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The Reduction of Common-Mode Voltage in Matrix Converter without Using Zero Space Vector

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영상태 벡터를 사용하지 않는 매트릭스 컨버터의 공통모드 전압 저감에 관한 연구

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ABSTRACT

This paper proposes a modified space-vector pulse width modulation (PWM) strategy which can restrict the common-mode voltage for three-phase to three-phase matrix converter and still keep sinusoidal input and output waveforms and unity power factor at the input side. The proposed control method has been developed based on contributing the appropriate space vectors instead of using zero space vectors. The advantages of this proposed method is to reduce the peak value of common-mode voltage to 42% beside the lower high harmonic components as compared to the conventional SVM method. Hence, the new table is also presented with the new space vector rearrangement. Furthermore, the voltage transfer ratio is unaffected by the proposed method. A simulation of the overall system has been carried out to validate the advantages of the proposed method.

1. INTRODUCTION

In two recent decades, as the need to increase the quality and the efficiency of the power supply and the power usage, three phase matrix converter becomes a modern energy converter and has emerged as one of the best energy conversion substitution which fulfills all the requirements of the conventionally used rectifier/ dc link/ inverter structures. Some advantages of the matrix converter can be seen as follows: the use of a compact voltage source, providing sinusoidal voltage with variable amplitude and frequency beside the adjustable input power factor from power supply side. As shown in Fig. 1, matrix converter has the simple topology and allows a compact design due to the lack of dc-link capacitor for energy storage.

The common-mode voltage produced by modern converters has been reported as a main source of early motor winding failure and bearing deterioration. The most common cause of this bearing damage is caused by the motor shaft voltages and the associated bearing currents resulted from dielectric breakdown and bearing lubricant. Since there exists the leakage current flow through parasitic capacitor between the stator core and stator winding, the life time of winding insulation is reduced and then, the motor insulation is easily broken beside the EMI is generated. As a result, it is very important to reduce common-voltage itself or to limit this voltage within certain bounds.

Due to the advantages of three-phase to three-phase matrix converter, several methods have been proposed to reduce the common-mode based on analyzing the indirect space vector modulation (ISV-PWM) rectifier-inverter system

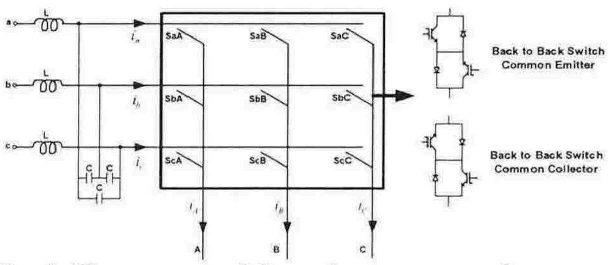

Fig. 1. The structure of three-phase ac-ac matrix converter

in [3], [5], [6]. However, this paper proposes a new modulation strategy which can restrict valuably to 42% the peak value of common-mode voltage beside lower high harmonic component compared to the conventional SVM method. This SVM technique is based on using a couple of active space vector instead of zero space vectors to complete the rest of sampling period.

2. CONVENTIONAL DIRECT SVM ANALYSIS

2.1 Direct SVM analysis of matrix converter

Three-phase matrix converter module includes nine bidirectional switches and the structure of three-phase ac-ac matrix converter is shown in Fig. 1. There are 27 switching configuration states, which means 27 possible space vectors can be used to control IM and can be split respectively into 3 groups. However, group III is not useful, only 18 non-zero space vectors in group I ($\pm 1, \pm 2, \ldots, \pm 9$) and 3 zero space vectors in group II ($0_a, 0_b, 0_c$), as shown in Table 1, can be usually employed in the current control techniques for matrix converter such as space vector modulation, DTC methods in [1][2][4][7].

In the conventional SVM algorithm for matrix converter, beside the inherent capability to achieve full control of output voltage vector, to obtain the unity input power factor, the direction of the input current space vector $\vec{i}_i$ must be the same of the input voltage space vector $\vec{v}_i$. The voltage sectors and current sectors are defined as in Fig. 2. In order to explain the modulation, reference will be made in Fig. 2(a) and (b), where the output voltage vector $\vec{v}_o$ and the input current vector $\vec{i}_i$ are assumed to be both lying in sector 1 ($-\pi/6 \le \alpha_i \le \pi/6$ and $0 \le \alpha_o \le \pi/3$) without missing the generality of As explained in [1], the following switching configurations -7, +9, -3, +1 and zero switching configurations are used to obtain the reference voltage and current vector. The entire SVM table is shown in Table 2 in which the duty cycle for each chosen vectors are computed as follows

