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SINGLE TO THREE PHASE Z-SOURCE MATRIX CONVERTER WITH HIGH TRANSFER RATIO

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ABSTRACT

In this project a new single to three phase(AC/AC) converter is proposed by using matrix converter and Z-source conversion concept. With this proposed converter limitations of conventional single to three phase matrix converter such as lower input-output voltage transfer ratio and unbalanced output currents is improved. The proposed direct AC/AC converters can buck or boost the amplitude of output voltage with desired frequency. Switching strategy based on sinusoidal pulse width modulation for Z-source inverter, is presented for proposed converter

1. INTRODUCTION

Three-phase Matrix converter (MC) was introduced by Gyugyi and Pelly in 1976 [2]. Three-phase Matrix converter is an ac/ac converter that can directly convert an ac power supply voltage into an ac voltage of variable amplitude and frequency without a large energy storage element. Despite attractive features of MC such as absent bulky and lifetime limited energy-storing capacitors, sinusoidal input and output currents, simple and compact structure, unity power factor for any load and bidirectional power flow, the most important disadvantage of three-phase matrix converter is lower input- output voltage transfer ratio which is limited to 87% for sinusoidal input and output waveforms [5][14][15].

There are several converters that are derived from three- phase matrix converter topology; one of them is single to three- phase matrix converter (STMC). STMC was first realized in 2001[3]. The first proposed configuration for STMC which is shown in Fig 1 is composed of six bi-directional switches and does not include an ac reactor and capacitance so the system cost and weight is decreased [3]. STMC compare to conventional ac/dc/ac converter, has several advantages such as lack of a large dc capacitor, as well known, a large dc capacitor requires a large space for its installation; in addition, it shortens the life time of converter system, therefore use of a large dc capacitor is not preferable. Fig 1 configuration has two main disadvantages, one of them is lower input-output voltage transfer ratio and the other is unbalanced output currents [3]. For improving unbalanced output currents disadvantage, several topologies have been proposed for STMC [6][11]. In these topologies (For example Fig 2 and Fig 3) extra switches and ac reactors and capacitors are used.

These extra capacitors, reactors and switches obstruct the miniaturization and weight reduction of the system toward conventional ac/dc/ac converter. All the proposed topologies for STMC [3-4] have lower input-output voltage transfer ratio problem, which is the main focus of this paper.

Z-source inverter was introduced by Fang Zheng Peng in 2003 [9]. The Z-source inverter has

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the unique feature that it can boost the output voltage by introducing shoot through operation mode, which is forbidden in traditional voltage source inverters. With this unique feature, the Z-source inverter provides a cheaper and simpler configuration compare to traditional voltage source inverters and boost converters [9]. The Z-source ac/ac converters focus on single-phase topologies [12][8] and three-phase topologies [1][13]. In applications where only voltage regulation is needed, the family of single-phase Z-source ac/ac converters proposed in [12-13] has a number of advantages, such as providing a larger range of output voltages with the buck-boost mode.

In this paper using matrix converter theory and Z-source conversion concept, a single to three-phase Z-source matrix converter (STZMC) is proposed. The proposed converter and switching strategy can boost amplitude of output voltage with desired frequency. The operating principles of the proposed STZMC are described. Simulation results verify validity and performance of the proposed converter.

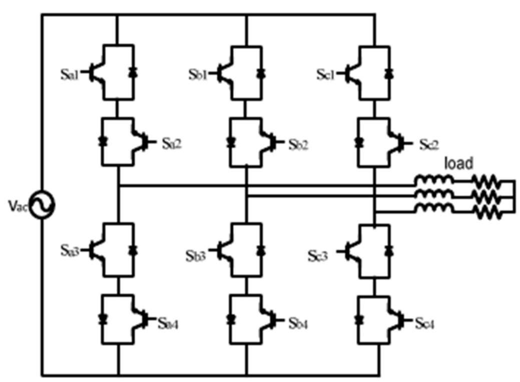

Figure l. Configuration of single to three-phase matrix converter (STMC) [3]

