International Journal of Power Electronics and Drive System (IJPEDS)
Vol.1, No.1, September 2011, pp. 1~6
ISSN: 2088-8694

Hysteresis Current Control technique based on Space Vector Modulation for Active Power Filter

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Abstract

In this paper, the hysteresis current control (HCC) technique based on space vector modulation (SVM) for shunt active power filter (APF) is proposed. The switching control algorithms of the HCC based SVM manage to generate compensated current according to the reference current. Harmonics extraction is based on the instantaneous active and reactive power theorem in time domain by calculating the power compensation. A closed loop control system is carried out and the error current is the difference between the reference current which is obtained from the power compensation and the actual current needs to be injected back into the power grid. By implementing this control strategy, the APF manages to generate better compensated harmonics currents to the power grid.

Keywords: *active power filter, hysteresis current control, space vector modulation, Matlab/Simulink*

1. Introduction

The circuit structure of the APF as shown in Figure 1 [1].for the sake of analysis, first define a special switch logic function s_k :

$$s_k = \begin{cases} 1 \\ 0 \end{cases} \tag{1}$$

(k=a,b,c) s_k =1,the upper bridge arm turns on and the lower bridge arm turns off, when s_k =0 the lower bridge arm turns on and the upper bridge arm turns off. The equivalent resistance of the power switching losses could be labeled R_s and equivalent resistance of the filtering inductances R_l can be seen as a whole—R, Based on Kirchhoff 's laws, the equations are set up, as shown below.

$$\begin{cases} C\dfrac{\mathrm{d}v_{dc}}{\mathrm{d}t} = \sum\limits_{k=a,b,c} i_k s_k - i_L \\ L\dfrac{\mathrm{d}i_k}{\mathrm{d}t} + ri_k = e_k - v_{dc}\left(s_k - \dfrac{1}{3}\sum\limits_{j=a,b,c} s_j\right) \\ \sum\limits_{k=a,b,c} e_k = \sum\limits_{k=a,b,c} i_k = 0 \end{cases} \tag{2}$$

i_L — load current of DC side

2. Research Method

Hysteresis current control is a kind of instantaneous feedback control model, the basic idea is to compare the given current signal which is detected by the converter with actual input current signal [2]. If the actual current is more than the given value, then make it decreases by changing the switching state of the APF, and vice versa. So, the actual current does dentate changes around the instruction current waveform and hysteresis current control make the deviation within a certain range.

The system compares directive current signal with actual current signal, and make the deviation as the input of hysteresis comparator which generates the PWM signal to control the circuit switch on/off.

Space voltage vector describes the spatial distribution of the AC side phase voltage—(v_{a0}, v_{b0}, v_{c0}) in complex plane. The following formula can be obtained.

Received Jul 10th, 2011; Revised Aug 13th, 2011; Accepted Sep 8th, 2011

ISSN: 2088-8694

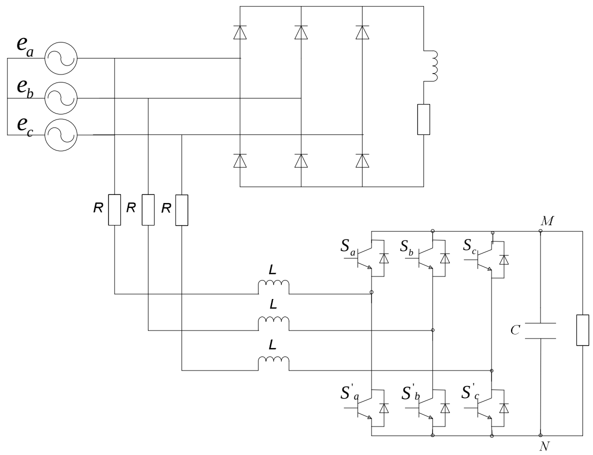

Figure 1. The circuit structure of the APF

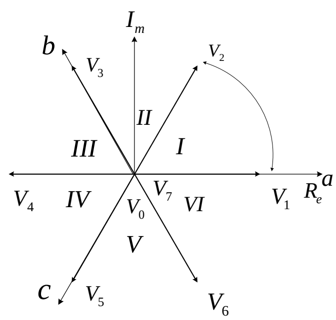

Figure 2.The distribution of Space voltage vector

The complex plane is divided into six fan-shaped areas by six space voltage vectors whose length are all $2v_{dc}/3$. For any space voltage vector V^* which is in the six fan-shaped area, can be synthesized by both sides space voltage vector of this sector.