Table1 Switching configurations used in SVM algorithm

Group	Switching configuration list	Switches on	V_o	α_o	I_i	β_i
I	+1	SaA SbB SbC	$2/3v_{ab}$	0	$2/\sqrt{3}i_A$	$-\pi/6$
	-1	SbA SaB SaC	$-2/3v_{ab}$	0	$-2/\sqrt{3}i_A$	$-\pi/6$
	+2	SbA ScB ScC	$2/3v_{bc}$	0	$2/\sqrt{3}i_A$	$\pi/2$
	-2	ScA SbB SbC	$-2/3v_{bc}$	0	$-2/\sqrt{3}i_A$	$\pi/2$
	+3	ScA SaB SaC	$2/3v_{ca}$	0	$2/\sqrt{3}i_A$	$7\pi/6$
	-3	SaA ScB ScC	$-2/3v_{ca}$	0	$-2/\sqrt{3}i_A$	$7\pi/6$
	+4	SbA SaB SbC	$2/3v_{ab}$	$2\pi/3$	$2/\sqrt{3}i_B$	$-\pi/6$
	-4	SaA SbB SaC	$-2/3v_{ab}$	$2\pi/3$	$-2/\sqrt{3}i_B$	$-\pi/6$
	+5	ScA SbB ScC	$2/3v_{bc}$	$2\pi/3$	$2/\sqrt{3}i_B$	$\pi/2$
	-5	SbA ScB SbC	$-2/3v_{bc}$	$2\pi/3$	$-2/\sqrt{3}i_B$	$\pi/2$
	+6	SaA ScB SaC	$2/3v_{ca}$	$2\pi/3$	$2/\sqrt{3}i_B$	$7\pi/6$
	-6	ScA SaB ScC	$-2/3v_{ca}$	$2\pi/3$	$-2/\sqrt{3}i_B$	$7\pi/6$
	+7	SbA SbB SaC	$2/3v_{ab}$	$4\pi/3$	$2/\sqrt{3}i_C$	$-\pi/6$
	-7	SaA SaB ScC	$-2/3v_{ab}$	$4\pi/3$	$-2/\sqrt{3}i_C$	$-\pi/6$
	+8	ScA ScB SbC	$2/3v_{bc}$	$4\pi/3$	$2/\sqrt{3}i_C$	$\pi/2$
	-8	SbA SbB ScC	$-2/3v_{bc}$	$4\pi/3$	$-2/\sqrt{3}i_C$	$\pi/2$
	+9	SaA SaB ScC	$2/3v_{ca}$	$4\pi/3$	$2/\sqrt{3}i_C$	$7\pi/6$
	-9	ScA ScB SaC	$-2/3v_{ca}$	$4\pi/3$	$-2/\sqrt{3}i_C$	$7\pi/6$
II	0_a	SaA SaB SaC	0	-	0	-
	0_b	SbA SbB SbC	0	-	0	-
	0_c	ScA ScB ScC	0	-	0	-

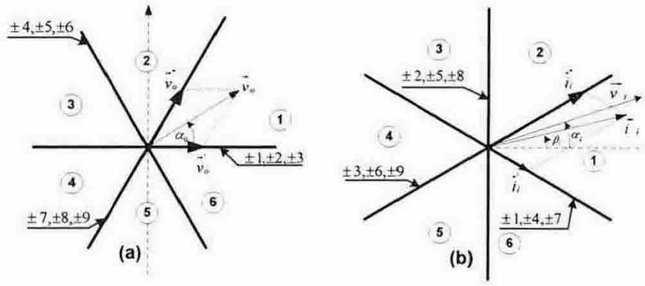

Fig. 2 (a) The output line-to-neutral voltage vector (b) and the input line current vector the analysis.

