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Experimental Study of Seven Level Magnetic Coupled Impedance Source Inverter

J N Reddy[1], D Lenine[2]* and M V Kumar[3]

[1]Department of EEE, JNTUA College of engineering, Ananthapuramu, AP-515001 India

[*2]Department of EEE, Rajeev Gandhi Memorial College of Engineering & Technology, Kurnool, 518501, India

[3]Department of EEE, JNTUA College of engineering, Ananthapuramu, AP, 515001, India

In midst of better incorporated single stage topologies, an Impedance source inverter is proposed with an ability of producing buck and boosted output voltages. For achieving high voltage gain, the semiconductor switches undergo high dv/dt stress and at starting inrush currents of large values due to resonance affects the performance of impedance source inverters. To decline these impacts, magnetic coupled impedance source inverters are developed which produces the same voltage gain at high modulation ratio, while diminishing stress across switches by utilizing the property of magnetic coupling. This paper presents analysis and design of seven levels magnetic coupled impedance source inverter by maximum constant boost pwm technique using Matlab / Simulink. A prototype model of magnetic coupled inverter is developed and controlled by FPGA Spartan controller.

Keywords: Impedance Source, Magnetic Coupled, Voltage Stress, Modulation Index, Seven Level

Introduction

The increment in proliferation of distributed generation and electric vehicles, the requirement for various power electronic converter topologies has grown rapidly[1]. To add boost ability, a dc–dc converter on front side is connected with dc–ac inverter on rear side. The extensively considered single-stage converters presently are impedance source inverter which is otherwise Z- source inverters[2-5]. The growth in Z-source inverters has continued in various aspects concentrating on prospective applications, modulating ratio, dc–dc converter simplifications, and ac–ac converter modifications.

Traditional Impedance Source Inverters

Figure 1 represents the circuit diagram of voltage source and current source based impedance source inverters[5]. Many impedance circuits are derived by changing the location of input DC voltage source. This changing position filters voltages of source and capacitor and current flowing through source and inductor[6-8]. The design of impedance source inverter is focused on producing dc-link voltage of lower values for achieving gain demanded thereby reducing the stress undergone by semiconductor switches. Various topologies in impedance network have been developed which includes cascading, component switching and magnetic coupling. The magnetic coupling approach is attractive among these topologies, because it produces high voltage gain by using fewer components along with coupled transformers or inductors[9,10].

Magnetic Coupled Inverter Topologies

Different proposals have been approached to expose that these inverter topologies have good accent in where the inductor in a conventional impedance inverters are replaced with a two winding transformer. The main purpose of using this mutual coupled inductor is to obtain high boosted voltage gain by controlling the turn's ratio of a transformer instead of controlling the shoot through duty ratio[11, 12]. However, the impedance network in not presented uniformly which hides the strength of the proposed circuit and the corresponding data. For this reason the two inductors are replaced with a pair of two winding transformer which is integrated with the entire circuit[12]. With this modification an improved voltage gain can be achieved. Referring to Figure 2, the inductors in impedance network are replaced with a pair of transformers which are magnetically coupled[13]. Therefore, the modified inverter has the components a diode on input side(D), pair of capacitors(C_1, C_2) and magnetic coupled inductors which are represented as W_1 and W_2. The winding W_1 is again represented as W_{1p} and W_{1s} which are named

