Application of STATCOM in ship Power system

Yanping Liu

School of Shanghai Maritime University, Shanghai 201306, China.

liuyanping0120@163.com

Abstract

In this paper, a method of reactive power compensation and harmonic suppression in ship power system is presented, that is, STATCOM(static synchronous compensator,STATCOM) is used on the AC side of ship power system. The improved reactive current and harmonic current detection method, that is, the improved detection method, is adopted. The current direct control method is used to control the STATCOM， suppression of harmonics in ship Power system by Feedforward Control Strategy. Finally, the operation performance of ship power system without STATCOM on MATLAB/SIMULINK platform is compared with that of ship power system without STATCOM connection. The simulation results show that STATCOM has a significant effect on reactive power compensation and harmonic suppression in ship power system, and the proposed improved method has good performance.

Keywords

Static Synchronous Compensator (STATCOM); Shipboard Power System; The improved $i_p - i_q$ detection method; Current direct control; Feedforward control.

1. Introduction

Electric propulsion system represents the future development direction of ship power, and has a bright application prospect in the field of ship and marine engineering. However, the ship electric propulsion system has some problems to be solved at the same time of improving the overall performance of the propulsion system. With the progress of science and technology and the need of production and life, the capacity of modern electric propulsion ship power system is increasing, and the reliability and power quality of power supply are also put forward higher requirements [1]. The economic and safe operation of ship power system has been paid more and more attention. The network loss is reduced, the power quality of the power supply is improved, the system safety is ensured, and the economic operation has become an actual problem for us.

The marine power system with electric propulsion, propulsion motor, inductive load and many power electronic devices need to provide more reactive power from the marine power grid. When the ship power grid can not meet the supply and balance of reactive power, it will reduce the voltage stability of the ship power grid, and then threaten the normal operation of the electrical equipment, so it is of great practical significance to compensate the reactive power of the ship power grid. Reactive power problems do not exist in isolation, often accompanied by harmonic problems [2].

The traditional reactive power compensation method is to use synchronous camera to compensate the power of ship power system. However, the traditional synchronous camera has slow response speed and can not achieve the purpose of instantaneous reactive power control, and it belongs to rotating equipment, such as large noise, large volume, difficult maintenance and high economic cost, which makes its application prospect in ship power system limited, so it is impossible to adapt to the development trend of ship reactive power compensation in the future, so it is inevitable to find a new alternative [3]. The superior STATCOM is used to replace the traditional synchronous camera to compensate the reactive power of the power grid, and the harmonic and reactive current detection methods are improved. secondly, the control strategy of STATCOM is studied to find a control method which can play the role of harmonic suppression, so that the reactive power compensation can achieve better results.

2. STATCOM model description

By studying the characteristics of electric propulsion ship power system and the composition and principle of STATCOM, the components and working conditions of STATCOM are comprehensively understood, and a suitable model is established.

STATCOM uses self-commutation power semiconductor bridge converter to compensate the reactive power of power grid. The main circuit includes DC link and AC link. The AC link is parallel to the power grid through the reactor or transformer. The reactor is used to suppress the harmonic components produced by STATCOM. In some low-voltage systems, the DC link can also be directly integrated into the power grid. The DC link is mainly an energy storage device, which stores the AC electric energy converted into DC through the converter. At the same time, the DC side voltage and current is converted into AC voltage and current through the converter to be transmitted to the system. The self-commutation converter is equivalent to an AC voltage source that generates fundamental and harmonic voltages. by controlling the size and phase of the fundamental voltage generated by the converter, or directly controlling the size and phase of the current generated by STATCOM, the circuit can absorb or emit reactive current that meets the requirements, suppress the voltage flicker of the system and maintain voltage stability. It can also absorb harmonics, balance reactive power between phases, realize dynamic reactive power compensation and improve power quality [4].