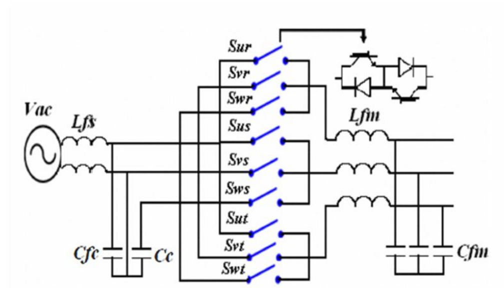

Figure 2. Single to three-phase matrix converter (STMC) configuration Proposed in [10]

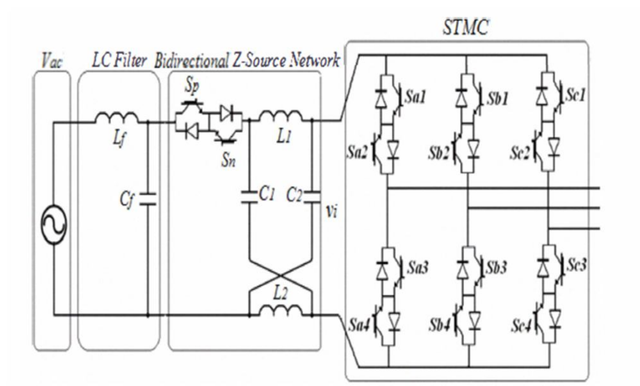

Figure 3. Single to three-phase matrix converter (STMC) configuration Proposed in [11]

2. PROPOSED SINGLE TO THREE-PHASE Z-SOURCE MATRIX CONVERTER

Fig 4 shows a block diagram of the proposed topology. In this block diagram ac input voltage (Vac) is boosted by the bidirectional Z-source converter to STMC input voltage ($v_i(t)$), and then the STMC modulates the frequency of ($v_i(t)$), Fig 5 shows circuit diagram of the proposed single to three-phase Z-source matrix converter (STZMC). It employs a bidirectional Z-source network for voltage boosting. The symmetrical bidirectional Z-source network, a combination of two inductors and two capacitors, are the energy storage/filtering element for the STZMC. Since the switching frequency is much higher than the ac source frequency, the requirements for the inductors and capacitors should be low. As shown in Fig 5, the proposed STZMC requires Six bidirectional switches to

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serve as a STMC and one bidirectional switch S_j(j=p,n) in bidirectional Z-source network.

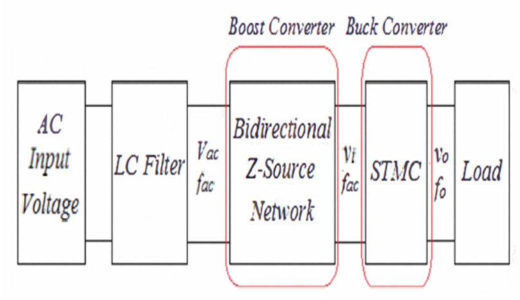


Figure 4. Block diagram of proposed converter

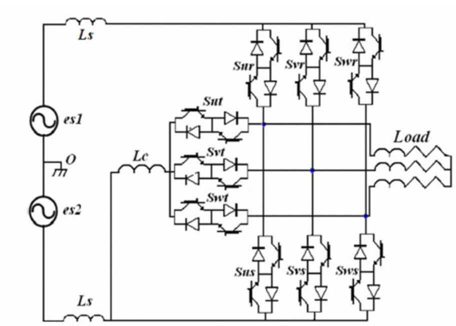


Fig 5. Circuit diagram of proposed converter (STZMC)

As shown in Fig 6, STMC part of STZMC can be modeled by a bidirectional switch and an ac current controlled source (or R-L load).

