Journal of Electronics and Information Science (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/jeis.2025.100214
ISSN 2371-9524 Vol. 10 Num. 2

Construction and Grid-Connection Control Verification of SVG Simulation Model for Power Collection Systems

Jiashun Zhu[1], Wen Li[1,*], Xinyu Miao[2], Tiansheng Sun[1], Jingyan Min[1]

[1]*School of Electrical Engineering, Yingkou Institute of Technology, Yingkou, 115000, China*
[2]*Yingkou Abe Wiring Co., Ltd., Yingkou, 115000, China*
**Corresponding author*

Keywords: Power Collection System; Static Var Generator (SVG); Grid-Connection Control; Reactive Power Compensation

Abstract: With the increasing grid-connection applications of power collection systems, their power electronic devices are prone to introducing reactive power loss, which affects the power quality of the power grid. A Static Var Generator (SVG) is therefore required to ensure grid-connection performance. This paper designs the SVG main circuit for power collection systems based on a voltage-source bridge circuit. Under ideal assumptions, a mathematical model in the abc coordinate system is established, where the on-off characteristics of devices are described by switching functions. A decoupled model in the dq coordinate system is then derived through 3s/2s and 2s/2r coordinate transformations. A grid voltage-oriented double closed-loop control strategy is adopted: the outer loop stabilizes the DC-side voltage using a PI controller, the inner loop tracks reactive current, and an intermediate voltage is introduced to eliminate variable coupling. Meanwhile, SPWM and SVPWM modulation modules are constructed. A simulation model is built based on MATLAB/Simulink (grid line voltage 400V, load 200kW active power/100kvar reactive power, grid-connection inductor 1mH, DC voltage 800V). The results show that: without SVG, the grid power factor is 0.894; after SVG operation, the voltage and current phases align within 0.15s, the power factor approaches 1, and the DC voltage stabilizes at 800V within 0.07s. The current THD is 1.49% with SPWM modulation and decreases to 1.30% with SVPWM. The research indicates that the SVG simulation model can meet the reactive power compensation requirements of power collection system grid-connection, improving the power quality and stability of the grid-connection side.

1. Introduction

Against the backdrop of the global energy structure transitioning towards cleanliness and distribution, the penetration rate of power collection systems (such as photovoltaic power generation, wind power generation, and energy storage systems) in power systems continues to rise[1]. These systems achieve grid-connection through power electronic converters, becoming a key link in promoting efficient energy utilization. However, the nonlinear characteristics of a large number of power electronic devices in power collection systems, as well as common inductive loads on the grid-connection side (such as transformers, asynchronous motors, and rectifiers), lead to significant reactive power consumption during system operation[2]. Although reactive power does not directly participate in energy consumption, it needs to be frequently exchanged between the power source and the load. Relying solely on generators for long-distance transmission not only increases active power loss in transmission lines but also may cause problems such as grid voltage sag and reduced power factor, seriously threatening the power quality and grid operation stability of power collection systems after grid-connection[3]. Therefore, designing an efficient and dynamic reactive power compensation scheme for the grid-connection scenario of power collection systems has become a core demand to ensure the safe and economic operation of the system.

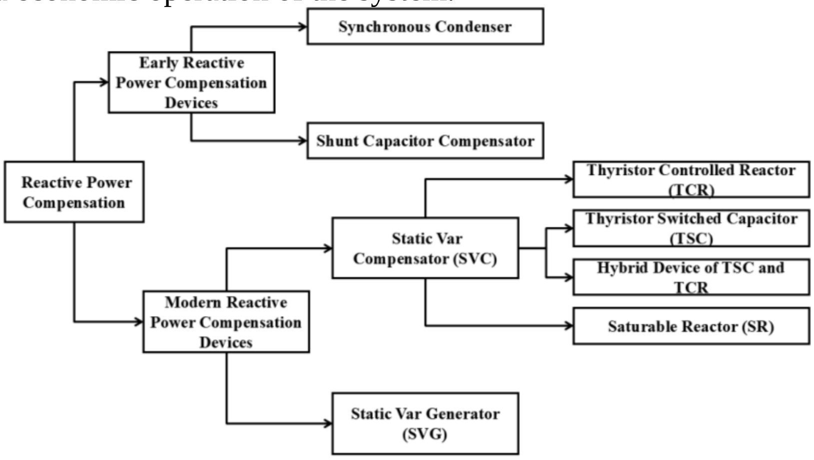


Figure 1 Flow Chart of Reactive Power Compensation Technology

The development of reactive power compensation technology has evolved from traditional mechanical regulation to power electronic control. Differences in the performance of various compensation devices directly affect their application scenarios (as shown in Figure 1). Early synchronous condensers can achieve continuous reactive power regulation but have drawbacks such as slow response speed, high loss, and loud noise, making them difficult to adapt to the dynamic grid-connection needs of power collection systems[4]. Static Var Compensators (SVC) such as saturable reactors and Thyristor Switched Capacitors (TSC) have improved response speed but suffer from severe harmonic pollution and limited phase-separated control capabilities, which may cause secondary impacts on the grid-connection current quality of power collection systems[5]. In contrast, Static Var Generators (SVG) based on inverter circuits composed of self-commutated switching devices can achieve bidirectional and continuous compensation of capacitive and inductive reactive power by dynamically adjusting the amplitude and phase of the AC-side output voltage and current[6]. They also offer advantages such as fast response speed, low harmonic current, low loss, and flexible phase-separated control, making them particularly suitable for the compensation needs of rapidly changing reactive power during the grid-connection of power collection systems.

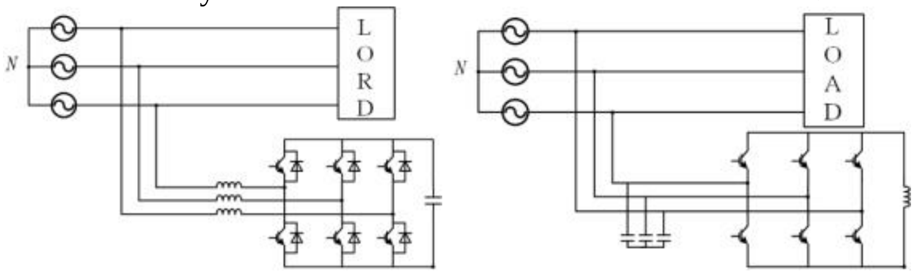
Domestic research on SVG began with the development of a 10kVA thyristor-controlled SVG experimental device by North China Electric Power University in 1986. After decades of development, significant progress has been made in theoretical modeling and engineering applications[7]. However, most existing studies focus on reactive power compensation in traditional power grids, and there are still deficiencies in research on SVG adaptability for the grid-connection scenario of power collection systems. Firstly, the power fluctuation on the grid-connection side of power collection systems is large, requiring higher dynamic response speed and voltage stability of SVG. Secondly, the pursuit of energy utilization efficiency by the system also requires SVG to minimize its own loss and harmonic interference while achieving reactive power compensation[8]. In addition, the control strategy and Pulse Width Modulation (PWM) technology of SVG directly affect its compensation accuracy and grid-connection performance. Further verification is needed on how to make SVG better adapt to the grid-connection characteristics of power collection systems through reasonable modeling and control design.

