Application of Dynamic Reactive-power Compensator Based on SVG in Coal Mines

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Abstract—With the improvement of automation degree of coal mine mechanical and electrical equipments, such as conveyors, crushers, mining motors, inverters, and a large number of non-linear loads, cause large reactive power consumption, power factor of coal mine power grid, power supply quality and stability, and bring greater influence to coal mine safety production and economic benefits.As a new generation of high voltage dynamic reactive power compensator,SVG (Static Var Generator) has fast response and compound functions,such as compensating reactive power, suppressing harmonic and imbalance with FC(Filter Capacitor), which plays a good role in improving the power quality of coal mine.This paper designs the system parameters of SVG in coal mine and introduces its application.

1. Introduction

With the improvement of automation degree of coal mine mechanical and electrical equipments, such as conveyors, crushers, mining motors and large fully mechanized mining equipments, inverters and a large number of non-linear loads, cause large reactive power consumption and high harmonics, equipment starting and working current increase, a large number of unnecessary power loss, lead to coal mine power grid power factor, power supply quality and stability decline, bring great influence to coal mine safety production. When the power factor of coal mine power grid is low, it may face high fines of power supply companies, which affects the economic benefits of coal mine enterprises[1][2].

To improve the power grid power factor, conventional reactive power compensation generally takes parallel capacitor centralized compensation.Its advantage is simple and reliable,and equipment cost is relatively low, but due to the amount of capacitor compensation is fixed, it cannot dynamicly and continuously compensates reactive power according to the grid real-time reactive load.To be worse,it is prone to under compensation or over compensation, and parallel resonance may occur[3]-[5]. As a new generation of high voltage dynamic reactive power compensation device , compared to static reactive power compensator SVC, SVG uses full-controlled power electronic devices IGBT (Insulated Gate Bipolar Transistor), and features fast response(below 10ms).SVG uses the cascade module multi-level wave shift phase technology,and the output harmonic is low.With coordination of FC compensator，SVG has compound functions,such as harmonic supression, which can effectively improve the power factor and power quality[6]-[9].

This paper briefly illustrates the working principle of SVG dynamic reactive power compensation device, and introduces the parameter design and application of SVG system in a coal mine.

2. Working principle of the SVG reactive power compensation device

2.1. Working principle of SVG

As shown in figure 1,the SVG converter valve is connected to the power grid by connecting the reactor. By adjusting the phase and amplitude of the output voltage on the AC side of the converter valve, the SVG device can absorb or emit reactive current, and achieve the purpose of dynamic adjustment of reactive power or voltage.

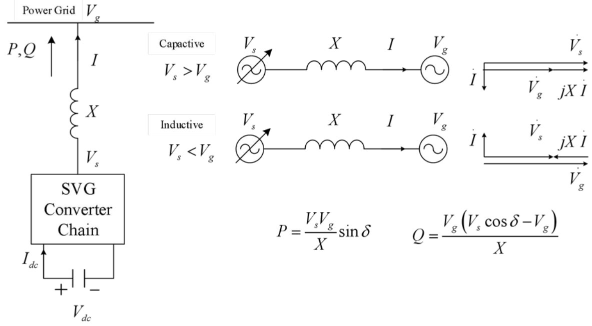

Fig.1 Sketch diagram of working principle of SVG

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The exchange of reactive power conducted between the SVG and the power grid is achieved by controlling the amplitude Vs of the output voltage of the SVG converter chain. If the SVG output is reactive, the control amplitude of Vs is greater than the amplitude of Vg; if the SVG output is reactive, the control amplitude is of Vs less than the amplitude of Vg.

The reactive power emitted by the SVG to the grid system is indicated by the following equation:

$$Q = \frac{VsCos\delta - Vg}{X} Vg$$

In this equation, Vs indicates the compensation voltage of the SVG output voltage and Vg is the power grid voltage of the power grid system.δis the leading angle of Vs according to Vg,and X indicates the inductance of the connection reactance between the SVG and the power grid system.

2.2. Overall Structure of SVG

The overall structure and main wiring of the SVG device are shown in Figure 2.

The main components of SVG device are: bus switch and breaker, MOV, cascade H-bridge IGBT converter chain, SVG soft starting switch(SST), soft starting resistor and inductor. High-speed optical fiber communication is adopted between SVG converter chain and SVG control and protection device to realize primary and secondary electrical isolation.

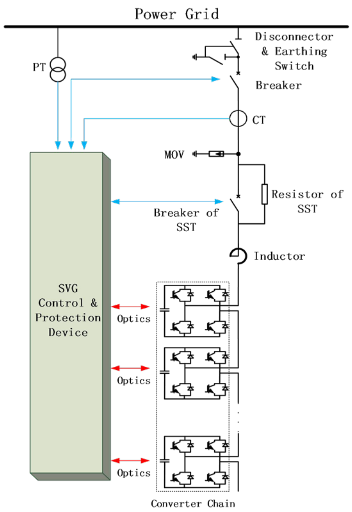

Fig.2 Sketch diagram of main electrical scheme of SVG

3. SVG Design and Implementation

This paper introduces the system design of the SVG dynamic reactive power compensation device in a coal mine.

