Acta Technica 62 No. 2B/2017, 753–760

STATCOM current detection method and control technology based on instantaneous reactive power theory[1]

Xuehai Pan[2]

Abstract. With the widespread application of impulsive loads and nonlinear loads in the power grid, reactive power and harmonic pollution of the power grid are also rising, which have a certain impact on people's lives. STATCOM can effectively suppress harmonics and reactive power, and has become the main mode of power quality control. STATCOM system model was set up in this paper. On the basis, two control techniques, hysteresis control and triangle wave control, were designed and simulated. The results show that the two techniques can track the instruction currents fast and accurately, and realize effective harmonic suppression and reactive power compensation. In practical application, the appropriate hysteresis width and triangle wave frequency should be chosen to achieve the optimal tracking compensation performance of STATCOM.

Key words. STATCOM, reactive power compensation, control technology.

1. Introduction

In recent years, with the extensive application of electronic power technology, people's living standards have been greatly improved. While enjoying the convenience of scientific and technological progress, its negative effects are gradually emerging [1]. On the one hand, many applications of electric equipment, such as electric arc furnace, electric locomotive, and frequency converter, bring more new challenges to power grid, such as voltage fluctuation, harmonic, over-voltage and under voltage. On the other hand, with the wide application of the Internet era of computer and electronic technology, some precision instruments and equipment for power quality is more and more sensitive, such as voltage sag and swell, flicker and other power quality problems, which may cause serious loss of sensitive load [2]. According to the statistics conducted by experts in American Academy of Electric Power, the United States loses hundreds of billions of dollars per year due to power quality

[1]This work is for fund projects: Shandong province science and technology development project (No. 2011GGA03156).

[2]Zibo Vocational Institute, Zibo, Shandong, 255314, China

problems. Disputes arising from the quality of power supply are also numerous, and its losses are incalculable [3]. Therefore, in order to realize the efficient, green and stable operation of power system, some necessary measures should be taken to control the power grid and reduce pollution. At present, the most widely used static synchronous compensator (STATCOM) not only can solve the power quality problems comprehensively, but also has the advantages of dynamic, adjustable, fast and so on [4]. Therefore, it has gradually become the development direction of reactive power compensation device in modern power system, and has extremely important engineering application value and very broad market potential.

2. State of the art

The basic principle of STATCOM is that by adjusting the amplitude and phase of the AC output voltage of the circuit, it absorbs from the grid or sends reactive current to the grid to compensate for the constant voltage of the access point, so as to realize reactive power current compensation of power grid [5]. The emergence of new electronic power devices has greatly promoted the development of STATCOM. STATCOM's early switching devices are mainly high voltage and high power gate turn off thyristors (GTO). With the progress of electronic power technology, insulated gate transistor (IGBT) and integrated gate commutated thyristor (IGCT) become the main force, which can compensate reactive power more quickly and more accurately. Compared with the traditional static var compensator (SVC), STATCOM has the characteristics of small size, high accuracy, high speed, and wide range [6]. Currently, STATCOM presents two major research trends. The scope of research is more and more widespread, not only in the high-voltage transmission system, but also in the user side. Two is the continuous use of new power electronic device system performance [7]. In the study of STATCOM dynamic control model, the control strategy and control design are also very important research points [8–10]. The controller of STATCOM consists of two parts: inner loop controller and outer loop controller [11]. The inner loop controller mainly generates a synchronous driving signal, and establishes dominant relation between the output current and the reactive command. The main task of the outer loop controller is to assist the inner loop controller and provide the reactive power reference value for the inner loop controller.

2.1. Methodology

The basic principle of hysteresis width selection in the control system is that the actual value i_{st} of the compensation current is compared to the reference value i_{ref} of the compensation current, and the current tracking difference Δi is obtained. When Δi is greater than the maximum value of the hysteresis width, $T1$ is energized, $T2$ is switched off, and the actual current is increased. When Δi is less than the maximum value of the hysteresis width, $T1$ is switched off, $T2$ is energized, and the actual current is reduced. In hysteresis control, the hysteresis width of hysteresis comparator has a great influence on the following performance of the compensation current. The equivalent structure of the hysteresis control circuit of the single-phase voltage source inverter is shown in Fig. 1.

