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Research on Dynamic Reactive Power Compensation Device of Urban Rail Transit Substation Based on SVG

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Abstract

The technology in the research of dynamic reactive power compensation device of urban rail transit substation based on SVG, through the application of synthesizer, effectively solves the asymmetric host of the strategic docking of reactive power compensation device of substation. This technology will provide a comprehensive fault for the substation, which will increase asynchronously. Other solutions for strategically conjugated urban rail transit substations cannot effectively solve the problem of asymmetric mainframes. The successful development of the research on the dynamic reactive power compensation device of urban rail transit substation based on SVG has analyzed the applicability of the power supply system and put forward the deficiencies in the application of the SVG device.

Keywords: *Urban Rail Transit, Dynamic Reactive Power Compensation, SVG Urban Rail Transi.;*

Introduction

Urban rail transit is the backbone of urban public transportation. It is a green and environmentally-friendly transportation system with the principle of sustainable development and is especially suitable for large and medium cities. There are many types of urban rail transit, which can be divided into urban railways, suburban railways, underground railways, light rail transportation, urban trams, single-track transportation, maglev lines, airport connecting railways, new transportation systems, etc. according to their uses. Urban rail transit refers to a vehicle transportation system that adopts rail structures for load-bearing and guidance. According to the requirements of the overall urban transportation plan, a fully enclosed or partially enclosed dedicated track line is set up to transport a considerable amount of passenger traffic in the form of trains or bicycles. Mode of transportation[1-3]. Urban rail transit includes: subway system, light rail system, monorail system, tram, maglev system, automatic guided rail system, and urban rapid rail system. In addition, with the development of the transportation system, other new transportation systems have emerged. The advantages of urban rail transit: low land use, large capacity; stable running time; safety and environmental protection, energy saving, reducing air pollution; reduced noise, the noise generated by rail transit is easy to control, through technical measures, such as the use of ultra-long seamless Steel rails can reduce the impact noise during train operation. The use of elastic wheels can reduce frictional noise. Noise can also be reduced through urban planning and necessary sound insulation[4-6].

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The dynamic reactive power compensation device of the urban rail transit substation can detect the power factor in the subway power supply system in real time, calculate the reactive power compensation capacity required by the rail transit substation, and control the input compensation capacitor capacity in real time to ensure The stability of the power factor of the urban rail transit grid.

1. Introduction of SVG device

1.1. Development of reactive power compensation devices

The development of reactive power compensation devices has roughly experienced three stages: mechanical switching passive compensation mode, thyristor switching static reactive power compensation mode and voltage source-based static synchronous compensation mode. It was used in the early mechanical power system. It was a fixed reactive power compensation device. Its compensation speed was slow, and because it was mechanically switched on and off, it limited the number of times it was used per day and was noisy. Static reactive power compensation (SVC) based on thyristor switching is a passive compensation device, which is used in power systems and AC traction power supply systems. It uses the conduction angle of the thyristor to control the switching reactor or It is a capacitor, which can be divided into two compensation methods: TCR+FC and TSC. TCR+FC is the mainstream SVC compensation method. It can quickly track the change of the traction load and filter out a small part of the harmonics, but it also A large number of harmonics are generated, which increases the requirements for filtering devices. The TSC type compensation method is more economical and does not generate redundant harmonics, but it cannot achieve continuous adjustment of reactive power and can only be adjusted in stages. SVG belongs to the third generation of reactive power compensation technology, which no longer uses large-capacity capacitors and reactors, but realizes the conversion of reactive energy through the high-speed switching of high-power power electronic devices IGBT.

1.2. SVG device composition, principle and technical characteristics

SVG devices mainly include transformers, reactors, power units, control and protection systems and other components and related accessories.

The basic principle of the SVG device is to connect the self-commutated bridge circuit in parallel to the power grid through a reactor or transformer, appropriately adjust the phase and amplitude of the AC side output voltage of the bridge circuit, or directly control its AC side current, so that the circuit absorbs or sends out the reactive current that meets the requirements to achieve the purpose of dynamic reactive power compensation. The schematic diagrams of different operating modes of SVG are shown in Figure 1.

