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A function detection method of MMC SM in VSC-HVDC

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A function detection method of MMC SM in VSC-HVDC

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Abstract. Aiming at the problems of large workload, low efficiency and incomplete function coverage in the maintenance process of VSC-HVDC project, this paper studies the SM detection technology of MMC. Firstly, it analyzes the background and significance of this research, then based on the elaboration of the working principle of SM, a SM function detection method is proposed. This method can not only realize the automatic detection of multiple mmc-sms, but also cover all the power components except the thyristor of SM, which greatly simplifies and improves the detection steps and efficiency. The feasibility and effectiveness of the method are verified by simulation analysis.

1. Introduction

As a new technology, based on voltage source converter high voltage direct current (VSC-HVDC) technology has been widely used in China in recent years with the putting forward of modular multilevel converter (MMC) at the beginning of this century [1]. Since the first project (Shanghai Nanhui) was put into operation in 2011, there have been 6 projects in operation, 2 projects under construction, and 1 project planning in China, and the world records have been constantly updated. At the same time, with the increasing number of projects, operation and maintenance has gradually become an important factor affecting the sustainable development of VSC-HVDC technology. Because all the converters of VSC-HVDC projects in China adopt MMC, it is very important to study the operation and maintenance technology of MMC.

In view of the structural characteristics of MMC [2], at present, in the production practice, the operation and maintenance of MMC mainly depends on the equipment supplier, detected one by one, which has the problems of heavy workload and low efficiency. In terms of scientific and technological research, it is mainly focused on MMC circulation suppression and voltage sharing control [3, 4], and the research on operation and maintenance technology is relatively lacking, and mainly lies in the detection of key components in MMC sub-module (SM). For example, Literatures [5, 6] studies the short-circuit and open circuit fault diagnosis of power switching device Insulated Gate Bipolar Transistor (IGBT). Literatures [3, 7, 8] studies the capacitance detection of capacitors by using the methods of measurement correction optimization, measurement circuit optimization and measurement equipment optimization respectively. Although these research results have certain help and reference value for the operation and maintenance of MMC, they can not meet the requirements of full function coverage of equipment detection.

Therefore, this paper studies the SM detection technology, and proposes a functional detection method for SM, which not only can realize the one-time automatic detection of multiple SM, but also covers all power components of SM except the thyristor, greatly simplifying and improving the steps and efficiency of detection work. The feasibility and effectiveness of this method are verified by simulation analysis.

2. MMC SM introduction

As the basic component of MMC, the SM is responsible for supporting voltage of DC bus in the start-up and operation phase of VSC-HVDC project. Therefore, to study the operation and maintenance technology of MMC, we must first have a full understanding of the development and application status, electrical structure and working principle of SM.

Therefore, this section briefly introduces the electrical structure and working principle of SM based on its development and application status, and then determines the applicable object and scope of the SM detection technology.

2.1. Electrical structure of SM

In 2003, in order to solve the problems of switch consistency and poor voltage sharing in the application of two-level converter topology to high-voltage scenes due to the manufacturing process of fully controlled semiconductor power device IGBT, MMC was formally proposed, in which the SM adopts half bridge structure, as shown in Figure 1, consisting of IGBT, B-bypass switch, T-thyristor, R-voltage sharing resistance, C-parallel capacitor.

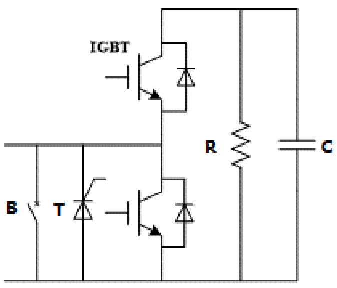

Figure 1. Half bridge SM.

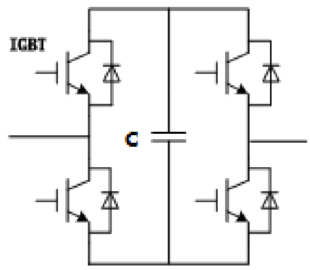

Figure 2. Full bridge SM.

It can be seen from Figure 1 that in order to ensure that the IGBT will not be damaged under the condition of reverse transient voltage, the diode is embedded in each IGBT module, so that the MMC with half bridge SM cannot block the short-circuit current circuit in case of short-circuit fault on the DC side [9]. In order to solve this problem, in recent years, new SM electrical structures are emerging [10], but they have made great sacrifices in cost.

