산업기술연구(강원대학교 산업기술연구소 논문집), 제21권 A호, 2001.
Journal of Industrial Technology, Kangwon Nat'l Univ.,Korea, No. 21 A, 2001.

폴전압을 이용한 SVPWM 인버터의 과변조 기법

An Overmodulation Strategy for SVPWM Inverter Using Pole Voltage

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Abstract

In this paper, a novel overmodulation strategy for space-vector PWM(SVPWM) inverters to utilize dc link voltage fully is presented. The proposed strategy uses the concept of SVPWM based on the zero sequence signal(offset voltage) injection principle. So, by modifying the pole voltage simply, the linear control of inverter output voltage over the whole overmodulation range can be achieved easily. The proposed strategy is so simple that its practical implementation is easy. The validity of the proposed strategy is confirmed by the experimental results.

키워드 : *공간벡터전압변조방식, 과변조 기법*
Keywords : SVPWM(Space Vector Pulse Width Modulation), Overmodulation

1. INTRODUCTION

Voltage Source PWM Inverters being capable of converting dc to ac power are widely used in several applications like ac motor drive, UPS. Of the various Pulse Width Modulation(PWM) methods, Space Vector PWM(SVPWM) is the preferred approach due to its wider linear voltage range, low harmonic distortion waveform characteristics and the fixed switching frequency[1]. However, the voltage utilization of SVPWM method can not exceed 90.7% of the six-step value.

To utilize the dc bus voltage fully, several overmodulation techniques have been proposed [2-5]. One group of these techniques is the graphical method that selects a trajectory tracing out the hexagon to provide average output voltage equal to the reference voltage[2-4]. Another is the voltage gain linearization method that compensates the reduced voltage gain[5]. These methods are so complex that their implementation is not easy.

This paper proposes an novel overmodulation strategy for SVPWM inverter. The proposed strategy uses the concept of the zero sequence signal injection method equivalent of the conventional SVPWM method[6]. And by modifying the pole voltage simply, the proposed method can, maintain the linearity between the output voltage and the reference voltage until six-step mode. Since, switching times of each inverter switch can be calculated directly from the pole voltage, The proposed strategy is implemented easily. Applied to constant V/f controlled induction motor drive, the proposed

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method allows smooth transitions through the entire operating range up to six-step operation.

2. SVPWM Method

2.1 Zero-sequence signal injection method for SVPWM

The various PWM methods for three phase inverter of Fig. 1 can be implemented by the zero-sequence signal injection method as shown in Fig. 2[6].

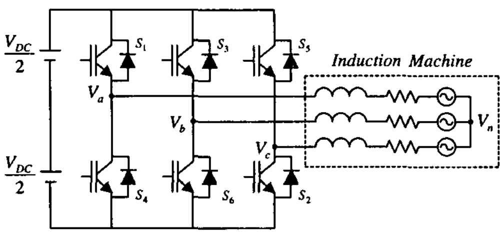


Fig. 1 PWM inverter

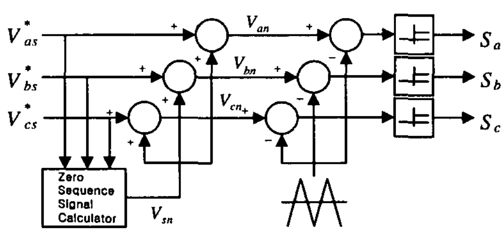


Fig. 2 PWM method employing the zero sequence signal injection principle

The pole voltage(V_{an}, V_{bn}, V_{cn}), phase voltage(V_{as}, V_{bs}, V_{cs}) and a offset voltage V_{sn} (or zero-sequence signal) are denoted as shown in Fig.1, and their relationships are

$$V_{an} = V_{as} + V_{sn} \tag{1}$$

$$V_{bn} = V_{bs} + V_{sn} \tag{2}$$

$$V_{cn} = V_{cs} + V_{sn} \tag{3}$$

In the three phase PWM Inverter, there is one degree of freedom that V_{sn} can be selected as any value on the condition that

$$-\frac{V_{dc}}{2} \le V^*_{an},\ V^*_{bn},\ V^*_{cn} \le \frac{V_{dc}}{2} \tag{4}$$

that is,

$$-\frac{V_{dc}}{2} - V^*_{\min} \le V_{sn} \le \frac{V_{dc}}{2} - V^*_{\max} \tag{5}$$

where,

$$V^*_{\max} = \max(V^*_{as}, V^*_{bs}, V^*_{cs}) \tag{6}$$

$$V^*_{\min} = \min(V^*_{as}, V^*_{bs}, V^*_{cs}) \tag{7}$$

Therefore, numerous PWM methods can be established by selecting the offset voltage V_{sn} appropriately. SVPWM method can be established by selecting V_{sn} as

$$V_{sn} = -\left(\frac{V^*_{\max} + V^*_{\min}}{2}\right) \tag{8}$$

The offset voltage, phase voltage and pole voltage in the SVPWM method are shown in Fig. 3. Adding the offset voltage to the given reference phase voltage, the pole voltage can be obtained. Switching times of each inverter switch can be calculated directly from the pole voltage.

