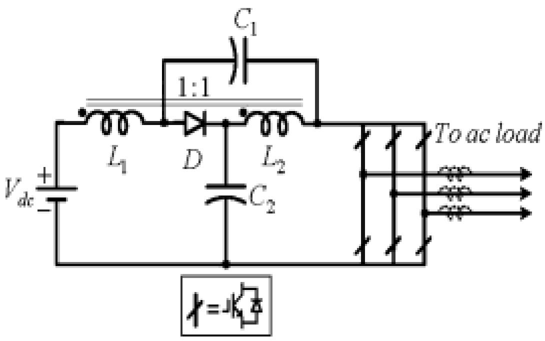
Keywords- dc–ac conversion, voltage-source inverter, Z-source inverter.

I.INTRODUCTION

Traditional voltage-source Inverters (VSIs) have similar limitations and problems. For VSIs: 1) the obtainable ac output voltage cannot exceed the dc source voltage. So a dc–dc boost converter is needed in the applications, for instance, with limited available dc voltage or with the demand of higher output voltage. 2) Dead time is required to prevent the shoot-through of the upper and lower switching devices of each phase leg. However, it induces waveform distortion. The Z-source inverter (ZSI) [1], as well as the derived quasi-Z-source inverters (qZSI) [2], [3], can overcome the aforementioned problems. They advantageously utilize the shoot-through of the inverter bridge to boost voltage in the VSIs (or open circuit in the CSIs to buck voltage). Thus, buck–boost functionality is achieved ease of use with a single-stage power conversion. They also increase the immunity of the inverters to the EMI noise [4], which may cause misgating and shoot-through (or open circuit) to destroy the conventional VSIs.

The voltage-fed Z-source inverter can have theoretically in- finite voltage boost gain. However, the higher the voltage boost gain, the smaller the modulation index has to be used. In applications such as grid-connected photovoltaic (PV) generation and fuel cell power conversion, a low-voltage dc source has to be boosted to a desirable ac output voltage. A small modulation index results in a high voltage stress imposed on the inverter bridge. Several pulse width modulation (PWM) methods [5], [6] have been developed with the attempt of obtaining as much voltage gain as possible and thus limiting the voltage stress across the switching devices. The maximum boost control [5] achieves the maximum voltage gain through turning all the zero states in the traditional VSIs to shoot-through zero states. Never the less, it brings in low-frequency ripples associated with the ac-side fundamental frequency. So, the constant boost control [6] has been proposed to eliminate those ripples and thus reduce the L and C requirement in the Z-source network, with slightly less voltage gain, compared to the maximum boost control. These PWM methods still have limits to further extend the voltage gain without sacrificing the device cost. Recently, some modified impedance source networks were proposed in [7]–[10] for the sake of increasing the output voltage gain. Among them, a T-source inverter [7] has the possibility of increasing voltage gain with the minimum component count. As will be discussed in the next section, it can be grouped into a general class of transformer-based Z-source inverters (trans-ZSIs) presented in this paper, which employ two transformer windings in the impedance network.

The voltage-fed Z-source/quasi-Z-source inverters cannot have bidirectional operation unless replacing the diode with a bidirectional conducting, unidirectional blocking switch [11].



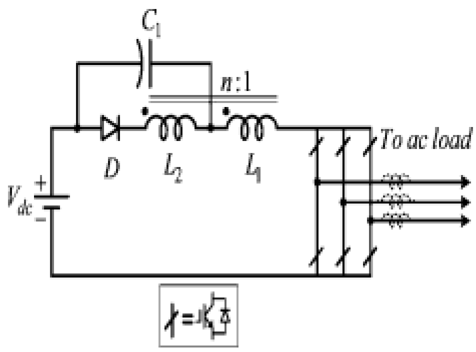


Fig.1.Voltage-fed quasi-Z-source inverter with coupled inductors. Fig.2.Voltage-fed trans-q-Z-source inverter.

