A New Reduced Common-mode Voltage SVM Method for Indirect Matrix Converters with Output Current Ripple Minimization

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Abstract

This paper presents a new space vector modulation (SVM) method for indirect matrix converters (IMCs) to reduce common-mode voltage as well as minimize output current ripple in a high voltage transfer ratio. In the proposed SVM, the three-vector modulation scheme is used in the rectifier stage, while the non-zero state modulation technique, where the three nearest active vectors are selected to synthesize the desired output voltage, is applied to inverter stage to reduce the CMV. The proposed SVM method can significantly reduce the output current ripple and common-mode voltage of the IMC without any extra hardware. Simulated results are provided to demonstrate the effectiveness of the proposed SVM method.

Keywords - Indirect matrix converter (IMC); space vector modulation (SVM); common-mode voltage (CMV); output current ripple.

1. Introduction

Three-phase matrix converters (MCs) are direct ac-ac converters that can generate three-phase ac output voltages with variables amplitudes and frequencies from a three-phase ac voltage source. Recently, they have received more considerable attention because their interest features: providing sinusoidal input/output waveforms, bidirectional power flow, controllable input power factor as well as compact design due to the absence of a bulky electrolytic capacitor. The MCs topologies are classified into two types: Direct matrix converter (DMC) and indirect matrix converter (IMC) [1]. The IMC topology as shown in Fig. 1 is able to produce the input and output waveforms with the same performances as the DMC topology, and also has more advantages, such as simpler commutation and clamp circuit, an option to reduce the number of power switches for low-cost applications [2].

On the other hand, common-mode voltage (CMV) problem is a limitation of the MCs as other pulse width modulation (PWM) converters. The CMV and its high *dv/dt* have been reported as a main source of motor winding failures and motor bearing damages. Several methods have been proposed to reduce the CMV for MCs [3], [4]. Although most of previous methods can reduce the CMV, output performance of MC is deteriorated; it is usually known as a trade-off between CMV reduction and output waveform quality.

In order to overcome the drawbacks of the conventional CMV-SVM methods, a new SVM method based on the near state PWM technique is proposed in this paper. The proposed SVM method can reduce the peak CMV to 42% compared to other methods, and it can also improve the output waveform quality by minimizing the output current ripple of the IMC.

2. Proposed SVM Method

As shown in Fig. 1, the IMC topology is composed of two decouple stages: Rectifier stage and inverter stage. The rectifier stage consists of six bidirectional switches, while the inverter stage is a traditional two-level voltage source inverter with six unidirectional switches. In order to generate balanced and sinusoidal input and output waveforms, the rectifier stage and inverter stage are modulated individually using SVM technique. In each stage, the SVM technique produces a combination of active vectors and zero vectors to synthesize a reference vector. After determining the applied vectors and their duty cycles, the switching pattern of the IMC synchronizes the switching states from both stages so that a correct balance of the input currents and the output voltages is obtained for each switching period.

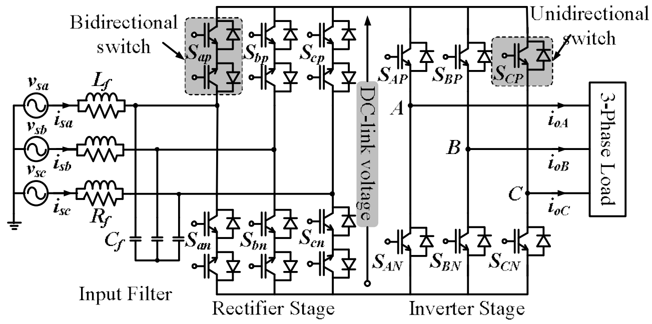

Fig. 1. IMC topology.