Based on the above background, this paper conducts research on the construction and grid-connection control verification of SVG simulation models targeting the grid-connection needs of power collection systems[9]. Firstly, considering the requirements of low loss and high efficiency for compensation devices in power collection systems, the SVG main circuit is determined to adopt a voltage-source bridge topology. Secondly, an SVG mathematical model in the abc coordinate system is established under ideal assumptions, the characteristics of switching devices are described by switching functions, and a synchronous rotating dq coordinate system is introduced to convert time-varying AC quantities into DC quantities to simplify control design[10]. Subsequently, a grid voltage-oriented double closed-loop control strategy is designed, combined with SPWM and SVPWM modulation technologies to achieve stable DC-side voltage and accurate tracking of reactive current. Finally, an SVG simulation model including the grid-connection scenario of power collection systems is built based on the MATLAB/Simulink platform. The grid-connection control effect of the designed SVG is verified by comparing the grid power factor, current waveform, and harmonic content before and after SVG operation. The research results of this paper can provide theoretical support and simulation basis for the design of reactive power compensation schemes on the grid-connection side of power collection systems, helping to improve the grid-connection stability and power quality of the system.

2. Working Principle and Mathematical Model of Static Var Generator

2.1 Working Principle of Static Var Generator (SVG)

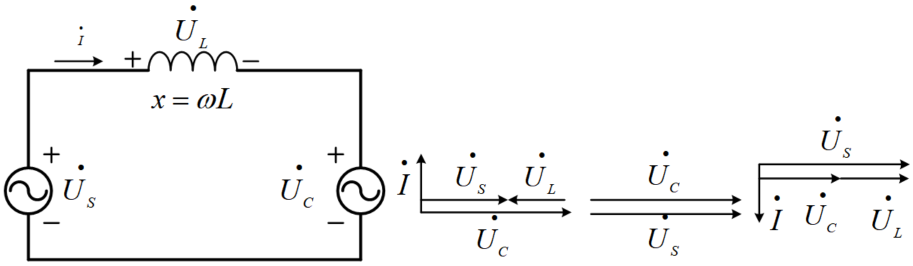
Static Var Generator (SVG) achieves bidirectional dynamic compensation of capacitive and inductive reactive power through an inverter circuit composed of self-commutated switching devices. Its main circuit core consists of two topological structures: voltage-source bridge circuit and current-source bridge circuit (as shown in Figure 2). Both are connected to the grid through inductors or directly, and control the magnitude of reactive current to achieve dynamic reactive power compensation by adjusting the amplitude and phase of the AC-side output voltage and current. Among them, the voltage-source bridge circuit is selected as the main circuit of this study due to its advantages of easy implementation, low loss, and high efficiency, which are more suitable for the requirements of energy utilization efficiency in the grid-connection of power collection systems. In contrast, the current-source bridge circuit has a relatively low proportion in practical applications due to the additional loss caused by the internal resistance of the DC-side inductor.



(a) Voltage-source bridge circuit (b) Current-source bridge circuit

Figure 2 Two Structures of SVG Main Circuit

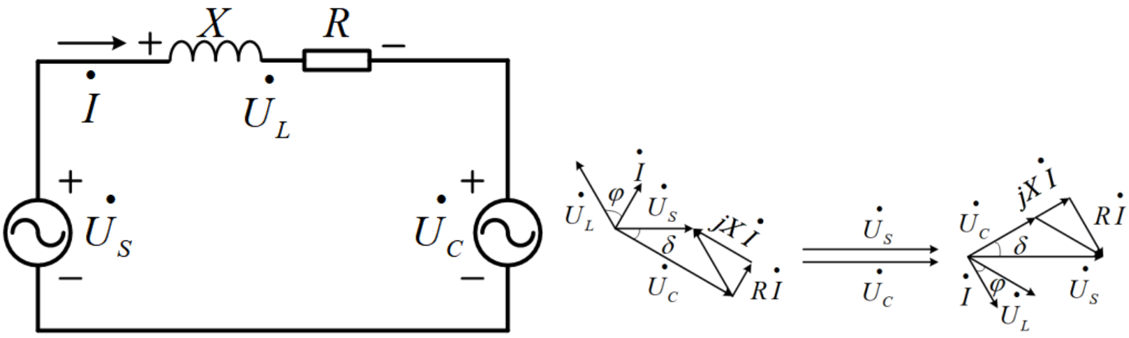
SVG is connected to the grid in parallel, and its operation process includes two core links: AC and DC. The AC link is directly connected to the grid or the load power supply side. The DC link is responsible for converting AC power into DC and storing it in energy storage components, while converting the stable DC voltage back into AC voltage and current through the converter and feeding it back to the grid. Based on the structural characteristics of the bridge converter, SVG can be equivalent to an adjustable voltage source or current source. Under ideal conditions considering only the fundamental frequency, its single-phase equivalent circuit and phasor diagram are shown in Figure 3. According to Kirchhoff's Voltage Law (KVL), the difference between the grid voltage and the SVG AC-side voltage is the voltage across the series inductor. The current absorbed by SVG from the grid can be calculated through this voltage. Therefore, adjusting the amplitude and phase of the SVG AC-side voltage can change the inductor voltage, thereby controlling the phase and amplitude of the grid current to achieve reactive power compensation. Specifically, when the amplitude of the SVG AC-side voltage is lower than the grid voltage, current flows from SVG to the grid, and SVG provides inductive reactive power to the grid, operating in the capacitive region with the voltage phase lagging the current by 90 °. When the amplitude of the SVG AC-side voltage is higher than the grid voltage, current flows from the grid to SVG, and SVG provides capacitive reactive power, operating in the inductive region with the current phase lagging the voltage by 90 °. When the voltage amplitudes are equal, there is no current exchange between SVG and the grid, and SVG does not participate in reactive power compensation.



