

Analysis of Several Typical AC Power Cable Crosstalk Simulation Tests

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Keywords: Cable crosstalk, AC and DC power supply, electromagnetic simulation.

Abstract. Based on the cable transmission line simulation method, this paper conducts cable string simulation analysis on common power signals, including: 115V 400Hz single-phase AC, 220V 50Hz single-phase AC, 380V 50Hz three-phase Y-type AC power. Meanwhile, through the programmable power supply, using the electric furnace as the load, the coupled voltage waveform on the cable under test is measured by an oscilloscope. Through the simulation and test methods, the crosstalk of several typical AC power lines to adjacent bare wires is analyzed. By changing the parameters such as cable spacing, cable length, the interference signal, the influence of the above parameters on the crosstalk of the power cable was studied, and the relevant research conclusions were formed. The comparison simulation and the measured results showed that the trend was basically the same. Conclusions about the power cable crosstalk in this paper can provide theoretical support for more deeply crosstalk research about other kinds of cables, such as communication cables, signal cables. Moreover, these conclusions can also offer useful suggestions to complex cable layout in practical projects.

Introduction

In complex platforms such as modern electrical and electronic products, ships, airplanes, EMUs, and automobiles, cables are widely used as bridges for connecting power sources, equipment, energy supply, and transmission signals. For some large-scale equipment, such as large aircraft, ships, etc., the total weight of the internal use cable can reach several tons, the cable routing is complicated, and electromagnetic interference is easily generated between the cable harnesses. Therefore, studying crosstalk between cables has important reference value for cable routing, cable optimization, and reducing cable crosstalk in actual engineering.

Domestic research on cable crosstalk mainly includes: Shi Xudong et al. studied the crosstalk of a single cable to a shielded twisted pair, crosstalk to a data transmission line [1]. Wang Shiyu studied the crosstalk of one end of the cable injected into single source and dual source, and obtained the waveform of the induced current [2]. He Xiaodong, Shan Qin, Ma Yunshuang and others studied the crosstalk of EMU cables and harnesses, and optimized the EMU wiring design [3-5]. Zhang Dan, Zhu Zhigao and others studied the problem of electromagnetic interference caused by cable crosstalk of EMUs, and optimized it [6, 7]. Liu Hongyi et al. proposed a method for quickly testing the common mode impedance of cable terminals [8]. Xu Wei, Yang Qingxi et al. studied the equivalent circuit model of ground overhead transmission line and its near-end and far-end crosstalk [9, 10].

Foreign studies on cable crosstalk mainly include: V. Solak et al. studied the influencing factors of power cable crosstalk, such as cable spacing, cable length and cable type, and analyzed comparative experimental results, simulation results and theoretical values [11]. Rustam R et al. studied the crosstalk and signal distortion of UAV cables, and gave a prediction example of crosstalk between power cables and data cables combined with simulation and measurement [12]. VeyisSolak et al. combined simulation and measurement to analyze the effects of cable spacing, length and type on crosstalk results [13]. R. R. Gaynutdinov et al. studied crosstalk between power cables and data cables [14]. Nils Holte proposed a statistical model of twisted pair crosstalk [15]. Dan Zhang et al. established a crosstalk theoretical model for two commonly used shielded cables [16]. Zhuo Li et al. proposed an improved five-step method to determine the electrical and geometric characteristics of cable bundles, mainly for cable crosstalk simulation studies [17]. Zhuo Li et al. proposed a simplified scheme for modeling electromagnetic crosstalk of complex cable bundles on orthogonal ground

planes, simulating the crosstalk of cables [18]. Yu Wenlu et al. used CST software to simulate the crosstalk and radiation of the internal wiring harness of the aircraft [19]. Xiaodong He et al. Study the effect of EMU circuit structure on cable crosstalk [20].

In summary, some scholars have studied cable crosstalk, and have insufficient research on parameters such as cable type, cable spacing, cable length, and interference signal type. Some scholars only simulate research and have no experimental data comparison; some scholars study cables. Crosstalk only focuses on frequency domain results, and no time domain results are studied. Throughout the literature at home and abroad, there is less information on systematic research on power cable crosstalk. Therefore, this article will focus on the detailed and in-depth study of the crosstalk phenomenon of power cables, and the research results can be used to guide the wiring and laying of power cables in actual projects.

Cable Transmission Line Simulation Method

According to the transmission line theory, the uniform transmission line can be divided into a plurality of micro-segments dz ($dz \ll \lambda$), and each micro-segment can be equivalent to a lumped parameter circuit, as shown in FIG. Set the complex voltage and complex current at the beginning z to $U(z)$ and $I(z)$ respectively. After the dz segment, the voltage and current are $U(z)+dU(z)$ and $I(z)+dI(z)$.