The basic circuit structure of STATCOM is divided into voltage type bridge circuit structure and current mode bridge circuit structure. Because of the low operation efficiency of current mode circuit, most of the STATCOM which is put into use at present adopts voltage type bridge circuit structure [5]. Figure 1 shows the single line diagram of electric propulsion ship power system connected to STATCOM. The schematic diagram of STATCOM is shown in figure 2, and the voltage bridge circuit structure is adopted in this paper.

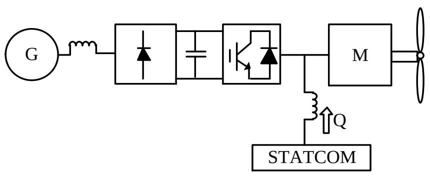

Fig. 1 Single line diagram of electric propulsion ship power system connected to STATCOM.

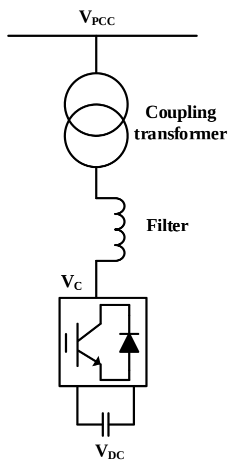

Fig. 2 Schematic diagram of STATCOM

STATCOM consists of a three-phase gate turn-off thyristor (GTO), transformer, a filter and a DC capacitor based on voltage source converter. The DC voltage source (usually a DC capacitor) is the input of the VSC, and the three-phase output is connected to the common coupling point (PCC). In order to adjust the bus voltage, STATCOM controls the injection system and the reactive power absorbed from the system. The relationship between active power and reactive power is expressed by the following equation.

$$S = 3\frac{V_{\mathrm{pcc}}V_{\mathrm{c}}}{x_{\mathrm{l}}}\sin\alpha - \mathrm{j}3\left(\frac{V_{\mathrm{pcc}}V_{\mathrm{c}}}{x_{\mathrm{l}}}\cos\alpha - \frac{V_{\mathrm{pcc}}^2}{x_{\mathrm{l}}}\right) = P - \mathrm{j}Q \tag{1}$$

Of which:

S: Apparent power

P: Active power

Q: Reactive power

V_{pcc}: Three-phase Voltage in PCC

V_{c}: STATCOM output three-phase voltage

x_{l}: Total reactance of STATCOM and PCC

α: The difference angle between V_{pcc} and V_{c}

In normal operation, α is close to zero, but in abnormal cases, the voltage deviates from its predetermined value. STATCOM will control the reactive power injected into PCC to adjust the bus voltage.

3. Improved i_p - i_q detection method

Harmonic and reactive current detection method is the key technology to realize effective reactive power compensation. Whether the reactive power component to be compensated can be accurately detected and whether it has good dynamic tracking performance directly determines the overall performance of reactive power compensation device [6]. Therefore, it is of general academic significance and application value to study the detection methods of harmonics and reactive current in order to solve the power quality problem of power system as a whole. A good reactive current detection method should meet the following three requirements: (1) good real-time; (2) high precision; (3) wide adaptability. In this paper, an improved $i_p - i_q$ detection method is proposed, which can accurately detect fundamental reactive current and three-phase harmonic current under the condition of asymmetrical three-phase voltage and current. The improved circuit detection schematic diagram is shown in figure 3.