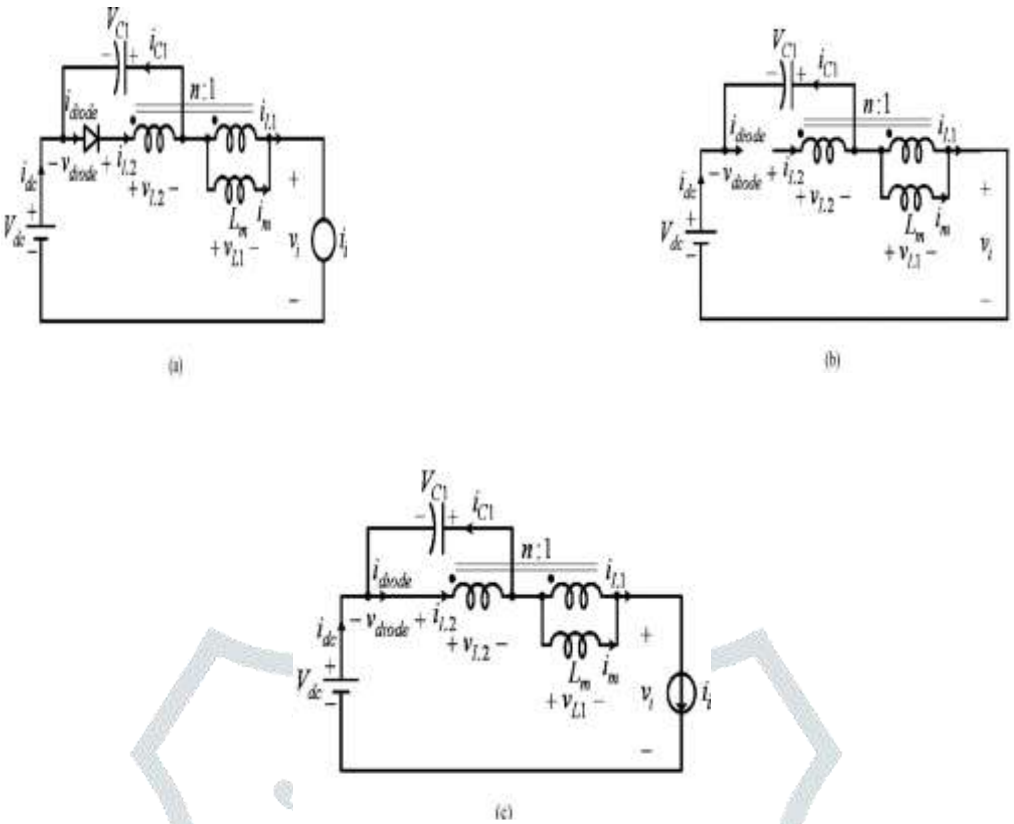


Fig.3. Equivalent circuits of the voltage-fed trans-qZSI viewed from the dc link. (a) With the transformer equivalent circuit. (b) Shoot through zero states.(c) Non-shoot-through states.

The trans-Z-source inverters can be derived from the voltage-fed quasi-Z-source inverters or the voltage-fed Z-source inverters. The trans-Z-source inverters inherit their unique features, and they can be controlled using the PWM methods applicable to the Z-source inverters. This paper will begin with the derivation of two voltage-fed trans-Z-source inverters from one of the quasi-Z-source inverters.