(a) Single-phase equivalent circuit of SVG (b) Single-phase equivalent phasor diagram of SVG

Figure 3 Single-phase Equivalent Circuit and Phasor Diagram of SVG

In actual operating scenarios, it is necessary to consider the loss of inductors and switching tubes. At this time, the loss can be equivalent to a linear resistor in series with the inductor, and its single-phase equivalent circuit and phasor diagram are shown in Figure 4. Since the converter itself only consumes reactive power, the SVG AC-side output voltage and current still maintain a 90 ° phase difference. However, due to resistance loss, there is a phase difference between the grid voltage and the SVG output current, and the current contains a small amount of active component to compensate for the resistance loss. Even with the influence of loss, by adjusting the amplitude relationship between the grid voltage and the SVG AC-side voltage, the amplitude and phase of the inductor current can still be accurately controlled, ensuring that SVG outputs the required reactive power to the grid and maintaining reactive power balance during the grid-connection of the power collection system.



(a) Single-phase equivalent circuit of SVG (with loss) (b) Single-phase equivalent phasor diagram of SVG (with loss)

Figure 4 Single-phase Equivalent Circuit and Phasor Diagram of SVG with Loss

2.2 Establishment of SVG Mathematical Model

The establishment of the SVG mathematical model is based on three ideal assumptions: symmetric three-phase SVG circuit parameters, ideal switching devices in the circuit, and a standard symmetric three-phase system voltage source. These assumptions simplify the derivation process and ensure the rationality of the model. The topology of the voltage-source SVG main circuit is shown in Figure 5, which clearly marks the three-phase AC grid voltages (ea, eb, ec), SVG AC-side output currents (ia, ib, ic), equivalent resistance R considering loss, grid-connection equivalent inductor L, 6 IGBT switching devices (S1~S6), and DC-side capacitor voltage Udc. The core composition of the SVG main circuit is within the dashed box.

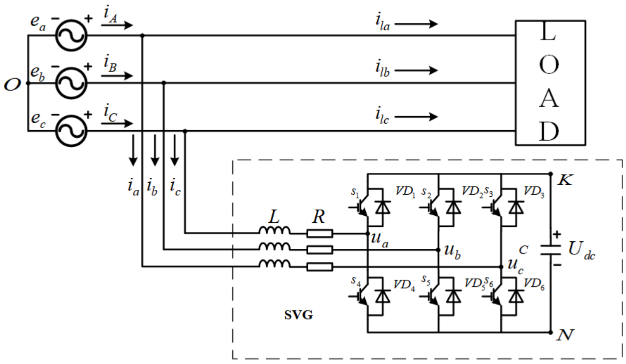


Figure 5 Topology of SVG Main Circuit

When establishing the SVG mathematical model in the abc coordinate system, the voltage loop equation is first listed for phase a according to Kirchhoff's Voltage Law (KVL) (Equation 1).

$$e_a = Ri_a + L\frac{di_a}{dt} + (u_{aN} + u_{NO}) \tag{1}$$

To describe the on-off characteristics of switching devices, a switching function Sn is introduced (Equation 2).

$$S_n = \begin{cases} 1 \ Upper\ bridge\ arm\ of\ phase\ n\ on, lower\ off \\ 0 \ Upper\ bridge\ arm\ of\ phase\ n\ off, lower\ on \end{cases} \tag{2}$$

When Sn=1, the upper tube of the corresponding bridge arm is turned on and the lower tube is turned off. When Sn=0, the upper tube is turned off and the lower tube is turned on. Based on this, the relationship between the a-phase bridge arm output voltage and the DC-side voltage can be obtained (Equation 3).

$$u_{aN} = S_a U_{dc} \tag{3}$$

Substituting this relationship into the KVL equation, the a-phase voltage loop equation expressed by the switching function can be derived (Equation 4).

$$e_a = Ri_a + L\frac{di_a}{dt} + (S_a U_{dc} + u_{NO}) \tag{4}$$

Similarly, the corresponding equations for phases b and c can be obtained (Equation 5).

$$e_b = Ri_b + L\frac{di_b}{dt} + (S_b U_{dc} + u_{NO})$$

$$e_c = Ri_c + L\frac{di_c}{dt} + (S_c U_{dc} + u_{NO}) \tag{5}$$

Combined with the ideal assumption of symmetric three-phase circuit parameters (Equation 6).

$$e_a + e_b + e_c = 0$$
$$i_a + i_b + i_c = 0 \tag{6}$$

Further simultaneous derivation yields the correlation between three-phase currents and switching functions (Equation 7).

$$u_{NO} = -\frac{1}{3}U_{dc}(S_a + S_b + S_c) \tag{7}$$

Meanwhile, the DC-side current equations are established through KCL (Equations 8 and 9).

$$i_{dc} = S_a i_a + S_b i_b + S_c i_c \tag{8}$$

$$i_C = i_{dc} - i_L = C\frac{dU_{dc}}{dt} = (S_a i_a + S_b i_b + S_c i_c) - \frac{U_{dc} - e_L}{R_L} \tag{9}$$

Finally, the SVG mathematical model described by switching functions in the abc coordinate system is integrated (Equation 10).

$$e_a = Ri_a + L\frac{di_a}{dt} + (S_a U_{dc} + u_{NO})$$
$$e_b = Ri_b + L\frac{di_b}{dt} + (S_b U_{dc} + u_{NO})$$
$$e_c = Ri_c + L\frac{di_c}{dt} + (S_c U_{dc} + u_{NO})$$
$$C\frac{dU_{dc}}{dt} = (S_a i_a + S_b i_b + S_c i_c) - \frac{U_{dc} - e_L}{R_L} \tag{10}$$

Although this model can intuitively reflect the correlation between AC-side currents and electrical quantities, the AC-side output quantities are time-varying sinusoidal quantities, which brings inconvenience to the design of the control system. To solve the problem of time-varying AC quantities in the abc coordinate system, a synchronous rotating dq coordinate system is introduced to convert the mathematical model from the stationary coordinate system to the rotating coordinate system. This process requires two coordinate transformations: first, converting the stationary three-phase coordinate system (3s) to the stationary two-phase orthogonal coordinate system (2s), and then converting the stationary two-phase coordinate system to the synchronous rotating dq coordinate system (2r). The specific transformation is realized through matrix operations, where the 3s/2s constant power transformation matrix (Equation 11) and its inverse transformation matrix (Equation 12) complete the dimensional simplification from three-phase to two-phase.

$$C_{3s/2s} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \tag{11}$$

$$C_{2s/3s} = C_{3s/2s}^{-1} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 & \frac{\sqrt{2}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{\sqrt{2}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \tag{12}$$