For this reason, although the new SM electrical structures are emerging in endlessly, the half bridge SM is still the mainstream choice of MMC in the world at present, and the only new SM adopted by the actual project (Wudongde power station - Guangdong and Guangxi multi-terminal Ultra-HVDC project) is the full bridge SM, as shown in Figure 2.

As the electrical structure of other new SM has not been applied in engineering, it will not be described here.

2.2. Working principle of SM

At present, the SM in the world is still based on the half bridge structure, so this paper focuses on the working principle of the half bridge SM, and other new SM will not be described in detail.

As shown in Figure 3, if IGBT1 and IGBT2 in the SM are named T1 and T2 respectively, three working states of the SM can be listed according to the switch states of T1 and T2:

- T1 and T2 are off at the same time. This state is SM locked state, which can only charge C, not discharge, and is mainly used in the precharging stage of MMC. At the same time, it can be seen that although T1 and T2 are turned off at the same time, the current circuit cannot be blocked, that is, the short-circuit current circuit cannot be blocked in case of short-circuit fault at the DC side.

- T1 is on and T2 is off. This state is SM input state, which can charge and discharge C, mainly used in normal operation stage of MMC.
- T1 is off and T2 is on. This state is SM cut-off state, which can not charge and discharge C. It is mainly used to realize the SM redundancy and fault SM cut-off function of MMC.

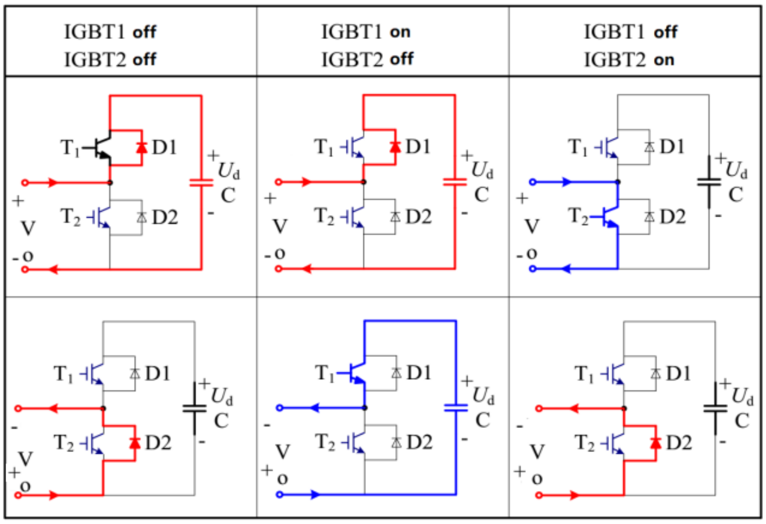

Figure 3. Working principle of half bridge SM.

It can be seen that the input and cut-off state of the SM can be equivalent to that of the shunt capacitor, as shown in Figure 4. MMC also realizes the control of DC bus voltage by using the equivalent relation of SM working state.

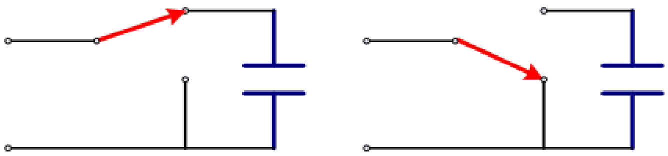

Figure 4. Equivalent diagram of SM.

According to Sections 2.1 and 2.2, for each power component of the SM, IGBT and C are the core, which are directly related to the establishment and control of DC bus voltage, in order to ensure the effective removal and maintenance of the SM, bypass switch is essential, in order to ensure the uniform distribution of voltage and energy release of the C, the voltage sharing resistance is essential, the main purpose of the thyristor is to ensure the safety of diode in case of system failure, which is used to shunt the fault current. However, at present, the actual engineering case (Chongqing-Hubei back-to-back project) chooses to use diode with greater flow energy, and no thyristor is set.

In conclusion, this paper takes the half bridge SM as the research object, and the research scope of detection technology covers all SM power components except the thyristor.

3. SM function detection technology

3.1. SM detection requirements analysis

In the VSC-HVDC project, the number of SM is very large, which results in the high cost of MMC compared with two-level and three-level converter. Taking Chongqing-Hubei back-to-back project (± 420kv, 1250MW×4) as an example, there are 25920 SM (including redundancy), so it is inevitable that SM failure occurs.

