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A Hysteretic Current Controller for Active Power Filter with Constant Frequency

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***Abstract*-In accordance with the advantage of conventional hysteretic current control method, this paper advances a novel control method for active power filter (APF). In conventional hysteretic current control, the hysteretic band (HB) is fixed and actual compensating current is limited in a fixed hysteretic band. When the voltage source inverter (VSI) works in high-frequency state, as the switching frequency changes the problems such as increasing switching losses and audible noise will appear. In response to this problem, the constant frequency hysteretic current control method based on variable hysteretic band is advanced in this paper. Firstly, the connection between hysteretic band and switching frequency must be found correctly. Then, the variable hysteretic band current controller is designed according to the connection. Finally, the Matlab simulation results show that the switching frequency of VSI is held nearly constant and the proposed controller can track reference current well. The problems of increasing switching losses and audible noise which happened in high-frequency state can be resolved in conventional hysteretic current control.**

Keywords-constant frequency; hysteretic current control; (Hysteretic Band) HB; Active Power Filter (APF)

Ⅰ. INTRODUCTION

Active power filter (APF) is a very useful tool for eliminating harmonic pollution in power systems. As compared with the conventional passive filters, APF has many significant advantages such as good controllability, fast response and high control accuracy etc. APF can also compensate non-characteristic harmonics, which makes it extremely attractive in certain circumstances. With the development of power electronic technology, APF finds its wide use in the modern industry.

Fig.1 is a simple system with a VSI-based APF. The three phase load current vector i_L with its harmonic current to be compensated is measured and its harmonic component is denoted as reference current vector i_c^*.APF output current vector i_c should be controlled to track the reference current vector. If the error $\Delta i = i_c - i_c^*$ is larger than a certain tolerance, the current control of the APF will be activated. The current controller will determine the VSI switching operation to yield proper terminal voltage for reducing the error Δi . The APF drive circuit will then realize the decision. It is clear that the current control block in Fig. 1 is significant to APF performance. It should respond quickly and determine optimal voltage space vector correctly in order to reduce the current error efficiently and in the meantime it is better to keep constant VSI switching frequency for safe operation.

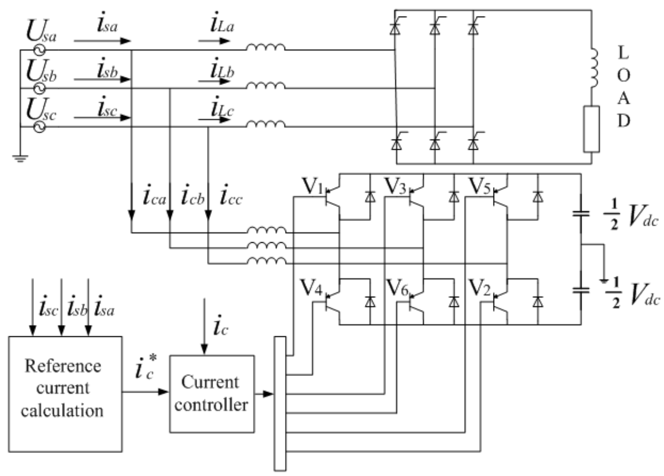


Fig.1 Schematic Diagram of System with APF

There are various current control methods proposed for active power filter configurations, but in terms of quick current controllability and easy implementation the hysteretic band current control method has the highest rate among other current control methods [1]. And the switching frequency varies constantly within a power frequency cycle. In principle the increasing inverter operation frequency helps to get a better compensating waveform. However, there are device limitations and increasing the switching frequency causes increasing switching losses, audible noise and other related problems. In this paper, the control of switching frequency is realized by introducing a constant frequency hysteretic current control algorithm. The main aim of this study is to investigate the effects of hysteretic bandwidth to the switching frequency of APF. The hysteretic band current controller changes the hysteretic bandwidth as a function of reference compensator current variation to optimize switching frequency. In this paper, the $i_p - i_q$ theory for detecting current is first briefly reviewed. Secondly, the constant frequency hysteretic current controller is described. Thirdly, simulation results are presented followed by the conclusion.

II. The $i_p - i_q$ Detecting Method

At present, the harmonic and reactive current detection method based on instantaneous reactive power theory in APF is used widely [2], [3]. The two methods which are called $p-q$ operational mode and $i_p - i_q$ operational mode can be received by calculating p , q or i_p , i_q based on three-phase circuits with instantaneous reactive theory. The $i_p - i_q$ operational mode is used in this paper. The principle of this method is shown in Fig.2.