II. VOLTAGE-FED TRANS-Z-SOURCE INVERTERS

In the voltage-fed quasi-Z-source inverter with continuous in- put current, two dc inductors can be separated or coupled. When the two inductors are coupled as shown in Fig. 1, the voltage across the inductor L_1 is reflected to the inductor L_2 through magnetic coupling. Then, one of the two capacitors, for instance C_2, can be removed from the circuit. The rearrangement of the circuit yields the structure as shown in Fig. 2. Furthermore, the voltage across L_2 can be made proportional to the voltage across L_1 by changing the turns ratio n_2 / n_1 . As the voltage constraint associated with one of the capacitors is released, the two windings, to some extent, behave more like a fly back transformer rather than the original coupled inductors [18], except that the currents flow simultaneously through both windings in some of the operation states. Therefore, it is named as the voltage-fed trans-quasi-Z-source inverter (trans-qZSI). Like the Z-source inverter, the trans-quasi-Z-source inverter has an extra shoot-through zero state besides the six active states and two traditional zero states. The shoot-through zero state can be realized by short-circuiting both the upper and lower switching devices of any one phase leg, any two phase legs, or all three phase legs. The shoot-through zero state contributes to the unique buck–boost feature of the inverter. Otherwise, when the dc voltage is sufficient to produce the desirable ac output voltage, a traditional PWM without shoot-through zero state is used. For analyzing the characteristics of the trans-Z-source inverters, this paper will focus on the two general continuous current modes as in the Z-source inverter: the shoot-through zero state and the non-shoot-through states [1], [19]. By replacing the two windings with an ideal transformer and a mutual inductance L_m (a model used in [20]), the overall equivalent circuit viewed from the inverter dc side can be obtained as shown in Fig. 3(a).). In the shoot-through zero state, the inverter is equivalent to a short circuit as
Shown in Fig. 3(b). Given that the inverter is in the shoot-through zero state for an interval of Dsh T during a switching cycle T, the voltages across L1 and L2 are

$$v_{L1} = V_{dc} + V_{C1} \qquad (1)$$

$$v_{L2} = \frac{n_2}{n_1} v_{L1}. \qquad (2)$$

Thus, the diode is reversed biased. Note that the symbol Dsh is used here for the shoot-through duty ratio in voltage-fed Z-source inverters.
In any of the non-shoot-through states for an interval of (1 − Dsh)T, the inverter bridge can be modeled as an equivalent current source as shown in Fig. 3(c). The non-shoot-through states include the six active states and two traditional zero states.
For the traditional zero states, the current source has a zero value (i.e., an open circuit). During one of the non-shoot-through states, one can get

$$v_{L2} = -V_{C1} \quad (3)$$

$$v_{L1} = \frac{n_1}{n_2} v_{L2} = -\frac{n_1}{n_2} V_{C1}. \quad (4)$$

The average voltage of both inductors should be zero over one switching period in the steady state. Thus, from (1) to (4), we have

$$\langle v_{L1} \rangle = \frac{(V_{dc} + V_{C1}) D_{sh} T + (-\frac{n_1}{n_2} V_{C1})(1 - D_{sh}) T}{T} = 0. \quad (5)$$

From the previous equation, the capacitor voltage can be calculated as

$$V_{C1} = \frac{n \cdot D_{sh}}{1 - (1+n) D_{sh}} V_{dc} \quad (6)$$

From (4) to (6), the dc-link voltage across the bridge in the non-shoot-through states can be boosted to

$$\hat{v}_i = \frac{1}{1 - (1+n) D_{sh}} V_{dc} = B V_{dc} \quad (7)$$

where the boost factor is

$$B = \frac{1}{1 - (1+n) D_{sh}}. \quad (8)$$

The peak value of the phase voltage from the inverter output is

$$\hat{V}_{ph} = M \cdot \hat{V}_i / 2 = M \cdot B \cdot V_{dc} / 2 \quad (9)$$

where M is the modulation index. When the constant boost control [6] is used, the voltage gain MB as defined in [5] is

$$G = MB = \frac{M}{1 - (1+n)(1 - \frac{\sqrt{3}}{2} M)} \quad (10)$$

It can be seen that if the turns ratio is 1, the inverter dc link voltage boost gain is the same with that of the original Z-source/quasi-Z-source inverters, but one capacitor is saved in the new trans-Z-source network. If the turns ratio is over 1, the inverter dc-link voltage boost gain can be higher given the same modulation index M. In other words, it needs a smaller shoot-through duty ratio Dsh (accordingly, a larger modulation index M) to produce the same ac output voltage than the Z source/ quasi-Z-source inverters do. The voltage gain MB versus the modulation index for the voltage-fed trans-quasi-Z-source inverter (with a turns ratio n = 2) is compared in Fig. 4 with that for the Z-source/quasi-Z-source inverters, using the constant boost control. The voltage stress Vs across the switching devices can be assessed by comparing its peak dc-link voltage against the minimum dc voltage G Vdc [6] needed for the traditional VSI to produce the same ac output voltage at M = 1. The ratio represents extra cost that the voltage-fed trans-quasi-Z-source inverter and Z-source/quasi-Z-source inverters have to pay for the voltage boost in association with the higher voltage stress. The ratio of the voltage stress to the equivalent dc voltage for the trans-quasi-Z-source inverter is Vs

