Improving Output Performance of a Z-Source Sparse Matrix Converter Under Unbalanced Input-Voltage Conditions

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***Abstract*—In this paper, we present a novel Z-source sparse matrix converter (ZSMC) and a compensation method based on a fuzzy logic controller to compensate unbalanced input voltages. The ZSMC is developed based on the structure of an SMC to reduce the number of unipolar power semiconductor switches and employs a Z-source network to overcome the inherent limitation of the low voltage transfer ratio of conventional matrix converters. Although the ZSMC is a two-stage converter, it directly connects between a source and a load through a Z-source network, which is designed to have smaller passive components as the only purpose is voltage boosting. Therefore, the output of the ZSMC is directly affected by disturbances of the input-voltage source. The operational principle of the ZSMC is described and its modulation strategy is explained. Simulation and experimental results are shown to verify the feasibility of the ZSMC and its compensation method.**

***Index Terms*—Compensation, fuzzy logic control (FLC), sparse matrix converter (SMC), unbalanced input voltage, Z-source network.**

I. INTRODUCTION

FOR ac–ac power conversion, there are two types of conversion systems: one is a traditional ac–dc–ac two-stage indirect conversion system and the other is an ac–ac one-stage direct conversion system as shown in Fig. 1. The traditional indirect converter produces variable-amplitude and/or variable-frequency output voltages with a stiff dc-link voltage that is acquired by a larger dc-link energy-storage component, such as an electrolytic capacitor. Unlike the traditional indirect converter, the direct converter connects any input phase to any output phase with an array of controlled power semiconductor switches without the dc-link energy-storage component. This direct-type converter is called a matrix converter [1]–[3].

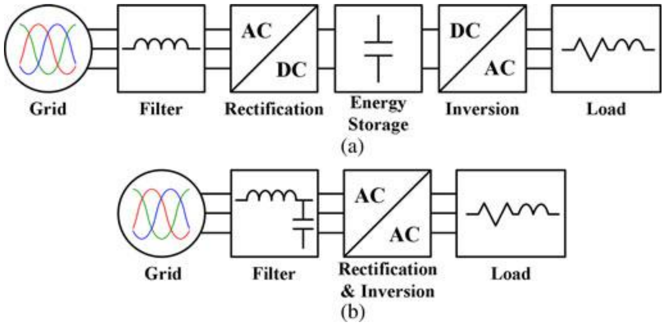

Fig. 1. Different types of power-conversion systems. (a) Conventional ac–dc–ac indirect conversion system and (b) ac–ac direct conversion system (matrix converter).

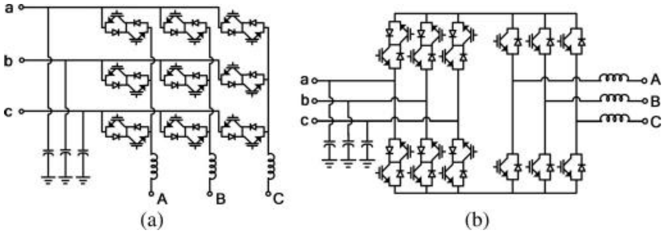

Fig. 2. Topologies of (a) direct matrix converter and (b) indirect matrix converter.

The matrix converters can be implemented with two different topologies: one is a direct matrix converter and the other is an indirect matrix converter shown in Fig. 2(a) and (b), respectively. The structure of the direct matrix converter is based on direct ac–ac power conversion by coupling the input and output sides with nine bidirectional switches, while the indirect matrix converter is based on ac–dc–ac power conversion without any dc-link energy-storage component. Although the direct and indirect matrix converters differ with respect to the circuit configuration, control strategy, efficiency, and complexity, they provide similar basic functionalities, such as sinusoidal I/O currents and bidirectional power flow with the same number of unipolar power semiconductor switches [4]–[7].

The matrix converter has received considerable attention because it has many desirable features, such as high power factor, sinusoidal input current, bidirectional power flow, and a compact design due to the lack of dc-link energy-storage components. Despite all these advantages, the matrix converter has not yet gained much attention in the industry due to its several unsolved problems. The critical drawbacks of the matrix converter are that

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a large number of power switches are required and the voltage transfer ratio of the matrix converter has a certain limit [8]–[11].

As can be seen from Fig. 2, both direct and indirect matrix converters require 18 turnoff power semiconductor switches and the configuration of a bidirectional switch requires careful commutation strategies and protection schemes to avoid damages from overcurrent or overvoltage spikes. This leads to an increase in complexity and a decrease in reliability of the overall converter system.