*Author for Correspondence
E-mail: lenine.eee@gmail.com

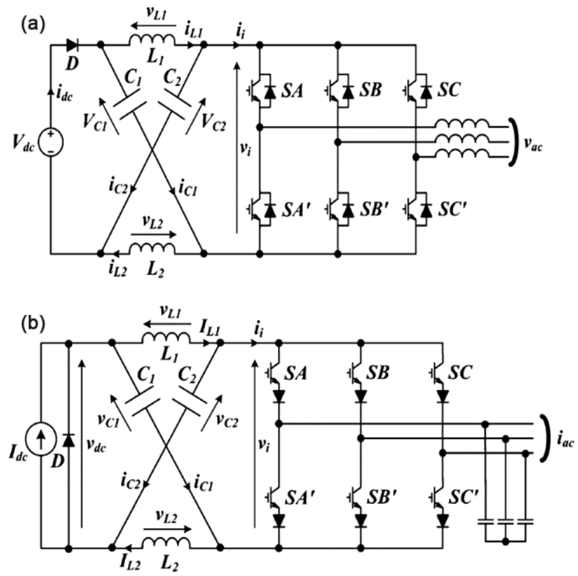

Fig. 1 — (a), (b) - Traditional Voltage and Current impedance source inverters

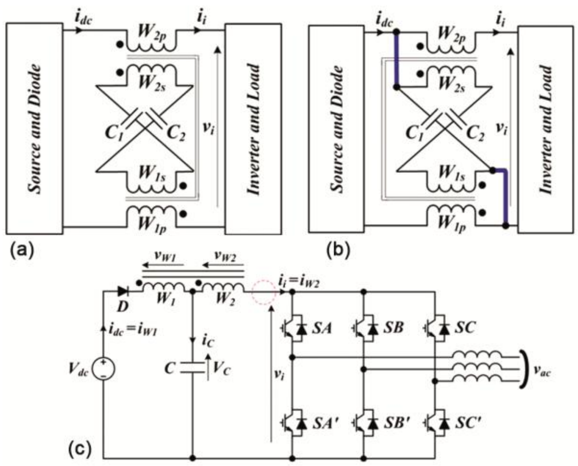

Fig. 2 — Representation of (a) Inserted couple transformer, (b) Proposed Trans impedance source, (c) Modified circuit for Trans impedance source inverter

as primary winding and secondary winding of transformer 1 and likewise the second transformer windings are represented as W_{2p} and W_{2s}[14, 15].

A magnetic coupled inserted transformer shown in Figure 2(a) is inadequate because of the isolated connections made between secondary windings of both the magnetic coupled inductors W_{1s}, W_{2s}, and the capacitors C_1 and C_2.The circuit shown in Figure 2 (b) is a revised circuit of Figure 2 (a) which is entitled as Trans impedance source inverter which is highlighted in the dotted lines. From the figure. 2(b), the Trans Z source inverter holds connection of capacitor C_1in parallel with series connected elements of capacitor C_2 along with secondary windings W_{1s} and W_{2s}[14].

Trans Z Source Inverter

Trans Z source inverter shown in Figure. 2(b), consists of two branches connected in parallel in which one branch consists of capacitor C_1 and another branch contains a series connected elements C_2, W_{1s} and W_{2s}. The number of turns of windings W_{1s} and W_{2s} are same; the cooperation between these two windings is negligible because of the assumed polarities. Therefore, due to the resemblance between these two parallel branches, they can be merged as one. An additional distinctive feature to be noted with reference to turn's ratio is that they need not be same. To achieve this objective, the currents through windings W_{1p} and W_{2p} is discharged through capacitor C_1. The windings W_{1p}, W_{2p} are capable of working together which are earlier coupled with W_{1s} and $W_{2s}$with same number of turns carrying equal currents. Based on this analysis, the inverter shown in Figure. 2(b) is modified to equivalent circuit shown in Figure. 2(c). From the Figure. 2(c) the following equations are derived.

Source and D are in series;

$$V_C = \frac{1-d_T}{1-(\gamma_T+1)d_T}V_{dc} \qquad \text{... (1)}$$

Source at dotted position;

$$\left.\begin{aligned} V_C &= \frac{\gamma_T d_T}{1-(\gamma_T+1)d_T}V_{dc} \\ v_{ac} &= \frac{1}{1-(\gamma_T+1)d_T}(0.5M_T V_{dc}) \end{aligned}\right\} \qquad \text{... (2)}$$

Where the suffixed T refers to the proposed inverter. The circulation of shoot through current is moreover same as of conventional impedance source inverter which flows through winding W_2 and switches which is formulated as:

$$\hat{\imath}_i = \hat{\imath}_{w2} = I_m = (1+\gamma_T)I_{dc} \qquad \text{... (3)}$$

It may be concluded from equations 2 and 3, trans impedance source inverter produces more voltage gain when compared with conventional impedance source inverter for $\gamma_T \geq 1$. However, the shoot through current is higher in the former when compared with the latter inverter topology which is because of low shoot through time with a specified limits which is determined by using the condition

$0 \leq d_T < 1/(1+\gamma_T)$. The modulation range opted for the proposed inverter is within the specified limits of $0 \leq M_T < 1.5/(1-d_T)$. But the upper limit in this condition should be greater value however the value of d_T is lower. The proposed inverter is examined by developing an experimental set up to verify its performance regarding voltage gain with respect to varying modulation ratio due to γ_T the turns ratio of magnetic coupled transformer.