$$\frac{V_s}{GV_{dc}} = \frac{BV_{dc}}{GV_{dc}} = \frac{\sqrt{3}}{2}\left(1 + \frac{1}{n}\right) - \frac{1}{n \cdot G}. \quad (11)$$

When n = 1, it is the same with the relative voltage stress in the Z-source inverter. The voltage-fed trans-Z-source inverter has less voltage stress across the inverter bridge for the same dc–ac output voltage gain. Hence, this circuit is beneficial to applications, in which a high voltage gain is required. Similarly, another trans-Z-source inverter can be reconfigured. If C1 is removed in Fig. 1 instead of C2. This trans-Z-source inverter is the same as the T-source inverter proposed in [7]. It is obvious that it essentially has the same operation principle, voltage gain, and voltage stress as the previously developed voltage-fed trans-quasi-Z-source inverter, except for different capacitor voltage stress and different input current drawn from the dc source. Therefore, Figs. 1, 2 can be classified as a class of voltage-fed trans-z-source inverters. The capacitor voltage is

$$V_{C1} = \frac{1 - D_{sh}}{1 - (1+n) D_{sh}} V_{dc}. \quad (12)$$

III.SIMULATION AND EXPERIMENTAL RESULTS

A prototype for the voltage-fed trans-quasi-Z-source inverter is built to validate the analysis. The system configuration for the simulation and experiments of the voltage-fed trans-quasi-Z-source inverter is shown in Fig. 4. The switching frequency for the SPWM is 10 kHz. The capacitance of C_1 is 400 μF. The transformer consists of two bifilar windings. The turns ratio n_2 / n_1 is 2:1. The magnetic inductance measured from the primary side is 207 μH. There is no snubber circuit for the inverter bridge, due to the very low leakage inductance (around 100 nH mainly from the outside connection) and the parasitic capacitance in the tightly coupled bifilar windings. The parasitic capacitance lowers the dv/dt and more interestingly increases the effective boost ratio. That is because the inductor L_1 is still charged during the IGBT turn-off transition until the dc-link voltage increases and the diode then becomes forward biased. However, it is still able to achieve the desired dc voltage boost ratio by controlling the shoot-though duty ratio.