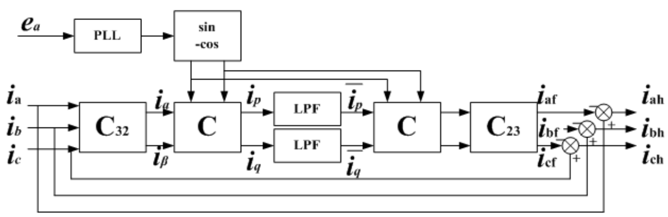


Fig.2 $i_p - i_q$ Operational Mode Schematic Diagram

In which

$$C = \begin{bmatrix} \sin\omega t & -\cos\omega t \\ -\cos\omega t & -\sin\omega t \end{bmatrix}, C_{32} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}$$

In this method, the phase of the sine signal of $\sin\omega t$, which is in phase of the network power voltage of phase A e_a and the relevant cosine signal of $-\cos\omega t$ are needed. They can be got by (PLL) and the sine signal circuit and cosine signal circuit. i_p , i_q are calculated according to definition. The $\overline{i_p}$, $\overline{i_q}$ can also be calculated with i_p , i_q after LPF filter. So with $\overline{i_p}$, and $\overline{i_q}$, i_{af} , i_{bf} and i_{cf} can be calculated and then so i_{ah} , i_{bh} and i_{ch} . When detecting the harmonic and reactive current together, the calculated route i_p should be disconnected. However, when detecting reactive current only, just do inverse transformation of i_q .

III. Constant Frequency Hysteretic Current Controller

The hysteretic band current control method is popularly used because of its simplicity of implementation, among the various PWM techniques [4], [5]. Besides fast-response current loop and inherent-peak current limiting capability, the technique does not need any information about system parameters. However, the current control with a fixed hysteretic band has the disadvantage that the switching frequency varies within a band because peak-to-peak current ripple is required to be controlled at all points of the fundamental frequency wave [6], [7].

Therefore, the constant frequency hysteretic current control method based on variable HB is advanced in this paper. The principle of this method is shown in Fig.3 and the control technology of HB is added to conventional hysteretic current controller.

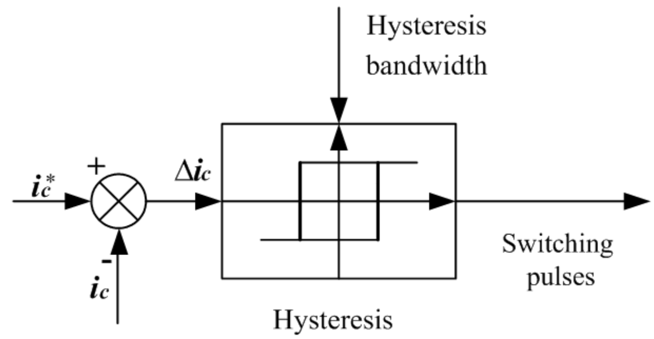


Fig.3 Variable Hysteretic Band Current Controller

Firstly, the switching state of VSI in hysteretic current control is analyzed. Conveniently, take the case of phase A. Fig.4 is the schematic diagram of the switching state of phase a controlled by hysteretic controller. In Fig.4, i_{ca} is the feedback current and it is the actual compensating current and the namely output current of VSI. $i_{ca} = \begin{cases} i_{ca}^+ & di_{ca}/dt > 0 \\ i_{ca}^- & di_{ca}/dt < 0 \end{cases}$, U_0 is the output voltage of VSI, U_{sa} is the network power voltage and V_{dc} is DC voltage of APF.

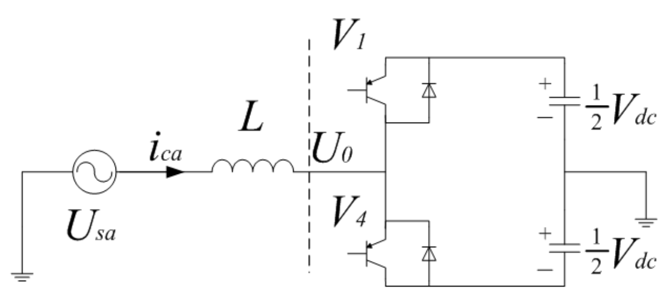


Fig.4 Hysteretic Controller Schematic Diagram

The system circuit equation can be got with the schematic diagram.

