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Boost DC-DC Converter Based Z-source Inverter with High Frequency Link

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ABSTRACT

This paper proposes a new topology of DC-DC converters with high gain of boost. The suggested circuit consists of Z-source inverter, high frequency transformer and diode rectifier. In this topology the output voltage amplitude is not limited to DC voltage source and transformer turn ratio similar to traditional high frequency DC-DC converters and can be regulated with Z network shoot-through state control. Besides, it is more reliable against short circuit. By using high frequency modulation, the size of transformer is reduced and it is proper in isolation between high voltage and low voltage circuits. The performance of suggested inverter and switching algorithm are validated with simulation results using MATLAB/SIMULINK software.

Key words: DC-DC Converter; high frequency transformer; Z-source inverter; boost factor

1. INTRODUCTION

In several power conversion applications, it is required to convert a variable DC voltage source to a constant output dc voltage. This is performed by DC-DC converters [1-5].These converters are used in several applications such as regulated DC power supplies, renewable energy systems, electrical vehicles, distributed generation systems, and power factor Correction process. In some applications such as photovoltaic systems, boosting of DC voltage level with high gain is assumed. Recently, DC-DC boost converters based high switching frequency has received attention in research and renewable energies applications [1, 6-9]. Increased switching frequencies enable reduction in the numerical values and energy storage of the passive components that limit achievable transient response and account for the majority of converter size and cost. Furthermore, higher frequency can substantially improve transient performance and control bandwidth [1-5]. Based this theory, there are two main topologies for DC-DC converters: (1) High Frequency Resonant Boost Converter (2) isolated type. The isolated type of DC-DC converter utilizes high frequency (HF) transformer to increase DC voltage level. The isolated type is preferred when high voltage gain is required and it is proper for medium and high power applications [1-2].

The basic diagram of isolated type of DC-DC converter can be described as follows: first convert the DC voltage of source in the primary side of converter into high frequency signal through power electronic conversion, then couple the high frequency signal to the secondary side through a high frequency transformer, finally revert the high frequency signal to the DC voltage level through rectifier [1].

In the applications that DC voltage of source is variable, it is needed to regulate output DC voltage to setpoint flexibility. In the conventional systems the other converter as a DC–DC boost chopper is utilized to regulate output DC voltage. In this paper, the Z-source inverter is employed instead of DC–DC boost chopper. The Z-source inverter utilizes Z-impedance network between the DC source and inverter circuitry to achieve boost operation. The voltage boost is achieved by providing a shoot through state when both switches in the same phase leg are on which is not possible with traditional inverter topology. The Z-source inverters in the comparing of traditional inverters are lower costs, reliable, lower complexity and higher efficiency [10–14].

The voltage regulation of isolated high frequency DC-DC converter is available by controlling of Z- source boost factor. The proposed DC/DC converter is studied in two modes: open loop and closed loop control scheme.

This paper is organized as follows. Section II introduces Traditional isolated high frequency DC-DC converter. Traditional Z-source inverter and the analyze of Z-source inverter circuit is explained in section III. Section IV presents the proposed topology. Simulation results on proposed converter are provided in section V and finally section VI draws the conclusions.

2. ISOLATED HIGH FREQUENCY DC-DC CONVERTER

Fig. 1(a) shows the basic block diagram of the isolated high frequency DC-DC converter. In this system, the voltage of DC source is modulated with a converter to a high-frequency square-wave and passed through a HF transformer and again with a converter, it is demodulated to DC form. The main function of the high frequency transformer is voltage transformation and isolation. Since the volume of the transformer is inversely proportional to the frequency, the high frequency transformer will be much smaller than the conventional one [1].

In applications that voltage of DC source is variable, to regulate output DC voltage, the DC-DC chopper can be utilized as Fig. 1(b).

The DC-DC chopper regulates DC voltage level to reference level then the regulated DC voltage is converted to a high frequency square-wave with inverter. HF transformer couples the high frequency signal to the secondary side with turn ratio of N.

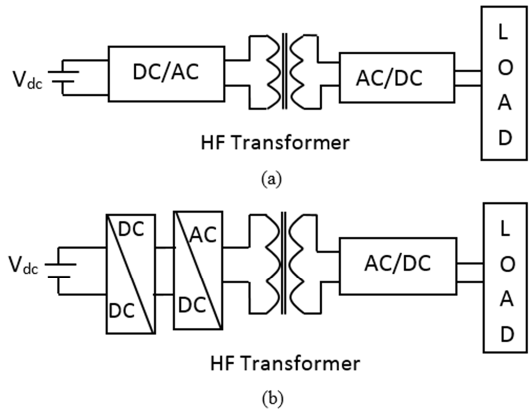


Figure 1. (a) Isolated high frequency transformer DC DC, (b) regulated type of high frequency DC-DC.