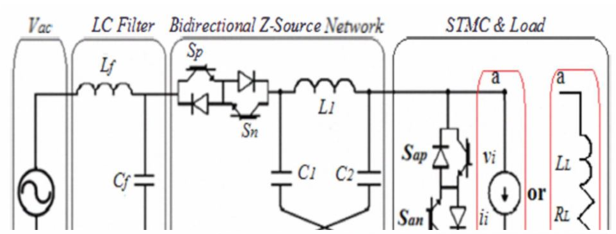


Fig 6. Equivalent circuit of the proposed STZMC viewed from the input voltage source

III. PERFORMANCE ANALYSIS OF PROPOSED CONVERTER

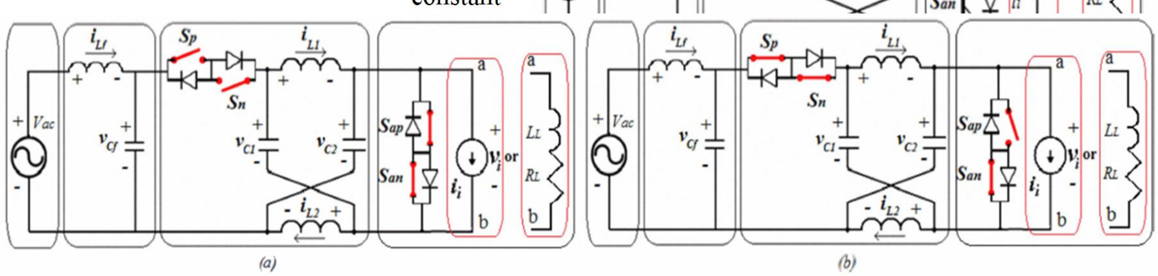
A.Performance analysis of bidirectional Z-source network

The bidirectional Z-source network of STZMC is used for boosting $V_i(t)$. Table I shows the proposed switching strategy for bidirectional Z-source network of STZMC (Fig 6) in positive and negative period of input voltage, where Ts and D show sampling time and duty cycle respectively also number 1 and Q show switches are on and off respectively.

Table 1:Proposed switching strategy for bidirectional z-source network in one sampling time.

Period	Positive		Negative	
	Shoot-through time	Nonshoot-through Time	Shoot-through time	Nonshoot-through time
Switch	DTs	(1-D)Ts	DTs	(1-D)Ts
S_p	0	1	0	1
S_n	0	1	0	1
S_{ap}	1	0	1	1
S_{an}	1	1	1	0

Operation analysis of bidirectional Z-source network of STZMC is quite similar to dc/ac Z-source converter. The converter switching frequency is larger than input voltage frequency so input voltage per sampling time can be seen as constant



. Fig 7 shows equivalent circuit of bidirectional Z-source network of STZMC in shoot-through and nonshoot- through time of positive period.

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Fig 7. Equivalent circuit of bidirectional Z-source network of STZMC in positive period
a)shoot-through time b) nonshoot-through time

Equations in shoot-through time:

$$\begin{bmatrix} L_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & L_f & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & C_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & C_f & 0 \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_{L1} \\ i_{L2} \\ i_{Lf} \\ v_{C1} \\ v_{C2} \\ v_{Cf} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ i_{Lf} \\ v_{C1} \\ v_{C2} \\ v_{Cf} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ V_{ac} \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (1)$$

Equations in nonshoot-through time:

$$\begin{bmatrix} L_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & L_f & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & C_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & C_f & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & L_L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_{L1} \\ i_{L2} \\ i_{Lf} \\ v_{C1} \\ v_{C2} \\ v_{Cf} \\ i_i \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 & 0 & 0 & -1 \\ -1 & -1 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & -1 & -R_L \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ i_{Lf} \\ v_{C1} \\ v_{C2} \\ v_{Cf} \\ i_i \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ V_{ac} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (2)$$

Equations (1) and (2) show current and voltage equations in shoot-through and nonshoot-through time respectively. In steady state, average voltage of the inductors over one sampling time (Ts) should be zero. So we have:

$$v_{L1} = Dv_{C1} - (1-D)v_{C2} + (1-D)v_{Cf} = 0 \quad (3)$$

$$v_{L2} = Dv_{C2} - (1-D)v_{C1} + (1-D)v_{Cf} = 0 \quad (4)$$

Assuming that the inductors L1 and L2 and capacitors C1 and C2 have the same inductance (L) and capacitance (C), so the bidirectional Z-source network becomes symmetrical and we have:

