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.

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 $\theta_{j}$, then $U_{j}$ can be composed of $U_{1}, U_{2}$ and a zero one $U_{Z}$.
\[ U_j = d_1U_1 + d_2U_2 + d_0U_3 \]  
\[ d_1 = m_c \sin(60^\circ - \theta_j) \]  
\[ d_2 = m_c \sin \theta_j \]  
\[ d_0 = 1 - (d_1 + d_2) \]  

Where \( d_1, d_2, d_0 \) are duty ratios of voltage vectors \( U_1, U_2, \) and a zero one \( U_3 \) 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](image)

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.

\[ I_j = d'_1I_1 + d'_2I_2 + d'_0I_0 \]  
\[ d'_1 = m_c \sin(60^\circ - \theta_c) \]  
\[ d'_2 = m_c \sin \theta_c \]  
\[ d'_0 = 1 - (d'_1 + d'_2) \]  

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 \( \theta_c \). \( m_c \) is modulation index of input current. If reference voltage \( I_j \) locates in other sectors, its modulation process is also similar to that above.

\[ \left[ \begin{array}{c} \bar{u}_a \\ \bar{u}_b \\ \bar{u}_c \end{array} \right] = T_{phl} \left[ \begin{array}{c} u_a \\ u_b \\ u_c \end{array} \right] \]  

That is

\[ U_o = T_{phl}U_i \]  

Similarly

\[ I_i = T_{phl}^T I_o \]  

Where \( T_{phl} \) is the modulation function matrix for matrix converter,

\[ U_o = [u_{AB} \ u_{BC} \ u_{CA}]^T, \ U_i = [u_a \ u_b \ u_c]^T. \]

When \( T_{phl} \) is properly chosen, it is deduced as follows:

\[ \left[ \begin{array}{c} \bar{u}_a \\ \bar{u}_b \\ \bar{u}_c \end{array} \right] = \left[ \begin{array}{c} d_1 + d_4 \\ -d_1 \\ -d_4 \end{array} \right] \bullet u_{AB} + \left[ \begin{array}{c} d_3 + d_4 \\ -d_3 \\ -d_4 \end{array} \right] \bullet u_{BC} \]  

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

\[ d_1 = d_1d'_1 = m \sin(60^\circ - \theta_j) \sin(60^\circ - \theta_c) \]  
\[ d_2 = d_2d'_1 = m \sin \theta_j \sin(60^\circ - \theta_c) \]  
\[ d_3 = d_3d'_2 = m \sin(60^\circ - \theta_j) \sin \theta_c \]  
\[ d_4 = d_2d'_2 = m \sin \theta_j \sin \theta_c \]  
\[ d_0 = 1 - (d_1 + d_2 + d_3 + d_4) \]  

Where \( d_0-d_4 \) are total duty cycles after composition.

\[ t_i = d_iT_s \quad (t=0, 1, 2, 3, 4) \]

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.

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.
(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.
(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

The authors gratefully acknowledge the contributions of L. Huber, D. Borojevic, F. Blaabjerg, and Dehong Xu (Zhejiang University, China) for their work on the original version of this document.

VII. REFERENCES