3. Z-SOURCE INVERTER

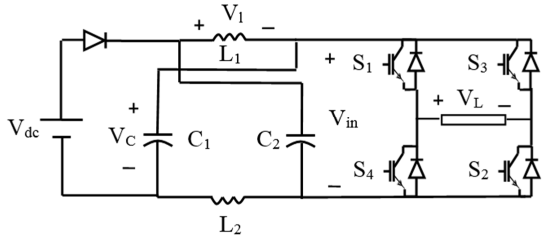
The Z-source inverter structure is shown in Figure 2(a). Assuming that the inductors L1 and L2 and capacitors C1 and C2 have the same inductance (L) and capacitance (C), respectively, the Z-source network becomes symmetrical. The equivalent circuit of shoot-trough state and non shoot-through state is shown in Fig. 2(b) and Fig. 2(c), respectively. With the analyze of circuit Vin is obtained as [10, 14]:

$$V_{in} = \left(\frac{1}{1-2\frac{T_{sh}}{T}}\right)V_{dc} \quad (1)$$

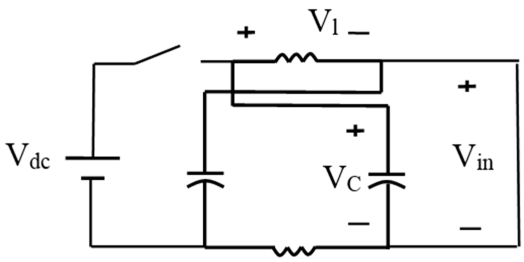
$$B = \frac{1}{1-2\frac{T_{sh}}{T}} \quad (2)$$

Where T is period of switching and B is boost factor and it is clear that $B \geq 1$.

This configuration, unlike the traditional inverters, has one extra zero state (or vector) when the terminals are shorted through both the upper and lower devices of any one leg or any two legs. So inverter is turned in to shoot-through state when the output voltage level is traditional zero.



(a)



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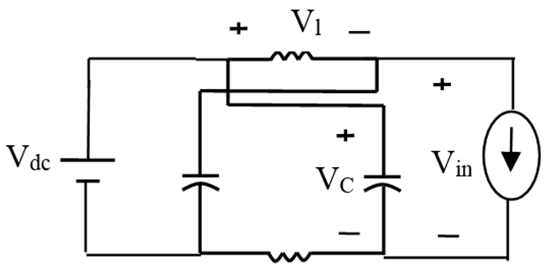


(c)

Figure 2. Circuit diagram of (a) single phase Z-Source, (b) Z-Source in shoot through state, (c) Z-Source in non shoot through state.

4. PROPOSED STRUCTURE

Fig. 3 shows the proposed DC-DC converter based HF transformer that utilizes Z-source. In this paper, advanced DC-DC converter is suggested which employs one dc input voltage source, Z-source inverter, HF transformer and Diode rectifier .In Fig. 3, the input DC voltage is modulated to high frequency square-wave signal by Z-source inverter and the amplitude of square-wave can be boosted related to DC voltage level of source. HF square wave passes through HF transformer with turn ratio of N. By neglecting the losses of HF transformer, the HF transformer can be treated as a proportional amplifier. The simplified model of the HF transformer is presented as:

$$V_s = \frac{N_s}{N_i} V_i \tag{3}$$

V_i, V_s are the primary and secondary voltage amplitude in HF transformer, respectively and N points to turn ratio. By neglecting the on-stated voltage drop of inverter power electronic switches, V_i equals V_{in}, therefore (3) can be written:

$$V_s = B\frac{N_s}{N_i} V_{dc} \tag{4}$$

In secondary side of transformer, the HF square wave is converted to DC voltage by rectifier and capacitor. As compared to traditional inverters, the Z-source inverter has an extra switching state: shoot-through. During the shoot-through state, the output voltage of Z network, V_{in} in Fig. 3 is zero. In this case, besides S_1, S_3 the other switches i.e. S_2, S_4 are turned on, while in non shoot-through state only S_1, S_3 are turned on according to Table I.