$$\delta_1 = \frac{2}{\sqrt{3}} q \sin\left[\alpha_o - (k_v - 1)\frac{\pi}{3}\right] \sin\left[\frac{\pi}{6} - \left(\alpha_i - (k_i - 1)\frac{\pi}{3}\right)\right] \quad (1)$$

$$\delta_2 = \frac{2}{\sqrt{3}} q \sin\left[\alpha_o - (k_v - 1)\frac{\pi}{3}\right] \sin\left[\frac{\pi}{6} + \left(\alpha_i - (k_i - 1)\frac{\pi}{3}\right)\right] \quad (2)$$

$$\delta_3 = \frac{2}{\sqrt{3}} q \sin\left[k_v \frac{\pi}{3} - \alpha_o\right] \sin\left[\frac{\pi}{6} - \left(\alpha_i - (k_i - 1)\frac{\pi}{3}\right)\right] \quad (3)$$

$$\delta_4 = \frac{2}{\sqrt{3}} q \sin\left[k_v \frac{\pi}{3} - \alpha_o\right] \sin\left[\frac{\pi}{6} + \left(\alpha_i - (k_i - 1)\frac{\pi}{3}\right)\right] \quad (4)$$

$$\delta_5 = 1 - \frac{2}{\sqrt{3}} q \sin\left[\alpha_o - (2k_v - 1)\frac{\pi}{6}\right] \sin\left[\alpha_i - (k_i - 1)\frac{\pi}{3}\right] \quad (5)$$

where $q = V_o / V_i$ is voltage transfer ratio, k_v k_i are respectively the voltage and current sectors

From equation (5), the interval time for zero switching configuration δ_o must be not negative. Hence, the well-known maximum voltage transfer ratio of matrix converter is $\sqrt{3}/2$.

2.2 Common-mode voltage analysis

Fig. 3 shows a matrix converter connected to an induction motor. It is common to connect the induction motor to neutral of the secondary side of the input transformer and motor frame to the same ground. The basic equations are

$$\begin{aligned} v_A - v_{sg} &= Ri_A - L\frac{di_A}{dt} \\ v_B - v_{sg} &= Ri_B - L\frac{di_B}{dt} \\ v_C - v_{sg} &= Ri_C - L\frac{di_C}{dt} \end{aligned} \quad (6)$$

Assume that the induction motor has the symmetric equivalent resistance and inductance. As a result, $i_A + i_B + i_C = 0$ and the leakage current is zero, the common-mode voltage is

$$v_{sg} = \frac{v_A + v_B + v_C}{3} \quad (7)$$

Regardless of the ac source, as can be easily seen that the common mode voltage only depends on the switching state of matrix converter. From Table 1, the possible common-mode voltage v_{sg} is given as follows

$$v_{sg} = \begin{cases} \frac{1}{3} v_{phase} & , Group I \\ v_{phase} & , Group II \\ 0 & , Group III(/used) \end{cases} \quad (8)$$

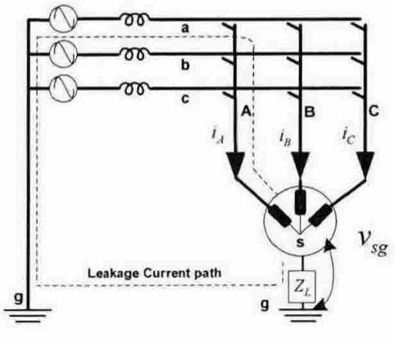

Fig. 3. Path of motor leakage current

3. A PROPOSED SVM STRATEGY

In order to explain about the proposed SVM technique, the switching configurations of matrix converter used in SVM techniques is assumed that the current and the voltage of matrix converter are entirely constant within one sampling period, T_s. Hence, instead of using the zero space vector at the end of each sampling period, two opposite space vectors are used with the same interval time to contribute to the voltage and current reference vector. However, with the proposed SVM method, the couple of vector selected should have the smallest magnitude between 18 vectors in group I.

For example, when both reference vectors $\vec{v}_o$ and $\vec{i}_i$ are located in sector 1 as previous assumption. Beside the four active switching configurations are chosen −7, +9, +1, −3, two more active switching configurations used are +2 and −2 as shown in Fig. 4. It can be verified that there is only one switching configuration sequence characterized by only one switching commutation for each switching change. that is the following sequences in a half side of switching pattern, +2, −3, +9, −7, +1, −2 following duty cycles $\delta_5/2$, δ_4, δ_2, δ_1, δ_3 and $\delta_5/2$ as shown in Fig. 6. This leads the switching commutations to 10 in each sampling period.