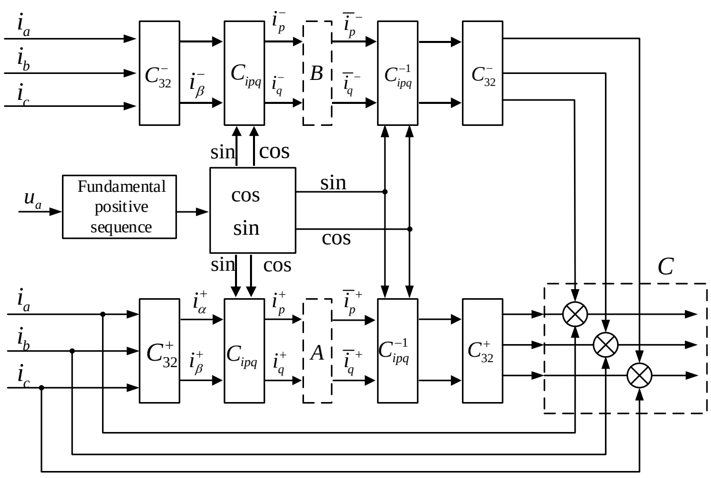

Fig. 3 improved $i_p - i_q$ detection method

$C_{32}^{+}=\sqrt{2/3}\begin{bmatrix}1 & -1/2 & -1/2\\ 0 & \sqrt{3}/2 & -\sqrt{3}/2\end{bmatrix}$ 、 $C_{32}^{-}=\sqrt{2/3}\begin{bmatrix}1 & -1/2 & -1/2\\ 0 & -\sqrt{3}/2 & \sqrt{3}/2\end{bmatrix}$ 、 $C_{ipq}=\begin{bmatrix}\sin\omega t & -\cos\omega t\\ -\cos\omega t & -\sin\omega t\end{bmatrix}$, the detection steps are as follows:

1. The positive sequence phase angle of a phase voltage fundamental wave is obtained, and the transformation matrix C_{ipq} is obtained by sine cosine generator [7].

2. Obtaining three-phase instantaneous current, positive sequence current components i_α^+ and i_β^+ obtained by C_{32}^+ transform; negative sequence components i_α^- and i_β^- of current obtained by C_{32}^- transform. Then the positive sequence active current i_p^+ and reactive current i_q^+, and the negative sequence active current i_p^- and reactive current i_q^- are obtained by C_{ipq} transformation, respectively.

3. ① Taking the fundamental reactive current as the detection target, it is only necessary to disconnect the current i_p^+ and i_p^- at A, B and make i_q^+ and i_q^- pass through the low-pass filter. Then i_q^+ is transformed by C_{ipq}^{-1} and C_{23}^+ to obtain fundamental positive sequence reactive current, $\overline{i_q^-}$ by C_{ipq}^{-1}, C_{23}^- to obtain fundamental negative sequence reactive current, and the fundamental reactive current can be obtained by summation at C; ② Taking the total harmonic current as the detection target, the i_p^+, i_q^+, i_p^-, i_q^- pass through the low-pass filter at A, B, respectively. Then, after inverse transformation, C_{23}^+, C_{23}^- outputs three-phase fundamental positive and negative sequence current respectively, and then makes a difference with the three-phase current at C, that is to say, the three-phase total harmonic current is obtained; ③If the generalized reactive current is taken as the detection target, that is, the sum of fundamental reactive current and harmonic current is taken as the target, then the current A and S are disconnected at A, B, and D and F pass through the low-pass filter. Then, after a series of inverse transformation, C_{23}^+, C_{23}^- outputs the three-phase fundamental positive and negative sequence active current respectively, and then makes a difference with the three-phase current at C, that is to say, the generalized reactive current is obtained.

4. STATCOM control method

4.1 Current direct control

The STATCOM control method directly determines the control performance and output performance of STATCOM [8]. It mainly processes the instruction signal sent from the reactive current detection link to form the driving signal of the control target. Therefore, the appropriate advanced control method can realize the target control quickly and accurately. There are many control methods of STATCOM. According to whether the output current of STATCOM is directly controlled or not, it can be divided into two categories: indirect current control and current direct control [9]. The performance and applicable results of the two methods are shown in Table 1 below.

Table 1 comparison of indirect current control and direct control

Type	Advantage	Disadvantage	Applicable situation
Indirect control	1. Low switching frequency 2. The structure of the controller is simple 3. Good economy	1. The response speed is slow, usually 4 times 6 cycles. 2. The phase change range of output AC voltage is very small, and the	Most of them are used in the installation of large capacity STATCOM.

			control accuracy is very high for phase detection. 3. The stability of the control system is poor	
Direct control (PWM)	Hysteretic comparison method	1. The circuit is simple 2. The dynamic response is fast. 3. The instantaneous tracking effect is better.	1. The switching frequency is high and not fixed 2. The switching loss is large.	Suitable for small capacity situations
	Triangular wave comparison method	1. The circuit is simple and easy to implement. 2. Switching frequency fixed 3. Low harmonic content	The tracking error is slightly larger	

Through the analysis and summary of the above control methods, this paper adopts the direct current control of triangular wave comparison, and introduces the instantaneous reactive power theory and synchronous coordinate transformation to improve the control accuracy [10]. As shown in figure 4, the direct current control process diagram using dq0 transform in STATCOM is shown.