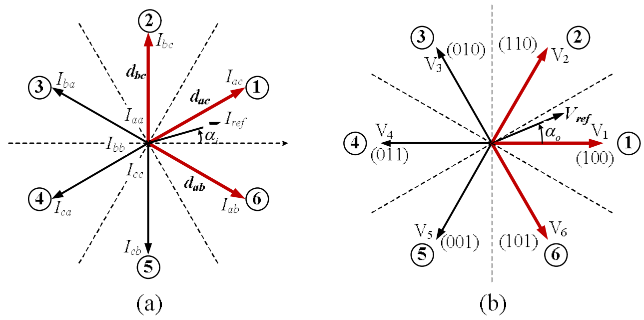

Fig. 2. Space vector diagram of (a) rectifier stage and (b) inverter stage.

In order to reduce the CMV for the IMC, non-zero state approaches are applied to control the inverter stage, i.e. only active vectors are used to generate the desired output voltage. Among non-zero state approaches, the near state PWM approach is preferred to others due to its advantageous, such as smaller total harmonic distortion (THD) of the line-to-line output voltage and low switching losses. The principle of the near state PWM technique uses three nearest active vectors to the reference output voltage vector to synthesize the reference output voltage vector. Assume that the desired output voltage is located in sector 1 $(-\pi/6 \le \alpha_o \le \pi/6)$, three active vectors V_6, V_1 and V_2 are selected as depicted in Fig. 2(a). Hence, the corresponding duty cycles d_6, d_1 and d_2 are calculated as follows:

$$
\begin{aligned}
d_6 &= 1 - \frac{3V_{oref}}{2\overline{V}_{dc}}\cos(\alpha_o) - \frac{\sqrt{3}V_{oref}}{2\overline{V}_{dc}}\sin(\alpha_o) \\
d_1 &= -1 + \frac{3V_{oref}}{\overline{V}_{dc}}\cos(\alpha_o) \\
d_2 &= 1 - d_6 - d_1
\end{aligned}
\tag{1}
$$

where α_o is the phase angle of desired output voltage V_{oref}.

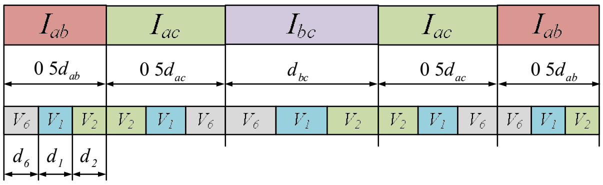

Fig. 3. Switching pattern of the IMC.

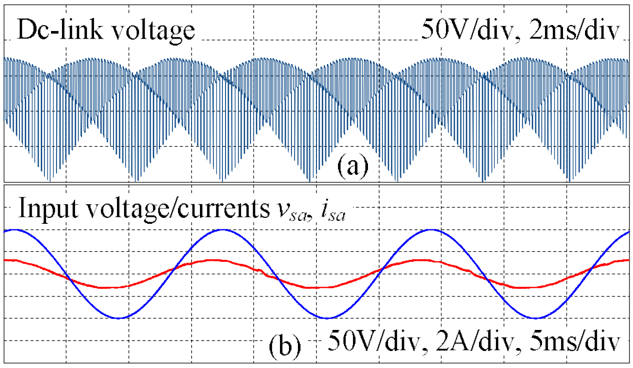

Fig. 4. Waveforms of (a) dc-link voltage and (b) input voltage/current.

In the rectifier stage, three-vector modulation scheme is used to control the desired input current and generate a positive dc-link voltage. Fig. 2(b) shows the space vector diagram for the rectifier stage. In each sector, three active current vectors are utilized the reference current vectors, instead of two active vectors as in conventional method. The duty cycles of three active vectors are determined as follows:

$$\begin{aligned} d_{ab} &= 1 - m_i \sin(\alpha_i + \pi/6) \\ d_{ac} &= -1 + \sqrt{3} m_i \cos(\alpha_i - \pi/6) \\ d_{bc} &= 1 - m_i \cos(\alpha_i) \end{aligned} \tag{2}$$

where m_i is the rectifier stage modulation index and α_i is the angle between the reference current vector and the real axis.