$$L\frac{di_{ca}}{dt} = U_0 - U_{sa} \tag{1}$$

And for U_0 , we can get the following:

$$U_0=\begin{cases} V_{dc}/2 & \text{The upper switch is ON, SA=1} \\ -V_{dc}/2 & \text{The lower switch is ON, SA=0} \end{cases} \quad (2)$$

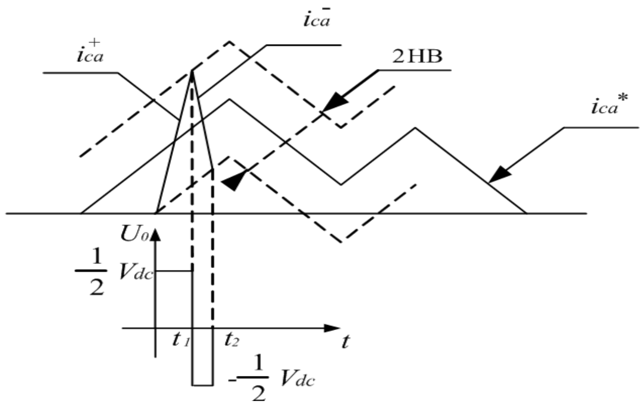


Fig.5 Current and Voltage Waves with Hysteretic Band Current Control (for APF)

The principle of hysteretic current control can be described as the follows: when the output current of VSI exceed the hysteretic upper limit $i_{ca}^{*}+\mathrm{HB}$, the hysteretic controller output $S=0$, and the lower switch is ON, the VSI output voltage $U_0=-V_{dc}/2$ and the output current of VSI i_{ca} will drop. In the same way, when i_{ca} is lesser than the hysteretic lower limit $i_{ca}^{*}-\mathrm{HB}$, the hysteretic controller output $S=1$, the upper switch is ON, the VSI output voltage $U_0=V_{dc}/2$ and the output current of VSI i_{ca} will rise.

Therefore, two equations can be calculated as follows:

$$\frac{di_{ca}^{+}}{dt}=\frac{1}{L}(0.5V_{dc}-U_s) \quad (3)$$

$$\frac{di_{ca}^{-}}{dt}=-\frac{1}{L}(0.5V_{dc}+U_s) \quad (4)$$

With the geometry of Fig. 4, we can get the following:

$$\frac{di_{ca}^{+}}{dt}t_1-\frac{di_{ca}^{*}}{dt}t_1=2\mathrm{HB} \quad (5)$$

$$\frac{di_{ca}^{-}}{dt}t_2-\frac{di_{ca}^{*}}{dt}t_2=-2\mathrm{HB} \quad (6)$$

$$T_C=t_1+t_2=\frac{1}{f} \quad (7)$$

Where t1 and t2 are the respective switching intervals and f is the switching frequency.

$\frac{di_{ca}^{+}}{dt}$, $\frac{di_{ca}^{+}}{dt}$, HB, t_1 and t_2 are treated as the unknown quantities and V_{dc}, U_s, f, L and $\frac{di_{ca}^{*}}{dt}$ as the known quantities. With the combination of the above five equations, the relationship of HB and f can be calculated.

$$\mathrm{HB}=\frac{V_{dc}}{8Lf}-\frac{L}{2fV_{dc}}\left(\frac{U_s}{L}+di_{ca}^{*}/d_t\right)^2 \quad (8)$$

Where f is modulation frequency, di_{ca}^{*}/d_t is the slope of command current wave. HB can be modulated at different points of fundamental frequency cycle to control the switching pattern of the inverter. For symmetrical operation of all three phases, it is expected that the HB profiles HB_a, HB_b and HB_c will be same, but have phase difference. The constant frequency hysteretic band current controller changes the hysteretic bandwidth according to instantaneous compensation current variation (di_{ca}^{*}/d_t) and V_{dc} voltage to minimize the influence of current distortion on modulated waveform. In this paper, the constant frequency hysteretic band current controller is designed by Esq. 8. The constant frequency hysteretic bandwidth calculation block diagram can be received by Esq. 8

