THE CONTROL OF THIRD HARMONICS INJECTED PWM INVERTER IN OVER MODULATION MODE

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ABSTRACT - A new modified command voltage of the third harmonics injected PWM inverter is proposed in overmodulation mode. By analyzing the relationship between the modulation index and the peak of the fundamental component of the modified reference voltage, we can settle the problem in over modulation mode without iteration. Then we can increase the maximum fundamental component of the third harmonics injected PWM inverter comparative to six-step inverter continuously in over modulation mode.

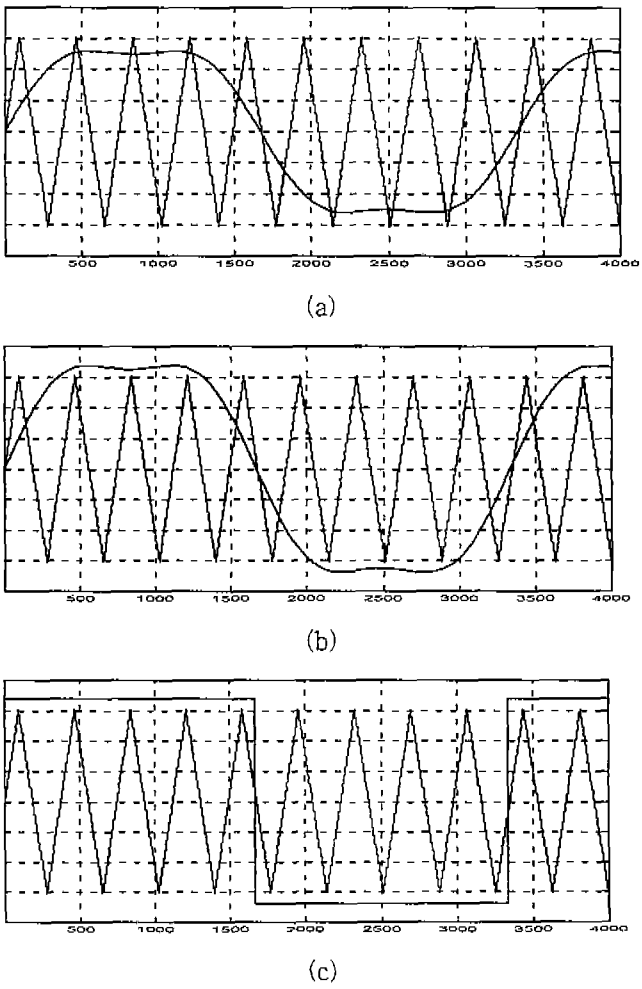
1. INTRODUCTION

The use of voltage source PWM inverter is increasing because of its advantages. But voltage source PWM inverter has its defect because it can't provide maximum voltage compared with six-step inverter. To increase the linear region of the control voltage, the third harmonics injected PWM inverter or voltage space vector PWM inverter can be used. But in any case, the PWM inverter finally goes to the over modulation mode. In case of the sine PWM voltage source inverter, there are some research to increase the maximum command voltage by reshaping the reference voltage in over modulation mode.[1],[2]

To use the maximum voltage of PWM inverter, the inverter should be run in the six-step mode after all. In over modulation mode the output voltage is not directly proportional to the modulation index. Therefore, the modulation index should be increased iteratively. In that case, the necessary time to control the output voltage is increased. To overcome the increased control time, the modulation index can be modified in advance.[3],[4] And to delay the overmodulation mode, the third harmonics injected PWM method can be used.[8],[9].

The voltage space vector PWM inverter extend the linear region of the control voltage and delay the over modulation mode. And there are some research in over modulation mode about voltage space vector PWM inverter.[5],[6]

The third harmonics injected PWM inverter has a extended linear region compared with sine PWM inverter. The third harmonics injected PWM inverter is simpler to implement than voltage space vector PWM inverter, and has a linear region comparable to voltage space vector PWM inverter.



(a)

(b)

(c)

Fig. 1 The mode of the third harmonics injected PWM inverter
(a) linear mode
(b) overmodulation mode
(c) six-step mode

But, in case of third harmonics injected PWM inverter, there is no study in over modulation mode.

Therefore in this study, the third harmonics injected PWM inverter which is superior to sine PWM inverter, is analyzed in over modulation mode. The modified command voltage is developed to retain the fundamental component in the third harmonics injected PWM inverter in overmodulation mode. And the simulation results demonstrate that this modified command voltage can be used for on-line control of ac drives.

2. OVER MODULATION MODE OF THE THIRD HARMONICS INJECTED PWM INVERTER

The third harmonics injected PWM is simple to implement than any other PWM method such as voltage space vector PWM. It have the advantage and can be used to large capacity but simple inverter.