The switching pattern of IMC shown in Fig. 3 is based on the combination of the switching states of both rectifier and inverter stage. The duty cycles are given by:

$$\begin{aligned} d_{6ab} &= d_6.d_{ab}\ ; \quad d_{1ab} = d_1.d_{ab}\ ; \quad d_{2ab} = d_2.d_{ab} \\ d_{6ac} &= d_6.d_{ac}\ ; \quad d_{1ac} = d_1.d_{ac}\ ; \quad d_{2ac} = d_2.d_{ac} \\ d_{6bc} &= d_6.d_{bc}\ ; \quad d_{1bc} = d_1.d_{bc}\ ; \quad d_{2bc} = d_2.d_{bc} \end{aligned} \tag{3}$$

3. Simulated Results

In order to evaluate the proposed SVM method, some simulations are carried out with a three-phase *R-L* load using PSIM 9.0 software. Fig. 4 shows the waveforms of dc-link voltage, input phase voltage and filtered input current. Fig. 5 shows that the three-phase output currents are balanced and sinusoidal, and the output phase voltage is a three-level voltage. Fig. 6 shows the CMV of the IMC with the proposed SVM method. As we can see, the peak value of CMV is 57.7 V, which corresponds to $1/\sqrt{3}$ of the input phase voltage magnitude, i.e. this method is able to reduce the CMV as other reduced CMV-SVM methods for IMC.

In order to evaluate the improvement of the output current quality of the proposed SVM method compared to the previous methods, the THD of the output current is depicted in Fig. 7. The THD of the output current acquired with the proposed SVM method is smaller than those achieved with other reduced CMV-SVM methods. Thus, we can say that the output current ripple of the IMC is minimized with the proposed SVM method.

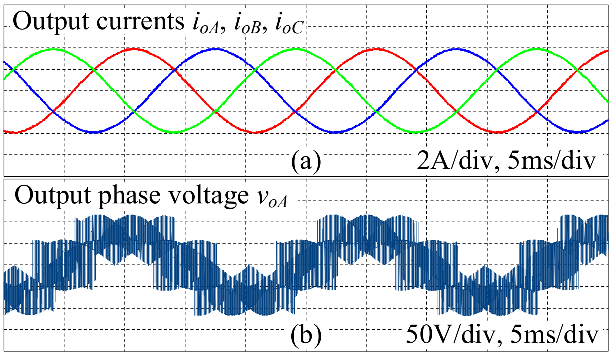

Fig. 5. Waveforms of (a) three-phase output currents and (b) output phase voltage

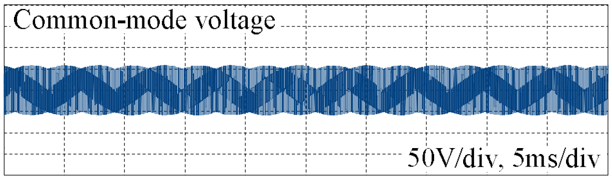

Fig. 6. Waveforms of CMV.

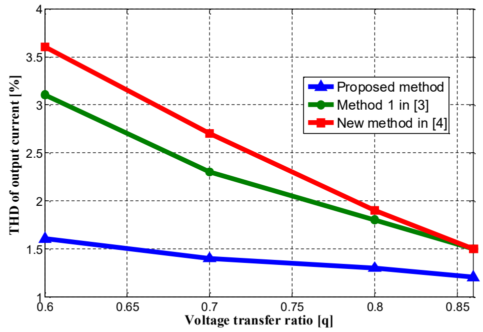

Fig. 7. Comparison results in THD of output current.

4. Conclusions

This paper presents a new SVM method that can reduce the CMV as well as minimize the output current ripple for an IMC. The proposed SVM method is based on three-vector modulation scheme for the rectifier stage along with the non-zero state modulation strategy for the inverter stage of the IMC. In the proposed method, the CMV is reduced and the output current ripple is also minimized compared to other CMV reduction methods. Simulated results are provided to demonstrate the effectiveness of the proposed method.

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