The 2s/2r transformation matrix (Equation 13) and its inverse transformation matrix (Equation 14) realize the state conversion from stationary to rotating. Their combination can obtain the direct 3s/2r transformation matrix (Equation 15) and its inverse transformation matrix (Equation 16).

$$C_{2s/2r} = \begin{bmatrix} \cos\varphi & \sin\varphi \\ -\sin\varphi & \cos\varphi \end{bmatrix} \tag{13}$$

$$C_{2r/2s} = C_{2s/2r}^{-1} = \begin{bmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{bmatrix} \tag{14}$$

$$C_{3s/2r} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\varphi & \cos(\varphi - \frac{2}{3}\pi) & \cos(\varphi + \frac{2}{3}\pi) \\ -\sin\varphi & -\sin(\varphi - \frac{2}{3}\pi) & -\sin(\varphi + \frac{2}{3}\pi) \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \tag{15}$$

$$C_{2r/3s} = C_{3s/2r}^{-1} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\varphi & -\sin\varphi & \frac{\sqrt{2}}{2} \\ \cos(\varphi - \frac{2}{3}\pi) & -\sin(\varphi - \frac{2}{3}\pi) & \frac{\sqrt{2}}{2} \\ \cos(\varphi + \frac{2}{3}\pi) & -\sin(\varphi + \frac{2}{3}\pi) & \frac{\sqrt{2}}{2} \end{bmatrix} \tag{16}$$

Substituting the abc coordinate system model through 3s/2r transformation, the SVG mathematical model in the dq coordinate system is obtained (Equation 17).

$$\begin{aligned} L\frac{di_d}{dt} &= -Ri_d + \omega L i_q + e_d - u_d \\ L\frac{di_q}{dt} &= -Ri_q - \omega L i_d + e_q - u_q \\ C\frac{dU_{dc}}{dt} &= \frac{3}{2}(S_d i_d + S_q i_q) - \frac{U_{dc} - e_L}{R_L} \end{aligned} \tag{17}$$

In the equation, ud, uq and id, iq are the grid voltage and current components on the dq axes respectively, and Sd, Sq are the switching functions on the dq axes. The rotation angular velocity needs to be synchronized with the fundamental angular velocity of the grid. In practical applications, the phase angle of the grid voltage is obtained through a Phase-Locked Loop (PLL) to determine this angular velocity. Currently, the time-varying AC quantities in the abc coordinate system are converted into DC quantities in the dq coordinate system, which greatly simplifies the design process of the subsequent control system.

3. SVG Simulation Analysis

3.1 Construction of SVG Simulation Model

To verify the effectiveness of the aforementioned SVG working principle and control strategy, this study builds a Static Var Generator (SVG) simulation model suitable for the grid-connection scenario of power collection systems based on the Simulink platform of MATLAB software. The overall system simulation diagram is shown in Figure 6.

The model takes a voltage-source bridge converter as the core and covers key functional modules required for SVG grid-connection operation, including a three-phase grid voltage module, a three-phase symmetric load module, a voltage-source bridge converter module, a pulse width modulation signal generation module, a Phase-Locked Loop (PLL) module, and a converter control module. The signal interaction and energy flow between each module follow the SVG working principle, forming a closed-loop simulation system. The grid-side power factor is a core indicator to measure the SVG reactive power compensation effect, so a power factor calculation module is specially built in the model. This module collects grid-side voltage and current signals to calculate and output the power factor value in real-time. If the power factor is close to 1 after SVG operation, the compensation effect is excellent; if there is a large deviation from 1, the control parameters need to be optimized. In addition, the Sinusoidal Pulse Width Modulation (SPWM) module generates PWM signals by comparing sinusoidal modulation waves with triangular carrier waves, and controls the fundamental component of the output voltage by adjusting the amplitude ratio m (the ratio of the peak value of the sinusoidal modulation wave to the peak value of the triangular carrier wave). The Space Vector Pulse Width Modulation (SVPWM) module generates PWM signals conforming to the spatial vector synthesis logic through sector selection, vector action time calculation, and vector switching point determination. The two modulation modules can be separately connected to the main circuit to compare the influence of different modulation technologies on the harmonic content of the SVG AC-side output current. The parameter settings of the simulation model strictly match the actual application scenarios and ideal assumptions. The grid-connection inductor is 1mH (to balance the grid-connection current fluctuation), and the rated value of the DC-side capacitor voltage is 800V (to ensure the stability of the converter's inverter output). The on-off logic of the switching devices is accurately controlled by the signals output by the control module, ensuring that the model not only simplifies non-core interference factors but also truly reflects the operating characteristics of SVG.