Technically speaking, SVG has the following characteristics compared with traditional reactive power devices.

1) Wide operating range. The reactive power output can be adjusted dynamically and continuously in both directions, and it can follow the load change. It can send out inductive reactive power or capacitive reactive power, so that the power factor is close to 1.

2) Fast response time. The reactive power load of the subway is a frequently fluctuating load. The SVG response time is usually about 5ms, and the response time is fast, which can achieve better compensation effects.

3) No harmonics are generated. Using multi-level PWM and other technologies, its own harmonic content is very low, no special filter device is required, and it can be used as a filter device to filter the system.

4) Small footprint. The main substation has a high cost increase due to the shortage of urban land. SVG has a small area, which can reduce the land acquisition and construction cost of the main substation.

5) No system series or parallel resonance occurs. SVG does not use a large number of capacitors or

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reactors, will not cause system resonance or harmonic voltage amplification, equipment and system operation is more reliable.

6) Diversified functions. In addition to reactive power compensation, it also has the functions of filtering, suppressing voltage fluctuations and flicker.

SVG devices are technologically advanced, but there are still some aspects that need to be improved.

1) Price. SVG device is a new application device in the subway, and the current price is relatively high, each SVG device is priced at about 2 to 3 million.

2) Life span. Subway equipment generally requires 30 years of life, while the design life of SVG devices is 20 years, and the actual life may be shorter.

3) Operation and maintenance. The main components of SVG devices are mostly imported IGBT components, which is inconvenient for the operation and maintenance of the equipment in the future.

Although the SVG device has the above problems, its advanced and comprehensive functions still represent the trend in the field of reactive power compensation, which is the development trend of power systems or subway power supply systems. Technological development requires a process, and the above problems will be improved and resolved to a certain extent in an increasingly competitive environment.

2. Features of subway power supply system

Most domestic urban subways use centralized power supply. The power supply system is mainly composed of external power supply, main substation, medium voltage ring network, traction and step-down hybrid substation (referred to as traction substation) and step-down substation. The AC110kV power supply of the power system is stepped down to AC35kV through the main substation, and transmitted to the traction substation and the step-down substation through the AC35kV medium voltage ring network. In the traction substation, the AC35kV AC power source is rectified to DC1500V or DC750V through the rectifier unit to supply power to the train (traction load); in the step-down substation, the transformer steps down the AC35kV AC power to AC0.4kV AC to the station and Power supply for power lighting equipment (dynamic lighting load) in the section. The main features of the subway power supply system are as follows.

Power supply system. Including two major power supply systems: AC and traction power supply. The AC system adopts the three-phase symmetrical power supply system; the traction system adopts the DC power supply system. The AC system is rectified into direct current through the equivalent 24-pulse wave.

3. Overall circuit structure of SVG device

The basic structure of the SVG device is shown in Figure 1, including a three-phase voltage source inverter (VSC), LCL filter and control and protection unit. The basic principle is that the controller detects the reactive component in the load current in real time, and the current is used as a command to control the SVG to generate currents with the same amplitude and opposite phase, so that the power grid only contains active components.

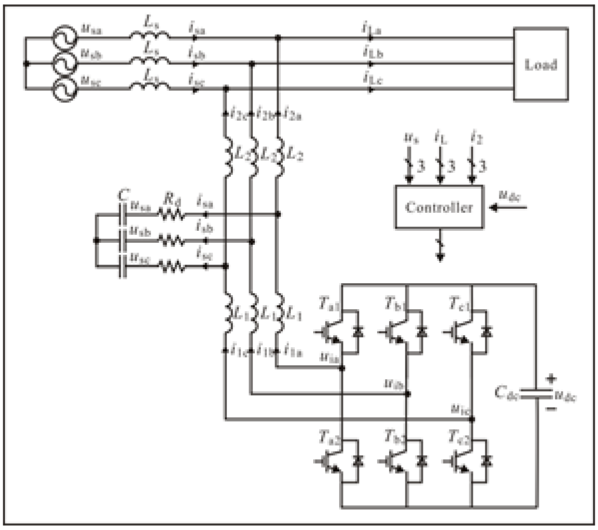

Figure 1. The basic structure of SVG.

