Three Modulation Modes of SVM for AC-AC Matrix Converter

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Abstract-- **People usually research modulation mode 3 of SVM for matrix converter discussed in this paper. Actually, other different modulation modes of SVM for matrix converter are worth studying. Two novel modulation modes are put forward for matrix converter for the first time in this paper, expanding its modulation modes of SVM. First, SVM for matrix converter is described. Then the 3 modulation modes of SVM for matrix converter are discussed carefully. Third, the simulation model is set up for each modulation mode. Finally, not only the flexibility of these three modulation modes is verified but also some important creative conclusions are obtained by simulation experiments. The former two modulation modes put forward in this paper are obviously prior to the mode 3 which is often studied for matrix converter, which could be a theoretically important creativity for matrix converter. They are worthy of further being studied.**

Keywords—matrix converter; SVM; modulation modes; modeling; simulation

I. INTRODUCTION

AC-AC matrix converter is an environmental protection converter with a novel topology and excellent transformation properties, whose successful applications and industrializations will be a landmark in the variable frequency industry in the world. In the study of modulation strategy for matrix converter, people often research the symmetrical modulation mode of SVM centered by one zero vector, i.e. the mode 3 discussed in this paper. Actually, there are other modulation modes of SVM for matrix converter. The modulation modes of SVM for common DC-AC converter gave me much enlightenment, making me think of other modulation modes of SVM for matrix converter. The aim of this paper lies in following three aspects. (1) it makes people acknowledge there are other methods of SVM for matrix converter; (2) as for the same reference vector in SVM for matrix converter, there could be more than one modulation modes to reach the same result; (3) it is necessary to analyze different modulation modes of SVM applied for matrix converter, which helps choose and optimize modulation strategy for matrix converter. Three-phase to three-phase matrix converter is only discussed in this paper.

II. SPACE VECTOR MODULATION FOR MATRIX CONVERTER

The topology of the matrix converter discussed in this paper is shown in Fig.1. Its SVM is fictitiously divided into a voltage-fed rectifier input stage and an inverter output stage, which are directly connected on the DC side shown in Fig.2. In these two stages, SVM method is applied for input current and output voltage space vectors respectively. Then the AC-AC converter is derived by eliminating the fictitious DC link.

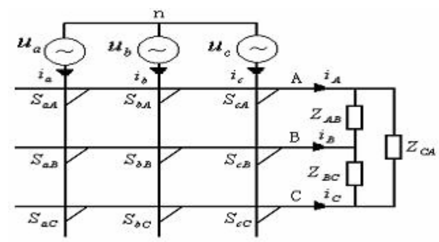

Fig. 1. The simplified topology of 3-3 matrix converter

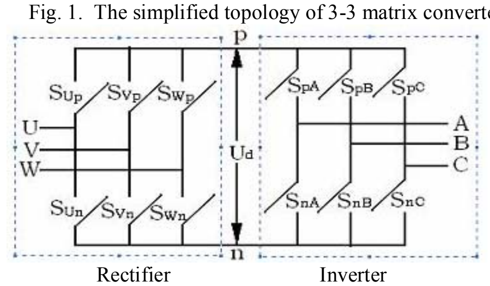

Fig.2. The equivalent topology of 3-3 matrix converter

A. SVM of DC-AC converter

Six power switches have eight possible switching combinations in the DC-AC converter. So there are 8 voltage space vectors defined by these 8 switching combinations, which consist of a uniform hexagon including six effective space vectors and two zero ones. The hexagon is divided into 6 equal sectors. The demanded output voltage space vector V_J located in a sector can be synthesized by the adjacent two effective vectors and one zero vector consisting of this sector according to SVM method. The basic output voltage space vectors and the corresponding switching states are represented in Fig.3.

