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FACTS 기기의 고조파 저감을 위한 이중밴드 히스테리시스 전류 제어에 관한 연구

최원경, 최정혜, 김범식, 신은철, 이상빈, 유지윤
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A Study on Double Band Hysteresis Current Control based on 3-Level Inverter to reduce the harmonic component in output current of FACTS devices.

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Abstract - The current control using a conventional hysteresis controller of a STATCOM based on two level VSI (Voltage Source Inverter) has high switching frequency and variable modulation frequency. This will increase the switching loss. In addition, the current error is not strictly limited. So, in this paper to reduce the switching frequency and to maintain the constant modulation frequency, a novel double band hysteresis current controller based on 3-level VSI is proposed. A conventional hysteresis current control and a novel hysteresis current control was tested with digital simulation and verified the advantage of the novel hysteresis current controller.

1. Introduction

With the development of power semi-conductor devices, the inverter based SVCs have been newly proposed. Static synchronous compensator (STATCOM) is the one of the inverter based Static Var Compensators (SVC)[1]. A STATCOM is the fastest reactive power compensation device hitherto. As injecting or absorbing reactive current, STATCOM can regulate the voltage at PCC (Point of Common Coupling). Consequently the voltage stability and transient stability can be greatly improved if the voltage regulator can give a fast and stable response[2][3].

Such as ac motor drives, active filers and UPS in most high-performance industrial systems, the current controller is the essential part of STATCOM. Recently, the various current control algorithms of STATCOM have been proposed for better performance [4]-[8]. These included a synchronous-frame proportional int- egral (PI) current control, predictive current control, deadbeat current control and hysteresis current control. Among the algorithms, when we take into consideration easy implementation, quick response, maximum current limits and insensitive to load parameter variation, most of all, the hysteresis current controller is suitable for a control scheme. But the current control using a conventional hysteresis controller based on 2-level VSI in STATCOM has the disadvantage that variable modulation switching frequency may happen due to fixed hysteresis band and high switching frequency may happen due to fewer zero voltage vectors and small effective voltage vectors. This will increase the switching loss. In addition, the current error is not strictly limited[4].

So, in this paper to reduce the switching frequency and maintain the constant modulation frequency, a novel double band hysteresis current controller based on 3-level VSI is proposed. Proposed algorithm is the method to use a 3-level VSI, a two double band hysteresis controllers, current error values, region detector, Switching Table (ST) method to apply zero voltage vector for reducing the switching frequency and a new variable band width definition for maintain the constant modulation frequency in synchronous rotating reference frame.

2. Hysteresis Current Control for a D-STATCOM

2.1 Mathematical Modeling of D-STATCOM

The D-STATCOM consists of a VSI with the capacitor of the DC energy source shown Fig.1. It is controlled to regulate the voltage in the same way as an SVC. A coupling transformer is used to connect to the distribution voltage level.

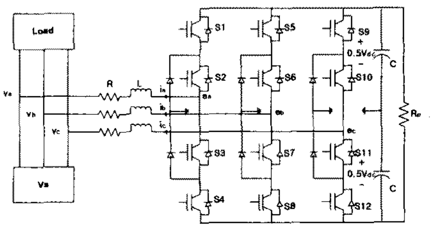


Fig.1 The system configuration of a D-STATCOM

By controlling the inverter output voltage relative to the system voltage, reactive power magnitude and direction can be regulated. If the VSI AC output voltage is lower than the system voltage, reactive power will be absorbed into D-STATCOM. If the VSI AC output voltage is higher than the system voltage, reactive power will be supplied by D-STATCOM.

The system is assumed as a three-phase balanced one, by using the Park's transformation, synchronous rotating reference frame modeling can be obtained as (1).

$$p\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R/L & \omega \\ -\omega & -R/L \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \frac{1}{L}\begin{bmatrix} e_d - v_d \\ e_q - v_q \end{bmatrix} \quad (1)$$

where, ω is the angular speed of the reference frame and v is the voltage at the PCC.