3.1. Substation Power Data

The substation system of this coal mine adopts 6kV single busbar segment topology, with double power supply. The bus switch is designed between section I and section II bus bars, and each section is equipped with ventilation fans, air compressors, main hoists and power supply transformer in living area.

The active power of section I busbar is 1870kW, and the power factor before compensation is 0.79.

The active power of section II busbar is 1520kW, and the power factor before compensation is 0.81.

When the main equipments of the mine are running, the power grid system mainly has 3rd and 5th harmonics.

3.2. System Parameter Design of SVG

In order to ensure that the buses of segments I and II meet the compensation power factor requirements, section I and II are equipped with an SVG dynamic reactive power compensation device and filter capacitor FC. With FC device, in addition to filtering the grid system harmonic, it can also effectively reduce the SVG device capacity and equipment investment.

SVG directly connects 6kV high voltage bus without step-down transformer. The electrical wiring diagram of the system is shown in Figure 3.

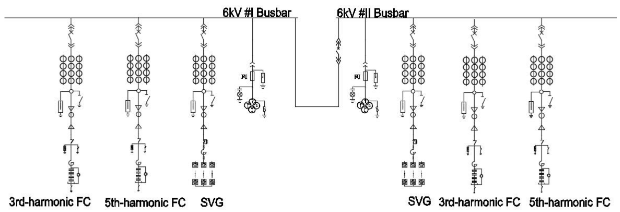

Fig.3 Sketch diagram of electrical scheme of SVG

To meet the requirement of power factor lower than 0.95, the compensation capacity of SVG unit is calculated as follows:

tanφ=tan(arccos(0.95))=0.328

tanφ1=tan(arccos(0.79))=0.775

tanφ2=tan(arccos(0.81))=0.724

Compensation capacity: 1870kW * (tan φ 1-tan φ) = 835 kvar

SVG compensation capacity of Section II bus: 1520kW * (tan φ 2-tan φ) = 601 kvar

Considering the subsequent expansion, the buses of section I and II are equipped with a set of dynamic reactive power compensation device with voltage level 6kV and rated capacity of 2Mvar SVG, and a total capacity of 500kvar FC device (including filtering for 3rd and 5th harmonics), which can realize the continuous adjustment of 1.5 Mvar inductive ~ 2.5 Mvar capacitive power output.

3.3. Design of SVG Modules

The converter chain is the core part of the SVG device, realizing the power exchange between the SVG device and the power grid system.

SVG adopts the cascade H bridge voltage source converter structure, and uses the carrier shift phase SPWM pulse width modulation technology,which can

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effectively reduce the loss of SVG link unit,obtain a better output voltage waveform and reduce the harmonic output of SVG device. Figure 4 and 5 show the schematic diagram and physical objects of SVG chain unit elements.

The 6kV SVG unit of this project adopts the 8- levels IGBT converter chain unit cascade.

IGBT is the core element of SVG chain units, and each chain unit consists of four single-tube IGBT forming a single-phase full-bridge circuit. Considering the different rated current of SVG with different capacity levels and the design requirements of voltage margin, the IGBT modules with different parameters and specifications are selected.

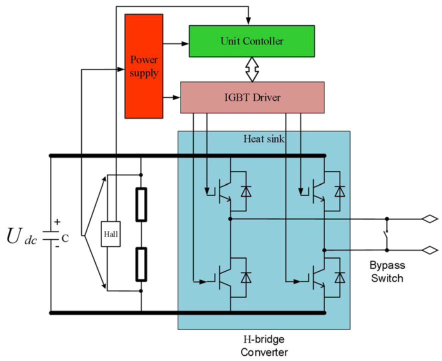

Fig.4 Sketch diagram of SVG chain-unit

Fig.5 Photo of SVG chain-unit

The rated capacity of SVG device in this project is 2 Mvar and the rated current is 192A. Considering the margin, the rated voltage of 1700V and the rated current of 400A IGBT is selected.

3.4. Design of Control and Protection System of SVG

The control and protection system of SVG device includes SVG control and protection device, valve control device, HMI, etc. Figure 6 shows the photo of control and protection system cabinet of SVG.

Fig.6 Photo of control & protection system cabinet of SVG

The SVG control and protection device receives the analog sampling information and the switching quantity state, performs the SVG control and adjustment strategy, and transfer the adjustment and control instruction to the valve control device through the high-speed optic fiber,as is shown in Figure 7. The CPU board of the control and protection device adopts the high-speed digital signal processor DSP with large-capacity programmable gate array FPGA architecture, which can realize the calculation of dozens of us-level periodic sampling control, and meet the requirement of SVG dynamic response time of less than 10ms.