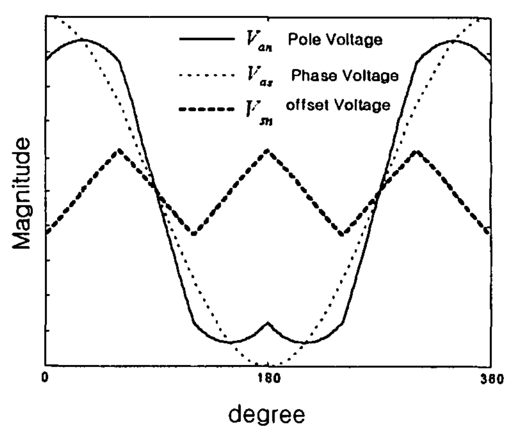


Fig. 3 Modulation waveform of SVPWM

The maximum of the magnitude of pole voltage can not exceed $V_{dc}/2$ in the linear voltage range. Therefore, the maximum phase voltage is limited to $V_{dc}/\sqrt{3}$ that is 90.7% of the six-step value.

2.2 Overmodulation in SVPWM

In the overmodulation region, the magnitude of the reference pole voltage becomes larger than $V_{dc}/2$. But the output pole voltage is limited to $V_{dc}/2$ as shown in Fig. 4. The offset voltage V_{sn} in the overmodulation region is modified as (10) when the minimum-phase-error PWM method is used[7].

$$V_{sn} = -\frac{V_{dc}}{2}\left(\frac{V^*_{max}+V^*_{min}}{V^*_{max}-V^*_{min}}\right) \quad (9)$$

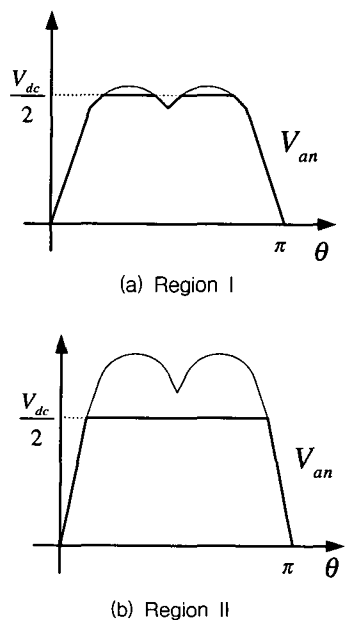


Fig. 4 Voltage waveform of SVPWM in the overmodulation region

When the pole voltage is saturated, the output voltage fundamental component is less than the reference voltage. It means that the voltage linearity is lost in the overmodulation region. So, in this paper, a simple scheme to the output voltage fundamental component equal to the reference voltage is proposed.

The overmodulation region is divided into two subregion, region I and region II. The saturated modulation wave is different in each subregion as shown in Fig. 4. Region I and II begin at modulation index M_i = 0.907 and 0.951, respectively. The modulation index is defined as

$$M_i = \frac{V_1}{2V_{dc}/\pi} \quad (10)$$

where, V_{dc} is dc link voltage and V_1 is the fundamental component magnitude of the line to neutral inverter output voltage.

3. Proposed Overmodulation Strategy

This paper proposes an novel overmodulation strategy for SVPWM based on the offset voltage injection principle as mentioned above. In the proposed method, to provide the linearity of the output voltage and the reference voltage over the whole overmodulation range, the pole voltage is modified.