Table I. Switchıng States And Output Voltage of Case Study

Voltage Level	Output Voltage	State	ON Switches
Level 1 (active state)	1 V_{in}	Non Shoot-Through	S_1, S_2
Level 0 (zero state)	0 (V)	Non Shoot-Through	S_1, S_3 or S_2, S_4
Level 0 (zero state)	0 (V)	Shoot-Through	S_1, S_4 or S_2, S_3 or S_1, S_2, S_3, S_4
Level -1 (active state)	-1 V_{in}	Non Shoot-Through	S_3, S_4

In this paper, proposed topology is turned in to shoot-through state when output voltage level is traditional zero therefore some or all of the zero states are changed to shoot-through. Table I shows the switching states and output voltage of case study. As shown in Table I, proposed topology is in the shoot-through state when S1 and S4 are on and the output voltage is zero similar to non shoot-through level 0 state and other states are like traditional inverters switching algorithm.

As expressed in (1) and (2) the rate of voltage boost depends on shoot-through time during switching period, so by controlling shoot-through time a desirable DC output voltage can be obtained.

Relation between shoot-through and traditional zero state is expressed as:

$$D = \frac{T_{sh}}{T_{zs}} \tag{5}$$

Where T_{zs}, T_{sh} are total zero state time and total shoot-through time during switching period, T. It is considered that by increasing D, boost factor B increases, as a result the Z network output voltage V_{in} in Fig. 3 increases and load voltage is controlled. In the proposed topology the modulation index of the inverter is kept constant and the output voltage of Z-source is controlled by a shoot-through duty ratio, therefore the THD is nearly constant for different boost ratio of output voltage.

As compared to structure shown in Fig. 1(b), the proposed structure needs no switch in DC-DC part. Besides, the suggested structure is more reliable against short circuit. Switching algorithm of z-source inverter is based on the principle of phase-shifted PWM.

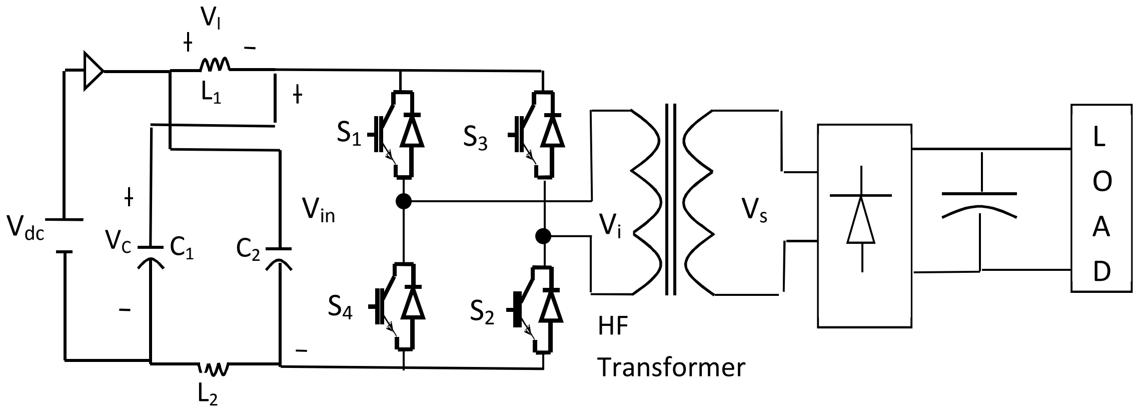


Figure 3. Proposed Structure

The technique of output feedback control is incorporated to determine the switching actions of the z-source inverter. Fig. 4 presents control circuit of proposed structure in the closed loop scheme. The output load voltage is compared to reference value. The PI controller is applied to regulate the error between the load voltage and its reference. Next the PI controller output is compared to triangular waveform with high frequency and square pulse with duty cycle of D is generated. The frequency of triangular waveform is more than z-source inverter output frequency.

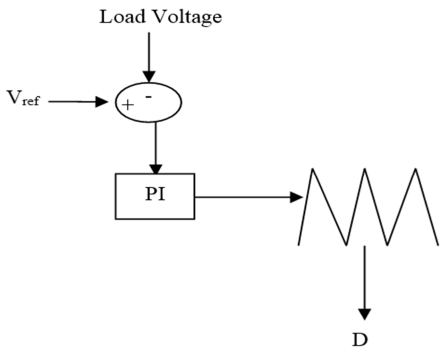


Figure 4. Control diagram of proposed structure in closed loop scheme.

