Design of high voltage grid-connected switch energy storage circuit control system

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Abstract. The paper proposes and designs the control system of the high voltage grid-connected switch energy storage circuit based on ARM, in order to ensure the normal operation of the power system. In view of the problem that the high voltage grid-connected switch controlled by Lab-VIEW software currently takes a long time for spring energy storage and the system response speed is slow, which is not conducive to timely cutting off the fault source. The hollow current transformer and voltage transformer are used to collect the current signal and voltage signal on the main line of the power system respectively. Then the processed signal is input into the internal analog to digital conversion unit of the system microcontroller for analog to digital conversion, and the processed signal is calculated and judged logically by using the system microcontroller and the principle of three-point method measurement. If there is a defect in the energy storage circuit of the grid-connected switch, the corresponding defect treatment method shall be adopted according to the judgment result, and the electrical isolation switch circuit breaker control instruction signal shall be issued at the same time, and then the system drive circuit shall execute the protection action. At the same time, on this basis, the software structure of the system and the specific process of calculating and processing tasks are given. The results of system performance test show that the designed system can not only ensure the high voltage grid-connected switch to meet the mechanical properties and low voltage action characteristics, but also reduce the energy storage time of the spring, shorten the system reaction time, which is conducive to cutting off the fault source in time and avoiding the expansion of the accident range.

1. Introduction
High voltage grid-connected switch is an important switch in power system such as power plant and substation. It is mainly used to ensure the safety of high-voltage electrical appliances, work safety during maintenance, and play the role of isolating voltage. Under normal circumstances, high-voltage grid-connected switch can be divided into various types according to the installation location, class difference, mode of action, whether there is a grounding switch, operating mechanism and the number of insulation column included. With the rapid development of intelligent high voltage grid-connected switch, people use computer technology, CAN bus technology, digital signal processing technology and many other advanced technologies to embed high voltage and high voltage grid-connected switch into high voltage electrical products to realize the automatic control of high voltage distribution system[1]. However, in the actual application process, high-voltage grid-connected switch energy storage motor burn-down accidents occur frequently, especially when the high-voltage electrical equipment of unattended substation breaks down, the remote dispatch cannot timely obtain the current
state information of equipment and make correct decisions, which leads to the delay of fault treatment and enlarges the accident scope[2]. In order to solve the above problems and ensure the normal, stable and reliable operation of the power system, power grid and substation, it is necessary to design an effective high-voltage grid-connected switch energy storage circuit control system.

2. High voltage grid-connected switch energy storage circuit control system

In this paper, the hollow current transformer and voltage transformer are respectively used to collect the current signal and voltage signal on the main line of high-voltage electrical appliances in the power system, and the collected current signal and voltage signal are preprocessed by setting, voltage dividing and filtering through the analog signal conditioning circuit. The processed signal is input into the internal analog to digital conversion unit of the system microcontroller for analog to digital conversion, and then the current signal and voltage signal are calculated and judged logically by the system microcontroller. If the main circuit is judged to be faulty, corresponding measures shall be taken according to the judgment results, and the electrical disconnecting switch circuit breaker control instruction signal shall be sent out at the same time, and the system driving circuit shall perform the protection action. At the same time, the specific fault types of trunk lines and the occurrence of fault events are stored in the system[3].

In addition, the high voltage grid-connected switch energy storage circuit control system also has an analog trip circuit. When there is a very large short circuit fault in the power system circuit, the analog tripping circuit can directly perform the tripping process and cut off the fault without going through the system microcontroller. The high voltage and high voltage grid-connected switch energy storage circuit control system has two kinds of communication interfaces: RS485 bus and Ethernet RJ45.

2.1. hardware of high voltage grid-connected switch energy storage circuit control system

2.1.1. system microcontroller design

ARM series MB9BF218TH/SH embedded microprocessor is used as the core of high voltage grid-connected switch energy storage circuit control system. The highest clock frequency can reach 144MHz, contains A 24-channel 12-bit A/D converter; It has eight multifunctional serial ports, and each channel supports four different functional configurations. The internal chip has sufficient I/O interface and the ability of rapid calculation and processing tasks, which can meet the real-time requirements of the control system of the energy storage circuit of the high-voltage grid-connected switch for different levels of fault treatment[4].