Since a matrix converter connects a source and a load without any energy-storage component, its output voltage can only be synthesized directly with input line-to-line voltages. Under this restriction, the maximum output voltage that the matrix converter can produce without entering the overmodulation range is equal to 86% of the maximum input voltage [3]. For electrical drive applications, it means that a derated motor or a nonstandard motor is required. Furthermore, disturbances at the input source are immediately reflected to the load. The unbalanced input voltages can result in unwanted output harmonic currents and the short-time input-voltage sag can bring the voltage sag on the load. These can deteriorate the performance of the load [12]–[14].

Research on alternative topologies that exhibit identical functionality but utilize a reduced number of power switches has been carried out recently [15]–[17]. The matrix converters with a reduced number of power switches are also called sparse matrix converters (SMCs) and they are developed based on the structure of the indirect matrix converter. Research on the overmodulation operation has been carried out to overcome the intrinsic limitation of the low voltage transfer ratio as well [18]–[20]. However, the overmodulation can only be achieved at the expense of the quality of input current and output voltage.

To overcome these problems, a novel circuit structure of a Z-source SMC (ZSMC) and its modulation strategy is proposed [21], [22]. The ZSMC reduces the number of power switches by employing the circuit structure of the SMC and overcomes the inherent limitation of the reduced voltage transfer ratio by employing a Z-source (impedance-source) network in the dc-link. The Z-source converter concept was firstly introduced in [23] and various modulation methods for the Z-source converter have been published thereafter [24]–[27]. In this paper, the operational principle and control schemes of the ZSMC are described and the behavior of the ZSMC under unbalanced input-voltage conditions is investigated.

Although the ZSMC is a two-stage converter, it connects between a source and a load with a Z-source network, which is not large enough to suppress all voltage ripples caused by input disturbances. Therefore, if the input voltages of the ZSMC are unbalanced, the output voltage is directly affected and, in turn, undesirable harmonics can occur in the output current. There are several papers that present strategies to mitigate the effect of unbalanced input voltage in the output side of a matrix converter [28], [29]. In this paper, a new compensation method based on a fuzzy logic controller (FLC) is presented to improve the output performance of the ZSMC under an unbalanced input-voltage condition. It is supported by simulation and experimental results to demonstrate the validity of the ZSMC.

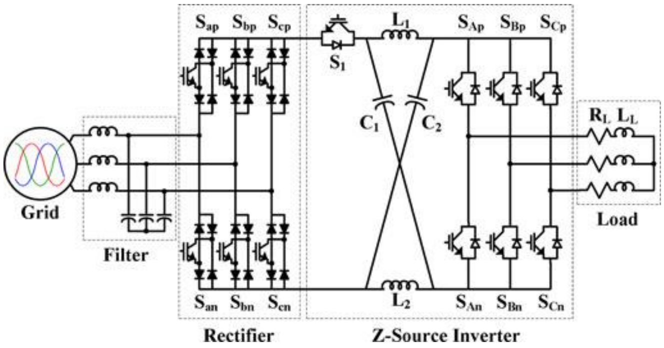

Fig. 3. Proposed configuration of the ZSMC.

II. Z-SOURCE SPARSE MATRIX CONVERTER

To reduce the number of power semiconductor switches and to overcome the intrinsic limitation of the voltage transfer ratio with the maximum value of 0.866, the novel circuit structure of a ZSMC is presented. This configuration has a simple modulation strategy as added benefit.

A. Topology

The circuit configuration of the ZSMC is shown in Fig. 3. The ZSMC is a two-stage converter that consists of a rectification stage and a Z-source inversion stage. By restricting the operation to a positive unipolar dc-link voltage and employing a zero dc-link current commutation strategy, the rectifier stage can be reduced to the configuration with six power switches as shown in Fig. 3.

The Z-source network consists of two inductors (L_1 and L_2) and two capacitors (C_1 and C_2) connected into an X-shape to form a two-port impedance network that can be open circuited and short circuited on either end. This unique configuration of the Z-source network provides the advantage of buck and boost feature and it improves the performance and reliability of the overall converter system. Furthermore, this combined circuit serves also as a filtering component for the converter. 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. Therefore, the passive component requirement should be smaller than the conventional converter.

As can be seen from Fig. 3, an additional power switch S_1 is inserted in the dc-link before the Z-source network to ensure zero-current commutation in the rectification stage. The control of the dc-link switch S_1 is straightforward. Since the voltage blockage from the Z-source network to the rectifier is required during the shoot-through period, S_1 is opened. Since the capacitors in the Z-source network are charged to higher voltages than the rectified input source 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.