Combined with the actual operation of the project, there are four possible problems of SM power components [11]:

- overvoltage / undervoltage of C. Because MMC obtains high voltage through multiple parallel capacitors in series, and the voltage of the input C will decrease with the power transmission, the control system needs to replace the SM to maintain the DC bus voltage, so once the control system is disturbed, the C may have over-voltage / under voltage completely.
- IGBT breakdown short circuit. At present, the biggest problem of IGBT is that it can't withstand the high voltage and current of thyristor level. Therefore, VSC-HVDC project in China generally does not have the ability of overload operation. At the same time, considering that the rise rate of short-circuit current of VSC-HVDC project reaches μs level, it means that once the project fails, IGBT is prone to strike under the condition of over-voltage and over-current short circuit fault.
- the B misoperates or refuses to operate. As a circuit breaker, the operation reliability of the bypass switch can be generally guaranteed. However, at present, the SM generally adopts the self-charging mode, the working power is directly supplied by the C. Once the power circuit fails, the bypass switch will fail to operate, and the misoperation is mostly caused by the poor anti-interference ability of the control circuit.
- aging of R. In practical engineering, the damage rate of the R is generally low, because the R is mainly used to balance the voltage and discharge the stored energy of the C of each SM, and the voltage and current under normal operation are not large. However, once the R is aged, the change of resistance value will affect the control operation of SM.

It can be seen that the research of SM function detection technology needs to focus on the test requirements of C, IGBT switching capacitance, B closing and opening capacitance, and R.

3.2. Analysis of MMC SM detection principle

Based on Section 3.1, this paper proposes an SM function detection method, and the corresponding detection device is shown in Figure 5.

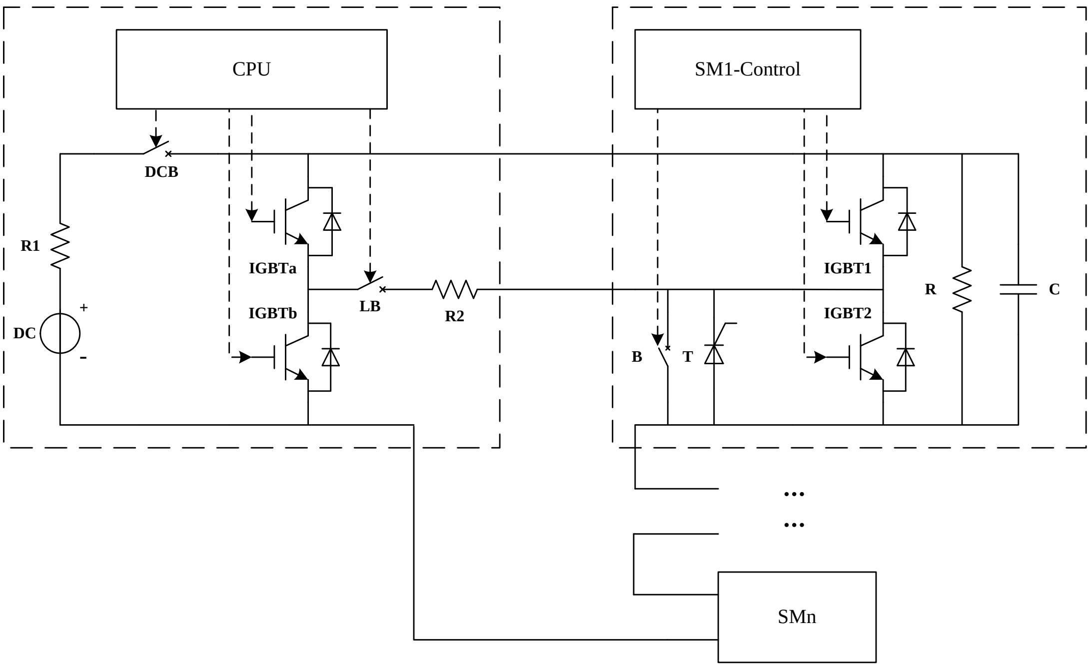

Figure 5. Schematic diagram of MMC SM detection.

It can be seen from Figure 5 that the SM function detection device mentioned in this paper consists of DC-DC power supply, DCB-power switch, IGBT, LB-load switch and R2-load resistance. Combined with Figure 5, the specific steps of SM function detection method proposed in this paper are as follows:

- device initialization and test wiring are completed. Set the DCB in the detection device to the opening position, turn off the IGBT, and connect the control circuit and power circuit of the tested SM.
- SM C and B detection.

