Design of the Safe Driving and Acquisition Module for Nodeless Three-phase AC Switch Machines

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ABSTRACT

In order to reduce the cost and the volume of the driving module for three-phase AC switch machines, a design method of the safe driving and acquisition module is proposed. The designed module is realized by means of the remote communication and the local power acquisition for power conversion. The nodeless mode is employed by the hardware of the proposed module. Based on the high-power density conversion circuit, the switch machine can be powered by the three-phase AC 380V which is converted from the trackside single-phase AC 220V. The feasibility of the safe driving and acquisition module is verified by the experiment.

CCS CONCEPTS

• **Hardware**; • **Hardware validation**; • **Physical verification**;

KEYWORDS

Three phase AC switch machine, Safe driving and acquisition module, Power factor correction

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1 INTRODUCTION

Nowadays, most railway signal control systems are based on the centralized control mode. Commonly, the system is centrally installed indoors, and the signal cable is employed as the transmission medium to connect the indoor control system with the outdoor-controlled equipment. However, this kind of indoor centralized control mode has some disadvantages, such as limited laying length of signal cables, easy mixing of lines, inconvenient maintenance, and high cost [1-3].

As the core equipment of rail transit turnout switching and locking, the reliability of the switch machine will have an important impact on railway traffic safety and transportation efficiency [4, 5]. In practical application, three-phase AC switch machines have the advantages of sufficient power, reliable action, low motor failure rate, and small maintenance workload. Therefore, the three-phase AC switch machine is widely used in the field of railway transportation [6, 7].

However, most of the existing three-phase AC switch machine driving modules adopt a centralized control mode, which not only needs to provide an additional AC 380V circuit for the power supply but also needs to use a relay to control the output. Relays are commonly employed in the traditional driving module, the relay is susceptible to environmental influences, and failures such as node aging and adhesion would occur when it worked for a long time. Moreover, the traditional driving module also has problems of high cost, large volume, and difficult maintenance [8-11]. Therefore, the traditional driving module is not suitable to be employed in outdoor control equipment. In consideration of the above disadvantages, a design method of the safe driving and acquisition module for the nodeless three-phase AC switch machine is proposed in this work. In order to realize the trackside control for three-phase AC switch machines with the high-power density and low cost, the nodeless output mode is adopted by the designed module. In this way, the switch machine can be powered by the three-phase AC 380V converted from the trackside single-phase AC 220V.

The rest of this paper is arranged as follows. Section 2 presents the overview of the proposed safe driving and acquisition module, and the structure diagram of the designed module is presented in this part. The hardware design and the software design of the module are illustrated in Section 3 and Section 4, respectively. In Section 5, the feasibility of the proposed safe driving and acquisition module is verified by building a test environment. Finally, conclusions are given in the last section.

2 OVERVIEW OF THE SAFE DRIVING AND ACQUISITION MODULE

The safe driving and acquisition module is designed based on the principle of fault safety. By using power electronic devices to design DC boost conversion and three-phase inverter circuits, the power supply method of the traditional driving module is replaced. Because of the integration of safety drive and safety acquisition, the redundant remote communication, the switch machine position acquisition, and the module output signal monitoring are realized. The power factor correction (PFC) circuit and the output circuit of the designed module adopts the safety control technology of double closed-loop control output based on voltage and current. At the same time, the two out of two structure is adopted to ensure the reliability of acquisition, double CPU voting is carried out for external input and internal output, and the safety processing is carried out according to the voting results. In addition, the safety logic control circuit of the module controls the PFC circuit (the first stage drive circuit) and the output circuit (the second stage drive circuit) to realize the safe drive output, which can ensure that when any stage drive circuit is abnormal, the strong voltage circuit has no output.

The safe driving and acquisition module can mainly realize the following functions:

1) Trackside AC 220V is used as strong current input to realize the safe driving of the switch machine.

2) It can collect and monitor the output voltage and current signals of the driving module in real-time, and has the functions of temperature detection, voltage monitoring, and overcurrent protection.

3) The real-time and safely collection of the current position information of the switch machine, such as, positioning, reverse position, and four open states.

4) Driving the switch machine safely. When the switch machine completes the action, the module can stop output automatically.