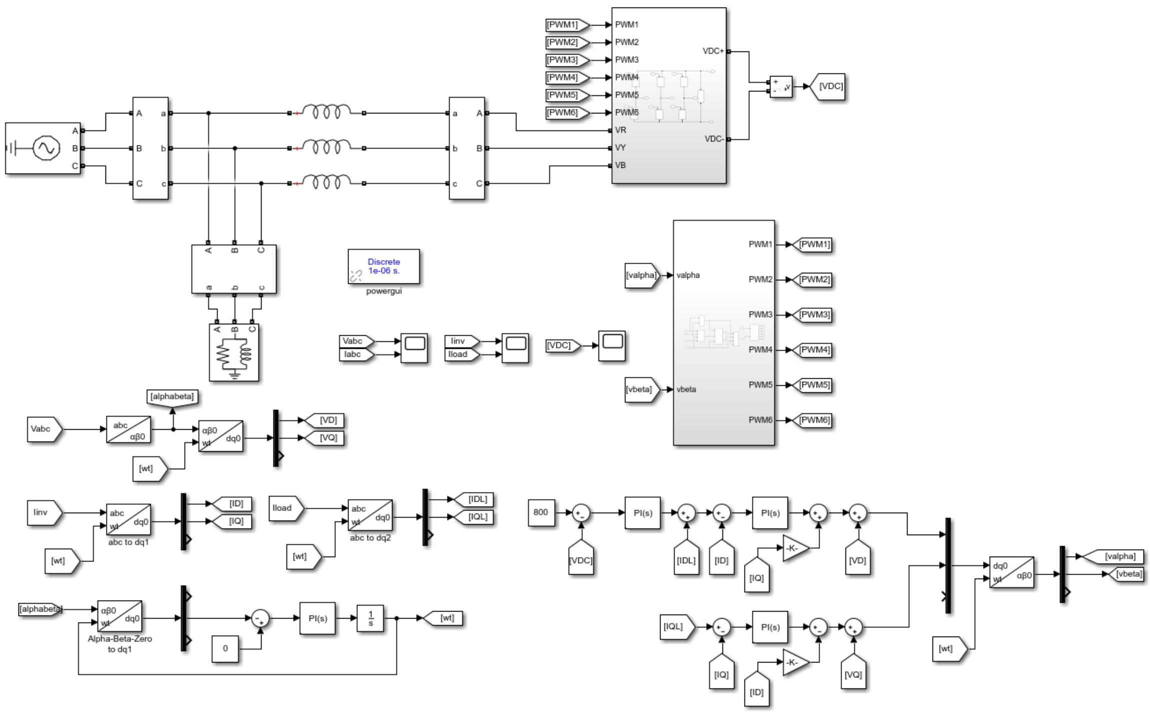


Figure 6 Simulation Diagram of Three-Phase Static Var Generator SVG System

3.2 Simulation Result Analysis

This SVG simulation verification is based on the grid-connection scenario of power collection systems, with the following core parameters: load active power 200kW, reactive power 100kvar, grid-side line voltage 400V, system frequency 50Hz, grid-connection inductor 1mH, and rated DC-side capacitor voltage 800V. The total simulation time is 0.5 seconds. According to the load parameters, the theoretical grid power factor without SVG is about 0.8944. This is used as a benchmark to compare the grid operating characteristics before and after SVG operation to verify the reactive power compensation effect.

Without SVG, the waveform of the grid-side phase a voltage and current is shown in Figure 7. From the waveform comparison, it can be clearly observed that the voltage phase is significantly ahead of the current phase. This phenomenon directly reflects the reactive power deficit caused by the inductive load in the grid. The corresponding grid power factor waveform is shown in Figure 8. The actual monitored value is consistent with the theoretical calculated value, stabilizing around 0.8944, which further confirms that the grid power quality is greatly affected by reactive power loss and urgently needs dynamic compensation through SVG.

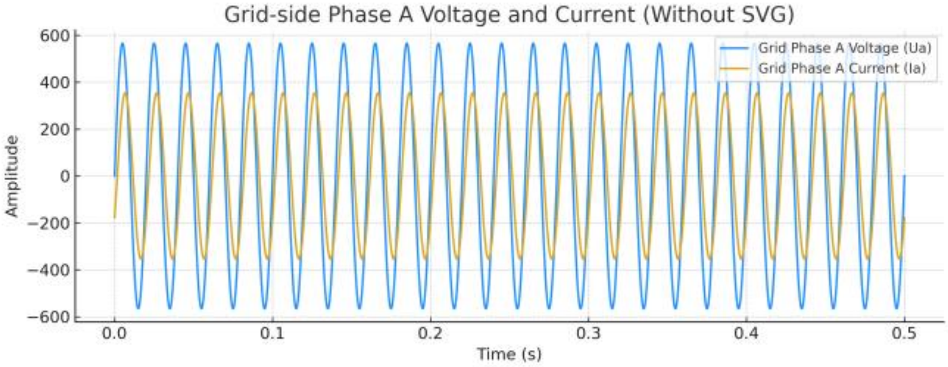


Figure 7 Waveform of Grid-side Phase a Voltage and Current Without SVG

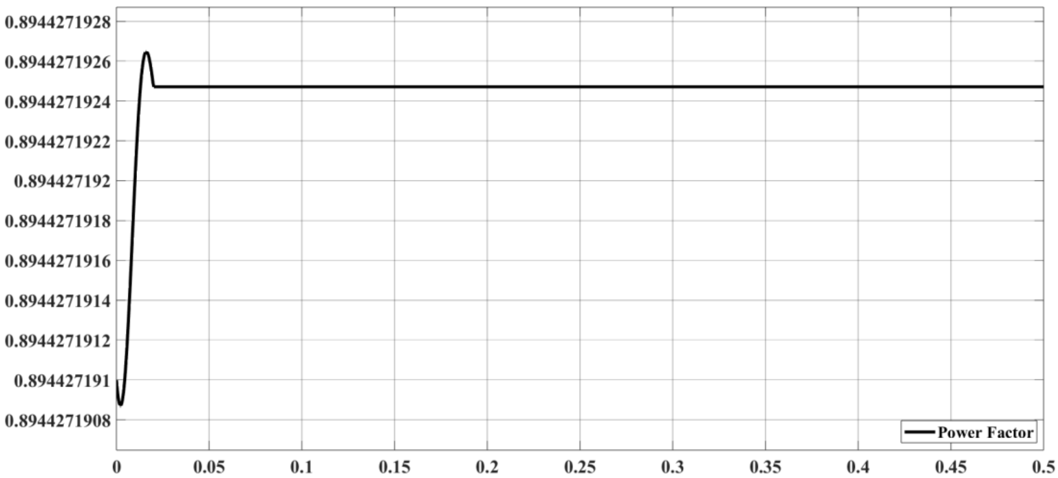


Figure 8 Grid Power Factor Waveform Without SVG

After SVG operation, the grid-side power quality and system stability are significantly improved. From Figure 9 (waveform of grid-side phase a current with SVG), SVG can quickly respond to the grid's reactive power demand and complete compensation within about 0.15 seconds after operation. The stability of the DC-side capacitor voltage is a key indicator to measure the effectiveness of the SVG control strategy. Figure 10 (waveform of DC-side capacitor voltage) shows that the capacitor voltage stabilizes at the rated value of 800V within about 0.07 seconds after the start of the simulation, with no obvious overshoot or fluctuation. This proves that the adjustment accuracy and response speed of the voltage outer loop PI controller meet the design requirements, providing reliable DC-side support for the stable operation of SVG. Figure 11 (grid power factor waveform with SVG) intuitively shows that the power factor quickly approaches 1 after SVG operation, completely solving the reactive power deficit problem without compensation and verifying the effectiveness of the SVG reactive power compensation function.