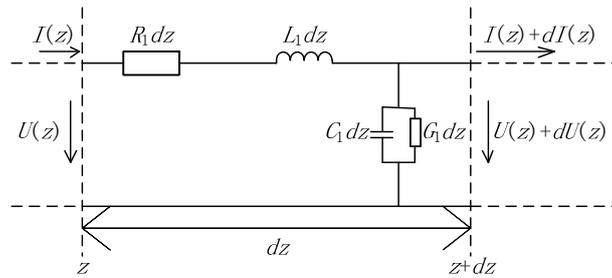


Figure 1. Micro-segment equivalent circuit diagram

According to the Figure 1, the transmission line equation can be obtained:

$$\begin{cases} \frac{dU(z)}{dz} = -[R_1 I(z) + j\omega L_1 I(z)] \\ \frac{dI(z)}{dz} = -[G_1 I(z) + j\omega C_1 U(z)] \end{cases} \quad (1)$$

The general solution of the equation is:

$$\begin{cases} U(z) = A_1 e^{-\gamma z} + A_2 e^{\gamma z} \\ I(z) = A_3 e^{-\gamma z} + A_4 e^{\gamma z} \end{cases} \quad (2)$$

Among them:

$$\gamma = \sqrt{(R_1 + j\omega L_1)(G_1 + j\omega C_1)} \quad (3)$$

This equation can solve the voltage and current at any point on the line and the relationship between them.

The cable simulation software performs electromagnetic simulation calculation on the cable based on the transmission line theory. The simulation steps are as follows:

1) Meshing. The cable harness is divided into a limited number of straight segments, and the simulation software meshes each small section of the metal cross section. In order to ensure the

calculation accuracy, the grid size generally needs to be less than 1/10 of the wavelength corresponding to the highest frequency of the simulation.

2) Model extraction. The transmission line parameters R , L , and C of each small cable are extracted and input to the 2D field solver for calculation. Each segment is converted into a transmission line equivalent circuit, and finally all equivalent circuits are connected into a complete circuit model, replacing the entire cable harness, as shown in Figure 1.

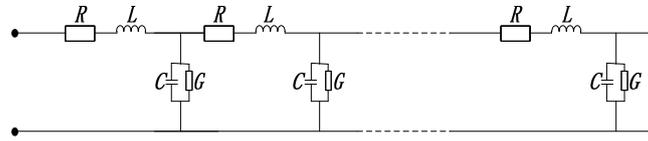


Figure 2. Cable Harness Equivalent Circuit Schematic

3) Calculate the solution. Add load and excitation sources to the cable harness and add current and voltage monitoring points to solve the time-domain and frequency-domain transmission characteristics of the electromagnetic energy on the cable harness. The focus of this paper is on the crosstalk of cable harnesses. Figure 2 shows the schematic diagram of the simulated 2D circuit connections. Among them, P1 and P2 are voltage monitoring points on the excitation cable and the coupling cable, respectively.

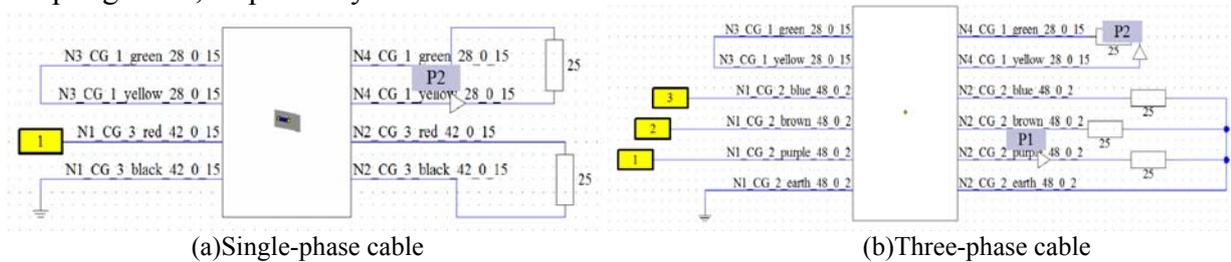


Figure 3. Single phase cable crosstalk circuit connection diagram

During the simulation calculation, the change of current and voltage on the cable harness is transmitted to the 3D electromagnetic field simulation module, thereby generating electromagnetic interference to the space electromagnetic field and the adjacent cable harness. The 3D electromagnetic simulation converts the spatial time-varying electromagnetic field to the cable harness, and then simulates the time domain and frequency domain transmission on the cable harness through the 2D cable harness simulation. This field-channel joint simulation method can solve the problems of crosstalk between multiple cable harnesses, radiation emission of cable harnesses, and radiation sensitivity of cable harnesses.