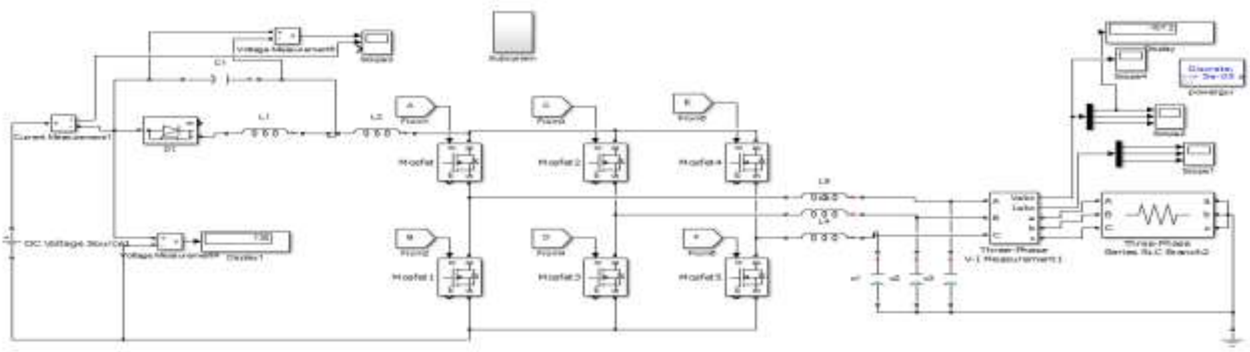
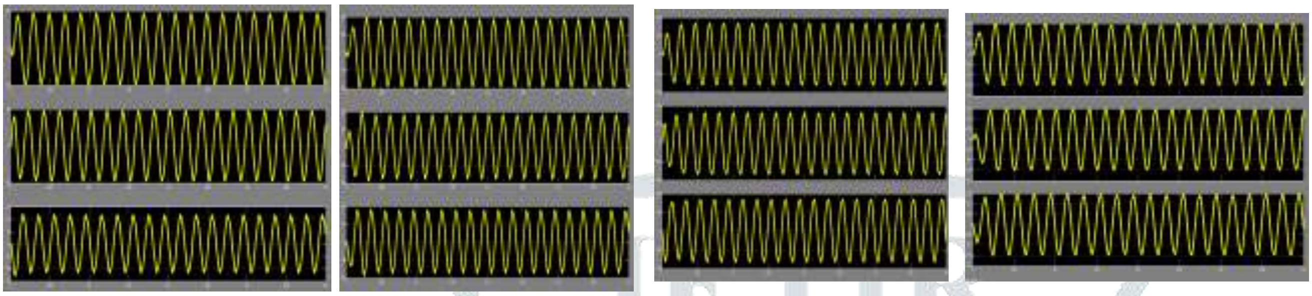


Fig.4.Simulation system configuration of the voltage-fed trans-qZSI.



(a) (b) (c) (d)

Fig.5.Simulation output results for different values of modulation index.

For a fixed DC input voltage of 130V, by changing the modulation index the AC output voltage is varied. For constant DC input voltage 130V, modulation index 0.5, the AC output voltage is 46V (Fig 5a). For modulation index 0.9, the AC output voltage is 51V(Fig 5b). For modulation index 1.5 the AC output voltage is 177V(Fig 5c). For modulation index 2.0 the AC output voltage is 248V(Fig 5d). Hence, it can be observed that for modulation index less than 1, the AC output voltage is less than DC input voltage and for modulation index greater than 1, the AC output voltage is greater than DC input voltage. The table 1 shows the output AC voltages for different modulation index values with fixed input DC voltage.

Table 1

Comparison of output voltages for different modulation index values

SI.NO	INPUT DC VOLTAGE	MODULATION INDEX	OUTPUT AC VOLTAGE
1.	130 V	0.5	46 V
2.	130 V	0.9	51 V
3.	130 V	1.5	177 V
4.	130 V	2.0	248 V

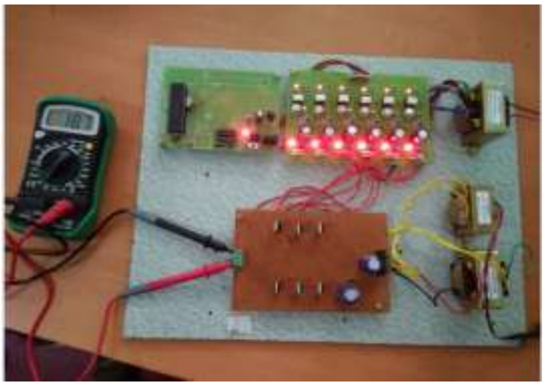


Fig.6.Hardware prototype of the voltage-fed trans-qZSI.

The proposed voltage-fed trans-qZSI is validated by building the prototype of the same as shown in fig. 6. It consists of main circuit, driver circuit and control circuit. The main circuit consists of power supply unit which has 230/12V stepdown transformer. The 12V AC supply is given to rectifier which converts AC to DC. The trans q z source network boosts the DC voltage upto 18V. This DC voltage is converted to AC by an inverter which gives 18.7V output line voltage. Hence, it is observed that by using voltage fed trans-qZSI, the DC voltage is boosted and converted to AC voltage.