3.1 Overmodulation Region I
(0.906≤ M_i ≤0.951)

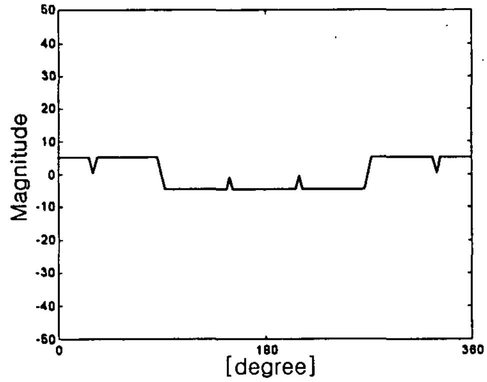
In the region I, to achieve the output voltage fundamental component equal to the reference voltage, the pole voltage is modified by adding the new offset voltage V_{sn}' as

$$V_{an} = V_{as} + V_{sn}' \quad (11)$$

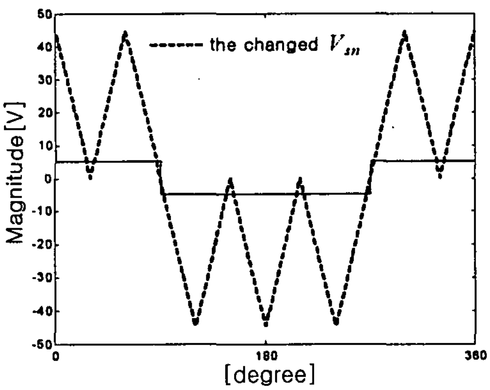
This new offset voltage V_{sn}' can be obtained by adding the compensation voltage V_{comp} to the orignal offset voltage V_{sn} as

$$V_{sn}' = V_{sn} + V_{comp} \quad (12)$$

Fig. 5(a) shows the compensation voltage V_{comp} that is made of a square wave and the offset voltage of which polarity is changed according to polarity of a square wave as shown in Fig. 5(b). The magnitude of the square wave is determined by the Fourier analysis.



(a) Compensation voltage



(b) new offset voltage and square wave

Fig. 5 The compensation voltage in overmodulation Region I

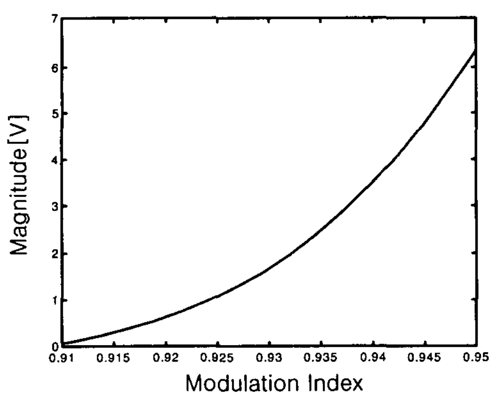


Fig. 6 the magnitude of compensation voltage

Fig. 6 shows the magnitude of square wave in terms of the modulation indexes. After compensation, the pole voltage and phase voltage are shown in Fig. 7.

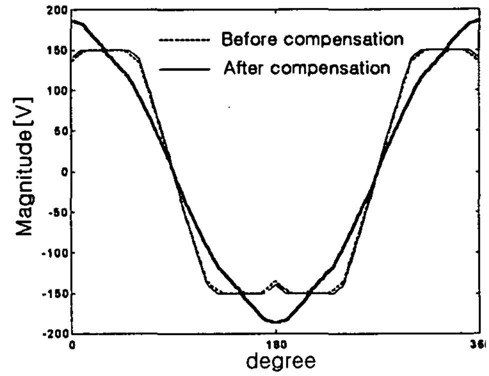


Fig. 7 Voltages in the overmodulation region I

3.2 Overmodulation Region II

(0.951 ≤ M_i ≤ 1)

In the region II, the compensation voltage is only a square wave as shown in Fig. 8. The magnitude of square wave is also determined by the Fourier analysis like the region I.

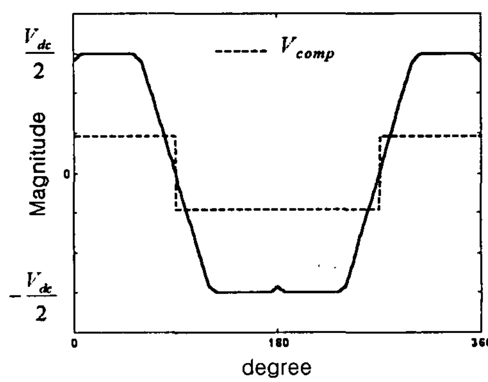


Fig. 8 The compensation voltage in overmodulation region II

Fig. 9 shows the magnitude of square wave in terms of the modulation indexes. After compensation, pole voltage and phase voltage are shown in Fig. 10. With this simple overmodulation method, the linearity of the output voltage and the reference voltage until six-step mode can be maintained. The switching times of each inverter switch can be calculated directly from the modified pole voltage in region I and region II. Therefore, it is implemented easily.