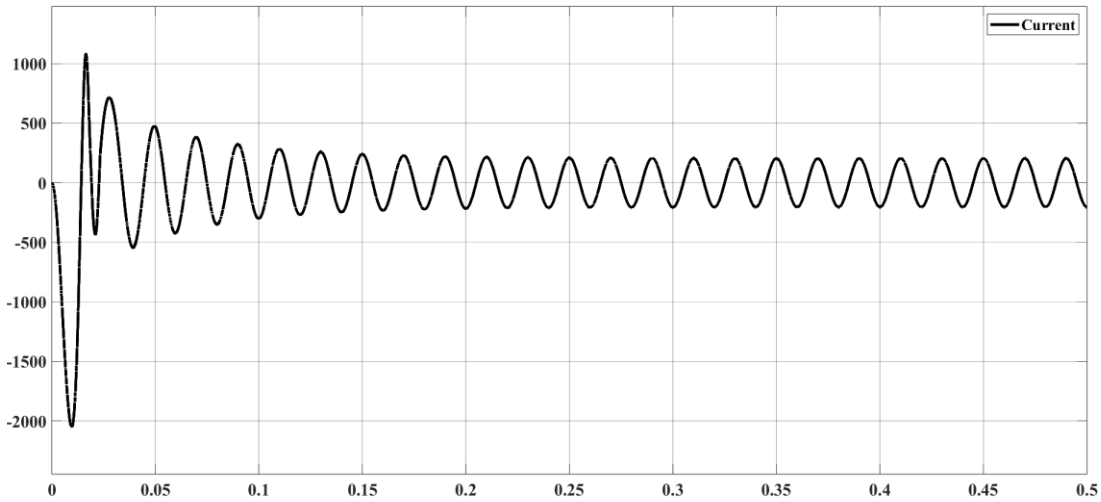


Figure 9 Grid-side Phase a Current With SVG

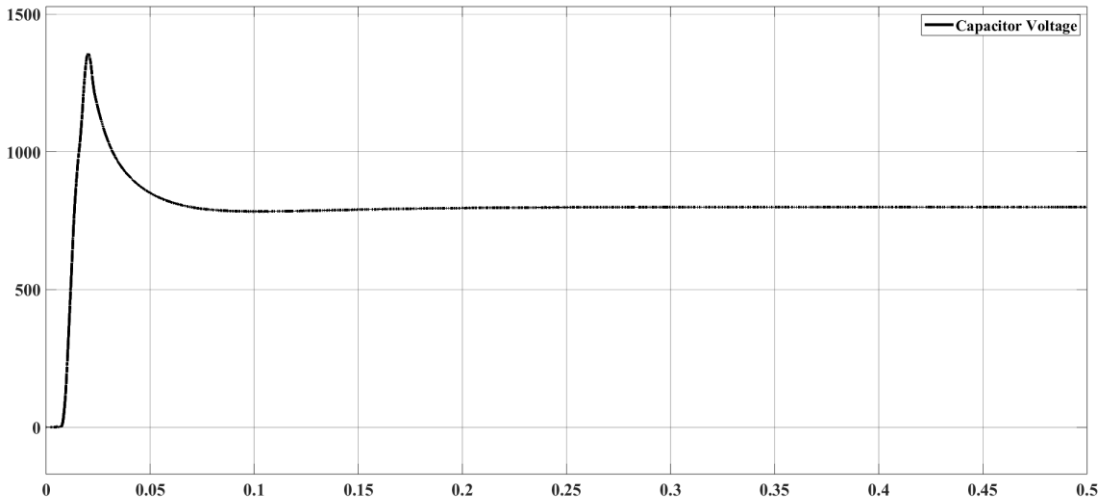


Figure 10 Waveform of DC-side Capacitor Voltage

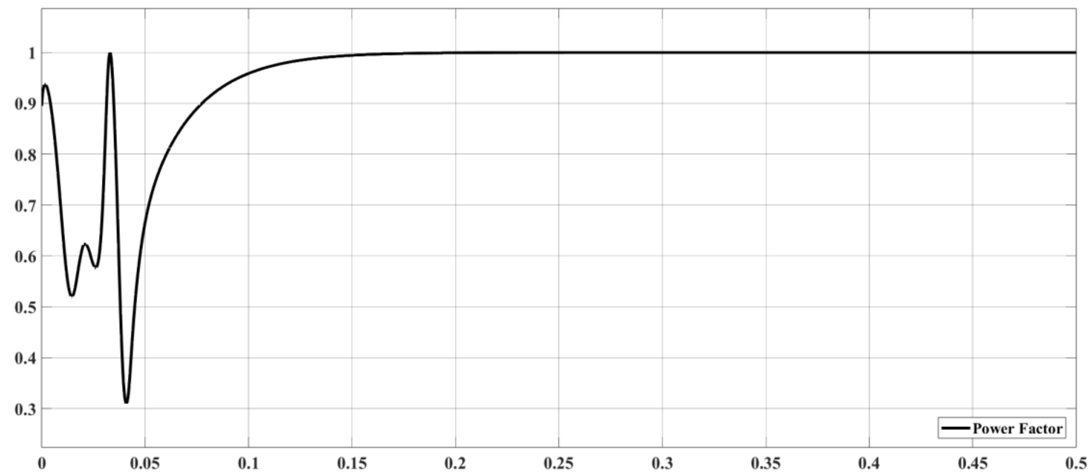


Figure 11 Grid Power Factor Waveform With SVG

To further evaluate the influence of different pulse width modulation technologies on SVG output characteristics, harmonic analysis is performed on the SVG AC-side output current using SPWM and SVPWM modulation respectively. With SPWM modulation, the waveform of the SVG AC-side output current is shown in Figure 12, and the corresponding harmonic analysis of phase a current is shown in Figure 13. The detected Total Harmonic Distortion (THD) is 1.49%. With SVPWM modulation, the current waveform is shown in Figure 14, and the harmonic analysis is shown in Figure 15, with the THD reduced to 1.30%. The comparison shows that the current distortion rate under both modulation technologies is at an extremely low level, which can be ignored for grid harmonic interference. However, SVPWM modulation performs better in suppressing low-order harmonics, which can further improve the quality of the SVG AC-side output current and is more suitable for the low-harmonic requirements of power collection system grid-connection.