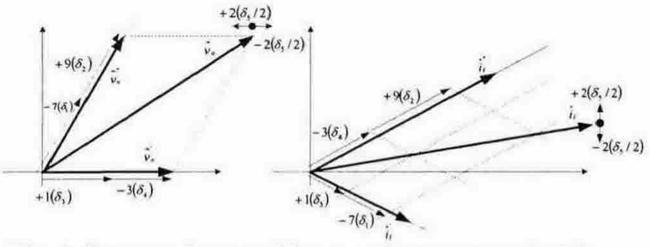

Fig. 4 Output voltage and input current vector principle

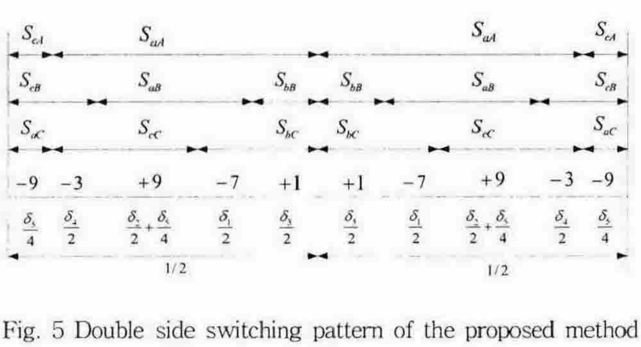

Fig. 5 Double side switching pattern of the proposed method

Table 2 Switching table for the half side of the proposed SVM method

Cur. Sec. ⇒	Sector 1 or Sector 4						Sector 2 or Sector 5						Sector 3 or Sector 6					
⇓Vol. Sec.	$\delta_5/4$					$\delta_5/4$	$\delta_5/4$					$\delta_5/4$	$\delta_5/4$					$\delta_5/4$
Sector 1 or Sector 4	***+2***	-3	+9	-7	+1	***-2***	***+7***	-8	+2	-3	+9	***-7***	***+3***	-1	+7	-8	+2	***-3***
Sector 2 or Sector 5	***-5***	+4	-7	+9	-6	***+5***	***-7***	+9	-6	+5	-8	***+7***	***-6***	+5	-8	+7	-4	***+6***
Sector 3 or Sector 6	***+5***	-6	+3	-1	+4	***-5***	***+1***	-2	+5	-6	+3	***-1***	***+6***	-4	+1	-2	+5	***-6***
Sector 4 or Sector 1	***-8***	+7	-1	+3	-9	***+8***	***-1***	+3	-9	+8	-2	***+1***	***-9***	+8	-2	+1	-7	***+9***
Sector 5 or Sector 2	***+8***	-9	+6	-4	+7	***-8***	***+4***	-5	+8	-9	+5	***-4***	***+9***	-7	+4	-5	+8	***-9***
Sector 6 or Sector 3	***-2***	+1	-4	+6	-3	***+2***	***-7***	+6	-3	+2	-6	***+4***	***-3***	+2	-5	+4	-1	***+3***

Note: The duty cycle for each active vector is a half of the same duty cycle as in table 2

4. SIMULATION RESULTS

Some simulation results are carried out by Matlab/Simulink to validate the proposed SVM method. The system is simulated with three-phase balanced R-L load (42 Ω, 10mH) and power source 380[V] 60Hz with 2KHz sampling frequency. Reference with the output $f_{out}=50\ Hz$ $q=0.841$ in Fig 6 and $f_{out}=100\ Hz$ $q=0.454$ in Fig. 7. As can be easily seen that the peak value of v_{sg} in the conventional SVM is 311[V] corresponding to $V_{phase(peak)}$ while the peak value of v_{sg} in the proposed method is 179[V] corresponding to $1/3\,V_{phasetophase(peak)}$. The reduction of common-mode voltage leads to

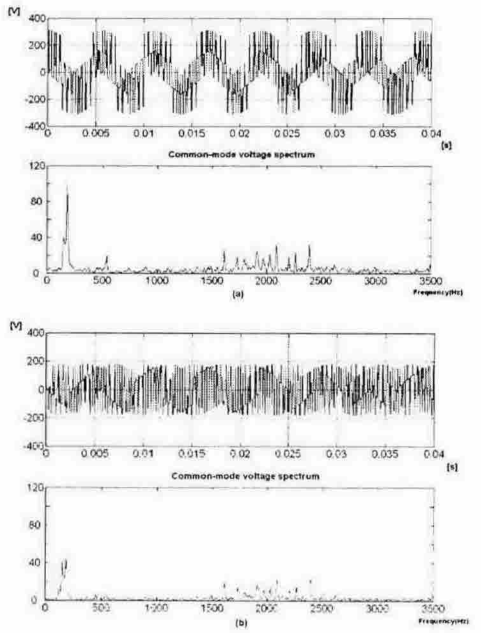

Fig. 6 Waveform and harmonic spectrum of v_{sg} with $f_o=60[Hz]$ $q=0.841[Hz]$ (a) Conventional SVM (b) Proposed SVM