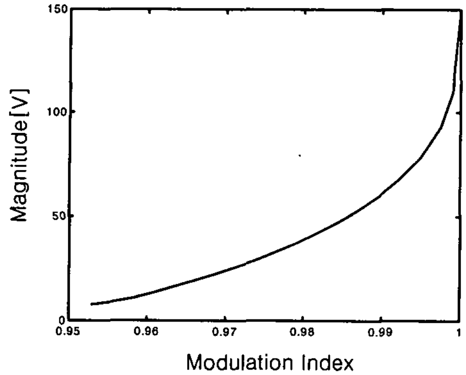


Fig. 9 the magnitude of compensation voltage

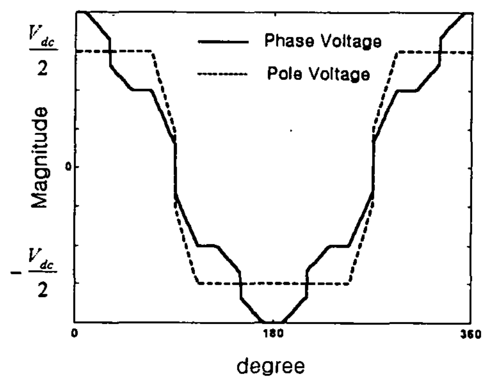


Fig. 10 Voltage waveform in the overmodulation region II

4. Experimental Results

The experiment was carried out to verify the proposed scheme for an IGBT inverter and an induction motor as shown in Fig 11. The switching frequency is 5[kHz] and the DC link voltage is 300[V]. TMS320C31 DSP is used as the main control processor.

Fig. 12 shows the compensation voltage for several modulation indexes. Fig. 13 and 14 show the pole voltage and the phase voltage by the proposed scheme, respectively. (a) and (b), (c) and (d) are voltages of region I and region II, respectively. Since the gate signal on times t_a , t_b , t_c of inverter switches can be calculated directly from the pole voltage, the proposed scheme is implemented easily.

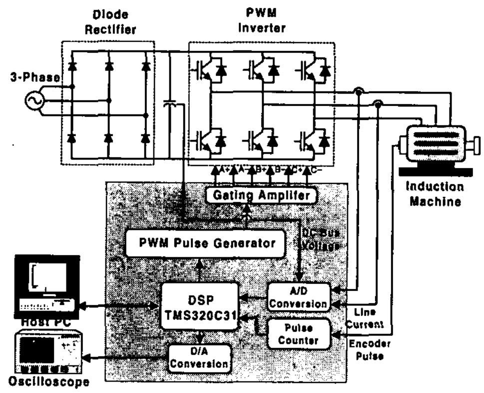
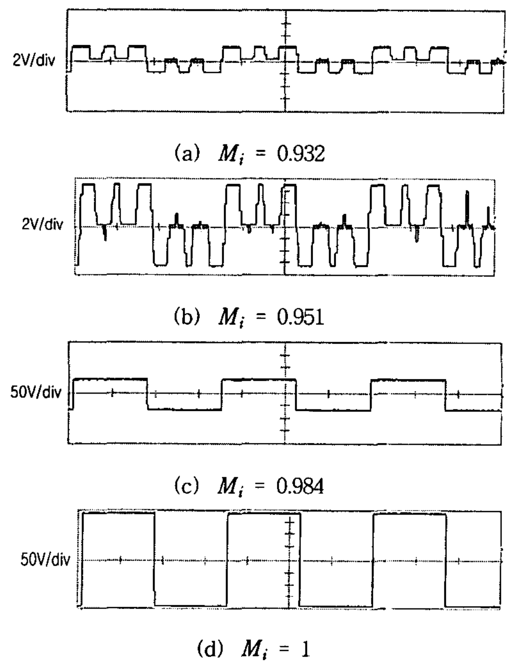


Fig. 11 Experimental System



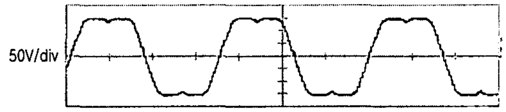
(a) M_i = 0.932

(b) M_i = 0.951

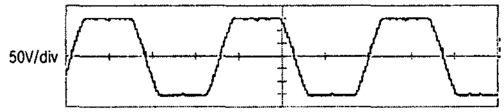
(c) M_i = 0.984

(d) M_i = 1

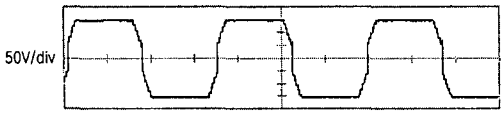
Fig. 12 Compensation voltage (5ms/div)