Experimental Set-Up

As the windings of transformer designed are bifilar, a parasitic capacitance is added with to the bifilar windings. The addition of capacitance increases the voltage gain and reduces the voltage stress across the switches. Based on this reason, the inductor L_1should be charged during the commutation of switch till the dc link voltage is boosted to a maximum value when the diode is forward biased. The parameters of the proposed inverter are tabulated as shown in Table-I. The modulation scheme used here for the design of proposed inverter is maximum constant boost modulation scheme. In this paper, hardware implementation of trans impedance source inverter and corresponding results are presented. The hardware results of the prototype model are compared with the corresponding simulation results as shown in Figure. 3. Figure. 3a shows experimental setup of proposed 7-level trans impedance source inverter

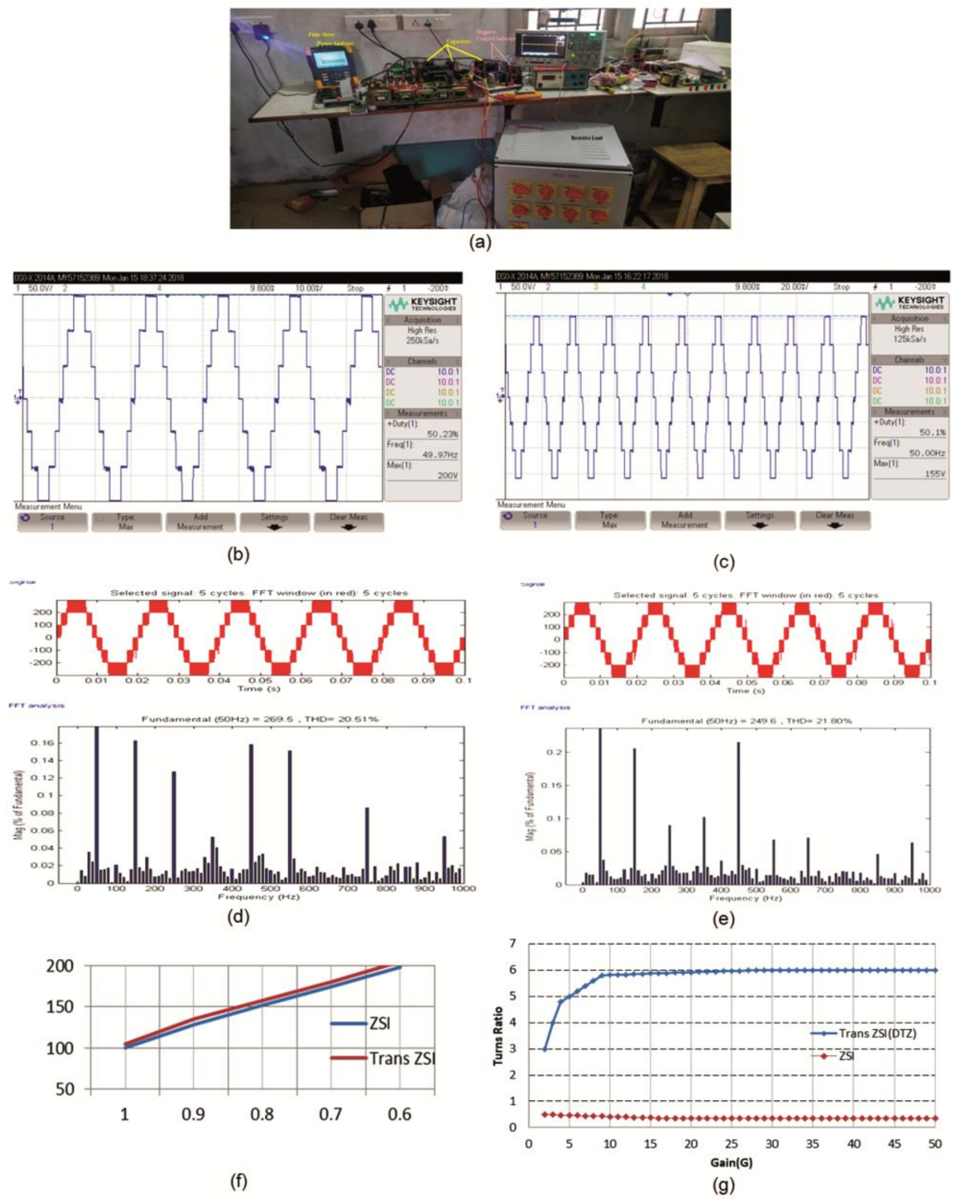

Fig.3 — (a) Hardware photograph of prototype trans impedance source inverter, (b),(c)Output voltage hardware waveforms of trans ZSI , (d),(e) Output Voltage simulation waveforms of Trans impedance source inverter, (f)Performance chart of output voltage between ZSI and Trans ZSI(g) Voltage gain versus turns ratio for for trans impedance source inverter operating at duty ration of 0.15 and modulation ratio of 0.87

Table 1 — Design Aspects for Simulation and Hardware Design of proposed Trans Impedance Source Inverter

Design Aspect	Magnitudes
DC Voltage source(V_{dc})	100 V
Magnetically coupled Impedance Source inverter	Primary Turns(w1)=62 Secondary Turns(w2)=42 No of Turns Ratio(γ_T)=1.47 Coefficient of coupling(k)=0.99 Mutual inductance(Lm)=0.3984mH Resistance of Transformer =0.084Ω Z-source capacitance C=240µF
Inverter Side ratings	fr =50 Hz fc =12 KHz df=0.17 (for boost operation) df=0 (for buck operation)
Load	Resistance R=50Ω/phase
Filter	L=6.8 mH/phase

Table 2 — Required Turns ratio to achieve required gain demand

Gain (G)	Traditional Impedance source (D_0)	Proposed Trans impedance source	