4. Main power device selection

SEMIKRON SKiiP4 module using 1200V/2400A. The traditional IGBT module is welded by three layers of materials: silicon wafer, ceramic insulating substrate (DCB, usually aluminum oxide), and

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module substrate (usually copper) (Figure 2). In the case of IGBT module intermittently and under heavy load operation, due to the different thermal expansion and contraction coefficients of the three layers of materials, mechanical stress occurs between the module substrate and the DCB. After long-term operation, the welding surface of the two will crack, which will eventually lead to the module damage.

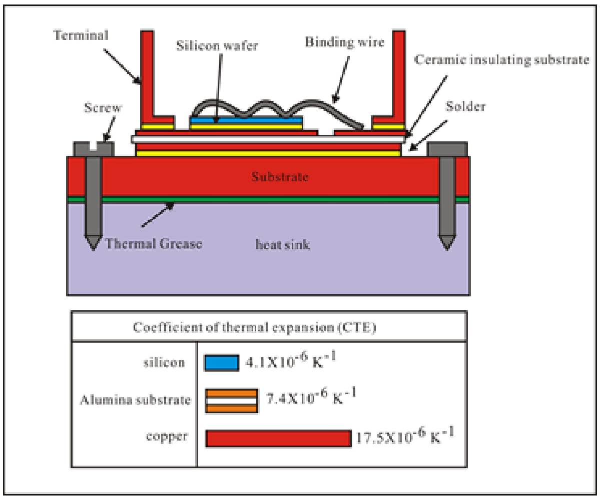

Figure 2. Internal structure of IGBT module.

In response to the cracking of the soldering surface between the DCB and the module substrate, the SEMIKRON SKiiP4 module removed the copper substrate and adopted a crimping method to avoid fatigue life problems. In view of the cracking of the welding surface between the silicon chip and the DCB, SKiiP4 uses sintering to replace the traditional welding. In traditional power modules, soldering is used between the chip and the copper-clad DCB board. Since the temperature of the solder joint is only 220-250℃, and the working junction temperature of the chip exceeds 100℃, this will reduce the mechanical strength of the solder layer, and thus reduce the fatigue life of the solder layer. The sintering process uses silver powder as the interface material, and the melting point of silver under normal pressure is 962°C, which greatly improves the fatigue life.

The above-mentioned status and analog information of SKiiP4 are output via CAN bus. The SVG device controller adopts the TI28335 control chip, which has 2 CAN interfaces, one is responsible for communication with the upper computer, and the other is dedicated to communicate with the three SKiiP4 modules inside the device to receive their status information. This provides great convenience for monitoring the running status of the device.

5. LCL filter design

In the design process of the LCL filter, in addition to satisfying the filtering effect of the high-frequency switching ripple current, the filter inductance must also be strictly limited. The inductance voltage drop of SVG is a linear superposition relationship with the grid voltage. Excessive inductance requires a higher DC bus voltage to ensure that the SVG works in the linear modulation area. At the same time, the basic principle of the LCL filter is that the filter capacitor and the grid-side inductance perform impedance shunting of the high-frequency current. Therefore, the shunting effect must be guaranteed. In this way, starting from the two points of limiting the filter inductance and ensuring the high-frequency current shunt effect, the following design steps can be obtained.

5.1. Determine the total filter inductance

For the fundamental reactive current, the filter capacitor of the LCL filter is equivalent to an open circuit, and the circuit can be simplified to the equivalent circuit shown in Figure 3a, where L in Figure 3a represents the total filter inductance of L1 and L2. Figure 3b is a phasor diagram of voltage and current when the grid-connected converter works under rectification and absorption hysteresis.