Suppose U_J locates in the first sector which is made up of two adjacent effective vectors U_1, U_2 and a zero one U_Z (Z=0, 7), and U_J leads U_1 by θ_J, then U_J can be composed of U_1, U_2 and a zero one U_Z.

$$U_J = d_1 U_1 + d_2 U_2 + d_0 U_Z \tag{1}$$

$$d_1 = m_v \sin\left(60^\circ - \theta_J\right) \tag{2}$$

$$d_2 = m_v \sin\theta_J \tag{3}$$

$$d_0 = 1 - \left(d_1 + d_2\right) \tag{4}$$

Where d_1, d_2, d_0 are duty ratios of voltage vectors U_1, U_2 and a zero one U_Z respectively. If reference voltage U_J locates in other sectors, its modulation process is similar to that above.

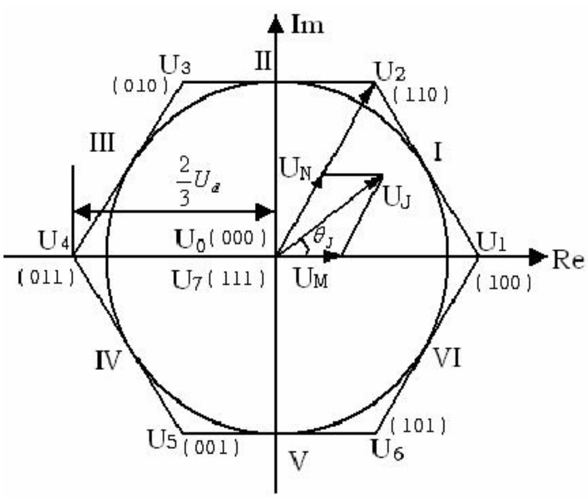

Fig.3. The composition of output voltage vectors and its switching states

It is concluded that the local-averaged output line-voltages can be synthesized by the switching states and duty ratios of the voltage vectors which constitute the sector in which the reference voltage vector locates.

B. *SVM for the AC-DC converter*

It is completely similar to the voltage space vector modulation of DC-AC converter. So the space vector modulated input currents can be obtained like that. Suppose reference current vector locates in the first sector.

$$I_J = d_1' I_1 + d_2' I_2 + d_0' I_0 \tag{5}$$

$$d_1' = m_c \sin\left(60^\circ - \theta_c\right) \tag{6}$$

$$d_2' = m_c \sin\theta_c \tag{7}$$

$$d_0' = 1 - \left(d_1' + d_2'\right) \tag{8}$$

Where d_1', d_2', and d_0' are duty ratios of I_1, I_2, I_0 respectively, I_J leads I_1 by θ_c, m_c is modulation index of input current. If reference voltage I_J locates in other sectors, its modulation process is also similar to that above.

C. *The comprehension for the former two*

The above-mentioned DC-link is imaginary, that is say the rectifying and inverting of matrix converter are conducted at the same time. Therefore the DC-link should be eliminated and the output-line voltages are obtained as follows.

$$\begin{bmatrix} \bar{u}_{AB} \\ \bar{u}_{BC} \\ \bar{u}_{CA} \end{bmatrix} = T_{VSI} T_{VSR}^T \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = T_{phL} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{9}$$

That is

$$U_o = T_{phL} U_i \tag{10}$$

Similarly

$$I_i = T_{phL}^T I_o \tag{11}$$

Where T_{phL} is the modulation function matrix for matrix converter,

$$U_o = \begin{bmatrix} u_{AB} & u_{BC} & u_{CA} \end{bmatrix}^T, \quad U_i = \begin{bmatrix} u_a & u_b & u_c \end{bmatrix}^T.$$

When T_{phL} is properly chosen, it is deduced as follows:

$$\begin{bmatrix} \bar{u}_{AB} \\ \bar{u}_{BC} \\ \bar{u}_{CA} \end{bmatrix} = \begin{bmatrix} d_1 + d_4 \\ -d_1 \\ -d_4 \end{bmatrix} \bullet u_{ab} + \begin{bmatrix} d_3 + d_4 \\ -d_3 \\ -d_4 \end{bmatrix} \bullet u_{ac} \tag{12}$$

formula (12) denotes that the output-line voltages can be composed by two input-line voltages.

