The Analysis and Model of AC Switch Indication Circuit

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Abstract. Alternating current (AC) switch machine is usually a few kilometers away from the signal building. When the cable X1 of AC switch indication circuit breaks, it indicates that the relay does not release. Based on this problem, AC switch indication circuit is analysed, a method for solving the distributed capacitance of cable is given, and a simulation model of the AC switch indication circuit is established. The test was carried out at Hami south station, and the validity of the simulation model was verified.

1. Introduction

The switch indication circuit is a circuit that reflects the switch position to the signal building[1]. The switch indication circuit is used for not only supervision, but also interlocking, so it must take more perfect fail-safe measure.

However, in an interlocking test conducted by Chengdu Railway Bureau, it was found that the switch indication relay was not released when the cable X1 disconectsed with the outdoor cable box, and the cable length was 4.429km. Coincidentally, 16 groups of alternating current (AC) switch in Urumqi Railway Bureau, whose control cable length was more than 2km, was found the same problem. It does not conform to the fail-safe principle[2].

In this paper, the simulation model of AC switch indication circuit is established to analyze the situation of cable X1 broken in this circuit, and verify the engineering improvement schemes.

2. AC switch indication

In the AC switch indication circuit, the primary side voltage of the transformer is AC 220V, and the secondary side voltage is AC 110V. DBJ is the switch normal indication relay, and FBJ is the switch reverse indication relay. Therefore, the positive half cycle circuit and the negative half cycle circuit of the power supply are analyzed respectively when analyzing the working principle of the switch normal indication. The switch reverse indication is the same.

The positive half cycle circuit of the power supply is shown in red line of Figure 1[3]. The current flow direction is as follows: transformer +→R1→1DQJ23-21→2DQJ131-132→1DQJF13-11→2DQJ111-112→switch machine contact 31-32→motor coil U→motor coil W→1DQJ11-13→transformer +.

The negative half cycle circuit of the power supply is shown in blue line of Figure 1. The current flow direction is as follows: transformer +→R1→1DQJ23-21→2DQJ131-132→DBJ4-1→switch machine contact 11-12→motor coil V→motor coil W→1DQJ11-13→transformer +.
In order to analyze the AC switch indication circuit conveniently, separate the AC switch normal indication circuit and switch reverse indication circuit, leave out the contact of relay and switch machine, and retain electrical components in the circuit. The equivalent circuit is shown in Figure 2.

It can be seen from Figure 2 that there are distributed capacitances between cable core wire and core wire, between core wire and metal sheath [4]. When the circuit X1 is disconnected with the circuit, the AC current will detour to the terminal relay through the distributed capacitance. The longer the cable length is or the more cable the parallel core wires are, the larger the distributed capacitance is and then the greater the current flow to the relay is. If the distributed capacitance is large enough, the relay would keep the energized state when the cable X1 disconnected with the circuit.

3. Circuit analysis and model

The AC switch indication circuit include three parts, namely, signal source, transmission channel and terminal impedance.

3.1. Signal source

The signal source part is composed of indoor AC signal source, transformer and outdoor rectifier circuit. The 50 Hz AC signal source loaded on the terminal relay after diode rectification is a periodic signal with high positive half cycle peak voltage and low negative half cycle peak voltage. The measured waveform is shown in Figure 3.

Discrete Fourier transform is applied to the voltage signal, and the spectrum characteristics is shown in Figure 4. The signal energy distribution is mainly concentrated in the 0 ~ 300 Hz wide-band.
signal, in which the 50Hz AC component accounts for a large proportion. In the process of transmission, this signal makes the influence of cable distribution capacitance intensified, and also causes the impedance at both ends of the relay to increase.

![Figure 3. Measured waveform of relay coil voltage signal](image1)

![Figure 4. Frequency spectrum analysis diagram of relay coil voltage signal](image2)

3.2. Transmission channel
The transmission channel is composed of outdoor signal transmission cable and switch machine motor coil. The parameters of the switch machine can be obtained directly from the test. The resistance and inductance parameters of cable also can be tested by conventional method. The cable distributed capacitance will be analyzed in detail, because the railway digital signal cable has the characteristics of many specifications, asymmetric or irregular arrangement of core wires.

In any circuit, a distributed capacitance is formed between two insulated conductors with differential pressure. Therefore, there is a distributed capacitance between the core wires of the cable and between the core wire and the metal sheath of the cable. The distributed capacitance value depends on the geometry of the cable, the length of the cable and the insulating material.

3.2.1. Test and solution method of the distributed capacitance between core wire and metal sheath
One core wire in the cable is selected as the tested object A, and all the other core wires are short circuited as test object B (short circuited to eliminate the distributed capacitance between other core wires), and then measuring capacitance $C_{AB}$ with capacitance tester, as shown in Figure 5.