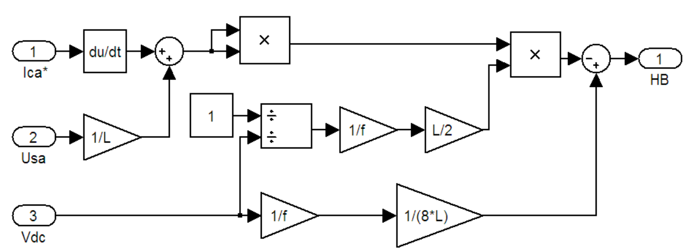


Fig.6 Constant Frequency Hysteretic Bandwidth Calculation Block Diagram

Esq. 8 shows HB as a function of modulation frequency, supply voltage, dc capacitor voltage and slope of the i_{ca}^{*} reference compensator current wave. Hysteretic band can be modulated as a function of V_{dc} and so that the modulation frequency f remains nearly constant. This will improve the PWM performances and APF substantially. So the proposed constant frequency hysteretic current controller can be designed as the form in Fig.7.

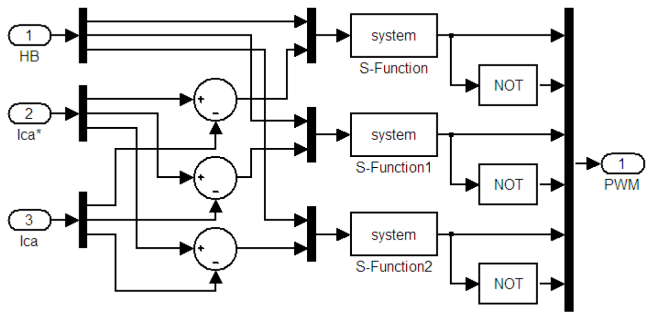


Fig. 7The Block Diagram of the Variable Hysteretic Band Current Controller

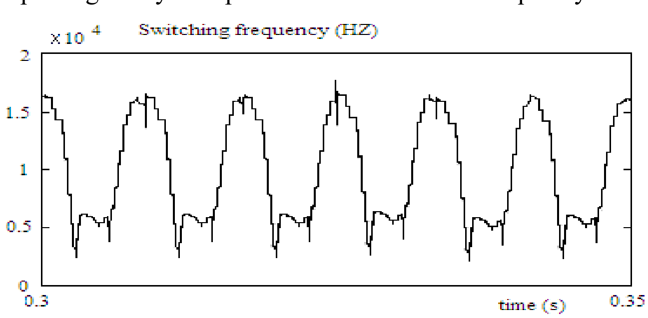
Ⅳ. SIMULATION RESULTS AND DISCUSSIONS

In order to check the validity of constant frequency hysteretic current controller, the simulation of Matlab6.5 is adopted. The circuit parameters are shown in TABLE. Ⅰ.

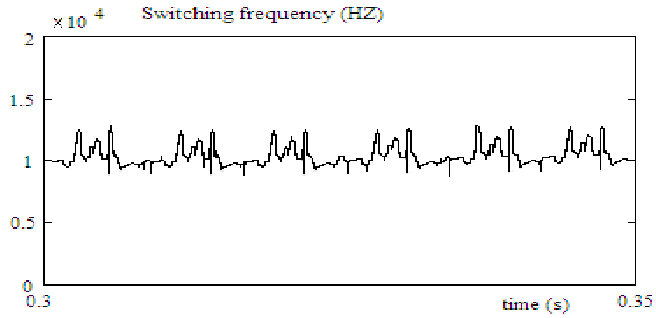
TABLE. Ⅰ CIRCUIT PARAMETERS

Fundamental frequency	60Hz
Switching frequency	10kHz
Usa	127V
Vdc	400V
Rectifier load resistance	10Ω
Inverter side inductance	1mH
Rectifier side inductance	1MH
Cdc	1000μF

Instantaneous switching frequencies are shown in Fig. 8, respectively. In constant frequency hysteretic band current control method, the instantaneous switching frequency remains constant with little deviation contrary to conventional fix band hysteretic current control method. In practical application, it is necessary to kept switching frequency to a certain limits, in order to determine switching device and its switching losses. In conventional hysteretic band current controller, it is not possible to determine not only hysteretic bandwidth but also switching frequency according to circuit parameters (*Cdc,L,Vdc,*). In constant frequency hysteretic band current controller, switching frequency remains constant respecting the system parameters and defined frequency.