$$d_1 = d_1 d_1' = m \sin\left(60^\circ - \theta_J\right) \sin\left(60^\circ - \theta_c\right) \tag{13}$$

$$d_2 = d_2 d_1' = m \sin\theta_J \sin\left(60^\circ - \theta_c\right) \tag{14}$$

$$d_3 = d_1 d_2' = m \sin\left(60^\circ - \theta_J\right) \sin\theta_c \tag{15}$$

$$d_4 = d_2 d_2' = m \sin\theta_J \sin\theta_c \tag{16}$$

$$d_0 = 1 - \left(d_1 + d_2 + d_3 + d_4\right) \tag{17}$$

Where d_0~d_4 are total duty cycles after composition.

$$t_i = d_i T_s \qquad (\iota = 0, 1, 2, 3, 4) \tag{18}$$

Where t_0~t_4 are the time switching on of 5 switch combinations respectively after the final composition of imaginary rectifying and inverting. The useful switch modulation table is deduced as represented in TABLE I.

III. MODULATION MODES OF SVM FOR MATRIX CONVERTER

Suppose reference input current vector and output voltage vector are in the sector one respectively. Three modulation modes of SVM for matrix converter are as follows. And modulation modes of other sector's combinations can similarly be obtained according to the table I.

(1) Modulation mode 1 of SVM for matrix converter: it is asymmetrical sequences. There are 8 times commutation in a switching period. There are 3 times commutation from one zero vector to another which is easier to realize. Two zero vectors act on for equal time respectively in a switching period. As is represented in Fig.4.

(2) Modulation mode 2 of SVM for matrix converter: it is symmetrical sequences. Although there are 12 times commutation in a switching period, there are 3 zero vectors to act in three different time respectively, which is more reasonable than that of one zero vector acting for the equal time T_0. Among them, 2 zero vectors act on 1/4 T_0, 1 zero vector act on 1/2 T_0. As is represented in Fig.5.

(3) Modulation mode 3 of SVM for matrix converter: it is symmetrical sequences. There are 10 times commutation and only one zero vector to act in a switching period. There are less switching frequency harmonics because of symmetry. As is represented in Fig.6.

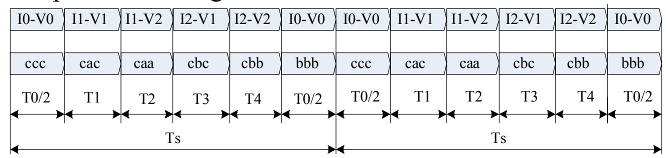

Fig.4. Modulation mode 1 of SVM for matrix converter

TABLE I
SWITCHING COMBINATIONS OF SVM FOR MATRIX CONVERTER

	V1				V2				V3				V4				V5				V6			
	α M	α N	β M	β N	α M	α N	β M	β N	α M	α N	β M	β N	α M	α N	β M	β N	α M	α N	β M	β N	α M	α N	β M	β N
I1	cac	caa	cbc	cbb	caa	cca	cbb	ccb	cca	cac	ccb	bcb	aca	acc	bcb	bcc	acc	aac	bcc	bbc	aac	cac	bbc	cbc
I2	cbc	cbb	aba	abb	ccb	ccb	abb	abb	ccb	bcb	aab	bab	bcb	bcc	bab	baa	bcc	bbc	abb	bba	bbc	cbc	bba	aba
I3	aba	abb	aca	acc	abb	aab	acc	aac	aab	bab	aac	cac	bab	baa	cac	caa	baa	bba	caa	cca	bba	aba	cca	aca
I4	aca	acc	bcb	bcc	acc	aac	bcc	bbc	aac	cac	bbc	cbc	cac	caa	cbc	cbb	caa	cca	cbb	ccb	cca	aca	ccb	bcb
I5	bcb	bcc	bab	baa	bcc	bbc	baa	bba	bbc	cbc	bba	aba	cbc	cbb	aba	abb	cbb	ccb	abb	aab	ccb	bcb	aab	bab
I6	bab	baa	cac	caa	baa	bba	caa	cca	bba	aba	cca	aca	aba	abb	aca	acc	abb	aab	acc	aac	aab	bab	aac	cac