Hysteresis current control is favored by domestic and foreign scholars with the advantages of easy to realize, dynamic response quickly and not sensitive to load parameters. However, due to the characteristics of three-phase hysteresis's independence and lack of coordination, the switch frequency is too high and the current error can't limit within the bandwidth. Space vector control method can achieve the optimal switch mode, reduced switch frequency; but this control method needs a lot of calculation and causes the time-delay of control easily which affect the response time of the current tracking. So it is necessary to put forward the control method combines hysteresis current control and SVPWM control, the new method has the advantages of both good current tracking and low switch frequency.

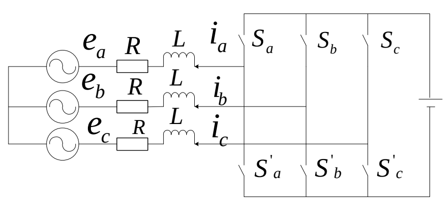

Figure 3. Topological structure

As shown in Figure 3, in the case of ignore the resistance of the ac voltage, the vector equation can be obtained

$$V = E + L\frac{\mathrm{d}I}{\mathrm{d}t} \quad (3)$$

V—output voltage vector of three-phase ac side
E—electromotive force vector of three-phase power grid
I— current vector of three-phase ac side

If the reference current vector is I^*, then the actual current error vector is ΔI

$\Delta I = I^* - I$ turn the into the simple formula $L\frac{\mathrm{d}\Delta I}{\mathrm{d}t} = E + L\frac{\mathrm{d}I^*}{\mathrm{d}t} - V$

In order to get the control equation of current error vector, the reference voltage space vector is defined as $V^*.V^* = L\frac{\mathrm{d}I^*}{\mathrm{d}t} + E \quad L\frac{\mathrm{d}\Delta I}{\mathrm{d}t} = V^* - V_k$ k=1,2,3…7

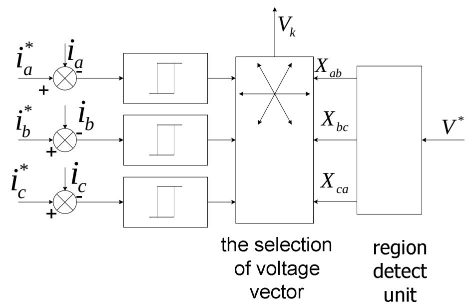

Figure 4. Hysteresis SVPWM current control principle diagram

Hysteresis SVPWM current control [3] is will dictate the current and feedback current through the retaining ring width hysteresis comparison, output corresponding unit, and through comparing the values of the states of the region detection instruction voltage vector by space voltage vector, finally, the output a suitable choice logic, thus make the three-phase current tracking instruction current rectifiers.

This control strategy outputs the corresponding the status values B_k (k=a, b, c) by the fixed width hysteresis comparison unit who compares the reference current I_k^* (k=a, b, c) with feedback current I_k (k=a, b, c) and outputs a appropriate V_k by space voltage vector choose logic unit.

Once the instruction voltage and current vector error are made certain, the location of vector space area is determined. In order to realize the current tracking control, a suitable three-phase voltage space vector V_k is selected. So the system makes the change ratio vector of the error current and vector of the error current in opposite directions.

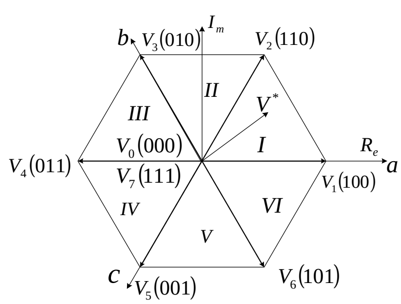

Figure 5. Area partition of V^*

If the width of the hysteresis is I_ω then the rules on how to select V_k can be categorized as follows:
Rule 1: when $\Delta I > I_\omega$, choose three-phase space voltage vector V_k, to make the corresponding $L\mathrm{d}\Delta I/\mathrm{d}t$ has the minimum component which is opposite to the error current vector ΔI, in order to make sure that the current vector ΔI limits the changing rate of the current in tracking the instructions, so as to inhibit current harmonic.
Rule 2: $\Delta I \le I_\omega$, the original V_k doesn't switch, it not only can limit the average switching frequency but also can increase stability of the SVPWM control method.