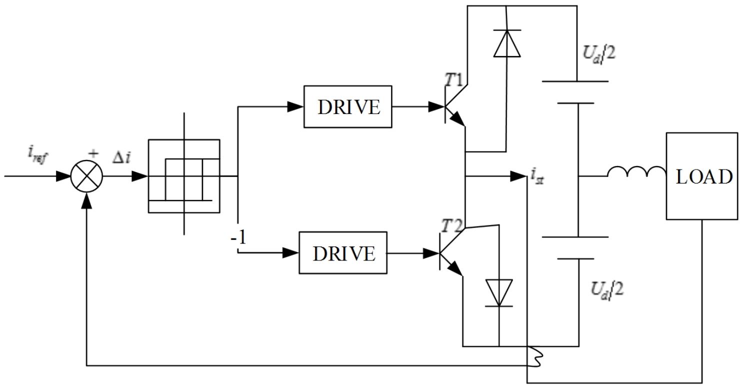

Fig. 1. Single phase hysteresis control structure diagram

Parameter design of PI regulator in control system is one of the most important parts of the system. In this paper, hysteresis control and triangle wave are used to control the two control modes. The control is divided into inner loop control and outer loop control. The current inner loop control system mainly consists of four parts: PI regulator, time delay, voltage inverter and current filter feedback. The reactive current channel control system diagram is shown in Fig. 2.

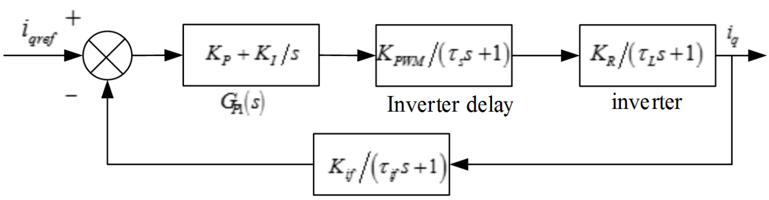

Fig. 2. Internal loop current control system diagram

Here, $G_{\mathrm{P1}}(s)$ represents the PI regulator, $K_{\mathrm{P}}+K_{\mathrm{I}}/s$ refers to the delay link, $K_{\mathrm{R}}/(\tau_L s+1)$ represents a voltage inverter; $K_{\mathrm{if}}/(\tau_{\mathrm{if}} s+1)$ represents current filtering feedback, K_{P} stands for the proportion of the PI regulators; K_{I} represents the integral coefficient of the PI regulator, K_{PWM} represents the magnification of the rectifier, τ_{s} indicates that the delay of the converter, which is equal to half the switching period, τ_{L} represents the inductance time constant, $\tau_{\mathrm{L}}=L/R$, $K_{\mathrm{R}}=1/R$; K_{if} represents the amplification factor of the feedback channel, and τ_{if} represents the time constant of the feedback channel.

Therefore, the transfer function of the current controller is represented as:

$$H(s)=\frac{K_{\mathrm{I}}K_{\mathrm{PWM}}K_{\mathrm{R}}K_{\mathrm{if}}(\tau_{\mathrm{x}}s+1)}{s(\tau_{\mathrm{L}}s+1)(\tau_{\mathrm{s}}s+1)(\tau_{\mathrm{if}}s+1)} \tag{1}$$

where $\tau_x = K_P/K_I$. In formula (1), it is assumed that $\tau_x = \tau_L = L/R$. The time constant of the feedback channel τ_{if} and the time delay of τ_s converter are very small. The first order system is replaced by a secondary order system, and the closed loop function is represented as

$$H_1(s) = \frac{\varphi_n^2}{s^2 + 2\theta\varphi_n + \varphi_n^2}. \tag{2}$$

where θ represents the load damping ratio of the two order system, $\theta = \sqrt{1/K\tau_{sf}}\Big/2$, $\varphi_n = \sqrt{K/\tau_{sf}}$, $\tau_{sf} = \tau_s + \tau_{if}$, $K = K_I K_{PWM} K_R K_{if}$.

When the load damping ratio of the secondary order system is $\theta = 0.707$, the overshoot and the tuning time of the system are optimal, and K can be calculated. Therefore, the values of parameters K_P and K_I can be obtained.

The voltage outer loop control system mainly consists of three parts: PI regulator, time delay and voltage inverter. The capacitor voltage control diagram is shown in Fig. 3.