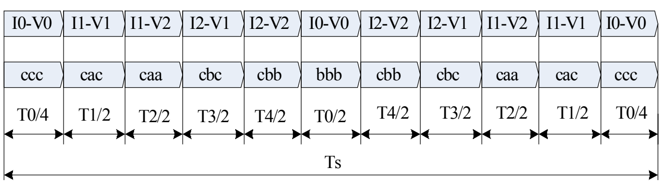

Fig.5. Modulation mode 2 of SVM for matrix converter

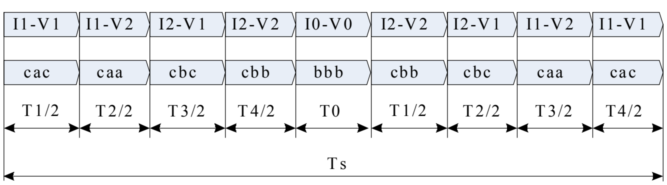

Fig.6. Modulation mode 3 of SVM for matrix converter

IV. VERIFICATION BY SIMULATION

Main parameters are set: input supply frequency is 50 Hz, output frequency is 120 Hz, modulation index is 0.85, switching frequency is 10kHz, load is three-phase RLC.

(1) A simulation model is set up for modulation mode 1 with S-function realizing the mode of SVM for matrix converter. And output voltage, output current and input current waveforms are obtained together with their respective spectrum analysis after the simulation model is operated. As are shown in Fig.7 to Fig.9.

According to the waveforms and their spectrum analysis, the modulation mode has been verified to be feasible. It has its own advantages.

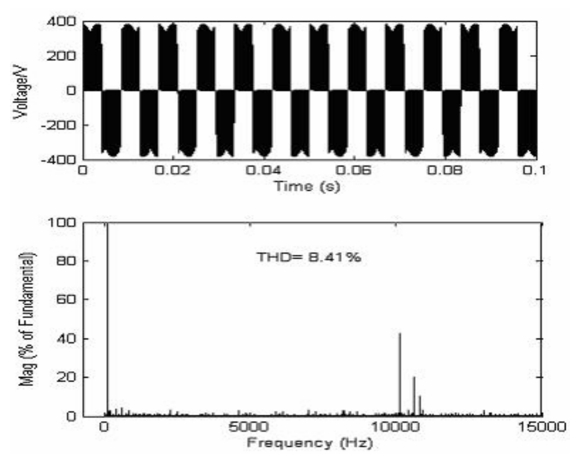

Fig.7. Output line voltage and its spectrum analysis

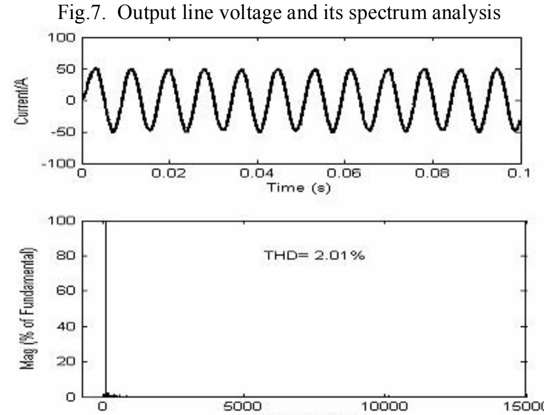

Fig.8. Output current and its spectrum analysis

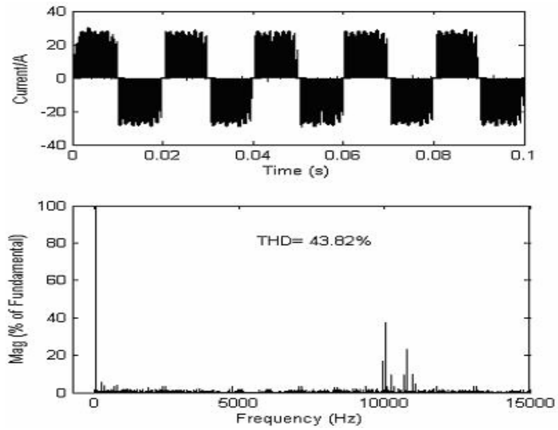

Fig.9. Input current and its spectrum analysis

(2) Modulation mode 2-3 is modeled by modifying S-function respectively. And output voltage, output current and input current waveforms are also obtained together with their respective spectrum analysis after the simulation model is operated. In modulation mode 2, the waveforms are presented in Fig.10 to Fig.12. In modulation mode 3, the waveforms are shown in Fig.13 to Fig.15.