(a) Conventional Hysteretic Current controller



(b) Constant Frequency Hysteretic Current Controller

Fig.8 Comparison of Two Switching frequencies under Two Different Control Methods

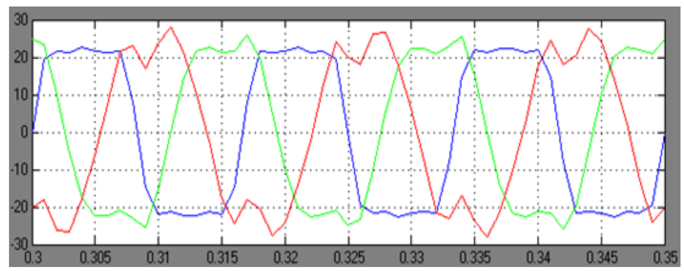


Fig.9 Three-phase current Waveform without Compensation in Power System

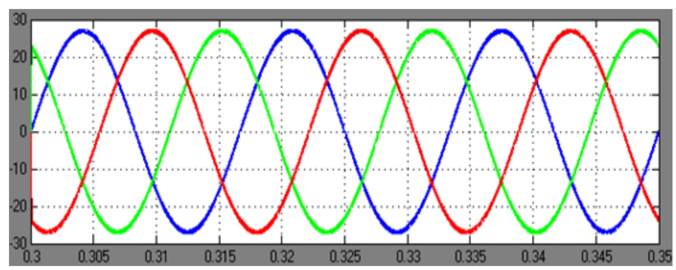


Fig.10 Three-phase Current Waveform with Compensation in Power System

The waveform of three-phase current in power system without compensation is shown in Fig.9 and that with compensation is shown in Fig.10. It can be seen from Fig.9 that many harmonic current exist in power system. And from Fig.10 with APF compensation, the waveform approaches as the sine one. The conclusions can be received as follows: the APF under the constant frequency hysteretic current control has satisfactory offset characteristic and can eliminate the majority of harmonics and resolve the problems of conventional hysteretic current control such as the phenomenon of increasing switching losses and audible noise when VSI worked in high-frequency state. The simulation results demonstrate the validity of constant frequency hysteretic current control method.

V. CONCLUSION

This paper demonstrates the validity of constant frequency hysteretic current controller for active power filter. It is found quite satisfactory to eliminate harmonics and reactive power components from utility current according to the results of simulation study of new APF control technique presented in this paper. The validity of this technique in order to compensate current harmonics is proved on the basis of simulation results. The simulation results show that the conventional band hysteretic current control and the constant frequency hysteretic band current control are equally good at filtering the harmonics generated by the non-linear load. The main difference between the two control methods should be in the high frequency harmonics generated by switching of the IGBTs. The instantaneous switching frequency remains constant in the new method contrary to conventional hysteretic current control method and the switching frequency should be kept in a certain limit determined by switching devices. The paper describes a constant frequency hysteretic current control of VSI switching technique where the bandwidth can be modified by di_c^* / d_t .Because the switching frequency is constant, so the problems of increasing switching losses and audible noise can be resolved.

REFERENCES

[1] Kuang Li, Guo-chun Xiao, Jin-jun Liu, Zhao-an Wang, “Comparison of four control methods to active power filters applied in accelerator power supplies,” 2004 IEEE 35th Annual, 2004, pp.794-799.

[2] H. Akagi, Y. Kanazawa, A. Nabae, “Instantaneous reactive power compensators comprising switching devices without energy storage components,” IEEE Trans. Ind. Appl. 20, 1984, pp.625–630.

[3] Sheng-qing Li,Yu-lou Peng,You-qing Zhou, “ Study on An Improved Adaptive Harmonic Current Detecting Method,” High Voltage Engineering, 2002, pp.3-5.

[4] Qiao C, Smedley K M, “Three-phase active power filters with unified constant-frequency integration control. Power Electronics and Motion Control Conference,” 2000.Proceedings.PIEMC 2000.The Third International, vol. 2, Aug 2000, pp.698-705.

[5] Xiao-bo Fan,Dai-run Zhan,Qian Sun, “Hysteresis Current Control Strategy for Three-phase Three-wire Active Power Filter,” Automation of Electric Power Systems, 2007,pp.57-60.

[6] B.K.Bose, “An adaptive hysteresis band current control technique of a voltage feed PWM inverter for machine drive system,” IEEE Trans. Ind. Electron, 1990, pp.402–406.

[7] S. Buso, S. Fasolo, L. Malesani, P. Mattavelli, “A dead beat adaptive hysteresis current control, ” IEEE Trans. Ind. Appl, 2000, pp.1174–1180.