ISSN: 2088-8694

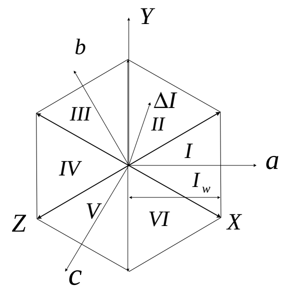

Figure 6. Area partition of ΔI

Thus, selection rules of space vector V_k can be obtained as table 1.

Table 1. Selection rules of space vector V_k

The area of V^*	The area of ΔI					
	I	II	III	IV	V	VI
I	V_1	V_2	V_2	$V_{0,7}$	$V_{0,7}$	V_1
II	V_2	V_2	V_3	V_3	$V_{0,7}$	$V_{0,7}$
III	$V_{0,7}$	V_3	V_3	V_4	V_4	$V_{0,7}$
IV	$V_{0,7}$	$V_{0,7}$	V_4	V_4	V_5	V_5
V	V_6	$V_{0,7}$	$V_{0,7}$	V_5	V_5	V_6
VI	V_1	V_1	$V_{0,7}$	$V_{0,7}$	V_6	V_6

The area of the vector ΔI is easy to be determined by determining the directional character of ΔI's components in the axes a, b and c. Define a function [4]

$$B_j = \text{sign}(\Delta i_j)\begin{cases} 1(\Delta i_j > I_w) \\ 0(\Delta i_j < -I_w) \end{cases}, (j = a, b, c) \tag{4}$$

Table 2.Region detection for vector ΔI

The area of ΔI	I	II	III	IV	V	VI
B_a	1	1	0	0	0	1
B_b	0	1	1	1	0	0
B_c	0	0	0	1	1	1

Then the logical relations can be obtained

$$\begin{cases} R_{\Delta I}(1) = B_a \overline{B_b}\,\overline{B_c} \\ R_{\Delta I}(2) = B_a B_b \overline{B_c} \\ R_{\Delta I}(3) = \overline{B_a} B_b \overline{B_c} \\ R_{\Delta I}(4) = \overline{B_a} B_b B_c \\ R_{\Delta I}(5) = \overline{B_a}\,\overline{B_b} B_c \\ R_{\Delta I}(6) = B_a \overline{B_b} B_c \end{cases} \tag{5}$$

The space has been divided into six domains *I~VI* by V_{ab} , V_{bc} , V_{ca}, so the area of the vector V^*can be judged according to the symbolic inspection [5]

Assume that:

$$\begin{cases} X_{ab} = \text{sign}(v_a^* - v_b^*) \\ X_{bc} = \text{sign}(v_b^* - v_c^*) \\ X_{ca} = \text{sign}(v_c^* - v_a^*) \end{cases}, \quad \text{sign}(x) = \begin{cases} 1(x > 0) \\ 0(x < 0) \end{cases} \tag{6}$$

Get the logical relations of V^*'s regional judgment [6]:

$$\begin{cases} R_{v^*}(I) = X_{ab} X_{bc} \overline{X_{ca}} \\ R_{v^*}(II) = \overline{X_{ab}} X_{bc} \overline{X_{ca}} \\ R_{v^*}(III) = \overline{X_{ab}} X_{bc} X_{ca} \\ R_{v^*}(IV) = \overline{X_{ab}}\, \overline{X_{bc}} X_{ca} \\ R_{v^*}(V) = X_{ab} \overline{X_{bc}} X_{ca} \\ R_{v^*}(VI) = X_{ab} \overline{X_{bc}}\, \overline{X_{ca}} \end{cases} \tag{7}$$

The area of vector ΔI and V^* are determined by the relevant logic operations above, then according to the logic variables of ΔI and V^*, the logic relationships on how to select V_k is obtained.