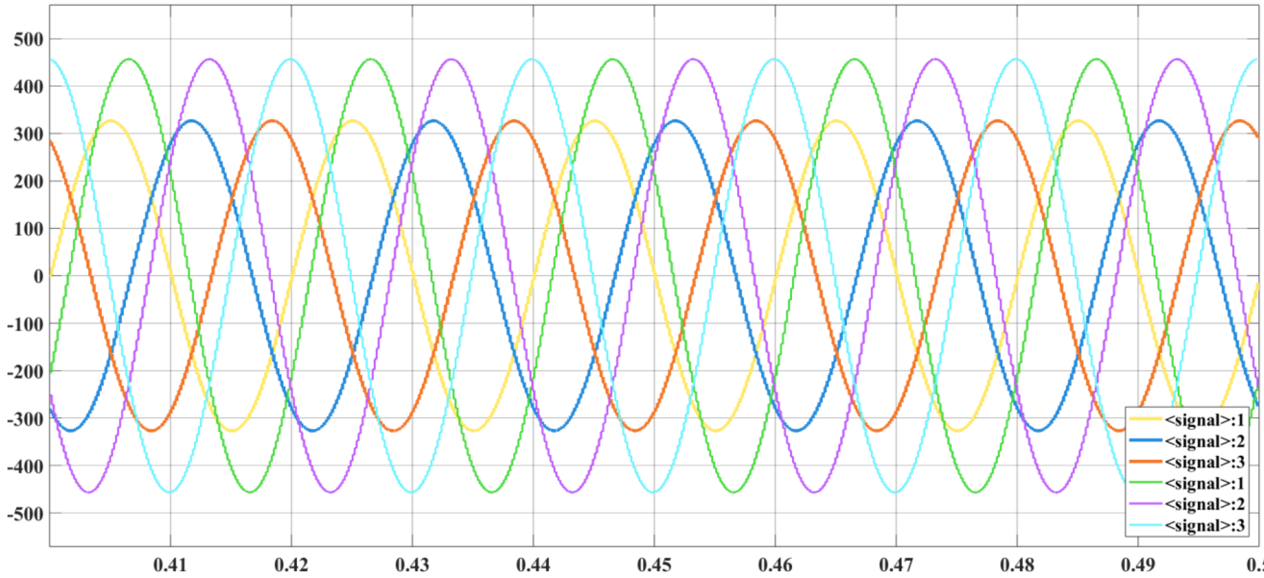


Figure 12 SVG AC-side Output Current Waveform With SPWM Modulation

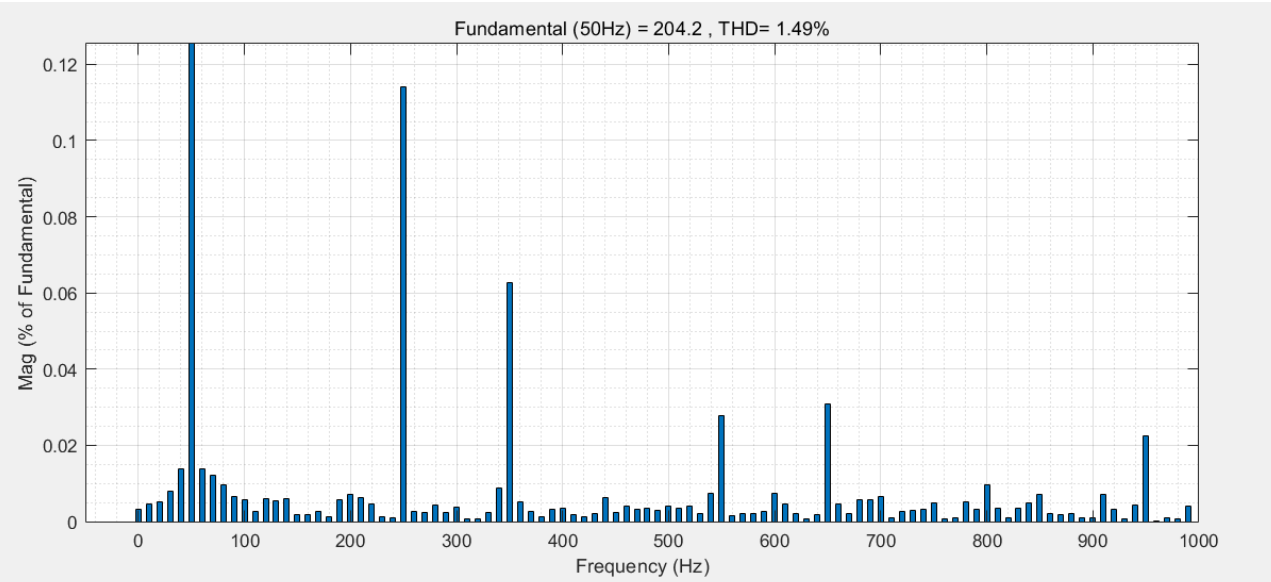


Figure 13 Harmonic Analysis of SVG AC-side Phase a Current With SPWM Modulation

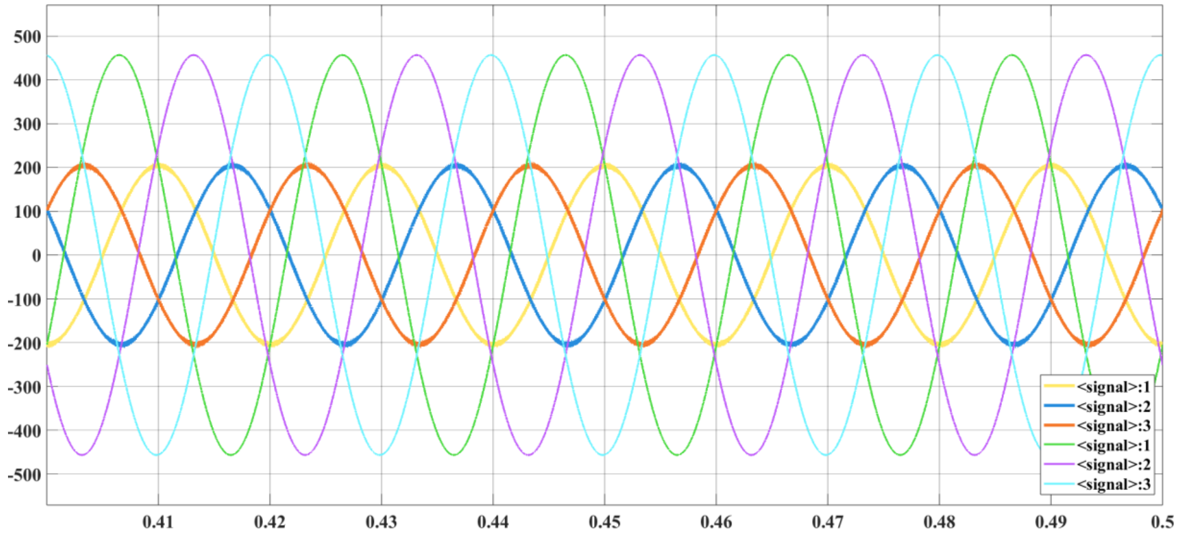


Figure 14 SVG AC-side Output Current Waveform With SVPWM Modulation

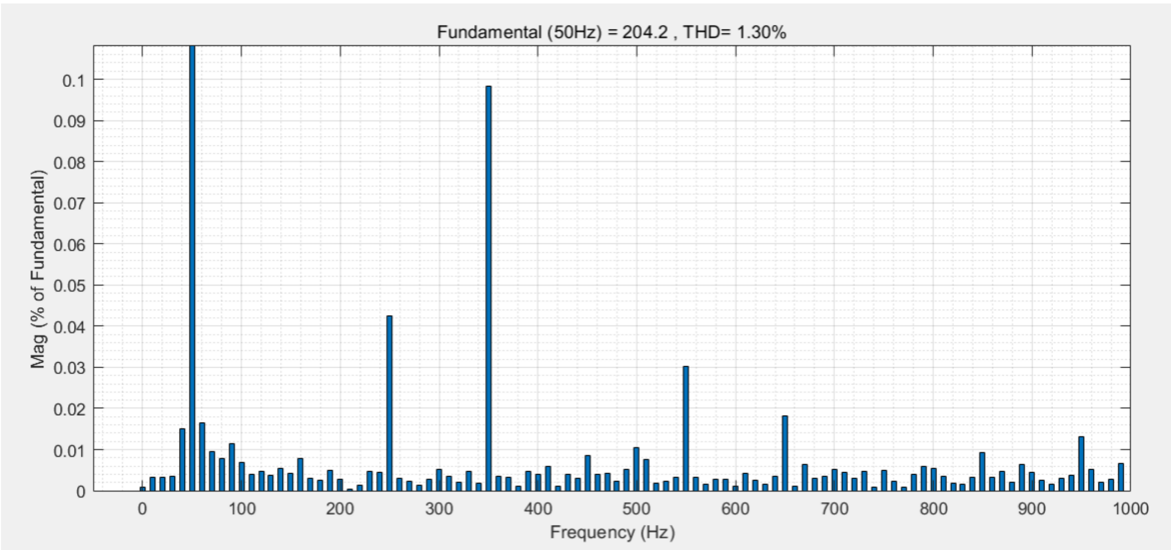


Figure 15 Harmonic Analysis of SVG AC-side Phase a Current With SVPWM Modulation

Based on the above simulation results, the built voltage-source SVG simulation model can accurately respond to the reactive power demand on the grid-connection side of power collection systems. The grid voltage-oriented double closed-loop control strategy can achieve fast tracking of reactive current and stable control of DC-side voltage. Combined with SPWM or SVPWM modulation technology, both can meet the grid power quality requirements. Among them, SVPWM modulation has a more significant advantage in harmonic suppression, providing a reliable simulation basis for the subsequent engineering application of SVG.

4. Conclusions

This study first analyzes the working principle of SVG, determines the adoption of a voltage-source bridge main circuit topology, and clarifies the mechanism of reactive power compensation by adjusting the phase and amplitude of the AC-side voltage. Secondly, an SVG mathematical model is established under ideal assumptions. The model containing switching functions in the abc coordinate system is first derived, and then the decoupled model in the dq coordinate system is obtained through 3s/2s and 2s/2r coordinate transformations to simplify control design. Subsequently, a grid voltage-oriented double closed-loop control strategy is designed, combined with SPWM and SVPWM modulation technologies to achieve stable DC-side voltage and reactive current tracking. Finally, a simulation model is built based on MATLAB/Simulink, with parameters such as 200kW active power/100kvar reactive power load and 400V grid set. The operating characteristics before and after SVG operation and the harmonic performance of the two modulation technologies are compared to verify the effectiveness of SVG compensation and the low-harmonic advantage of SVPWM. Meanwhile, the limitations of symmetric loads and the improvement direction of PI control are pointed out.

(1) The SVG simulation model based on the voltage-source bridge circuit, combined with the grid voltage-oriented double closed-loop control, can solve the reactive power deficit of power collection system grid-connection. Simulation results show that without SVG, the grid power factor is 0.894. After SVG operation, the voltage and current phases align within 0.15s, the power factor approaches 1, and the DC-side capacitor voltage stabilizes at the rated value of 800V within 0.07s, verifying the response speed and compensation accuracy of the model and control strategy.