The safe driving and acquisition module is mainly composed of power supply circuit, safety logic control circuit, PFC circuit, output circuit, safety and control circuit, and acquisition circuit. The hardware circuit structure is given in Figure 1, and the working principle is illustrated as follows:

1) Power supply circuit: obtain trackside AC 220V and output voltage with the peak value of 311V after rectification circuit.

2) PFC circuit: the voltage with an input peak of 311V is output to DC 650V after boost conversion. The input current information and output voltage information can be detected in real-time to control the output voltage value of boost conversion.

3) Output circuit: convert input DC 650V to AC 380V to provide input power for the switch machine.

4) Acquisition circuit: collect the output value of voltage and current by the three-phase inverter circuit, and collect the current working state of the switch machine.

5) Safety logic control circuit: make the two out of two logic judgment on the control command, combined with the output results of the acquisition circuit, and finally output the corresponding operation command by the driving module.

3 HARDWARE DESIGN OF THE SAFE DRIVING AND ACQUISITION MODULE

3.1 Power Circuit

The power supply circuit is designed to obtain AC 220V from the trackside. The power can be used for the input power of the rectifier circuit and the power conversion circuit, respectively. In particularly, the one circuit can convert AC 220V into DC 24V through the isolated power supply circuit, and then outputs DC 3.3V, 5V, 15V, and other weak voltages through the isolated DC-DC power supply conversion circuit to supply power for various chips and detection circuits. The other circuit is used as the input voltage of the strong voltage circuit.

3.2 Safety Logic Control Circuit

The safety logic control circuit adopts the standard of the two out of two structure. Each CPU obtains the control command sent by the remote-control center in real-time to form an independent closed-loop control circuit. Through the safety judgment of the control command and combined with the current position information of the switch machine, the corresponding drive signal is finally generated. The two out of two safety judgments can ensure that the module has no output when any of the dual CPUs fails or works abnormally, so as to ensure the safety of the system.

Each CPU of the safety logic control circuit has a temperature sensor, voltage monitoring, watchdog, IO interface, and ETH communication interface. The temperature sensor monitors the hardware temperature of the module board in real-time. Voltage monitoring real-time monitoring of weak current voltage in the module board. The watchdog monitors the running state of the CPU. When the software is abnormal, the CPU can be reset. IO interface is used to output safety and IO signals and PWM IO signals. ETH communication interface can realize real-time communication with the remote-control center. Signal transmission is carried out after isolation between safety logic control circuit and acquisition circuit, safety and control circuit and safety control drive circuit. If the collected voltage value and three-phase current value are normal, the CPU outputs safety and IO control signals to make the PFC circuit output DC boost conversion. At the same time, the CPU outputs the pulse width modulated IO drive signal to the drive circuit, controls the output circuit to work normally, and finally drives the three-phase AC switch machine to act. If any of the output voltage and three-phase current acquisition is abnormal, the CPU stops outputting safety and pulse width modulated IO signals, and the PFC circuit and output circuit stop outputting. After the drive is completed, the dynamic acquisition circuit is used to collect the position information of the switch machine, judge whether the turnout is in place, and report the turnout position information to the remote control center.