Cable Crosstalk Test Method

The tests carried out in this paper were carried out in a standard shielded room environment, including a 0.9m high test table, a grounded metal plate with a thickness of 0.63mm on the table, a 5cm thick foam support on the metal plate, and the cable placed on the foam support, parallel to the edge of the grounding plate as shown in Figure 3.

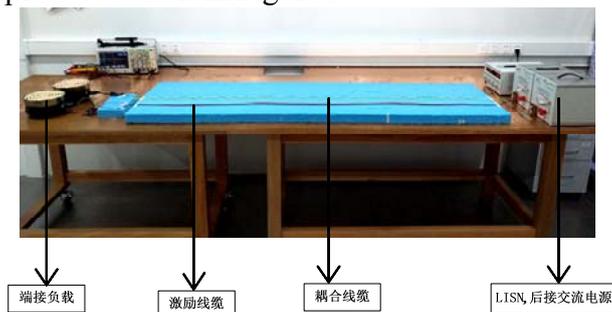


Figure 4. Test arrangement diagram

The excitation cable and the coupling cable are placed in parallel with a spacing of d and a cable length of L . One end of the excitation cable is connected to the LISN and the other end is connected to the electric furnace as a load. Here, the LISN has two functions, one is to provide stable impedance to the output, and the other is to isolate the influence of the interference at the power supply end on the excitation cable. The LISN backend selects different power inputs based on different test cables. A variety of typical power modes can be implemented using programmable power supplies, including 115V 400Hz, 220V 50Hz, and 380V 50Hz.



Figure 5. Power supply equipment

For single-phase power supply, two LISNs are used, one connected to the high-order line and one connected to the zero line as shown in Fig. 5. For the Y-type three-phase power supply, four LISNs are required, and three of the high-order lines are connected to the zero line as shown in Fig. 6.

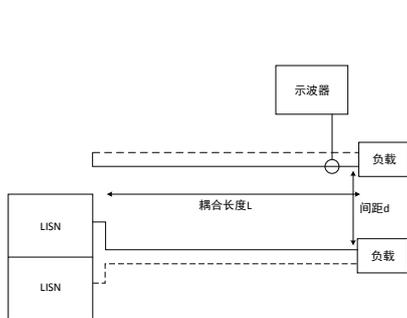


Figure 6. Single-phase power supply test schematic

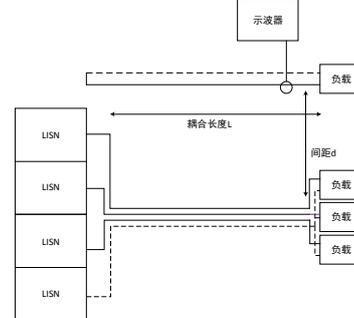


Figure 7. Three-phase power supply test schematic

The other end of the cable is connected to the circuit as a load, and the voltage waveform on the high bit line is measured by the oscilloscope.

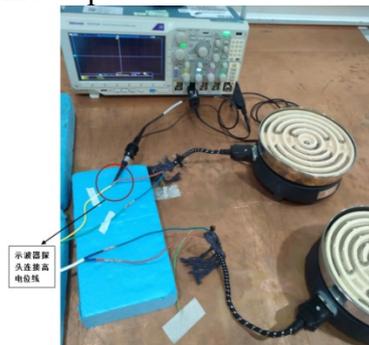


Figure 8. Coupling voltage waveform measured by oscilloscope

Cable Crosstalk Modeling

The cable simulation model used in this paper is shown in Figure 8. According to the measured environment, a metal grounding plate is established in the CST, and two cable paths are established 5 cm above the flat plate, the length is set to the variable L , and the spacing is set to the variable.

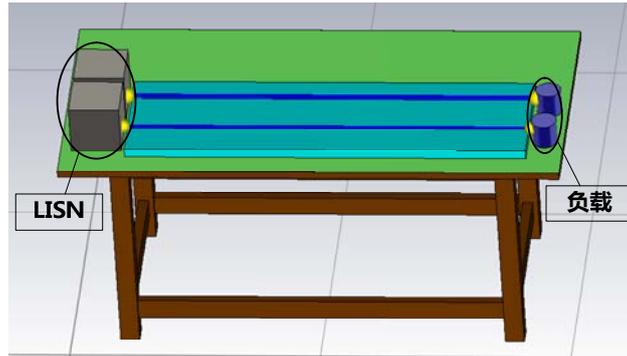


Figure 9. Cable crosstalk simulation model diagram

The cross section of the power cable is modeled according to the type of power signal. The AC and DC signal parameters used in this paper are: 380V 50Hz three-phase Y-type AC, 115V 400Hz single-phase AC, 220V 50Hz single-phase AC.