2.1.2. system analog signal conditioning circuit design

The main function of designing the analog signal conditioning circuit of the system is to realize the pretreatment of the current signal and voltage signal on the main line of high-voltage electrical appliances in the power system, such as setting, voltage dividing and filtering, etc., so that the processed signal can meet the processing requirements of the system microcontroller. In the practical application, the measured current and the protection current of the high-voltage grid-connected switch are detected separately in consideration of their normal operation. As shown in figure 2, the system analog signal conditioning circuit diagram is given. In FIG. 2, AVIN represents the output current/voltage signal of the hollow current transformer and voltage transformer; AREF represents the
reference voltage of the high-voltage main line of the power system, which is mainly responsible for raising the reference voltage. The voltage division circuit composed of 5.88 ohms and 1.5 ohms resistance is responsible for voltage dividing treatment between AVIN and AREF; Made up of 750Ω resistance and 0.1μF capacitance of low-pass filter circuit is mainly responsible for dealing with air-core current transformer and voltage transformer output high frequency noise signal; AVOUT is connected with the input channel of ADC in the system microcontroller to convert the acquired signals into analog or digital ones[5].

2.1.3. system clock circuit and temperature detection circuit design
In order to accurately record the fault time and the environment temperature on the high-voltage electrical main line of the power system, the real-time clock circuit and the temperature detection circuit are designed by using SD2068A chip and DS18B20 chip, which have the advantages of high data transmission efficiency, digital adjustment, strong anti-interference, low power consumption and so on.

2.2. analysis and treatment of defects in energy storage circuit of grid-connected switch

2.2.1. defect analysis of grid-connected switch energy storage circuit
The reason for the failure of closing of the high voltage grid-connected switch is that the operating time of the system relay is less than the completion time of the energy storage of the high voltage grid-connected switch spring, which results in the failure of the energy storage of the high voltage grid-connected switch spring and the defect of the spring energy storage circuit.

2.2.2. grid-connected switch energy storage circuit defect treatment
(1) Adjust the setting time of the control system relay, so that the system energy storage motor can set time to complete the relay spring energy storage, and leave enough space. By using a stopwatch to measure the energy storage time required by the high voltage grid-connected switch spring and adjusting the setting time of the control system relay, the setting time delay is greater than the actual energy storage time of the system energy storage motor, and the margin space is fully considered;

(2) Because of the energy storage electric pilot run time in the outdoor environment, the transmission mechanism caton that may occur due to the weather and other factors. That makes the grid switch spring energy storage time extension, severe cases may far exceed the system interconnection switch spring energy storage time relay setting time. The transmission mechanism of energy storage spring of grid-connected switch can be lubricated to solve the defect of energy storage not in place.

According to the above processing method, the remote and local closing can be performed smoothly, and at the same time, the system microcontroller also stops sending 'abnormal signal of grid-connected switch spring energy storage circuit'.

2.3. system software structure design

2.3.1. three-point measurement principle of system power parameters
The real-time display, three-phase protection, remote monitoring, communication and thermal memory of the control system of the high-voltage grid-connected switch energy storage circuit are realized by software. The reliability and complexity of the software structure determine the final performance of the high voltage grid-connected switch energy storage loop control system. System software part design is the fundamental purpose of when a device or circuit in circuit overload phenomenon, the realization of high voltage grid switch three-phase circuit parameters such as current, voltage of real-time measuring calculation, to cut off the source of trouble in time to prevent the accident range further, at the same time, can also according to the preset interconnection switch trip protection threshold to decide whether to control movement. In order to accurately and quickly judge
whether the equipment or the line has faults, the control system adopts the three-point method to measure and calculate the effective values of current and voltage.