(2) Comparing SPWM and SVPWM modulation, the THD of the SVG AC-side current under both is extremely low, with no significant grid harmonic interference. Moreover, SVPWM is better at suppressing low-order harmonics, providing a better scheme for low-harmonic grid-connection operation.

(3) The SVG model and control strategy designed in this study are based on three-phase symmetric load design. Although the compensation effect is good, they do not cover the asymmetric load scenarios that may exist in actual power grids. The traditional PI control has the risk of overvoltage and overcurrent at the initial stage of system operation. In the future, the control of asymmetric loads can be optimized, and new algorithms can be introduced to improve the adaptability and safety of complex power grids.

Acknowledgments

This study was supported by the Undergraduate Innovation and Entrepreneurship Training Program of Yingkou Institute of Technology (Grant No.: S202414435027; Project Title: Energy Harvesting Charger; Project Leader: Jiashun Zhu).

References

[1] Li Q S, Dong X W, Wang Y X, et al. Transient Stability Analysis and Enhancement Strategy of Grid-Following Converters Considering DC Voltage Control[J]. Acta Energiae Solaris Sinica, 2025, 46(10):403-411.

[2] Xu Y, Wang Y Q, Zhang W L. Application Research of Phase Compensation Control for Load Converters in Multi-Terminal DC Distribution Systems[J]. Light & Lighting, 2025, 49(05):130-132.

[3] Gao S R, Yu Y. Improved VSG Control Method for Grid-Forming Converters Based on Backstepping Control[J]. Zhejiang Electric Power, 2025, 44(10):102-111.

[4] Qiang D D, Li W W, Dai X C, et al. Research on Improved Hybrid Multi-Segment SVPWM Strategy Based on Single-Phase Three-Level Converters[J]. Electronic Design Engineering, 2025, 33(20):8-12+17.

[5] Liu A. Research on Single-Phase Power Factor Correction System Based on BOOST Converters[J]. Electrical Engineering Materials, 2025,(05):95-99.

[6] Yang F Y, Gao J Q. Key Points and Applications of VSC-Based Flexible HVDC Transmission Technology[J]. Science and Technology & Innovation, 2025,(19):152-154.

[7] Liu Z J, Kang P P, Gao Y X. Research on Improving Transmission Capacity of Weak Receiving-End Systems Using SVG[J]. Qinghai Electric Power, 2022, 41(04):23-27.

[8] Jin C, Wu W J, Ge J, et al. Research on Improving Voltage Stability of AC-DC Hybrid Power Grids by Applying SVG[J]. Electric Engineering, 2020,(21):40-43.

[9] Yang X M, Gao L B. Application of Dynamic Reactive Power Compensation SVG in Wind Power Transmission

Systems[J]. Technology Innovation and Application, 2016,(36):202.
[10] Soham D, Sushmit M, Kaushik B. Power Electronic Converter-based Flexible Transmission Line Emulation[J]. IEEE Transactions on Industrial Electronics, 2019,67(8).