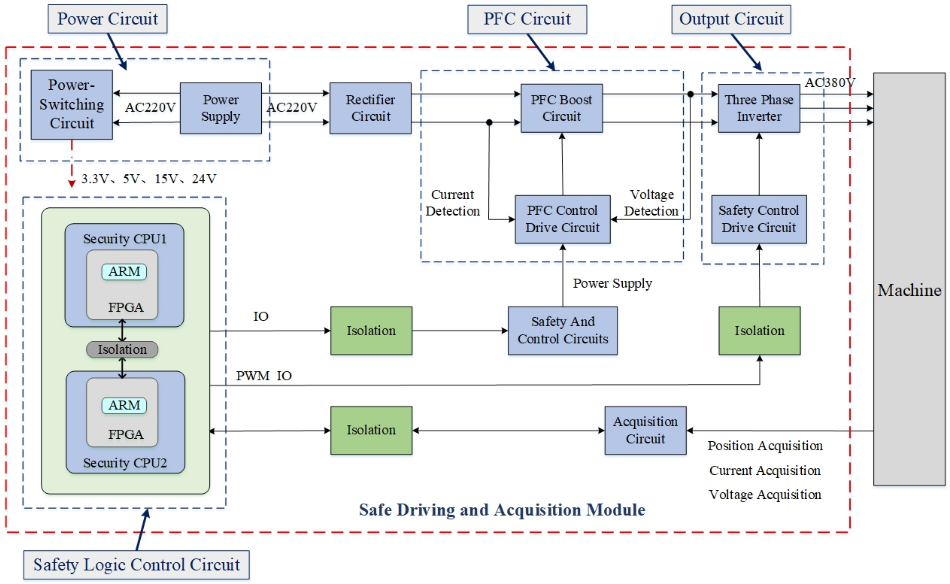

Figure 1: Structure Diagram of the Safe Driving and Acquisition Module for Nodeless Three-Phase AC Switch Machines.

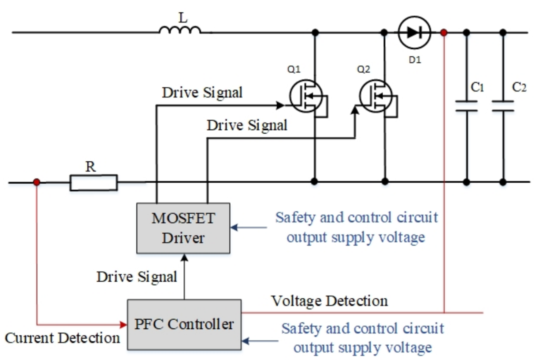

Figure 2: Structure of the PFC Circuit.

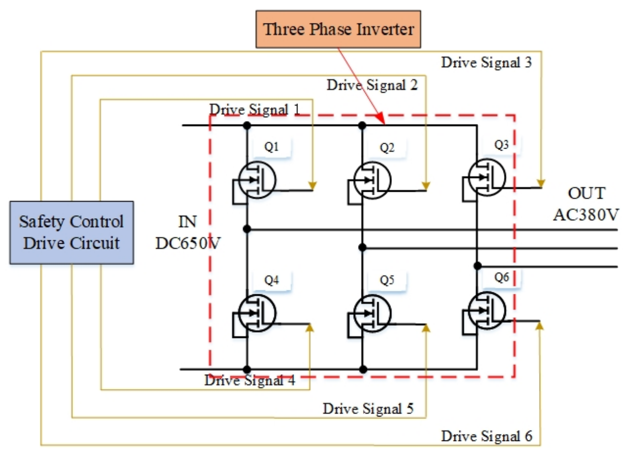

Figure 3: Structure of the Output Circuit.

3.3 PFC Circuit

The designed PFC circuit is shown in Figure 2, mainly including the PFC control drive circuit and the PFC boost circuit.

As shown in Figure 2, two parallel MOSFETs are adopted by the PFC boost circuit, which can effectively reduce the circulating current of the MOS transistor and reduce the loss of MOSFET. During the operation of the PFC circuit, the power supply voltage required by the PFC controller and the MOSFET driver can be provided by the safety and control circuit. The PFC controller uses double closed-loop control to output one MOSFET drive signal, and then output two of the same MOSFET drive signals after passing through MOSFET driver to provide drive signals for Q1 and Q2 switches, respectively. Moreover, the harmonics of the input circuit and the influence of the module on the power grid can be reduced.

The PFC controller can control the output MOSFET drive signal by detecting the input current to ensure that the input current is in phase with the input voltage, so as to improve the power factor of the whole circuit and output a stable DC 650V. If the PFC circuit works abnormally, the safety logic control circuit stops outputting safety and IO signals, the safety and circuit stops providing driving voltage for the PFC controller and MOSFET driver, and the PFC circuit stops working. At this time, the boost function cannot be realized and there is no output voltage, which can ensure the safety of operators and effectively improve the safety of the trackside control system.

3.4 Output Circuit

The output circuit mainly includes the three-phase inverter circuit and the safety control drive circuit, as shown in Figure 3.