1) close the DCB and SM2-SMn B, charge and calculate the capacitance of SM1 C, and detect the closing capacitance of SM2-SMn B;

2) close the LB, B of SM1, IGBTa on and open B of SM2, charge and calculate the capacitance of C of SM2, and detect the closing capacitance of B of SM1 and the opening capacitance of B of SM2;

3) cycle 2) operate, charge and calculate the capacitance of SM3-SMn C, and detect the breaking capacitance of SM3-SMn B;

4) disconnect the B of SM1, and detect the disconnection capacitance of the B of SM1;

5) disconnect the B of SM2-SMn-1 and turn off IGBTa.

The calculation principle of C of SM is as follows:

Ignoring the internal resistance of the DC, there is a capacitor charging time constant:

$$\tau=R1\times C \tag{1}$$

In the process of capacitor charging, select multiple sampling points, record the time and voltage of each sampling point, and record at 10τ, such as: (0.5τ, U1), (τ, U2), (1.5τ, U3), (2τ, U4), (10τ, U5).

According to the capacitance charging formula:

$$\Delta t=R1\times C\times In[(U0-U1)/(U0-U2)] \tag{2}$$

Where U0 is the rated voltage of capacitance U5, $\triangle t = t2-t1$.

The calculation formula of the available capacitance is as follows:

$$C=\Delta t/(R1\times \ln[(U0-U1)/(U0-U2)]) \tag{3}$$

Where C is the parallel capacitor capacitance of SM.

- IGBT test of SM.

1) IGBTa and SM1-SMn IGBT2 on, and detect the opening capacitance of SM1-SMn IGBT2.

2) SM1-SMn IGBT2 off in turn, and detect the turning off capacitance of SM1-SMn IGBT2.

3) IGBTa and SM1-SMn IGBT2 off.

4) disconnect the DCB, IGBTb and SM1-SMn IGBT1 on, and detect the turning on ability of SM1-SMn IGBT1.

5) SM1-SMn IGBT1 off in turn, and detect the turning off capacitance of SM1-SMn IGBT1.

6) IGBTb and IGBT1 off of SM1-SMn.

- detection of R of SM.

1) close the B of SM2-SMn, IGBTb and SM1 IGBT1 on, discharge the C of SM1 and calculate the R.

2) SM1 IGBT1 off, close SM1 B, turn off SM2 B, SM2 IGBT1 on, discharge C and calculate R of SM2.

3) cycle 2) operate, discharge C and calculate the R of the SM3-SMn.

4) disconnect the B of SM2-SMn-1, IGBTb off.

The calculation principle of voltage sharing resistance of SM is as follows:

In the process of capacitor discharge, select several sampling points according to the time constant, and record the time and voltage of each sampling point, such as (0.5 τ, U1), (τ, U2), (1.5 τ, U3), (2 τ, U4).

Follow the discharge formula of capacitor:

$$\Delta t=R//R2\times C\times \ln[(U0/U1)-(U0/U2)] \tag{4}$$

The formula for calculating the R can be obtained

$$R//R2=\Delta t/(C\times \ln[(U0/U1)-(U0/U2)]) \tag{5}$$

Given the load resistance R2, R can be obtained. Where R is the voltage sharing resistance value of SM.

- after the test, remove the wire.

If the test is not carried out as planned, it indicates that there is a problem. You can check the problem SM by consulting the feedback record

4. Simulation verification

In this paper, four SM are tested at the same time as an example to verify the feasibility and effectiveness of the method.

Based on MATLAB / Simulink, the function detection method of SM proposed in this paper is verified. The parameters of SM detection device are shown in Table 1. Take Chongqing-Hubei back-to-back project as an example, the power component parameters of SM are shown in Table 2. The simulation results are shown in Figure 6, and four SM are tested at one time. The simulation results are shown in Table 3 and Figures 7-8.

Table 1. SM detection device parameters.