Let Is be the effective value of grid current, UL be the effective value of the inductor voltage, ULd be the d-axis component of the effective value of the inductor voltage, ULq be the q-axis component of the effective value of the inductor voltage, Us be the effective value of the grid phase voltage, Ui be the inverter bridge The effective value of the AC phase voltage, φ is the power factor angle of the grid voltage phasor $\dot{U}_s$ and the grid current phasor $\dot{I}_s$.

The relationship between the inverter bridge output

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voltage, grid voltage and inductor voltage drop is:

$$U_i = \sqrt{U_s^2 + \omega^2 L^2 I_s^2 - 2U_s \omega L I_s \sin\varphi}$$
(1)

In formula (1), ω is the angular frequency of the grid. If φ=-90°, the grid-connected converter injects lagging reactive power into the grid, and Ui is the largest, which is:

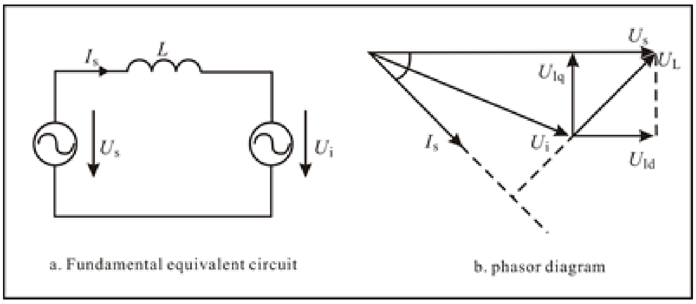

Figure 3. Inverter bridge output voltage.

$$U_i = U_s + \omega L I_s$$
(2)

For the SKiiP4 module with a rated voltage of 1200V, it is reasonable to set the DC bus voltage Udc=700V. The maximum AC phase voltage output by the three-phase three-wire voltage type PWM inverter bridge using Space Vector Modulation is:

$$U_{i\max} = \frac{U_{dc}}{\sqrt{6}} = 286V$$
(3)

Considering the 7% overvoltage of the power grid, in order to ensure that the three-phase VSC inverter works in the linear modulation area, the maximum filter inductor voltage is:

$$U_{L\max} = U_{i\max} - U_s = 286 - 235 = 51V$$
(4)

Under reactive current, the maximum filter inductance is:

$$L_{\max} = \frac{U_{L\max}}{\omega I} = \frac{51}{314 \times 760} = 0.21mH$$
(5)

Taking into account the output voltage loss caused by the dead zone and the voltage margin required in the current dynamic process, the filter inductance L=0.18mH.

5.2. Determine the inductance of L1 and L2

L1 and L2 divide the total filter inductance equally to get the best filter effect. Taking into account that too small L1 will bear larger high-frequency ripple current, resulting in higher noise and loss, therefore, the inverter side and grid side inductance are respectively L1=0.12mH, L2=0.06mH.

5.3. Determine the filter capacitor C

To ensure the bypass effect of the filter capacitor on the high-frequency ripple current, the capacitive reactance XC must be less than 20% of the grid-side inductance and inductance XL2. The switching frequency is fSW=3kHz, the filter capacitor is designed as C=250μF, and the ratio of capacitive reactance XC to grid-side inductance inductance XL2 is 18.8%, which can meet the requirements. The output current and frequency spectrum of the designed LCL filter are shown in Figure 4. It can be seen that the ripple current content of 3kHz and its multiples is very small, and it has a good high-frequency filtering effect. THD in Figure 4 is the total harmonic distortion rate.