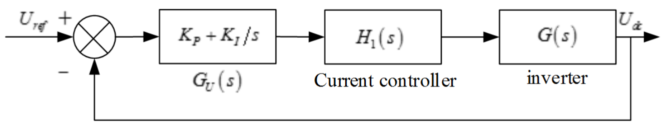

Fig. 3. External loop voltage control system diagram

The transfer function between the input current and the output current and voltage is:

$$G(s) = K_0 \frac{1 - s\tau_z}{1 + s\tau_p} \tag{3}$$

Where, there is $K_0 = 3R_L U_m/(4U_{dc})$,$\tau_p = 0.5R_L C$, $\tau_z = L/R_i$. R_i represents the input impedance of the inverter, $R_i = U_m/I_m$.

$$G_U(s) = K_{up} + K_{ul}/s = K_{ul}(\tau_u s + 1)/s. \tag{4}$$

where $G_U(s)$ stands for the PI regulator, $\tau_u = K_{up}/K_{ul}$, K_{up} and K_{ul} are the ratios of PI regulator and integral coefficient, respectively.

The same as the regulation process of current inner loop control, the first order inertial system is used instead of the secondary order system, which is represented by $H_1(s)$.

$$H_1(s) = 1/(2\tau_{sf}s + 1). \tag{5}$$

Therefore, the transfer function of the voltage controller is represented as:

$$W(s) = \frac{K_{ui}K_0(\tau_u s + 1)(1 - \tau_z s)}{s(\tau_p s + 1)(2\tau_{sf}s + 1)}. \tag{6}$$

It is assumed that $\tau_u = \tau_p$, and $K_I = K_{ui}K_0$. Quantity τ_z has little influence on the peak response time and the rising time of the system, which can be neglected. Then the closed loop transfer function is:

$$W_1(s) = \frac{\varphi_{\mathrm{n}}^2}{s^2 + 2\theta\varphi_{\mathrm{n}} + \varphi_{\mathrm{n}}^2}\,. \tag{7}$$

where, $\theta = \frac{1}{2}\sqrt{1/2K\tau_{\mathrm{sf}}}\,(1 - \tau_{\mathrm{z}}K_l)$ and $\varphi_{\mathrm{n}} = \sqrt{K/2\tau_{\mathrm{sf}}}$. Similarly, the values of $\theta = 0.707$, parameters K_{uP} and K_{uI} can also be calculated.

3. Result analysis and discussion

Through the above analysis, Matlab is used for modeling and simulation, and the triangle wave control and hysteresis control are simulated in two ways. The waveforms of the current under two control modes are obtained.

Hysteresis control simulation analysis: two hysteresis widths 6 % and 3 % are selected. The waveforms obtained by simulation are shown in Fig. 4 and Fig. 5.

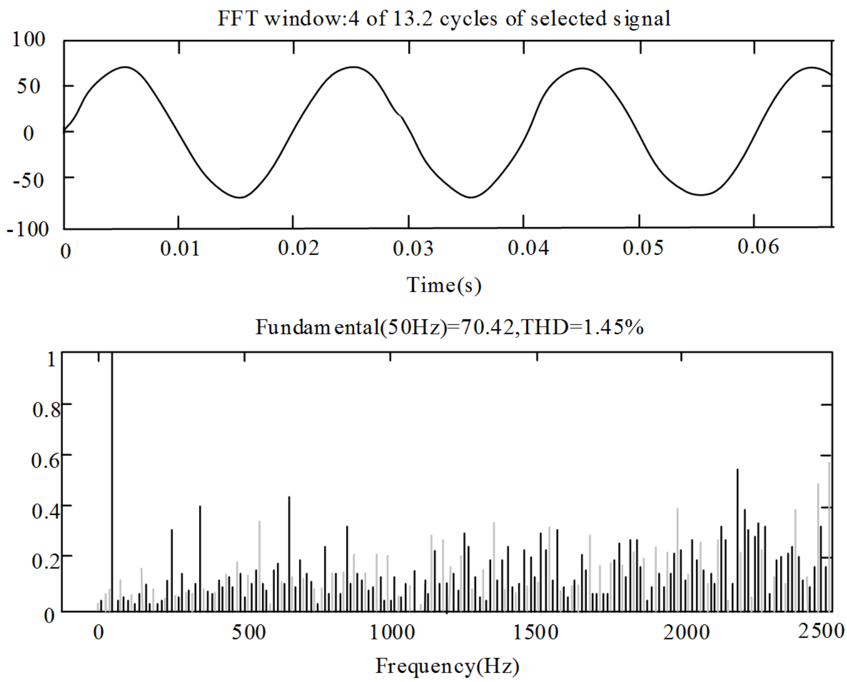

Fig. 4. A phase compensation current i_{st} and spectrum generated by STATCOM at 6 % of the hysteresis width

Two conclusions can be drawn from Fig. 4 and Fig. 5. One is the hysteresis control, which can track the reference wave rapidly and accurately under two conditions with the hysteresis width of 6 % and 3 %. The other is that the hysteresis width is bigger, the tracking reference current error is bigger, and the compensation current harmonic is also bigger.