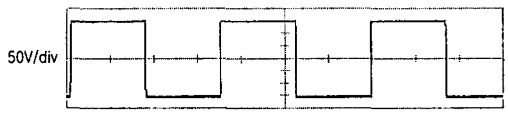
(a) M_i = 0.932



(b) M_i = 0.951

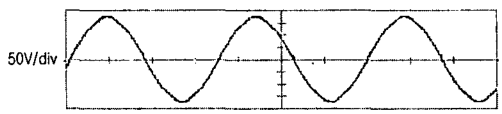


(c) M_i = 0.984

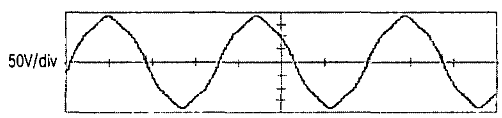


(d) M_i = 1

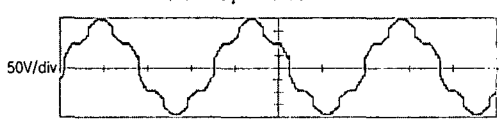
Fig. 13 Pole voltage (5ms/div)



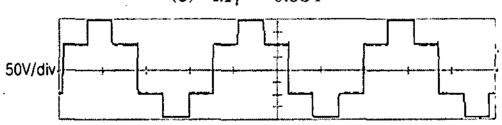
(a) M_i = 0.932



(b) M_i = 0.951

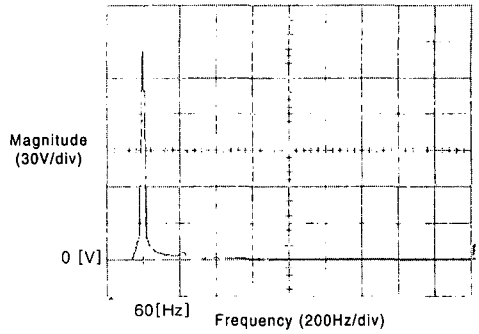


(c) M_i = 0.984

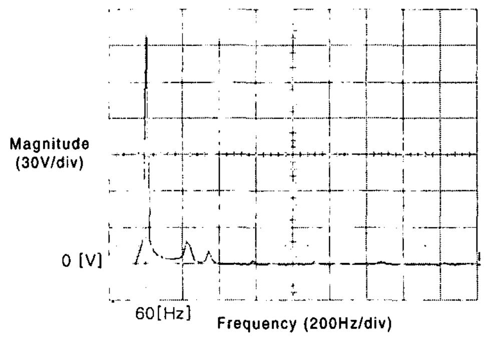


(d) M_i = 1

Fig. 14 Phase voltage (5ms/div)



(a) M_i = 0.951 (181.6[V])



(b) M_i = 0.984 (188[V])

Fig. 15 spectrum of the output voltage

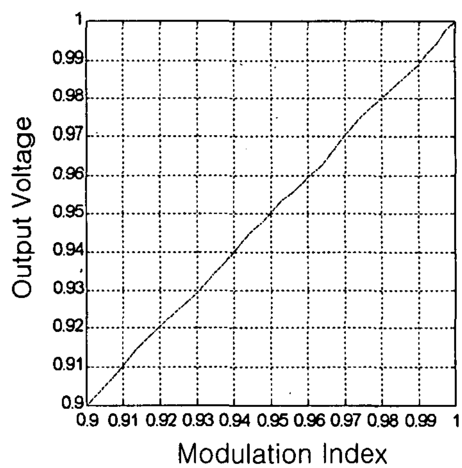


Fig. 16 the output voltage

Fig. 15 shows FFT spectrum of the output voltages. It is shown that the fundamental component of output voltage equals well to the reference voltage. Fig. 16 shows that by the proposed scheme, the linearity between the output voltage(normalized by $2V_{dc}/\pi$) and the reference until six-step mode can be maintained. Applied to constant V/f controlled induction motor drive, the proposed method allows smooth transitions through the entire operating range up to six-step operation.

5. Conclusion

In this paper, a novel overmodulation strategy for space-vector PWM inverters was proposed. The proposed strategy uses the concept of SVPWM based on the offset voltage injection principle. By modifying the pole voltage simply, the overmodulation scheme that is implemented easily can be obtained. And it can provide easily a linear relationship between the reference voltage and output voltage up to six-step mode. The validity of the proposed scheme was confirmed by experiment.

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