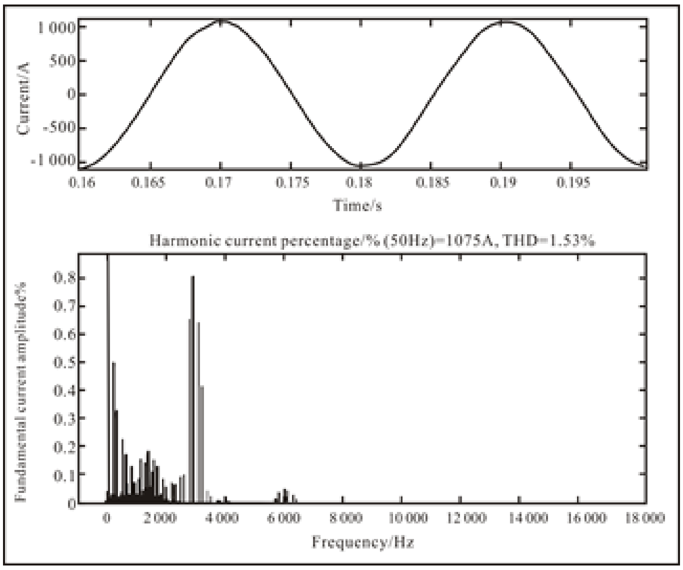

Figure 4. LCL filter output current and spectrum.

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6. DC bus capacitor design

For a three-phase balanced system, the reactive power exchange is carried out between the three phases, and the DC bus capacitor only needs to absorb the 3kHz switching frequency and its doubled ripple current. Through Matlab simulation, the effective value of the total DC ripple current of the SVG device can be obtained. For 360A. Based on the characteristics of high frequency and high current, it is more appropriate to use metalized film capacitors as DC bus capacitors. Film capacitors have stronger current-carrying capacity than traditional electrolytic capacitors, do not need to be connected in series, can self-heal, and do not have electrolyte decomposition problems, have high reliability and long life, and are widely used in electric locomotive traction converters. Its disadvantage is that the density per unit volume is low, but because it does not need to be connected in series, its large volume can be partially compensated.

Considering reliability, 480uF/880V film capacitors imported from epcos are used. Using 18 capacitors in parallel, each capacitor bears 20A current. The data sheet of the capacitor shows that its rated current is 50A, and it is more sufficient to assume a 20A current margin. The 18 capacitors are divided into 3 groups, 6 in each group. The 3 groups of capacitors and the three-phase SKiiP4 are installed nearby to reduce the equivalent inductance of the DC loop and the IGBT turn-off voltage spike, and improve the working reliability of the main power module.

7. Experimental results

Experiments were conducted on the developed SVG device. Figure 5 is the steady-state waveform of the load of the compensation capacitor cabinet. In Figure 5: Channel 1 is the full-load compensation current waveform of the SVG device, with an effective value of 740A and good sine; Channel 2 is the capacitor cabinet current, which is affected by the distortion of the grid voltage , The capacitive current contains harmonic components; channel 3 is the compensated grid current, it can be seen that the reactive current is completely compensated, and the remaining is the harmonic current component; channel 4 is the DC bus voltage of the SVG device with small fluctuations.

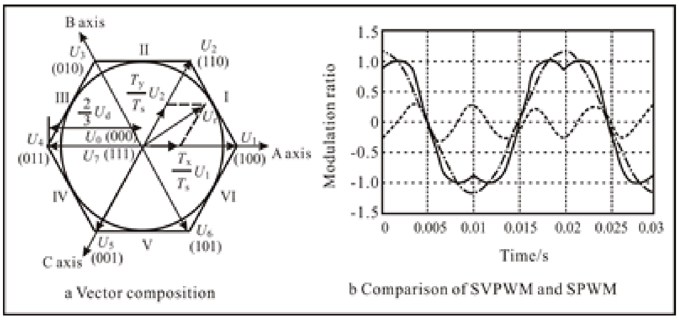

Figure 5 Basic principle of space vector pulse width modulation.

8. Conclusion

For the high-reliability SVG device of urban rail transit based on SVG, this paper proposes the use of SEMIKRON's 4th generation smart power module SKiiP4 as the main power device to improve fatigue life and provide detailed event information, which is helpful for troubleshooting; LCL filter is used to reduce filter inductance, combined with SVPWM to reduce DC bus voltage and switching loss; use film capacitors to increase the life of DC bus capacitors; use digital control to achieve a single loop ofundamped resistance current of LCL filter Control, completely eliminate the hidden danger of over-temperature damage to the damping resistor. The simulation and experimental results show that the scheme is correct and effective.

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