Table 3. The logical combinations of S_a, S_b, S_c

V_k	S_a	S_b	S_c
V_1	1	0	0
V_2	1	1	0
V_3	0	1	0
V_4	0	1	1
V_5	0	0	1
V_6	1	0	1
V_7	1	1	1

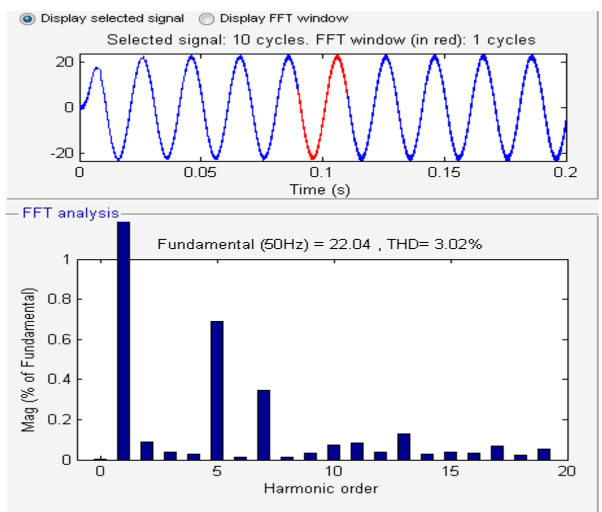

Fig. 7. The total harmonics distorted rate in hysteresis current control method

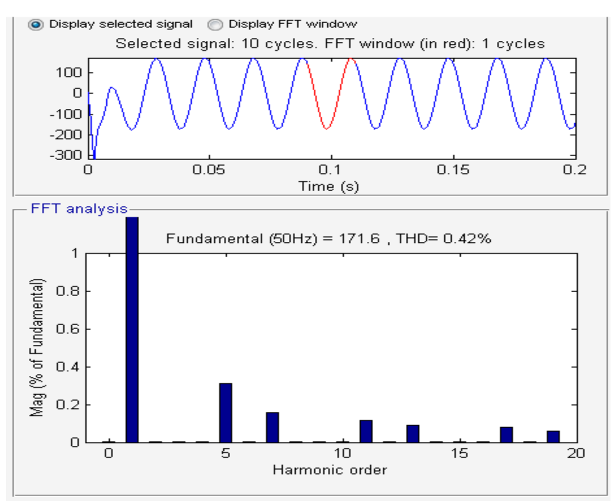

Fig. 8 . The total harmonics distorted rate in hysteresis SPWM control method

3. Results and Analysis

The two charts respectively indicate that the two control methods both can reduce the harmonic currents of large power grids. Compared with the experimental data, the present model has more superiority. The total distorted rate of the harmonics is 2.63% in the traditional hysteresis current control method (Figure.7), but it is 0.42% in the new control method (Figure.8). The new control technique also has the less direct current component.

4. Conclusion

The proposed APF has managed to produce the compensated harmonics current regardless to the changing of the loads. Hysteresis current control method based on space vector modulation has provided proper switching vectors to the APF by detecting the region and vectors of each state. Better compensated harmonics current is obtained by setting smaller tolerance bands for hysteresis comparators [7].

Acknowledgements

This thesis would not have been possible without the contributions of several people. To all of these people, I wish to express my gratitude. First and foremost, I would like to acknowledge to my supervisor-Professor Yun liang Wang, for his vital encouragement and patient guidance, all of which have been of inestimable worth to the completion of my thesis. Secondly, my special thanks go to all people have helped and taught me immensely during the two years and a half of my study in Tianjin University of Technology. The last but no least, my thanks would also go to my beloved parents for their boundless love and whole-hearted support over all these past years.

References

[1] Li Jian-lin , Xu Hobg-hua. Power electronic converter technology in wind power generation[M]. Beijing: China Machine Press 2008:47~50

[2] Wang Zhao-an，HuangJun. Power Electronic Technology [M].Beijing: China Machine Press 2000:47~50.

[3] Zhang Gang . Reach on 3-phase PWM rectifier based on hysteresis SVPWM [D].Tianjin: Tianjin University of Technology. 2008:21~25

[4] Bong-Hwan Kwon,Tae-Woo Kim， Jang-Hyoun Youm. A novel SVM-based hysteresis current controller [J].IEEE Transactions on Power Electronics，1998，13（2）：297-307.

[5] Kexin Wei，Gang Zhang，Shuiming Wang. System simulation of 3-phase PWM rectifier based on novel voltage space vector[C]. 7th International Conference on System Simulation and Scientific.

[6] David M.E. Ingram and S.D.Round. A novel digital hysteresis current controller for an active power filter. International Conference on Power Electronics and Drive Systems. 1997:744~749

[7] L.P.Ling and N.A.Azli. SVM Based Hysteresis Current Controller for a Three Phase Active Power Filter. National Power &Energy Conference.2004:1~2

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