5. SIMULATION RESULTS

System shown in Fig. 3 has been modeled by MATLAB/SIMULINK to study proposed topology. The system parameters are listed in Table II

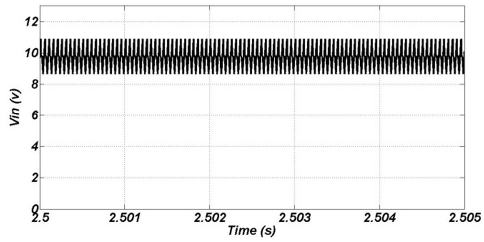
Table 2. Parameters of Case Study

10V	DC Voltage Source
5 mH	L_1=L_2
2300 μF	C_1=C_2
R=100 Ω,L=22mH	Load Impedance
0.0001 s	T (switching frequency of Z-source)
HF Transformer	1:10, 10kHZ

Three different duty cycles i.e. 0%, 25% and 50% have been considered for generated pulse. Fig. 5 presents the case study in *D*= 0%. In this duty cycle, according to (5) zero states are not turned to shoot-through state, therefore *B*=1. Fig. 5(a) presents the output voltage of Z network, V_{in} which is about 10V. HF square-wave of primary and secondary of transformer are shown in Fig 5(b) and (c) respectively. Fig. 5(d) presents load DC voltage. As shown in Fig. 5(d), desired DC level is 100.

Fig. 6 presents the case study in *D*= 25%. In this duty cycle, according to (5) 25% of zero states time changed to shoot-through states time. Fig. 6(a) presents the output voltage of Z network, V_{in} which is about 12.5V. HF square-wave of primary and secondary of transformer are shown in Fig 6(b) and (c) respectively. Fig. 6(d) presents load DC voltage. As shown in Fig. 6(d), desired DC level is 125 v.

Fig. 7 presents the case study in *D*= 50%. In this duty cycle, according to (5) half of zero states time changed to shoot-through states time. Fig. 7(a) presents the output voltage of Z network, V_{in} which is about 18.8V. HF square-wave of primary and secondary of transformer are shown in Fig 7(b) and (c) respectively. Fig. 7(d) presents load DC voltage. As shown in Fig. 7(d), desired DC level is 188 v.



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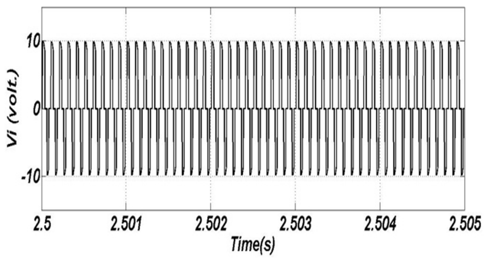

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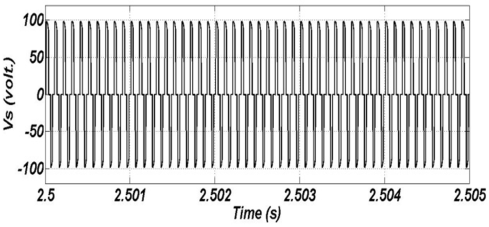

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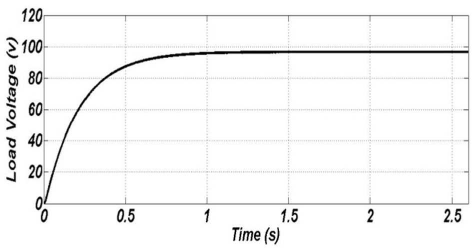
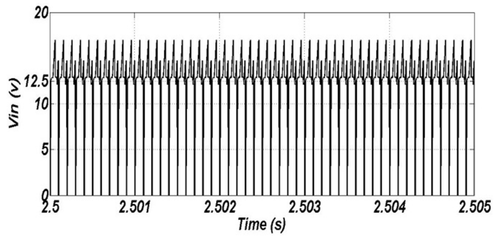


(d)

Figure 5. Case 1: D=0 (a) Vin (b) HF square-wave of primary side of transformer, Vi, (c) HF square-wave of secondary side of transformer, Vs, Load voltage .