IV.CONCLUSION

A class of trans-Z-source inverter has been presented for voltage-fed systems. When the turns ratio of the two windings is over 1, the voltage-fed trans- Z-source inverter can obtain a higher boost gain with the same shoot-through duty ratio and modulation index, compared with the original Z-source inverter; With new unique features, they can broaden applications of the Z-source inverters. For instance, the voltage-fed trans-Z-source inverters provide a promising potential in the applications with very low input voltage, such as the micro inverter for the photovoltaic systems. Simulation and experimental results of the voltage-fed trans-quasi-Z-source inverters have verified the analysis and feature.

REFERENCES

[1] F. Z. Peng, “Z-source inverter,” IEEE Trans. Ind. Appl., vol. 39, no. 2, pp. 504–510, Mar./Apr. 2003.

[2] J. Anderson and F. Z. Peng, “Four quasi-Z-source inverters,” in Proc. IEEE Power Electron. Spec. Conf., (PESC’08), pp. 2743–2749.

[3] T. Yu, X. Shaojun, Z. Chaohua, and X. Zegang, “Improved Z-source inverter with reduced Z-source capacitor voltage stress and soft-start ca- pability,” IEEE Trans. Power Electron., vol. 24, no. 2, pp. 409–415, Feb. 2009.

[4] M. Shen, A. Joseph, J. Wang, F. Z. Peng, and D. J. Adams, “Comparison of traditional inverters and Z-source inverter for fuel cell vehicles,” IEEE Trans. Power Electron., vol. 22, no. 4, pp. 1453–1463, Jul. 2007.

[5] F. Z. Peng, M. Shen, and Z. Qian, “Maximum boost control of the Z-source inverter,” IEEE Trans. Power Electron., vol. 20, no. 4, pp. 833–838, Jul. 2005.

[6] M. Shen, J. Wang, A. Joseph, F. Z. Peng, L. M. Tolbert, and D. J. Adams, “Constant boost control of the Z-source inverter to minimize current ripple and voltage stress,” IEEE Trans. Ind. Appl., vol. 42, no. 3, pp. 770–778, May/Jun. 2006.

[7] R. Strzelecki, M. Adamowicz, N. Strzelecka, and W. Bury, “New type T-Source inverter,” in Proc. Compat. Power Electron., (CPE’09), pp. 191– 195.

[8] F. Gao, L. Poh Chiang, R. Teodorescu, and F. Blaabjerg, “Diode-assisted buck-boost voltage-source inverters,” IEEE Trans. Power Electron., vol. 24, no. 9, pp. 2057–2064, Sep. 2009.

[9] C. J. Gajanayake, L. F. Lin, G. Hoay, S. P. Lam, and S. L. Kian, “Extended boost Z-source inverters,” IEEE Trans. Power Electron., vol. 25, no. 10, pp. 2642–2652, Oct. 2010.

[10] M. Zhu, K. Yu, and F. L. Luo, “Switched inductor Z-source inverter,” IEEE Trans. Power Electron., vol. 25, no. 8, pp. 2150–2158, Aug. 2010.

[11] H. Xu, F. Z. Peng, L. Chen, and X. Wen, “Analysis and design of Bi- directional Z-source inverter for electrical vehicles,” in Proc. 23rd IEEE Annu. Appl. Power Electron. Conf. Expo., (APEC’08), pp. 1252–1257.

[12] J. R. Espinoza and G. Joos, “Current-source converter on-line pattern generator switching frequency minimization,” IEEE Trans. Ind. Electron., vol. 44, no. 2, pp. 198–206, Apr. 1997.

[13] D. N. Zmood and D. G. Holmes, “Improved voltage regulation for current- source inverters,” IEEE Trans. Ind. Appl., vol. 37, no. 4, pp. 1028–1036, Jul./Aug. 2001.

[14] W. Bin, J. Pontt, J. Rodriguez, S. Bernet, and S. Kouro, “Current-source converter and cycloconverter topologies for industrial medium-voltage drives,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2786–2797, Jul. 2008.