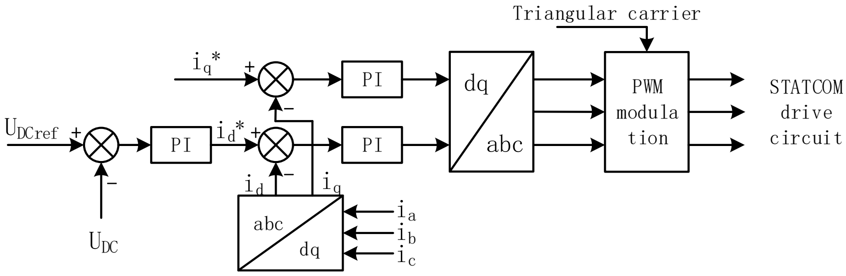

Fig. 4 Direct current control using dq0 transform in STATCOM

The double-closed-loop control structure is adopted, the outer ring is a voltage control ring, the inner ring is a current control ring [11], the stable control of the direct current side voltage and the tracking control on the reactive current can be realized, and the main control process is as follows:

1. the constant control of the direct current side voltage: introducing a voltage feedback link, comparing the direct current side real-time voltage U_{DC} with the direct current reference voltage U_{DCref} , After the difference is adjusted by PI regulator in the form of active reference current i_d^*, the active current flowing into STATCOM is controlled to keep the voltage on the DC side stable.

2. By introducing current feedback link, STATCOM output three-phase current i_a , i_b , i_c is transformed into dq coordinate system, and the active current component and reactive current component are obtained.

3.The active reference current i_d^* and the reactive reference current i_q^* are respectively subtracted from the active current component i_d and the reactive current component i_q output by the STATCOM. After the difference is adjusted by PI regulator, the dq-abc coordinates are inversely transformed into three-phase reference current, and finally the triangular wave is compared to determine the switching state of the converter.

4.2 Feedforward control strategy for harmonic suppression

When the power grid is distorted, the compensation current of STATCOM is mainly divided into two kinds, one is to compensate the reactive current generated by the client, which makes the current of the power grid consistent with the voltage waveform, the other is to control the compensation current to sinusoidal waveform from the point of view of reducing the power loss of the transmission line. In this paper, the latter method is adopted.

when the power grid voltage contains harmonic components, the influence of the direct current side bus voltage fluctuation on the system and the distortion of the output current of the alternating current side can be caused, On the basis of the original control scheme, a feed-forward control link describing the external input signal information is introduced in the system [12].

The introduction of feedforward control is equivalent to copying the information of the power grid on the AC side of the Statcom three-phase bridge arm, which of course includes harmonics, so that the STATCOM outputs a voltage harmonic component with the same amplitude and phase as the harmonics contained in the power grid [13], if the difference between the alternating current side and the power grid voltage is only the fundamental wave frequency, the current flowing through the connecting reactance only contains the fundamental wave component, and the harmonic component in the current is naturally eliminated, so that the control of the direct flow on the d and q axis is realized smoothly, figure 5 is a schematic block diagram of a system model for introducing a power grid voltage feedforward control.