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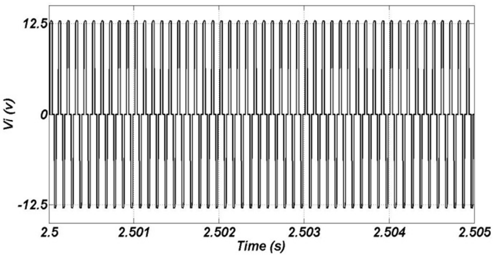

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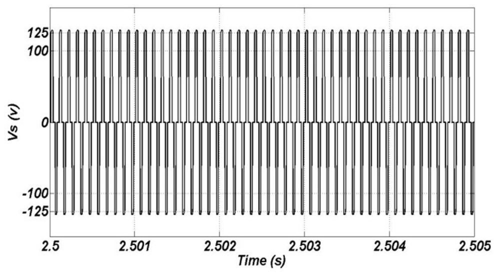

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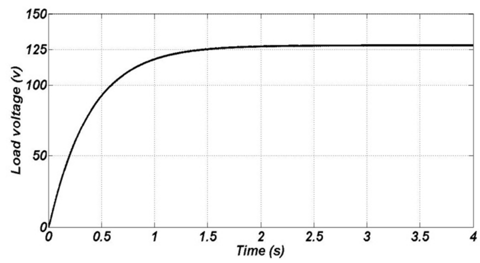
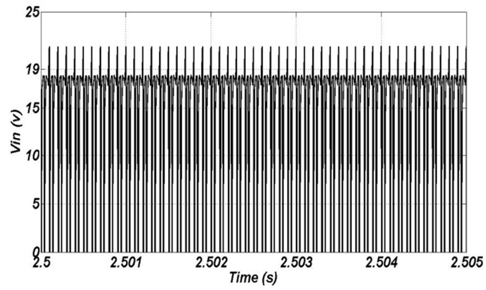
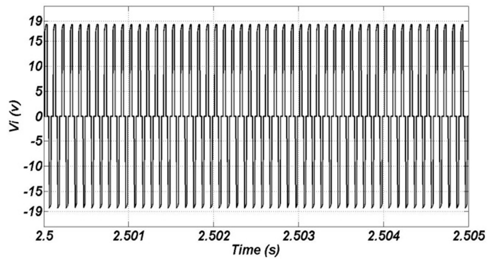


(d)

Figure 6. Case 2: D=25% (a) Vin (b) HF square-wave of primary side of transformer, Vi, (c) HF square-wave of secondary side of transformer, Vs, Load voltage .



(a)



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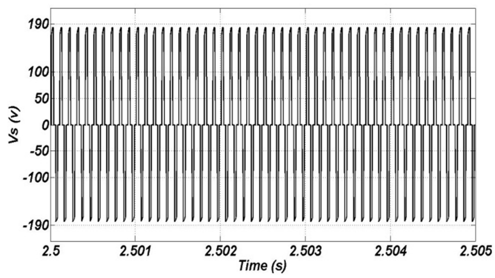

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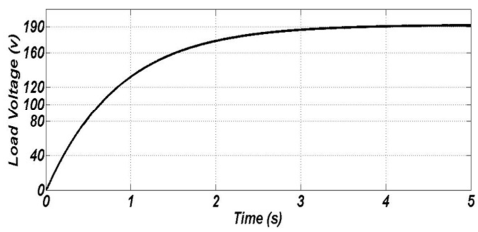

(d)

Figure 7. Case 3: D=50% (a) Vin (b) HF square-wave of primary side of transformer, Vi, (c) HF square-wave of secondary side of transformer, Vs, Load voltage .

To study the advantages of proposed DC-DC converter in the closed loop control scheme, the suggested structure is modeled based control scheme as Fig. 4. Sudden variation in the reference value of load voltage is occurred. The reference value is changed from 120v to 140v in t=3 s. Fig. 8 shows load voltage in closed loop scheme. As shown in Fig. 8, the load voltage that follows reference value.

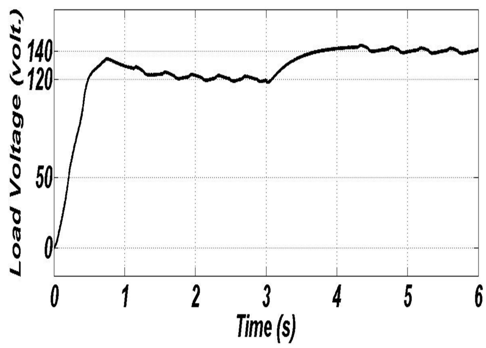

Figure 8. Load voltage in closed loop control scheme.

6. CONCLUSIONS

This paper proposed an advanced DC-DC converter based high frequency transformer employing Z-source to boost input DC voltage that can be controlled with Z networks shoot- through state. In addition, suggested converter has the ability of high voltage gain and the size of structure will be reduced because of high frequency switching.

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