The third harmonics injected PWM method, like any other PWM, lost the volt-sec in over modulation mode. The output voltage is less than the command voltage.

The command voltage and effective modulating waveform for third harmonics injected PWM in over modulation mode are shown in Fig. 2. There are two kind of mode in over modulation mode in third harmonics injected PWM.

If the modulation index is over $1.1547(2/\sqrt{3})$ and below 1.2(mode I), the command voltage waveform cross the unit line(peak of the triangle) twice, and if the modulation index is over 1.2(mode II), once. In the mode I, there are three region of the command voltage, and in the mode II, there are two region.

If the command voltage is over the peak of the triangle, the loss of effective output voltage is occurred.

To compensate the loss of volt-sec in the over modulation mode, modified command voltage is developed. To have a PWM which is linear over the full range of operation, the fundamental component of modified command voltage must be equal to the modulation index, that is,

$$V_{com}^{m} = \mathrm{Mi} \qquad (1)$$

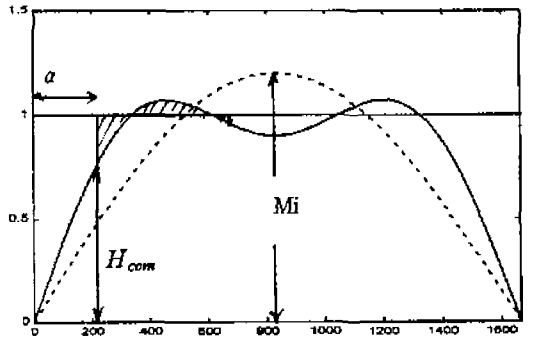
The fundamental component of modified command voltage is calculated by Fourier analysis, and to have the condition of (1), the angle α is calculated. The modified command voltage have the unit reference from the α. to have the equal value of fundamental component with the original command voltage at that modulation index.

And the height of command voltage Hcom is calculated. The modified command voltage, fundamental component of the modified command voltage and H in two kind mode of over modulation mode are defined as followings and they are indicated in Fig 2.

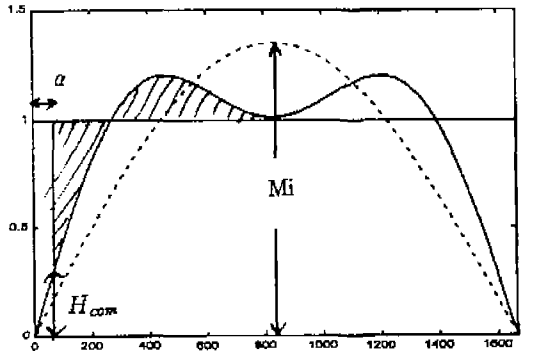
Over Modulation Mode I:

$$\begin{aligned} V_{com}^{m} &= \mathrm{Mi}\ (\sin(\theta) + 1/6\ \sin(3\theta)) \quad 0 < \theta < \alpha \\ &= 1 \qquad\qquad\qquad\qquad\qquad\quad \alpha < \theta < 2\pi/3-\alpha \\ &= \mathrm{Mi}\ (\sin(\theta) + 1/6\ \sin(3\theta)) \quad 2\pi/3-\alpha < \theta < \pi/2 \end{aligned} \qquad (2)$$

The fundamental component of (2) and H_{com} are as followings.



(a)



(b)

Fig. 2 Over modulation mode of the third harmonics injected PWM inverter
(a) 1.1547 < modulation index < 1.1547
(b) 1.2 < modulation index < 1.2732

fundamental component of V_{com}^{m}

$$= \mathrm{Mi}\ (1/2\alpha - 5/24\ \sin(2\alpha) - 1/48\ \sin(4\alpha)) + 3/2\ \cos(\alpha) - \sqrt{(3)}/2\ \sin(\alpha)$$

+ Mi 1/2 ($-\pi/12 + 1/2\alpha$)
+ Mi 5/24 ($\sin(4\pi/3)\cos(2\alpha) - \cos(4\pi/3)\sin(2\alpha)$
+ Mi 1/48 ($\sin(8\pi/3)\cos(4\alpha) - \cos(8\pi/3)\sin(4\alpha)$ (3)

$$H_{com} = \text{Mi } (\sin(\alpha) + 1/6 \sin(3\alpha)) \quad (4)$$

Over Modulation Mode II:

$$V_{com}^{m} = \text{Mi } (\sin(\theta) + 1/6 \sin(3\theta)) \qquad 0 < \theta < \alpha$$