In Figure 3, the three-phase inverter circuit is composed of six MOSFET power stage switches. Through the drive signal output by the

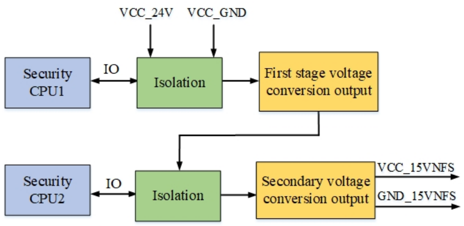

Figure 4: Structure of the Safety and Control Circuit.

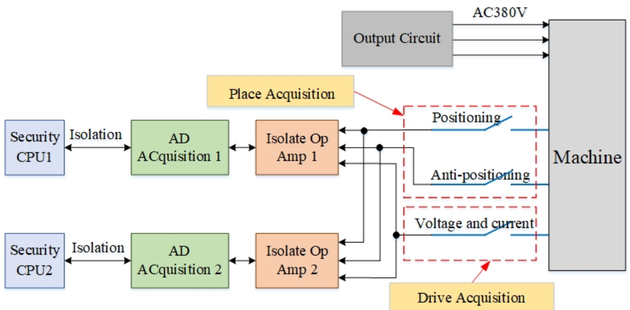

Figure 5: Structure of the Safety and Control Circuit.

safety control drive circuit, the input DC 650V can be converted as AC 380V to drive the switch machine. The three-phase inverter circuit can realize the soft-start function by controlling the driving signal of the power device, which can limit the starting current within the working current range. Thus, the output without instantaneous impulse current is ensured, the availability of the circuit can be improved, and the service life of the switch machine and the module can be prolonged.

3.5 Safety and Control Circuit

The dual CPU control is employed by the safety and control circuit. And Figure 4 shows the structure of the circuit.

As can be seen from Figure 4, the output IO of the safety CPU1 can realize the primary voltage conversion output through the power electronic device, and this voltage is the control voltage of the driver of the next circuit. The safety CPU2 output IO can realize the secondary voltage conversion output through power electronic devices as the input power supply of PFC controller and MOSFET driver in PFC circuit. When abnormal output is detected by the safety logic control circuit, it would stop the safety and IO signal output of CPU1 and CPU2, and the module can lead to the safe side without abnormal output, which can enhance the safety operation of the three-phase AC switch machine.

3.6 Acquisition Circuit

The acquisition circuit can be divided into two parts: the drive acquisition and the position information acquisition, as shown in Figure 5.

In Figure 5, the output IO of the safety CPU1 can realize the primary voltage conversion output through the power electronic device, and this voltage is the control voltage of the next-circuit driver.

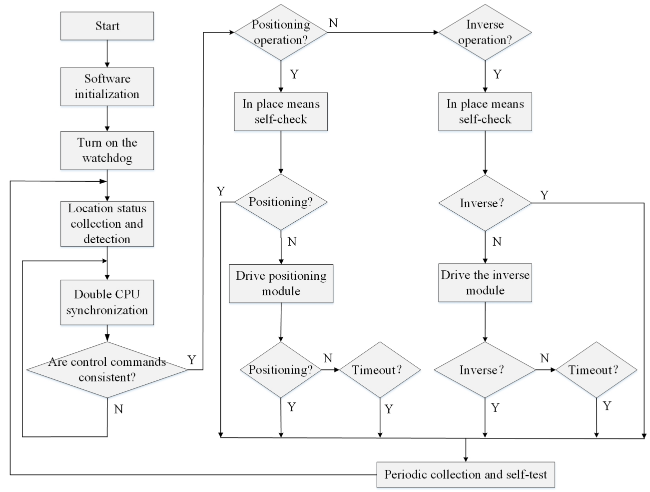

Figure 6: Software Flowchart of the Security Driver Module.

The safety CPU2 can output IO to realize the secondary voltage conversion output through power electronic devices as the input power supply of PFC controller and MOSFET driver in PFC circuit. When abnormal output detected by the safety logic control circuit, it would stop the safety and IO signal output of CPU1 and CPU2, and the module would lead to the safe side without abnormal output, which can enhance the safety operation of the switch machine.