DC	300V
R1	5Ω
R2	5Ω

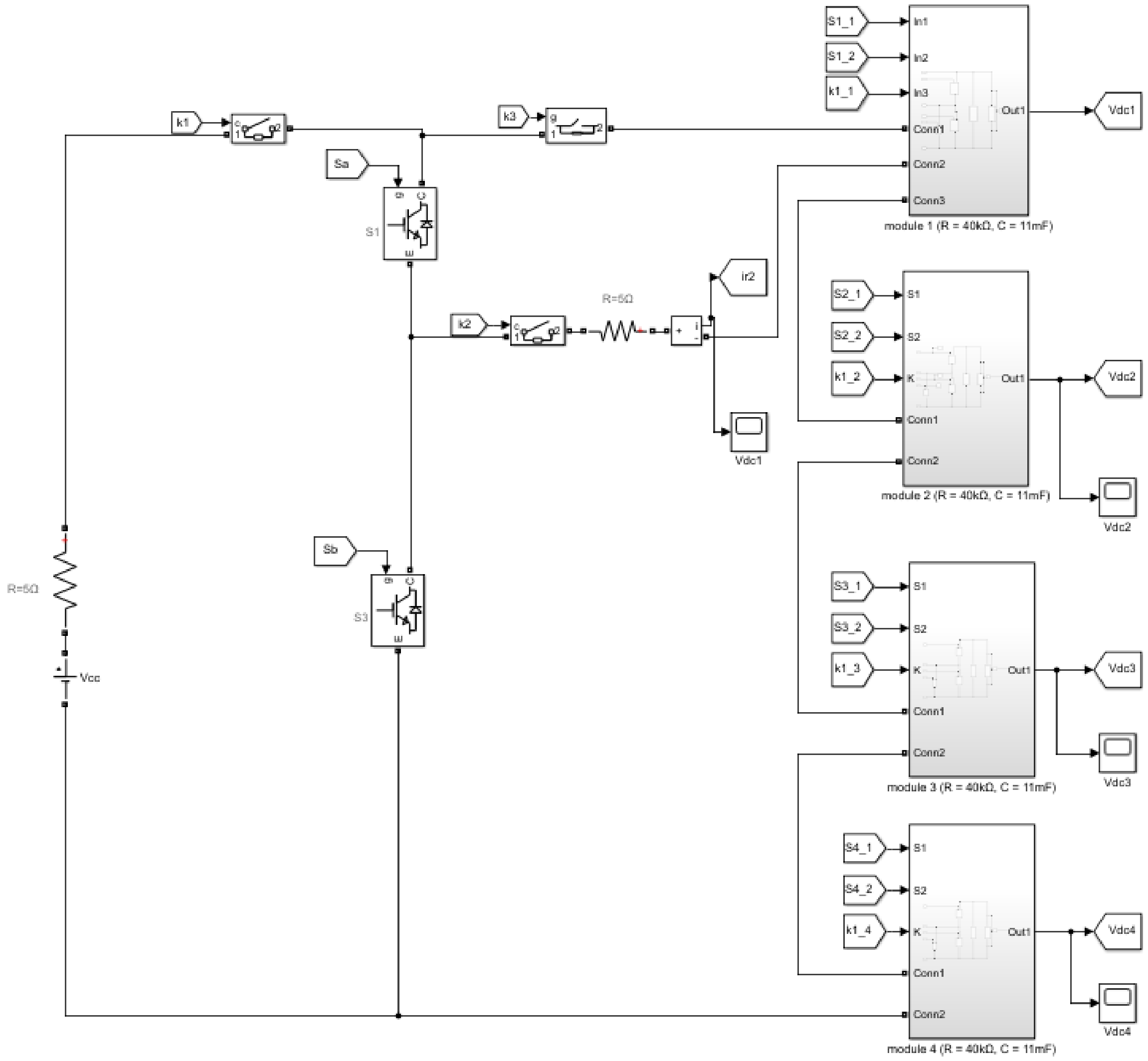

Figure 6. Simulation example.

Table 2. Power component parameters of SM.

IGBT	3300V/1500A
C	11mF/2200V
B	2500V/1250A
R	40KΩ

Table 3. Simulation results.