Taking the three-point method for measuring and calculating the effective value of the current as an example. It is assumed that there is a sinusoidal signal in the operation of the high-voltage electrical appliances. As long as there are three points of amplitude, frequency and initial phase, the characteristic quantity of the sinusoidal signal can be determined. Suppose \( I_m \) and \( \omega \) represent the amplitude and frequency of the current signal to be measured; \( \Delta t \) represents the sampling interval of the current signal to be measured; \( k \) represents the sampling sequence of the current signal to be measured; \( \phi_0 \) shows the initial phase of the current signal, using a three-point method to measure and calculate the current signal \( i(t) \). The specific calculation formula is as follows:

\[
i(t) = I_m \sin(\omega \Delta t k + \phi_0)
\]

Select any time as the starting time of current sampling, that is, \( k = 0 \), then the previous time and the next time can be represented by \( k = -1 \) and \( k = 1 \) respectively, then:

\[
i_{-1} = I_c \cos(-\alpha \Delta t) + I_v \sin(-\alpha \Delta t)
\]

\[
i_0 = I_c \cos(\alpha \Delta t \cdot 0) + I_v \sin(\alpha \Delta t \cdot 0)
\]

\[
i_1 = I_c \cos(\alpha \Delta t) + I_v \sin(\alpha \Delta t)
\]

According to the above formula, the following formula can be obtained:

\[
i_c = b_0 \cos(\alpha \Delta t) = \frac{i_1 - i_{-1}}{2b_0};
\]

The above formula can be summarized as follows:

\[
i_c = \frac{i_1 - i_{-1}}{2\sqrt{1 - \cos(\alpha \Delta t)}};
\]

Then, the effective value of the current signal \( i(t) \) to be measured is:

\[
i_e = \sqrt{\frac{I_r^2 + I_v^2}{2}};
\]

If the phenomenon of \( |\cos(\alpha \Delta t)| \geq 1 \) appears in the actual application process, it indicates that there is interference in the sampling points. In order to reduce the interference effect, more points should be collected and then digital filtering should be applied. The three-point method is adopted to measure and calculate the effective values of current and voltage, which has a roof with a small amount of calculation, and can greatly improve the response speed of the energy storage circuit of the high-voltage grid-connected switch.

### 2.3.2. high voltage grid-connected switch energy storage circuit control system program structure

High-pressure grid switch energy-storage circuit control system to complete the real-time requirements such as sampling calculation, fault diagnosis of high computing tasks, the task even at the same time display, keyboard scanning, and communications, such as real-time demand is not high computing tasks. In order to guarantee system program structure is clear enough, reduce the system server computation, the computing task is divided into four levels, according to the real-time requirements of computing tasks. For example, as slow tasks with low real-time requirements, such as calculation, processing and display, the system program is executed every 300ms and sends data according to user requirements. Keyboard scanning and other quick computing tasks, the system program is executed every 60ms; Sampling, measurement and calculation, fault judgment and other tasks handle task as real-time computing, completed by the system program interrupt; In addition, such as watchdog timer, high voltage detection and other routine computing processing tasks are executed every time the main loop of the system program.

### 3. System performance test results and analysis

The digital high-voltage grid-connected switch characteristic tester produced in the United States, ct-7500, was adopted in the field. The mechanical characteristics of the high-voltage grid-connected switch were tested by the reference[4] system and the arm-based high-voltage grid-connected switch energy storage loop control system proposed and designed in this paper. The comparative test results
are shown in table 1 and table 2 respectively. According to the comparative test results in table 1 and table 2, it can be seen that the mechanical properties of the high-voltage grid-connected switch are not significantly different between the reference[4] system and the design system. That indicate that the mechanical properties of the grid-connected switch are well preserved in the design system.