4 SOFTWARE DESIGN OF THE SAFE DRIVING AND ACQUISITION MODULE

The dual CPU software of the safe driving and acquisition module adopts the two out of two structure, which mainly can be used to complete the safe communication with the remote-control center and the commands issued by the control center. After any abnormality detected by the software, the module would stop the collection and output, and then would report to the remote-control center. The software flow chart of the safe driving and acquisition module is shown in Figure 6.

As can be seen from Figure 6, after the software is started and running, the flow can be described as:

1) Initialize the software, and the various registers are then configured and self-checked.

2) The status information of the switch machine is collected. The dual CPU is synchronized and uploaded to the remote control center.

3) The dual CPU synchronizes the control commands issued by the remote-control center.

4) Compare the output information of the collection circuit with the control commands. If they are inconsistent, use the drive module to drive the output. After the drive is completed, perform the in-place collection judgment again.

5) Compare the them again. If consistent, send the command execution completion message to the control center. If it is still inconsistent, then send the state (be in a four-open state) of the switch to the control center.

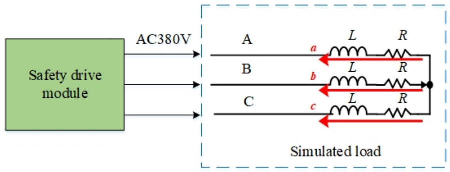

Figure 7: Resistance Inductance Analog Load.

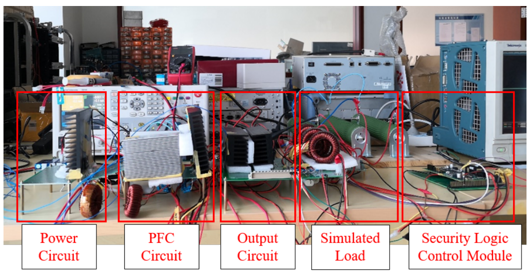

Figure 8: Security Drive Module Test Environment.

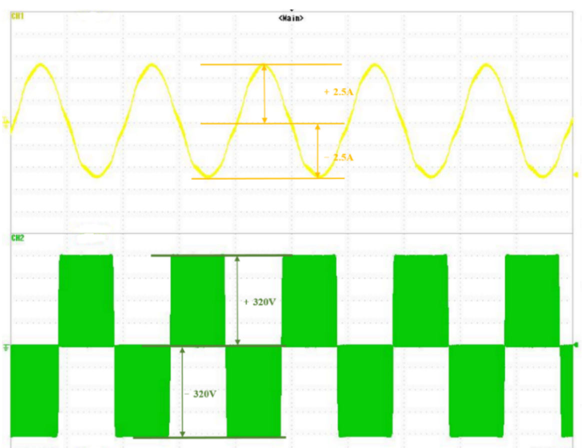

Figure 9: The Phase Current and the Line Voltage Waveforms.

6) When the module is idle, the module would perform self-checking operation according to the specified time.

5 EXPERIMENTAL RESULTS

The three-phase output of the safe driving and acquisition module is connected with the resistance inductance analog load to test the function. Among them, the analog load adopts star connection mode, and each phase is composed of resistance and inductance in series, as shown in Figure 7.

Figure 8 shows the test environment of the safe driving and acquisition module, which mainly includes the power circuit, the rectifier circuit, the PFC circuit, the output circuit, the safety logic control circuit, and the analog load.

The phase current and the line voltage of safe driving and acquisition module can be observed by an oscilloscope. The experimental results are shown in Figure 9As shown in Figure 9, the channel CH1 is the phase current waveform with a peak value of 2.5A (5A/div), and the channel CH2 is the line voltage waveform with a peak of about 320V (80V/div).

It can be seen from the experimental results that the three-phase inverter output can be realized through PFC circuit and output circuit. Moreover, the feasibility of the safe driving and acquisition module is verified by the experimental results.

6 CONCLUSIONS

Considering the disadvantages of the traditional driving module for the three-phase AC switch machine, a design method of the safe driving and acquisition module is proposed in this work. Based on the remote communication, nearby power collection, and power transformation, the nodeless-trackside safe driving and acquisition function of switch machines can be realized. By using the designed module, the laying of signal cables, the number of equipment rooms, and the workload of maintenance staff can be reduced significantly. Moreover, the trackside driving and control for three-phase AC switch machines can be realized with low cost and high reliability.

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