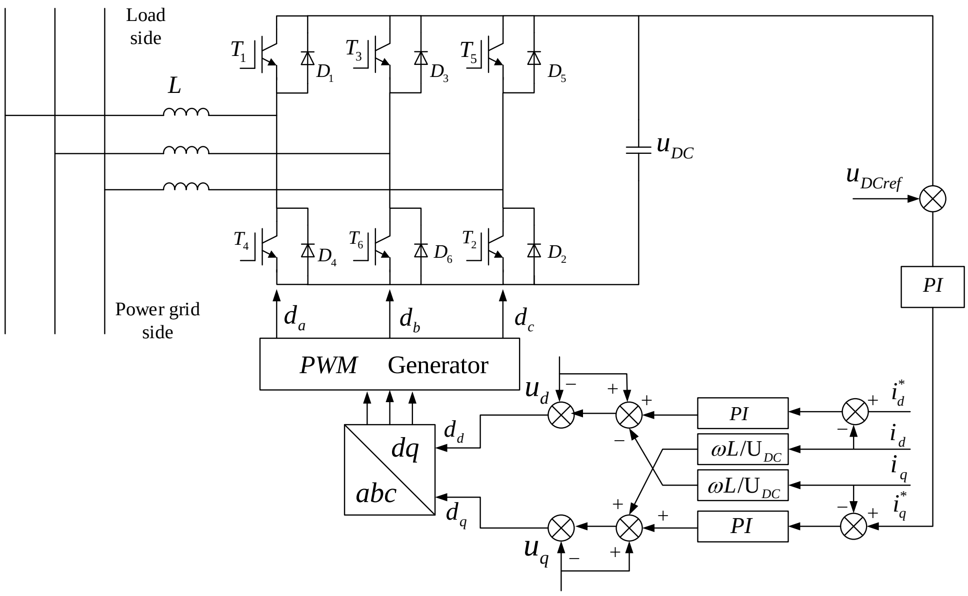

Fig. 5 schematic diagram of the system model after introducing the voltage feedforward control of the power grid

5. Results and discussions

In order to verify the performance of the proposed optimization method, STATCOM is connected to the AC bus of the network. In this paper, the STATCOM and controller model of ship power system are simulated on MATLAB/SIMULINK platform. The simulation results are compared with the operation results of the ship power system which is not connected with the STATCOM.

The results show that the proposed STATCOM optimization method is significant for the reactive power compensation and the harmonic suppression of the ship power system.