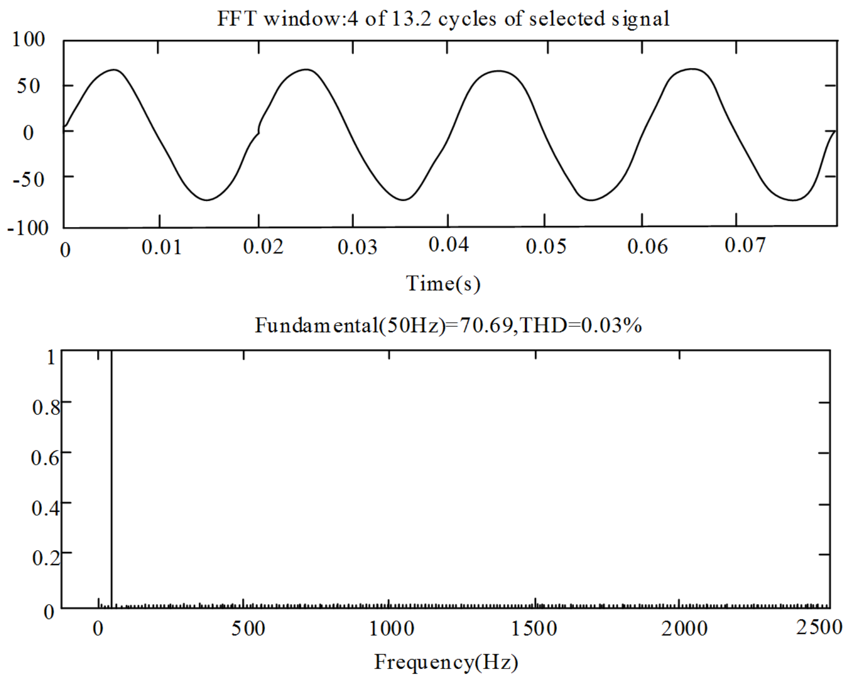

Fig. 5. A phase compensation current i_{st} and spectrum generated by STATCOM at 3 % of the hysteresis width

Simulation and analysis of triangle wave control: parameter setting in triangle wave control mode: frequency is set to 2 kHz; parameter of current controller $K_P = 8$, $K_I = 140$; parameter of voltage controller $K_{uP} = 0.5$, $K_{uI} = 1.5$. By simulation, the compensation current and its spectrum analysis results of phase A are shown in Fig. 6.

It can be seen from the Fig. 6 that the triangle wave control mode can track the reference wave quickly and accurately, but the distortion component of the compensation current is the same as that of the triangle wave.

Comparing the two control methods, the two control methods have their respective advantages and disadvantages. Therefore, according to the actual requirements of the STATCOM compensation effect and the switching frequency limits of the electronic power devices, STATCOM can have the best tracking compensation performance by choosing proper hysteresis width, triangle wave frequency and various parameters.