Table 1. Test results of mechanical characteristics of grid-connected switches in reference [4].

| Name/parameter | Break-brake time /ms | Closing time /ms | Break-brake over the same period /ms | Switching over the same period /ms |
|----------------|----------------------|-----------------|-------------------------------------|----------------------------------|
| A phase        | 28.5                 | 89.8            | 0.7                                 | 1.5                              |
| B phase        | 27.8                 | 89.7            |                                     |                                  |
| C phase        | 28.7                 | 88.8            |                                     |                                  |

Table 2. Test results of mechanical characteristics of grid-connected switches designed in this paper.

| Name/parameter | Break-brake time /ms | Closing time /ms | Break-brake over the same period /ms | Switching over the same period /ms |
|----------------|----------------------|-----------------|-------------------------------------|----------------------------------|
| A phase        | 28.6                 | 90.7            | 0.7                                 | 1.8                              |
| B phase        | 27.9                 | 90.8            |                                     |                                  |
| C phase        | 28.8                 | 89.4            |                                     |                                  |

By observing the test results shown in table 3 and table 4, it can be found that the grid-connected switch designed in this paper has no influence on the low-voltage action characteristics of the high-voltage grid-connected switch, because the critical action voltage of the high-voltage grid-connected switch is volatile.

Table 3. Test results of low-voltage operation characteristics of system circuit breakers in reference [4].

| Number of experiments/time parameters | Break-brake critical voltage/V | Critical operating voltage for closing/V |
|--------------------------------------|--------------------------------|-----------------------------------------|
| The first time                       | 87                             | 162                                     |
| The second time                      | 86                             | 162                                     |
| The third time                       | 87                             | 164                                     |

Table 4. Test results of low-voltage operation characteristics of circuit breakers in the design system.

| Number of experiments/time parameters | Break-brake critical voltage/V | Critical operating voltage for closing/V |
|--------------------------------------|--------------------------------|-----------------------------------------|
| The first time                       | 88                             | 163                                     |
| The second time                      | 84                             | 164                                     |
| The third time                       | 86                             | 168                                     |

In order to further test the performance of the designed system, the energy storage time of the high-voltage grid-connected switch of the two systems was compared and tested. The test results are shown in table 5. According to table 5 shows that compared with the present system [4], the designed system can effectively reduce the high voltage grid switch spring energy storage time. This is because the design system controls the setting time of the relay of the system by adjusting the energy storage circuit of the high-voltage grid-connected switch, so that the energy storage motor of the system can complete the energy storage of the relay spring within the setting time of the relay and leave a certain
margin. This effectively shortens the energy storage time of the grid-connected switch, and lays a good foundation for the quick and accurate cutting off of faults in the future.

Table 5. Comparison results of energy storage time of two grid-connected switch springs

| Number of experiments /per time | The system of literature [4] | Design system |
|--------------------------------|-----------------------------|---------------|
| Spring energy storage time consuming /s | 1: 7.79 2: 8.06 3: 7.94 | 6.36 6.21 5.97 |

After the completion of the high voltage grid-connected switch spring energy storage, if the system detects the overload, short circuit and other fault currents in the equipment or the circuit, the control command signal will be sent out, and the system will drive the circuit to perform the protection action. In order to test the response time of the designed system, a comparative test of fault response time was carried out at different levels of current, in which the rated working current was set as 8A, that is, the input current of the system microcontroller. Experimental results show that when the power system operation in the process of one phase current overload and short circuit faults on the literature [4], the highest system response time of 8ms and 9ms respectively. Design system response time no more than 4ms, highest can satisfy the real-time requirements of different grade computing tasks. The design system takes less time to store energy compared with the spring energy storage system in literature [4]. Once a fault occurs, it can cut off the fault source in the first time, ensuring the normal, safe and stable operation of power system equipment.

4. conclusion
In this paper, the control system of energy storage circuit based on ARM high voltage grid-connected switch is proposed and designed, using ARM series microprocessors with high performance, low energy consumption and high cost performance as the control core. In order to solve the problem that when the high-voltage electrical equipment of unattended substation breaks down, the remote dispatch cannot timely obtain the current state information of equipment and make correct decisions. This leads to the delay of fault treatment, the expansion of the scope of accidents, and the failure of the normal, stable and reliable operation of the power system. The system performance comparison test proves the rationality and feasibility of the design system. The system not only reduces the energy storage time of grid-connected switches, but also improves the response speed of the system, which lays a foundation for large-scale application of high-voltage grid-connected switches.

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