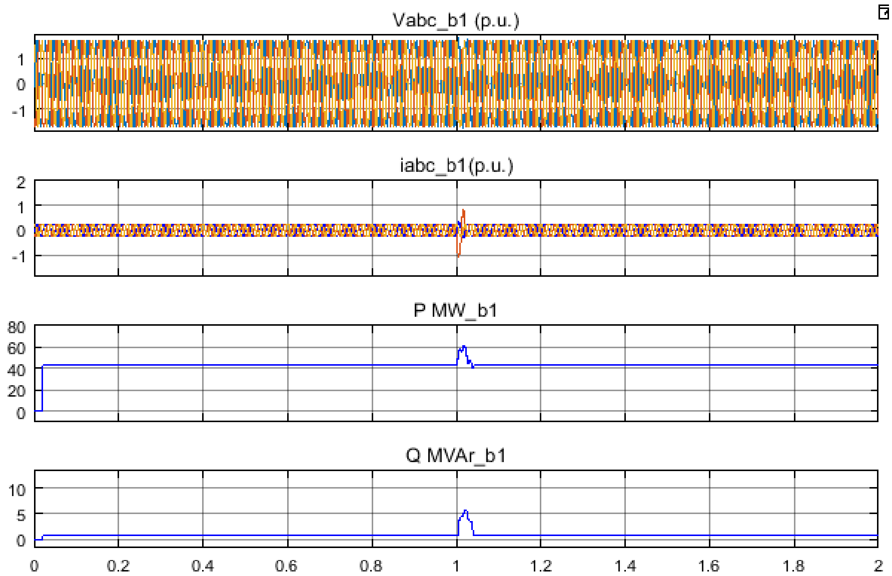

Fig. 6 Simulation diagram of ship power system without STATCOM connection

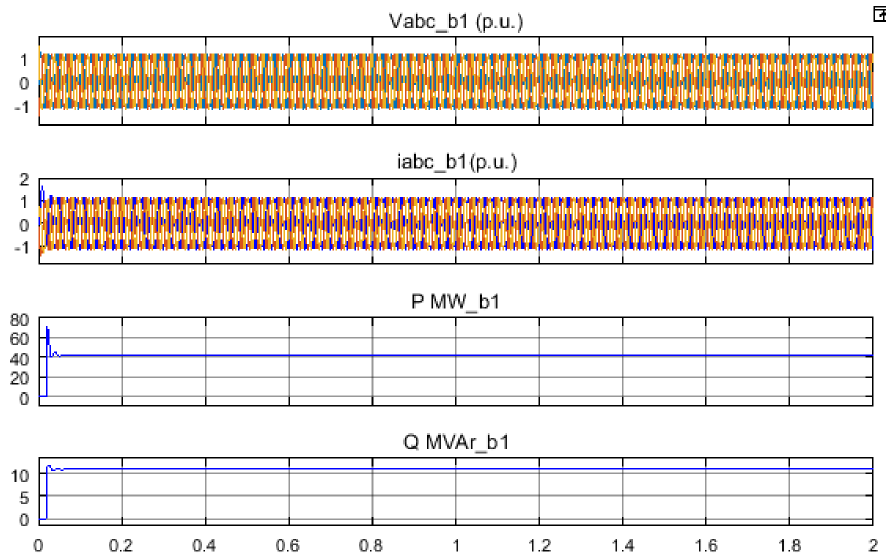

Fig. 7 Simulation diagram of ship power system connected to STATCOM

Acknowledgements

Natural Science Foundation.

References

[1] S.Panda and N.P.Padhy,"Comparison of particle swarm optimization and genetic algorithm for facts-based controller design,"Applied soft computing,vol.8,no.4,pp.1418–1427,2008.
[2] D.Radu and Y.Besanger,"A multi-objective genetic algorithm approach to optimal allocation of multi-type facts devices for power systems security,"in 2006 IEEE Power Engineering Society General Meeting.IEEE,2006,pp.8–pp.
[3] E.Rosolowski,B.Kasztenny,J.Izykowski,and M.M.Saha.Comparative analysis of impedance algorithms for series compensated lines.Proceedings of the Power System Protection Conference, Bled,Slovenia,1996:21-26.
[4] Chuanglin Fang.Practical problems and coping strategies of wind power industyr in China [C].World Non-Grid-Connected Wind Power and Energy Conference,2009:l-5.

[5] Keshavan BK,Nagesh Prabhu.Damping of sub synchronous oscil1ations using STATCOM-a FACTS device [C].IEEE Transmission and Distribution Conference and Exposition, 2009,1(1):1-7.
[6] ——,“A dstatcom controller tuned by particle swarm optimization for an electric ship power system,”in Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century,2008 IEEE.IEEE,2008,pp.1–6.
[7] MAHMUD M A,HOSSAIN M J，POTA H R, et al.Robust nonlinear controller design for three-phase grid-connected photovoltaic systems under structured uncertainties[J]. IEEE Transactions on Power Delivery, 2014, 29(3):1221-1230.
[8] Pranesh Rao,CrowML,Yang zhiping.STATCOM control for power system voltage control applications [J].IEEE Trans.on Power Delivery,2010,15(4):1311-1317.
[9] REMUS T,MARCO L,PEDRO R,et al.Grid converters for photovoltaic and wind power systems[J].WILEY,2011:1-4.
[10] F.Shahnia,S.Rajakaruna,and A.Ghosh,Static Compensators (STATCOMs) in Power Systems. Springer,2015.
[11] S.S.S.Farahani,M.Nikzad,M.B.Tabar,M.G.Naraghi,and A.Javadian,“Genetic algorithms for tuning supplementary statcom stabilizer in a multi machine electric power system,”Research Journal of Applied Sciences,Engineering and Technology,vol.3,no.8,pp.843–851,2011.
[12] Li Dingzhen, Chen Binyan. Research on static synchronous compensator based on MATLAB [J]. instrumentation,2011,48(551).
[13] Su Bowen. Statcom control strategy and simulation research [D]. Liaoning: Liaoning University of Science and Technology,2015.