IGBT	OK
C	11mF
B	OK
R	≈30KΩ

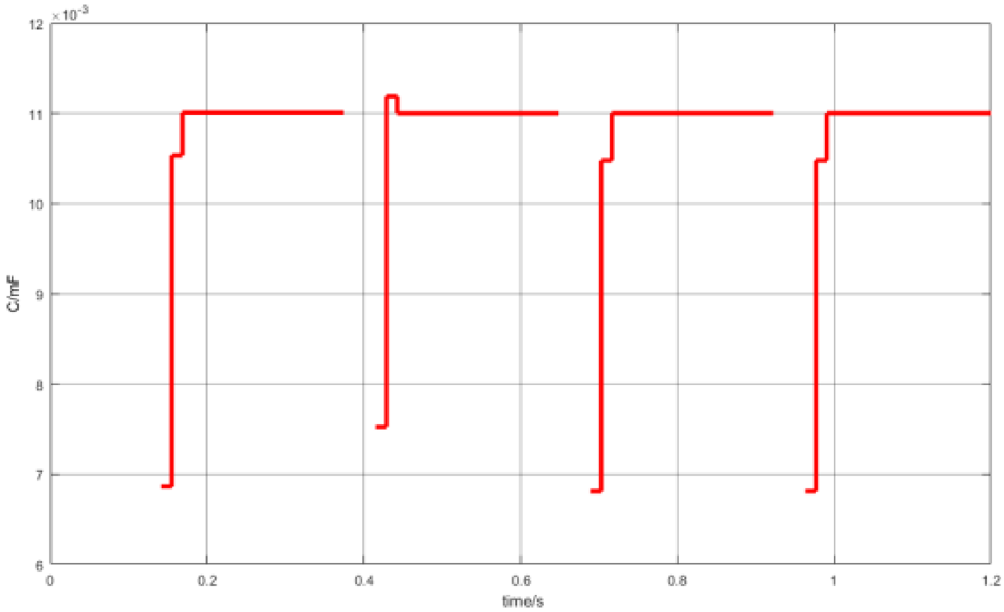

Figure 7. Calculation results of shunt capacitance.

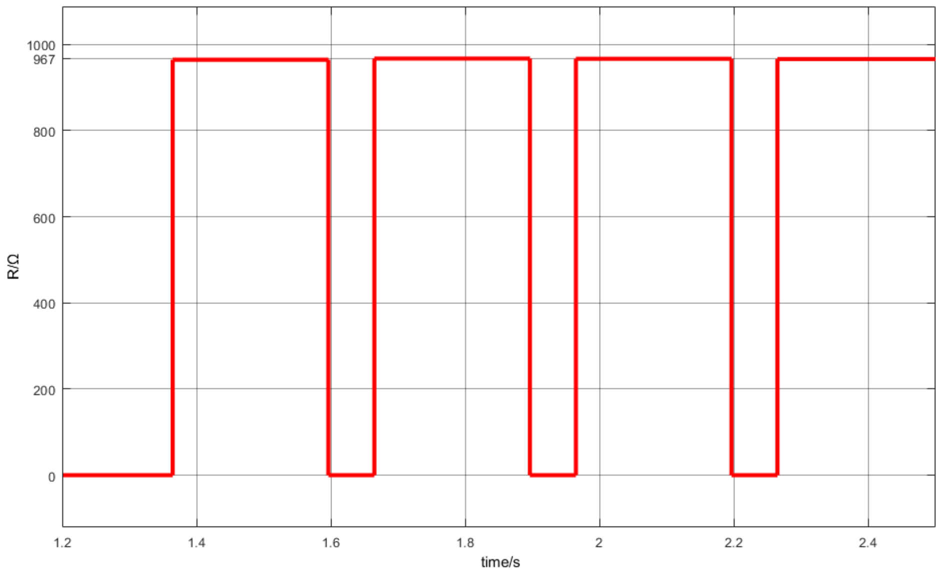

Figure 8. Calculation results of R2 / / R.

It can be seen from Table 3 and Figures 7-8 that this method can effectively realize one-time automatic detection of multiple SM, covering all power components of SM except for thyristor.

For the measurement deviation of the R, the main reason is that the R2 in the simulation example is too small, resulting in the deviation of the calculation results, which can be completely avoided in the practical application (in the simulation, taking R2 as the general assembly results in the simulation time too long, RC = 40KΩ× 11mf = 7.3 minutes, which can not be realized).

5. Conclusions

Aiming at the problems of heavy workload, low efficiency and incomplete function coverage of SM in the maintenance process of VSC-HVDC project, this paper introduces the current research status, expounds the working principle of SM, and finally a function detection method for SM is proposed, which can realize one-time automatic detection of multiple SM and cover all power components of SM except thyristor.

Taking Chongqing-Hubei back-to-back project as an example, the method is simulated and analyzed based on MATLAB / Simulink, which verifies the feasibility and effectiveness of the method.

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