According to the waveforms and their spectrum analysis, the modulation mode 2-3 has been verified to be feasible and also have its own advantages respectively. And commutation times and harmonic contents of these 3 modes are presented in table II.

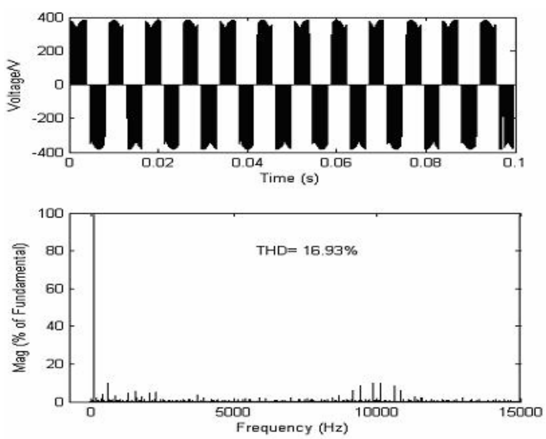

Fig.10. Output line voltage and its spectrum analysis

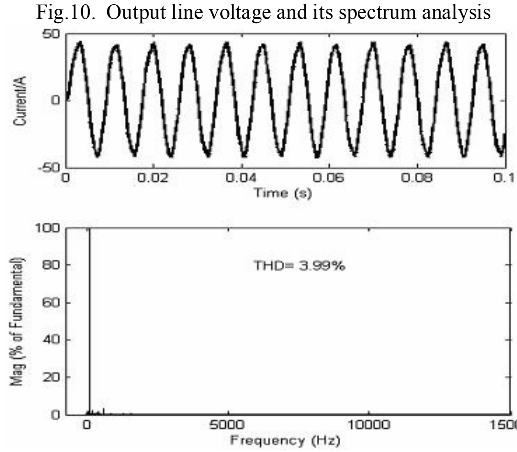

Fig.11. Output current and its spectrum analysis

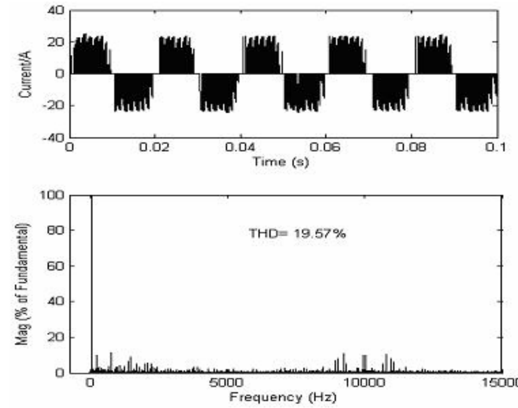

Fig.12. Input current and its spectrum analysis

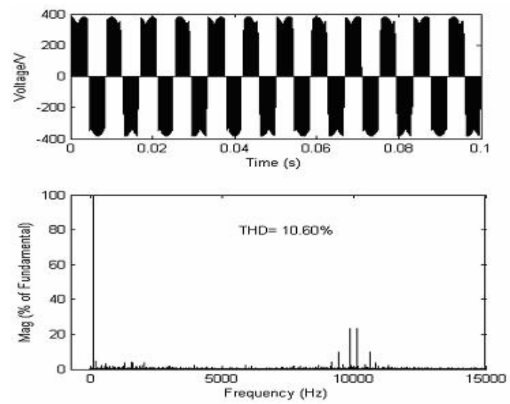

Fig.13. Output line voltage and its spectrum analysis

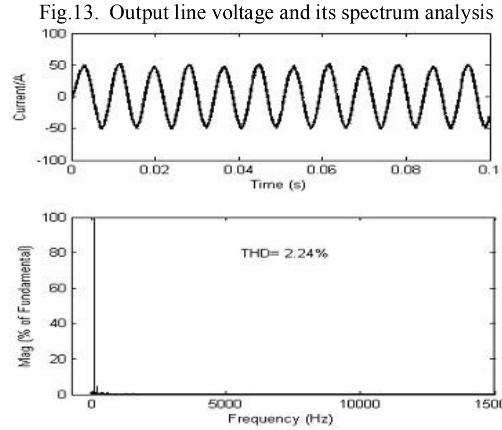

Fig.14. Output current and its spectrum analysis

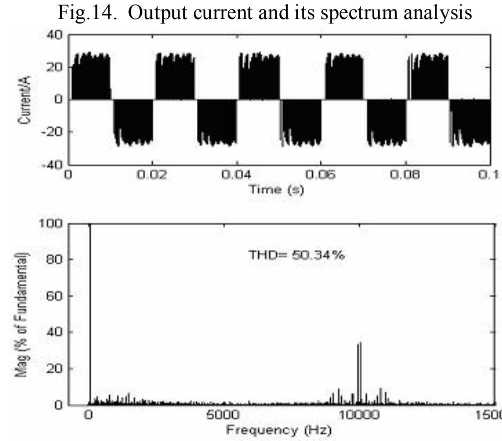

Fig.15. Input current and its spectrum analysis

TABLE II

COMMUTATION TIMES AND HARMONIC CONTENTS OF 3 KINDS OF MODES

	Mode 1	Mode 2	Mode 3
	8 times	12 times	10 times
Output voltage	8.41%	16.93%	10.60%
Output current	3.99%	3.99%	2.24%
Input current	43.82%	19.57%	50.34%

(3) Seen from the TABLE II, mode 1 is obviously prior to mode 3 which has often been studied for matrix converter being symmetrical in the center with one zero vector. As for mode 1, not only commutation times are fewer, but also harmonic contents are less. In addition, although mode 2 has more commutation times, its harmonic contents of input current are much more decreased compared with others. So these two novel modulation modes are worthy of being studied for matrix converter.

V. Conclusion

(1) Two novel modulation modes of SVM for matrix converter is put forward in this paper, as makes it's modulation range wider and more flexibilities and more choices.

(2) Mode 1 is obviously prior to mode 3 which has often been studied for matrix converter; mode 2 can decrease harmonic contents of input current to greater extent compared with others. Thus, these two novel modulation modes are worthy of being studied for matrix converter.