As the current derived from (1) is substituted for the definition of the instantaneous reactive power and the instantaneous real power, the reactive and the real power will be written as follow :

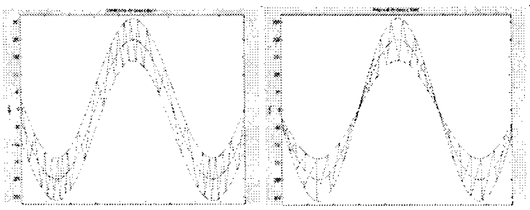
$$P=\frac{3}{2}|v||i|\cos\phi=\frac{3}{2}(v_d i_d+v_q i_q)\ =\ \frac{3}{2}v_d i_d(\because v_q=0)$$

$$Q=\frac{3}{2}|v||i|\sin\phi=\frac{3}{2}(v_d i_q-v_q i_d)\ =\ \frac{3}{2}v_d i_q(\because v_q=0) \qquad (2)$$

Therefore, the real power (P) and the reactive power (Q) are proportional to i_d and i_q, respectively. The real power (P) and the reactive power (Q) are controlled by i_d and $i_q$independently in synchronous reference frame.

2.2 Proposed Hysteresis Current Controller

In conventional method, Inverter driving method is 150-degree conduction method using twelve voltage vector. As a result, switching frequency increases. This will increase the switching loss. In addition, the current error is not strictly limited. Also, in fig.2.(a), conventional method has disadvantage that variable modulation switching frequency may happen due to fixed hysteresis band. Therefore it is inadequate in D-STATCOM.



(a) Conventional fixed band (b) Proposed variable band
Fig.2. Modulation frequency in fixed and variable band

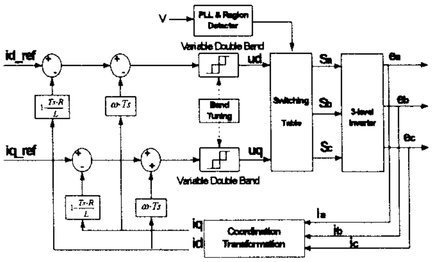


Fig.3. Proposed Hysteresis Current Control

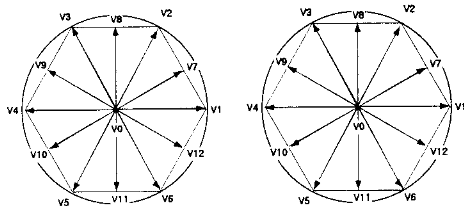
In this paper, as Fig. 2(b) to maintain constant modulation frequency and reduce switching frequency, a novel double band hysteresis current controller of a STATCOM based on three level VSI is proposed. Proposed current controller consists of variable band width definition, 3-level inverter, ST, region detector and rotational reference frame. Control block of proposed hysteresis current controller is following Fig. 3.

2.2.1 Generation of small vector

In this paper, to reduce the switching frequency, 3-level inverter is used. In conventional method following Fig. 4(a), large voltage vector, middle voltage vector and zero voltage vector can be generated. In comparison with conventional method, as showing Fig. 4(b) and table 1, the space vector of proposed 3-level inverter has advantage that can apply smaller vector. This can reduce switching frequency and limit current error.

Table 1 Proposed Hysteresis Control Switching Table

u_d	1					0.5					0					-0.5					-1				
u_q	1	0.5	0	-0.5	-1	1	0.5	0	-0.5	-1	1	0.5	0	-0.5	-1	1	0.5	0	-0.5	-1	1	0.5	0	-0.5	-1
Vector	V_2	V_7	V_1	V_{12}	V_6	V_2	V_{14}	V_{13}	V_{18}	V_6	V_8	V_8	V_0	V_{11}	V_{11}	V_3	V_{15}	V_{16}	V_{17}	V_5	V_3	V_9	V_4	V_{10}	V_5



(a) 2-level VSI (b)3-level VSI
Fig.4. Space voltage vector

2.2.2 Band Width definition (B_a)

In this paper, to maintain the constant modulation frequency, a noble band width definition method is proposed. Fig. 6 shows the its typical current and voltage for phase a with hysteresis current control. Where the Q_1 is switched on, the current i_a tends to cross the lower hysteresis band. Where the Q_4 is switched on, the rising current i_a^+ then touches the upper band. Neglecting the resistance, the following equations can be written in switching intervals t_1 and t_2.