The valve control unit is responsible for receiving the control regulation command issued by the control protection device, integrating the chain DC voltage detected by the unit controller, completing the underlying control adjustment algorithm, generating the PWM waveform and related control instructions to the IGBT unit controller,and reporting the real-time information of the converter chain.

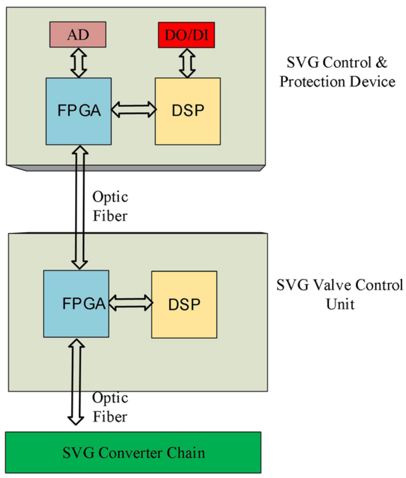

Fig.7 Sketch diagram of SVG control and protection device

3.5. Protection Function of the SVG

In order to quickly protect the SVG device in case of the power grid system failure and the SVG device itself failure, the SVG control and protection device is configured with the following protection functions:

System current: fast over-current protection, over-current protection, overload protection.

System voltage: over-voltage protection, under-voltage protection.

SVG converter chain: the converter chain sub-module level protection function, such as module DC over-voltage protection, over-current protection, over-heat protection, etc.

SVG control and protection device: communication fault protection, etc.

In addition, the SVG device is equipped with a micro-computer protection device at the incoming line switch cabinet side, which is independent of the SVG body protection. The microcomputer protection of the incoming line switch cabinet is mainly equipped with voltage protection, frequency protection, three-stage current, zero-sequence voltage / current and other protection functions.

3.6. Control Mode of SVG

(1) Constant voltage mode

To stabilize the voltage of the power grid system, the voltage of the power grid system is adjusted, and the output reactive power of the SVG device is automatically adjusted.

(2) Constant reactive power mode

The output is constant reactive power, the reactive output target value can be set between rated capacitive reactive power and rated inductive reactive power, automatically adjust the output reactive power of the device.

(3) constant power factor mode

The power factor of the grid system is feedback, the target value of the constant power factor can be set from + 1 to-1 (positive stands for capacitive power), and the output reactive power of the SVG device can be automatically adjusted.

(4) Integrated control mode of reactive power voltage

SVG is under controlling according to the interval range of the grid system voltage. The voltage of the grid system voltage is within the set range and operates in the constant reactive power mode. If the voltage exceeds the set value, SVG switches to the constant voltage mode.

(5) Transient compensation mode

The transient compensation mode is that when the power grid fails or the system is disturbed, the SVG device quickly outputs reactive power to support the system voltage. When the fault is removed and the system voltage returns to the normal range, the SVG device exits the transient compensation mode and switches to the original working mode.

The above control mode and control target value can be flexibly set, and the coal mine SVG reactive power compen-sation device uses the constant power factor control mode.

3.7. Cooling system of the SVG unit

The SVG device includes water cooling and forced air cooling.

When SVG capacity is large (generally 35kV and above, capacity greater than 30 Mvar), water cooling and special cooling water machine system shall be configured.While SVG capacity is small (generally 10kV and below, capacity less than 10 Mvar), forced air cooling is adopted to reduce the cost and floor area of SVG device.

The rated capacity of the SVG project is 6kV-2Mvar , forced air cooling is adopted.

4. Application

The SVG device is under operation in a coal mine.In the process of the coal mine load changes, SVG device dynamicly adjusts output reactive current, and section I, II bus power factor meet the requirement of greater than 0.95, and the highest up to 0.98.SVG effectively reduces the line loss and production electricity comsumption of the coal mine, and the power grid system harmonics are below 3%, which meets the national 6kV power grid system requirements standard of no more than 4% harmonic total content.

Figure 8 shows the transition waveform of the inductive power output to capacitive power output of SVG.

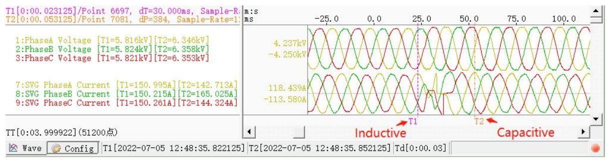

Fig.8 inductive to capacitive reactive power transition waveform of SVG

5. Conclusion

SVG dynamic reactive power compensation device is put into practical application with FC device,which can effectively improve the power factor and power quality of coal mine power grid, reduce the line loss and harmonic content, and improve the economic benefit of coal mine enterprises. This scheme can be a reference for the reactive power compensation and power quality management for coal mining enterprises.

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