![Figure 5. Test method for the distributed capacitance between core wire and metal sheath](image3)

![Figure 6. Test method for the distributed capacitance between core wire and core wire](image4)
According to equations (1), the value of \( C_1 \) can be calculated. \( C_1 \) is the distributed capacitance between the tested object core wire A and the metal sheath.

\[
\begin{align*}
C_A &= C_1 + \frac{C_{12} \times C_2}{C_{12} + C_2} \\
C_B &= C_2 + \frac{C_{12} \times C_1}{C_{12} + C_1} \\
C_{AB} &= C_{12} + \frac{C_2 \times C_1}{C_2 + C_1}
\end{align*}
\] (1)

3.2.2. Test and solution method of the distributed capacitance between core wire and core wire

Select one core wire in the cable as tested object A and another core wire in the cable as tested object B. All the other core wires are short circuited as tested object C (short circuited to eliminate partial capacitance between other core wires), and tested object C should be short circuited with metal sheath (short circuited to eliminate capacitance between test object C and metal sheath), and then measuring capacitance \( C_{AB} \), \( C_{AC} \), \( C_{BC} \) with capacitance tester, as shown in Figure 6.

According to equations (2), the value of \( C_{12} \) can be calculated. \( C_{12} \) is the distributed capacitance between the tested object core wire A and the tested object core wire B.

\[
\begin{align*}
C_{AB} &= C_{12} + \frac{C_{13} \times C_{23}}{C_{13} + C_{23}} \\
C_{AC} &= C_{13} + \frac{C_{12} \times C_{23}}{C_{12} + C_{23}} \\
C_{BC} &= C_{23} + \frac{C_{12} \times C_{13}}{C_{12} + C_{13}}
\end{align*}
\] (2)

According to the above distributed capacitance test and solution method, 42 core wires railway digital signal cable is selected for test, and the layout of core wires are shown in Figure 7[5]. The solution results of distributed capacitance between core wire and metal sheath are shown in Table 1, and the distributed capacitance between core wire and core wire is shown in Table 2.
Table 1. The distributed capacitance between core wire and metal sheath

| Distributed capacitance (nF/km) |
|----------------------------------|
| Between a core wire of quad and metal sheath | 6~7 |
| Between a core wire of Twisted pair and metal sheath | 0~0.2 |
| Between single core wire and metal sheath | 17~18.5 |

Table 2. The distributed capacitance between core wire and core wire

| Distributed capacitance (nF/km) |
|----------------------------------|
| Between two adjacent core wires in one quad | 17~18 |
| Between two diagonal core wires in one quad | 3~4 |
| Between two core wires in two adjacent Quad | 1.2 |
| Between two core wires in two nonadjacent Quad | 0 |
| Between a core wire in a quad and red single | 6 |
| Between red single and green single | 0.15 |
| Between two core wires in one twisted pair | 20 |

3.3. terminal impedance

The relay used in turnout indication circuit is JPXC-1000 bias relay, which is composed of two coils with direct current (DC) resistance of 500 Ω in series. The coil shows great impedance under the aforementioned wide-band signal source, and the impedance of the coil changes with the AC signal voltage and frequency, as shown in Figure 8.

Therefore, when setting the simulation parameters, the impedance of the relay coil is optimized to make the parameters of the simulation model more close to the actual working impedance of the relay.

3.4. Simulation model establishment

In Matlab / Simulink, the simulation analysis model of AC switch representation circuit is established, as shown in Figure 9. Among them, the signal source parts are the red 220 V power supply, BD1-7 transformer and diode module; the transmission channel parts are the green transmission cable module and switch machine coil UVW module; the terminal impedance is the blue JPXC-1000 relay module.
4. Experimental verification

In order to verify the validity of the simulation model, field test was carried out at Hami South Station of Urumqi Railway Bureau.

The test object is the 104# switch (cable length 5.21km) in Hami south station. The voltage of the relay coil under the normal condition and the condition of cable disconnected with circuit situation were tested under the condition of four core wires in parallel, three core wires in parallel, two core wires in parallel and single core wire.

Under normal and disconnected test records, the relay coil voltage root mean square (RMS) is shown in Table 4. Under normal condition, the errors between test results and simulation calculation results are not more than 1%; under X1 disconnected with circuit condition, the errors between test results and simulation calculation results are not more than 7%, which verifies the validity of simulation model.

Table 3. Comparison between simulation results and test results

| Cable paralleling                  | Relay coil voltage RMS (V) | Normal condition | X1 disconnected with circuit |
|------------------------------------|---------------------------|------------------|-----------------------------|
|                                    |                           | test  | simulation | error | test  | simulation | error |
| four core wires in parallel        |                           | 21.3  | 21.4       | <1%   | 13.6  | 13.6       | 0     |
| three core wires in parallel       |                           | 21    | 21.1       | <1%   | 10.7  | 11.2       | 4.6%  |
| two core wires in parallel         |                           | 20.5  | 20.5       | 0     | 9.04  | 9.2        | 1.8%  |
| single core wire                   |                           | 19.1  | 19.1       | 0     | 5.62  | 6.0        | 6.8%  |

5. Conclusion

(1) Through the analysis of the AC switch indication circuit, it is determined that the root cause of X1 disconnection relay not released is the cable distribution capacitances.

(2) This paper presents a method of measuring and solving the distributed capacitance of railway signal cable, which can obtain the distributed capacitance between any two cores or between any core wire and metal sheath in any number of cables (including cables with complex, asymmetric and irregular core wire arrangement).

(3) The simulation analysis model of the AC turnout representation circuit is established and compared with the field measurement data to verify the validity of the model. It can guide the simulation verification of engineering improvement scheme.

References

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