$$\frac{di_a^+}{dt}=\frac{1}{L_s}(\frac{E}{2}-V_a) \qquad (3)$$

$$\frac{di_a^-}{dt}=-\frac{1}{L_s}(\frac{E}{2}+V_a) \qquad (4)$$

From the geometry of Fig. 5, obtain the relation of band

$$\frac{d}{dt}(i_a^+-i_a^*)t_1=2B_a \qquad (5)$$

$$\frac{d}{dt}(i_a^--i_a^*)t_1=-2B_a \qquad (6)$$

Where f_s is the switching frequency

$$t_1+t_2=T_s=\frac{1}{f_s} \qquad (7)$$

Adding (5) to (6) and substituting (3),(4),(7), then

$$t_2-t_1=-\frac{2L_s}{Ef_s}[\frac{1}{L_s}V_a+\frac{di_a^*}{dt}] \qquad (8)$$

Subtracting (6) from (5), and substituting (3), (4),(7), can be written

$$t_2-t_1=-\frac{4B_a-\frac{E}{2f_sL_s}}{\frac{V_a}{L_s}+\frac{di_a^*}{dt}} \qquad (9)$$

Using (8) and (9), the expression for the a-phase hys teresis band can be written as

$$B_a=\frac{E}{8f_sL_s}[1-\frac{4L_s^2}{E^2}[\frac{1}{L_s}V_a+\frac{di_a^*}{dt}]^2] \qquad (10)$$

3. Simulation

To compare conventional current control method wit h proposed current control method, it was tested with digital simulation. The parameters used in this simulat ion is listed as below

Table 2 System parameters for simulation

Vs	3phase 220 [V] , 60 [Hz]
Line Imp.(Rt,Lt)	0.3 [Ω] , 0.003 [H]
R	0.23 [Ω]
L	0.005 [H]
C	3000 [μF]
Vdc_ref	600 [V]

4. Conclusions

In this paper, to complement the conventional hysteresis current controller, the improved hysteresis current controller for D-STATCOM is proposed and is tested with digital simulation. Using a Band width definition can maintain constant modulation frequency and using a 3-level inverter can generate more sub-divisible small vector and many zero voltage vector.

As a result, variable modulation frequency can be constant and switching frequency can be reduced. Also switching loss can be reduced. And current ripple and steady state current error can be limited.

5. Acknowledgment

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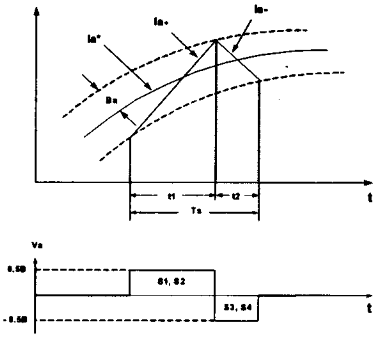
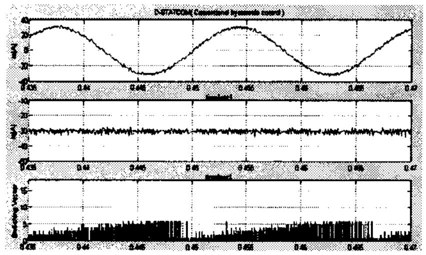
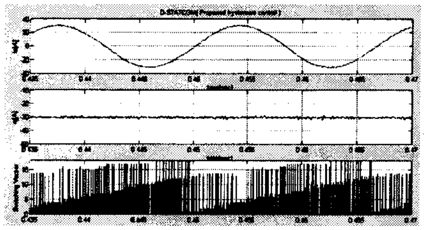


Fig.5. Current and voltage waveform with proposed hysteresis curre nt control

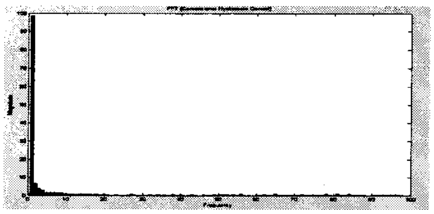


(a) Conventional method

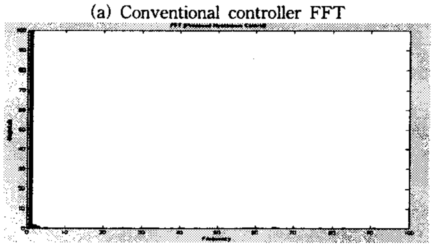


(b) Proposed method

Fig.6. Current and applied voltage vector

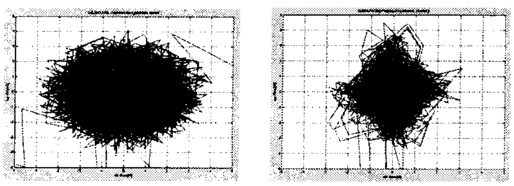


(a) Conventional controller FFT



(b) Proposed controller FFT

Fig.7. Harmonic analysis for inverter output current



(a) Conventional method (b) Proposed method

Fig. 8 Current error