$$v_C = v_{C1} = v_{C2} = \frac{1-D}{1-2D} v_{Cf} \quad (5)$$

Assuming the voltage drop across filter inductor and bidirectional Z-source network is negligible we have:

$$v_{Cf} = V_{ac}\ , \ \ v_C = v_i \quad (6)$$

From (5) and (6), the maximum output voltage of bidirectional Z-source network can be determined as:

$$v_i = \frac{1-D}{1-2D} \sqrt{2} V_{ac} \quad (7)$$

For designing capacitors and inductors of bidirectional Z-source network, (1-D)Ts

$$v_L = v_{L1} = v_{L2} = L\frac{di_L}{dt} \Rightarrow v_L = L\frac{\Delta i_L}{(1-D)T_s} \quad (8)$$

$$v_L = v_{Cf} - v_C\ ,\ L = L_1 = L_2 = \frac{(1-D)T_s \times (v_{Cf} - v_C)}{\Delta i_L}$$

If $\Delta i_L \le \frac{m}{100} i_L$, we have:

$$L \ge \frac{(1-D)T_s \times \left| v_{Cf,\max} - v_{C,\max} \right|}{m I_L} \times 100 \quad (9)$$

interval is used. In this interval
For capacitor sizing:

IV. SIMULATION RESULTS

In this section the simulation results are provided to verify the properties described earlier for the proposed STZMC and proposed switching strategy. The simulation parameters are listed in Table II. In the simulation, the ISPWM strategy is used for STMC part.

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he
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$$i_C = i_{C1} = i_{C2} = C\frac{dv_C}{dt} \Rightarrow i_C = C\frac{\Delta v_C}{(1-D)T_s} \quad (10)$$

$$i_C = i_L - i_i\ ,\ C = C_1 = C_2 = \frac{(1-D)T_s \times (i_L - i_i)}{\Delta v_C}$$

If $\Delta v_C \le \frac{n}{100} v_C$, we have:

$$C \ge \frac{(1-D)T_s \times \left| i_{L,\max} - i_{i,\max} \right|}{n v_C} \times 100 \quad (11)$$

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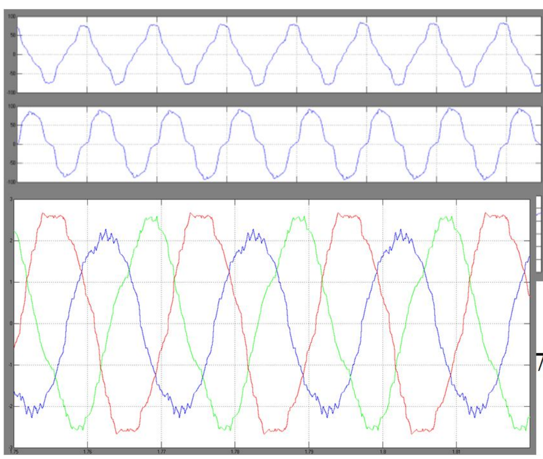
e of input voltage is fixed at 50V. Fig 8 shows output waveforms of bidirectional Z-source network (or input voltage of STMC), as seen in Fig 8(a) from equation (7) the output voltage is boosted and peak value is 65.61V, also Fig 8(b) shows load current of bidirectional Z-source network.

Table II. Simulation parameters

Parameter	Value
L_f	0.1mH
C_f	6µF
L_z	1mH
C_z	1µF
Load	R=11□
	L=85mH
Switching Frequency	1KHz
Input voltage	50V
Output voltage	65.61V



(a)

(b)

Fig 8. Output waveforms of bidirectional Z-source network(a)Output voltage(b)Output current

V. CONCLUSION

In this paper to improve limitations of single to three-phase matrix converter STMC, using matrix converter theory and Z-source conversion concept, a single to three-phase Z-source matrix converter (STZMC) is proposed. With the proposed converter and switching strategies, limitations of STMC such as lower input-output voltage transfer ratio and unbalanced output currents has been improved. The proposed direct ac/ac converters with minimum passive elements can boost amplitude of output voltage with desired frequency. Simulation results verified validity and performance of the proposed converter.

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