Design and Implementation of Z Source Sparse Matrix Converter for Variable Frequency Drives

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Abstract—This paper presents a novel Z-source sparse matrix converter (ZSMC) for variable frequency drives. The structure of a Sparse Matrix Converter (SMC) reduces the number of unipolar power semiconductor switches. But the innate limitation of SMC is the low voltage transfer ratio of conventional matrix converters. Hence, the ZSMC is developed that employs a Z-source network with SMC to boost up the voltage. Even though the ZSMC is a two-stage converter, it directly connects between a source and a load through a Z-source network. Since the only purpose of Z-source network is voltage boosting, ZSMC has been designed to have smaller passive components. Therefore, the output of the ZSMC is directly affected by disturbances of the input-voltage source. The circuit diagram of Z-Source Sparse matrix converter has been simulated using MATLAB/SIMULINK to verify its feasibility.

Index Terms—Compensation, Fuzzy Logic Controller, Sparse Matrix Converter, Z-Source network

1. INTRODUCTION

In variable frequency drives, there are two types of conversion systems for ac-ac power conversion such as two stage ac–dc–ac indirect conversion system and single stage ac–ac direct conversion system as shown in Fig.1. The conventional variable frequency system is based on voltage source inverter which consists of three stages of conversion like diode rectifier, dc link capacitor and inverter bridge [1]. The Variable frequency drives with voltage source inverters suffers from various limitations and problems such as low obtainable power output, lack of ride through capability and line may be polluted by the inrush and harmonic current from the diode rectifier. Later a new Z source based inverter has been introduced to overcome the above limitations of VSI. But it also involves two stage conversions with larger dc link energy storage components [2].

However the direct conversion system called Matrix Converter with an array of nine bidirectional switches,
connects any input phase to output phase without dc link energy storage components [3]-[4].

Matrix converter has become more prominent because of its advantages like sinusoidal input current, high power factor, less size and lack of dc link energy storage components. In spite of these advantages, due to its unsolved problems it has not yet gained much attention in the industry. The disadvantages of the matrix converter includes that it requires large number of power switches and limitations in the voltage transfer ratio [5]. Fig.2 shows the topologies of direct matrix converter and indirect matrix converter.

![Fig.2](image_url)  
Fig. 2 (a) Direct Matrix Converter (b) Indirect Matrix Converter

Hence, if the input voltages of the ZSMC are unbalanced, the output voltage is directly affected and so detrimental harmonics can occur in the output current. In this paper, under an unbalanced input-voltage condition compensation using controller is presented to improve the output performance of the ZSMC. It is supported by simulation results to demonstrate the validity of the ZSMC.

2. Z-SOURCE SPARSE MATRIX CONVERTER

The novel circuit structure of a ZSMC has simple modulation strategy, with less number of power switches and overcomes the limitations of low voltage transfer ratio. The operational principle of the ZSMC is described and the behavior of the ZSMC under unbalanced input-voltage conditions is investigated.
and short circuited on either end. This sole configuration of the Z-source network includes the advantage of buck and boost feature and it enhances the performance and reliability of the overall converter system. Also, the filtering component of the converter is provided by the combined circuits [12]. The Z-source network provides a second-order filter and is more effective to suppress voltage and current ripples than a capacitor alone used in a conventional ac–dc–ac converter. Hence, the passive component requirement should be smaller than the conventional converter.

![Proposed configuration of the ZSMC](image)

To ensure zero-current commutation in the rectification stage, an additional power switch S1 has been included in the dc link before the Z source network. Fig. 3 shows the configuration of Z source Sparse Matrix Converter. The control of the dc-link switch S1 is straightforward. During the shoot-through period, switch S1 is opened as it is necessary to block the voltage from Z source network to rectifier is required. Since the capacitors in the Z-source network are charged to higher voltages than the rectified input voltage during the shoot-through period, the integrated antiparallel diode of the insulated gate bipolar transistor (IGBT) is also turned OFF. During this period, the rectifier can perform the zero-current commutation safely. This eliminates the need of additional protection circuits in the rectification stage.

In contrast, during non shoot through periods to provide bidirectional power flow, the switch S1 is closed because the dc-link current needs to flow back and forth freely. During motoring mode operation, the dc link current is fed to the load through the Z source inverter and antiparallel diode of IGBT. During operation in the regenerative braking mode, the current can flow through the IGBT and feed back to the input-voltage source. A single supplementary IGBT is adequate, to provide voltage blocking capability from passive components to the input voltage source. It is worth to note that the zero-current switching occurs in S1 during the motoring mode because of no current flows through the switch but through the integrator antiparallel diode. However, during the regenerative braking mode, hard switching occurs, and in turn, a proper snubber circuit may be required to protect the switch.