(3) These 3 modulation modes have their own advantages and disadvantages. They can be selected to apply according to actual things.

VI. Acknowledgment

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VII. References

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VIII. Biographies

GUO Yougui was born in Hunan province, China, on April 4, 1968. He received the M. S. degree from the Xi’an Petroleum University, Shanxi China, in 1998, and the Ph.D. degree from the Central South University, Hunan China, in 2005. During the Ph.D. program, he contributed to the doctor’s degree paper “Research on control strategies and raising the voltage transfer ratio of AC-AC matrix converter “ and relative 3 projects about matrix converter as the first researcher and taking part in 2 national level projects. He is now an associate professor and doctor with some good experience in matrix converter modeling and simulation. His research jobs include developing the space vector modulation, double input line-to-line voltage composition, equivalent circuit model, voltage transfer ratio, DTC and other modulation strategies for matrix converter. He has five-year-old developing experience for matrix converter and Published 21 journal papers and 1 international conference paper closely relative to matrix converter as the first author. Among them, 8 ones are published in the first-level Chinese journals and 3 in Chinese kernel journals, 4 papers indexed by EI Compendex and 1 indexed by ISTP. He is currently with the College of Information and Engineering of Xiangtan University. His main research areas include matrix converter, other power converters, modulation techniques, computer control, et al.

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