$$= 1 \qquad \alpha < \theta < \pi/2 \quad (5)$$

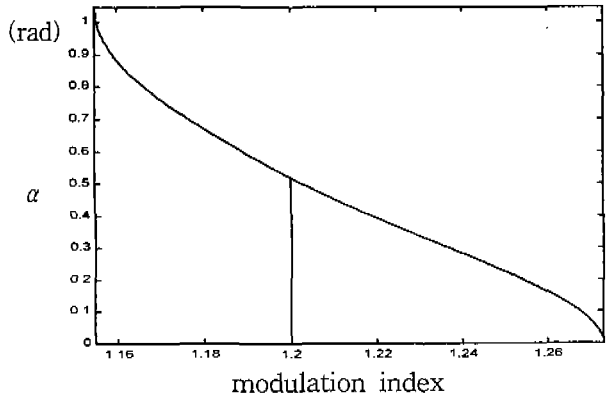


Fig. 3 Variation of angles of α versus modulation index Mi in third harmonics injected PWM

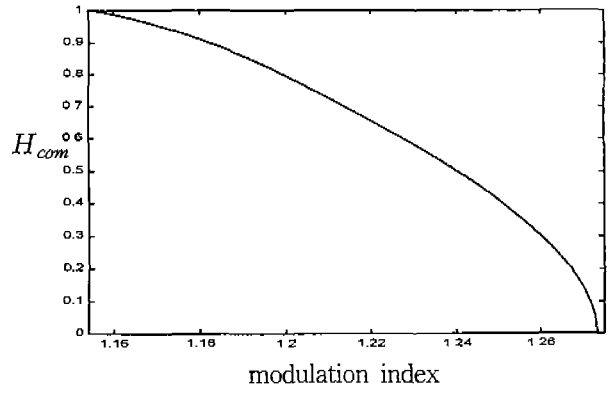


Fig.4 Variation of angles of control parameter H versus modulation index in third harmonics injected PWM

The fundamental component of (5) and H_{com} are as followings.

fundamental component of V_{com}^{m}

$$= \text{Mi } (1/2\alpha - 5/24 \sin(2\alpha) - 1/48 \sin(4\alpha)) \quad (6)$$

$$H_{com} = \text{Mi } (\sin(\alpha) + 1/6 \sin(3\alpha)) \quad (7)$$

4. SIMULATION RESULTS

The results of above analysis are shown in Fig. 3 and Fig. 4. The α is decreased as the modulation index increased. The trend of α versus the modulation index Mi is shown in Fig. 3, and the control parameter H versus Mi is shown in Fig. 4.

At Fig. 4, two kind of curve, one is when the modulation index is below the 1.2, and the other is when the modulation index is above the 1.2, is composed.

The simulation result of the method are shown in Fig. 5. The result are shown only in the over modulation mode when the modulation index is over 1.154. As a reference, the case of the original sine PWM is also shown. The fundamental component versus modulation index is appeared at three case.

As we can see in this figure, the fundamental component of sine PWM is not proportional to modulation index when the modulation index is over unity, and in the third harmonics injected PWM, it is not proportional to modulation index when the modulation index is over 1.1547.

fundamental component

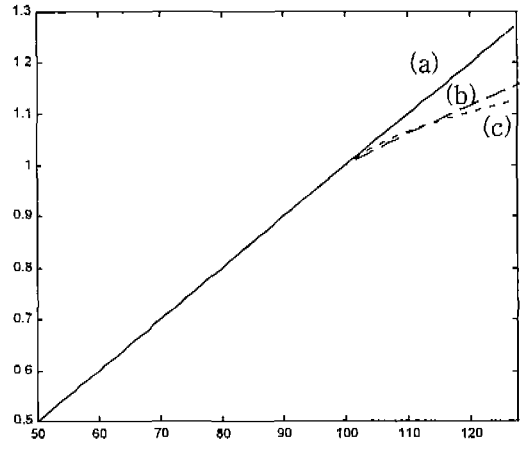


Fig. 5 Input/output relation of the third harmonics injected PWM

(a) modified third harmonics injected PWM
(b) original third harmonics injected PWM
(c) sine PWM

When the modified command voltage by this paper is applied, the fundamental component of the output voltage is linearly proportional to modulation index as in linear mode when the modulation index is below unity.

5. CONCLUSION

A new modified command voltage in the over modulation mode, at the third harmonics injected PWM inverter, is proposed. The modified command voltage compensate the non-linearity in the over modulation mode by equalizing the fundamental component of modified command voltage with the modulation index.

By that method, the modified command voltage carries the same fundamental component as carried by the unsaturated command voltage.

The third harmonics injected PWM has a linear region almost same as the voltage space vector PWM, but is simple to implement as the voltage space vector PWM, and have a extended linear region as the sine PWM, not so difficult to implement as sine PWM.

Therefore, with the modified third harmonics injected PWM, the advantage of the third harmonics injected PWM become larger.

6. REFERENCES

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