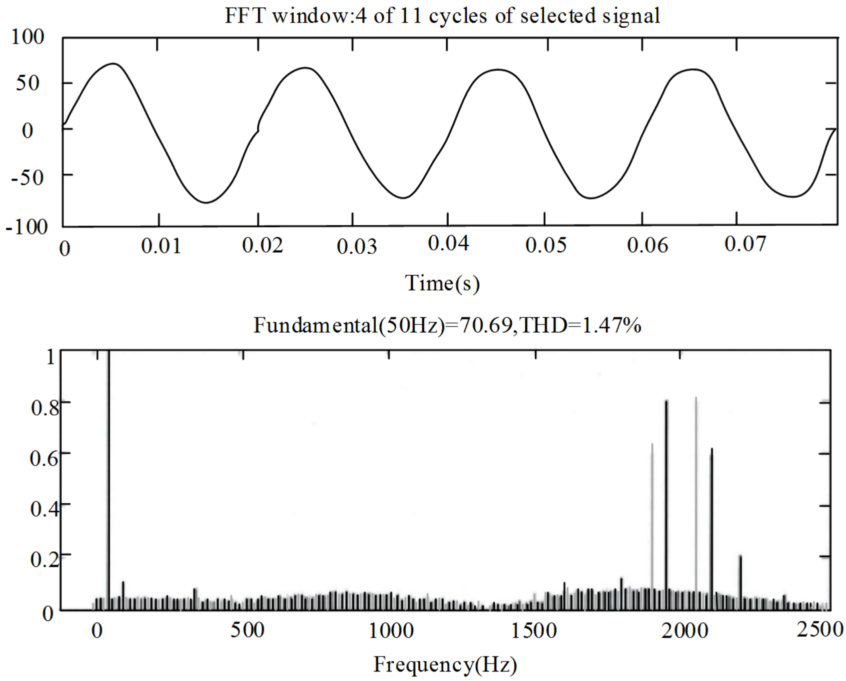

Fig. 6. The phase A compensation current i_{st} and spectrum generated by STATCOM of Triangular wave control

4. Conclusion

In this paper, the research of device pole control in STATCOM control technology was mainly studied. Device level control was mainly divided into PWM tracking technology control and square wave tracking technology according to the driving pulse. PWM tracking control waves were generated by space vector PWM or SPWM sinusoidal modulation. The hysteresis loop control method and the triangle wave control method in PWM tracking technique were simulated. The simulation results show that the switching frequency of the hysteresis control mode is not fixed. The smaller the hysteresis width, the higher the switching frequency, and the greater the switching loss will be. At the same time, the error of the compensating current tracking reference current is smaller, and the harmonic content in the compensation current is low. The switching frequency of the triangle wave control mode is fixed. This control method can track the reference wave rapidly and accurately. However, the high-frequency distortion component of the same frequency as the triangle wave will be introduced into the compensating current. According to the simulation results, in the actual STATCOM control system, the appropriate hysteresis width, triangle wave frequency and various parameters of the PI regulator should be selected according to the actual demand of the compensation effect and the switching frequency limit of the electronic power device. The research on the control technology of STATCOM is limited to the device level control level. Three kinds of integrated control technology, including system level control, device level control and device level control, should be further studied to improve STATCOM control technology.

References

[1] O. Hasnaoui, M. Allagui: *Dynamic performance improvement of wind farms equipped with three SCIG generators using STATCOM.* Journal of Energy in Southern Africa *25* (2014), No. 4, 128–135.

[2] J. I. Y. Ota, Y. Shibano, H. Akagi: *A phase-shifted PWM D-STATCOM using a modular multilevel cascade converter (SSBC)—Part II: Zero-voltage-ride-through capability.* IEEE Transactions on Industry Applications *51* (2015), No. 1, 289–296.

[3] R. Xu, Y. Yu, R. Yang, G. Wang, D. Xu, B. Li, S. Sui: *A novel control method for transformerless H-bridge cascaded STATCOM with star configuration.* IEEE Transactions on Power Electronics *30* (2015), No. 3, 1189–1202.

[4] X. Zhao, L. Shi, L. Chen, Z. Xia, A. R. Bendre: *Modeling and current control strategy for a medium-voltage cascaded multilevel STATCOM with LCL filter.* Journal of Power Technologies *95* (2015), No. 1, 1–13.

[5] R. Xu, Y. Yu, R. Yang, D. Xu: *Strategy based on passivity theory for nonlinear control of STATCOM with cascaded H-bridges.* Electric Power Automation Equipment *35* (2015), No. 1, 50–57.

[6] L. Prakash, A. M. Sundaram, K. Durairaj: *Digital implementation of a constant frequency hysteresis controller for dual mode operation of an inverter acting as a PV-grid interface and STATCOM.* Turkish Journal of Electrical Engineering and Computer Sciences *24* (2016), No. 5, 4406–4428.

[7] W. Hua, J. Qi, M. Jia: *An inductance Fourier decomposition-based current-hysteresis control strategy for switched reluctance motors.* AIP Advances *7* (2017), No. 5, paper 543.

[8] X. Zhao, L. Shi, L. Chen: *A new current control strategy of cascaded STATCOM with composite control.* Power System Protection and Control *43* (2015), No. 17, 98–106.

[9] S. Guo, P. Sun, S. Jing, Z. Wang: *Research on modeling and simulation of power control method for STATCOM based on predictive model.* Power System Protection and Control *43* (2015), No. 1, 88–92.

[10] S. Wu, Y. Kobori, N. Tsukiji, H. Kobayashi: *Transient response improvement of DC-DC buck converter by a slope adjustable triangular wave generator.* IEICE Transactions on Communications *E98.B* (2015), No. 2, 288–295.

Received October 10, 2017