		D_T	$1 \leq \gamma_T$
2	0.3937	0.14	3.107
5	0.4575	0.14	4.92855
10	0.47875	0.14	5.535
20	0.4893	0.14	5.8392
50	0.49575	0.14	6.20214

topology developed by using Spartan 6 and FPGA controller. The components used in the prototype model are 4uni-directional IGU04N60T IGBT's, 10 No's of FGA15N120 IGBT's with anti-parallel body diodes. The output waveforms are measured and recorded by using key-sight DSOX2014A Oscilloscope and THD is measured by using FLUKE 434 series-II power-quality analyzer. The seven level output voltage waveforms of proposed seven level trans impedance source inverter are shown in Figure 3b and Figure. 3c for modulation ratio of M= 0.9 and shoot through ratio of S= 0.1 and S=0.08. Figure 3(d&e) shows the simulation waveforms of the proposed trans impedance source inverter for the same values of modulation index and shoot through ratio as of shown in previous output voltage waveforms. Figure 3f shows the output voltage comparison of proposed trans impedance source inverter with the conventional impedance inverter Figure 3g shows the comparison of proposed trans impedance source inverter with conventional impedance source inverter in terms of voltage gain and with respect to turns ratio operating at duty ratio of 0.15 and modulation ratio of 0.87.

Conclusion

A practical investigation for design change of magnetically coupledinductors to a basic Z shaped impedance circuits is presented here. The proposed magnetic coupled inverter produces a seven level output voltage of high value at low modulation values and the voltage stress across the switches is also reduced based on the turns ratio of the mutual coupled inductor. The seven level output of trans ZSI is presented shown and the voltage stress on switches is compared for the Trans ZSI with a conventional ZSI. From the results it is concluded that the Trans ZSI produces high level of output voltage and low voltage stress across switch when compared with conventional ZSI for same values of modulation ratio.

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