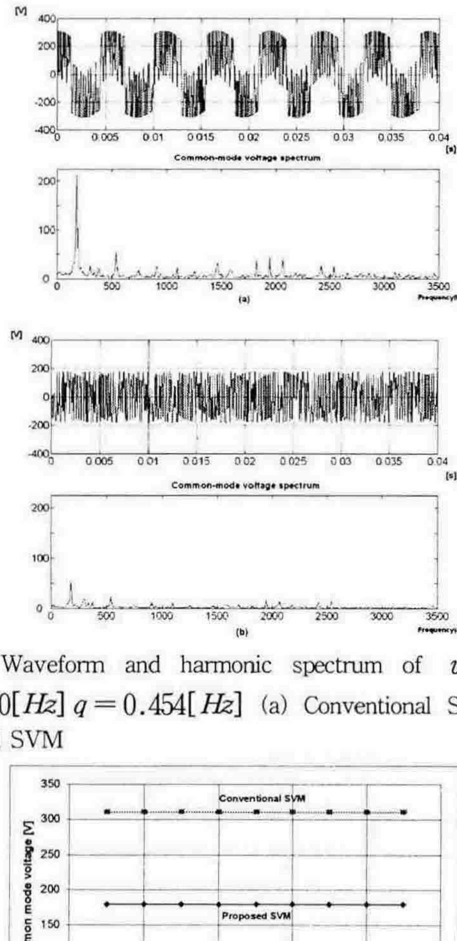

Fig. 7 Waveform and harmonic spectrum of v_{sg} with $f_o=100[Hz]$ $q=0.454[Hz]$ (a) Conventional SVM (b) Proposed SVM

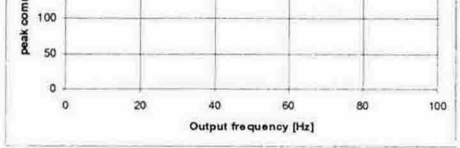

Fig. 8. Peak value of v_{sg} comparison

the reduction of the induced motor shaft voltage and possible degradation to its bearings [5]. The common-mode voltage decreases 42% regardless of transfer ratio modulation index, q and output frequency f_o, of the matrix converter in Fig 8

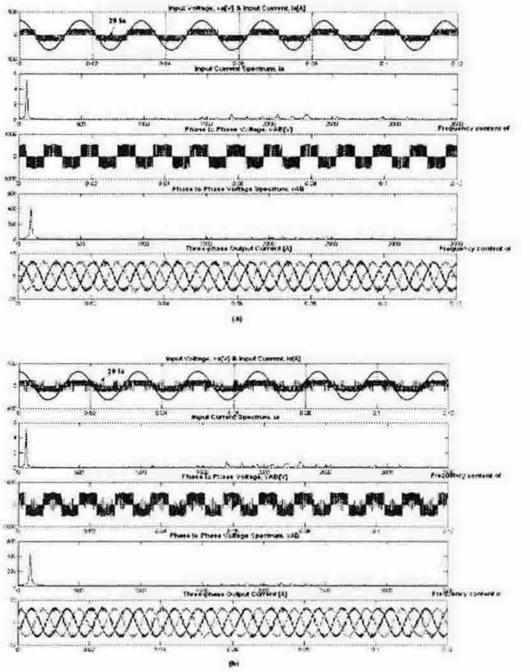

Fig. 9 Signal analysis of matrix converter with $f_o=50$ $q=0.841$ under (a) Conventional SVM (b) Proposed SVM

Furthermore, in Fig. 6 and 7, the harmonic spectrum of v_{sg} shows that the proposed SVM method has the lower high harmonics components compared to the conventional SVM method. In Fig. 9, all the signals related to current matrix converter are displayed under the reference output, $f_{out}=50Hz$ $q=0.841$. As can be seen that the unity power factor is available at the power supply side with the proposed SVM method and the conventional SVM method.

5. CONCLUSION

This paper has proposed a new SVM strategy which can restrict the peak value of common-mode voltage to 42% and lower high harmonic components compared to the conventional SVM method. It has been archived by replacing the zero space vectors by a couple of appropriate vectors and rearranging the suitable switching configuration in each sampling period. Thus, the voltage transfer ratio is unaffected by the proposed strategy. Some simulation has been carried out to validate the proposed method. With this proposed SVM method, only some extra C-code for software program is needed without any extra hardware.

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