A. Operational Principle and Equivalent Circuits

The foremost reason for employing Z Source network in ZSMC is to utilize its boosting feature for a wider range of the output voltage [13]. Assuming that the switching frequency is larger than the fundamental frequencies of the input voltage, it can be regarded as the Z-source inverter is fed by a constant dc-link voltage.

![Equivalent circuits of the Z-source inverter](image)

The ZSMC mainly operates in two different operating modes [14]: one is a shoot-through state mode, in which the energy is charged in the Z-source network, and the other is a nonshoot-through state mode (or a normal operating mode), in which the stored energy is used to synthesize the output voltages. If it is assumed that the Z-source inverter is fed by a constant dc-link voltage during one switching period, two
equivalent circuits for each of these operating modes can be drawn as shown in Fig.4.

Assuming that inductors L1 and L2 have the same inductance L and capacitors C1 and C2 also have the same capacitance C, the Z-source network becomes symmetrical.

\[ V_{L1} = V_{L2} = V_L \]
\[ V_{C1} = V_{C2} = V_C \]  

(1)

During the shoot-through state mode T0, the Z-source inverter stage is intentionally short circuited and the dc-link switch S1 is opened, which separates the dc-link from the rectifier stage. During this period, the rectification stage performs the commutation as mentioned earlier.

The shoot through can be achieved in seven different ways: short circuit of any one phase leg, any two phase legs, or all three phase legs. This produces a shoot-through zero state in which the energy is charged in the Z-source network. From the equivalent circuit of Fig.4.1 (a),

\[ V_L = V_s \cdot v_{ld} = 2V_C \cdot v_l = 0 \]  

(2)

During the nonshoot-through state mode T1, the Z-source inverter operates as normal inverter and the dc-link switch S1 is closed, which will allow the bidirectional flow of the dc-link current. From the equivalent circuit of Fig.4.1 (b), the following voltage relationship is:

\[ V_L = V_{dc} - V_s \cdot v_d = V_{dc} \]
\[ v_l = V_C - V_L = 2V_C - V_{dc} \]  

(3)

3. RESULTS AND DISCUSSION

A. Simulation and Results

Fig.5 Shows the simulated circuit diagram of Z-Source Sparse Matrix Converter. The load used here is Asynchronous machine that is three phase Induction Motor. The switch used here is MOSFET.

B. Under Balanced Input Voltage Condition

Under Balanced Input Voltage Condition [15], Circuit diagram of ZSMC has been simulated with Modulation Index 1 and various results were taken.

Fig.6 Input Voltage and Current under Balanced Input voltage condition

Fig.6 shows the Input voltage and current waveform of Z-source sparse matrix converter under Balanced Input Voltage Condition [16]. The Magnitude of input voltage is 340V and the maximum input current is 3.9 amps.
Fig. 7 shows the output voltage and current under balanced input voltage condition. The amplitude of the output voltage is 410v and Output current is 35 amps.

Fig. 8 shows the motor speed, torque and stator current under balanced input voltage condition. Here the speed of the three phase induction motor is 1500 rpm, the torques is 31 NM and the stator current is 32 amps.

Fig. 9 shows the motor speed, torque and stator current under balanced input voltage condition. Here the speed of the three phase induction motor is 1300 rpm, the torque is 31 NM and the stator current is 32 amps.

C. Under Unbalanced Input Voltage Condition

Under Unbalanced Input Voltage Condition, Circuit diagram of ZSMC has been simulated with Modulation Index 1 and various results are taken.

Fig. 10 shows the output voltage and current under Unbalanced input voltage condition. The amplitude of the output voltage is 410v and Output current is 35 amps.

Fig. 11 shows the motor speed, torque and stator current under Unbalanced input voltage condition. Here the speed of the three phase induction motor is 1500 rpm, the torques is 31 NM and the stator current is 32 amps.
Fig. 11 Motor Speed at 1500 rpm, Output motor Torque and Stator Current under Unbalanced input voltage condition.

Fig. 12 shows the motor speed, torque and stator current under unbalanced input voltage condition. Here the speed of the three-phase induction motor is 1300 rpm, the torques is 31 NM and the stator current is 32 amps.

The output current THD is shown in Fig. 13. It is observed that the input current the output THD is 1.48% with modulation index 1.

4. CONCLUSION

The ZSMC and its modulation method have been presented for efficient operation of variable frequency ac drives. The ZSMC is developed based on the circuit structure of an SMC and employs the Z-source network. This unique configuration enables the ZSMC to have a voltage-boost feature and high reliability with less number of the power semiconductors switches than a traditional matrix converter.

Furthermore, a current-compensation method based has been presented to improve the output performance of the ZSMC under unbalanced input-voltage conditions. The circuit diagram of ZSMC has been simulated using Simulink Software and the results confirm the boosting feature and the performance of the ZSMC under unbalanced input-voltage conditions.

REFERENCES