The cable cross section involved in the simulation and its parameters are shown in Figure 9 and Table 1.



(a)Y type wirecable(b)Single-phase or DC cable

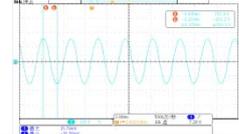
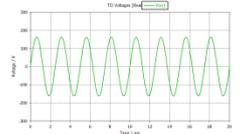
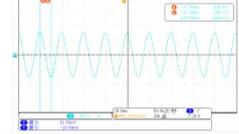
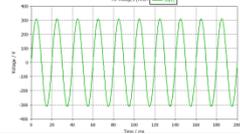
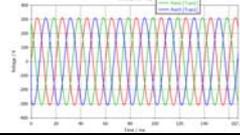
Figure 10. Power cable cross-section diagram

Table 1. Power cable cross section - material parameters

Cable	RVS2*0.5	RVB 2*0.75	RVV 2*1.5	RVV 4*1.5
Number of core wires / cross-sectional area:	28/0.15	42/0.15	48/0.2	48/0.2
Insulation material:	polyvinyl chloride	polyvinyl chloride	polyvinyl chloride	polyvinyl chloride
Insulation thickness	0.6mm	0.6mm	0.7mm	0.7mm
physical map				
section model				

The simulation and simulation models of several main excitation signals involved in this simulation include 380V 50Hz three-phase Y-type AC, 115V 400Hz single-phase AC, 220V 50Hz single-phase AC, as shown in Table 2.

Table 2 Excitation signal model

Excitation signal	Laboratory measured waveform	CST simulation waveform
115V 400Hz		
220V 50Hz		
380V 50Hz		

Simulation and Test Results

AC 115V 400Hz to Bare Wire

RVB 2*0.75 is used as the excitation cable, and RVS 2*0.5 is used as the coupling cable. Firstly, the length of the fixed cable is $L=1\text{m}$, and the spacing d is 5, 10, 15cm respectively. The test is obtained on the coupling cable with different spacing d . Voltage waveform:

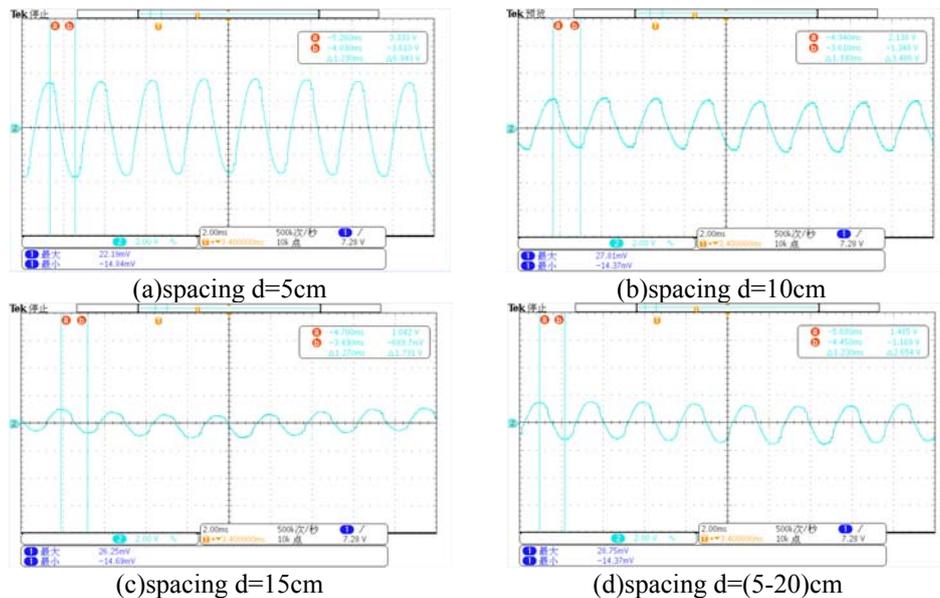


Figure 11. Test results with different d when $L=1\text{m}$

It can be seen that the frequency of the crosstalk signal on the coupled cable is consistent with the frequency of the excitation signal, and as the spacing d increases, the amount of coupling gradually decreases.

Then we increase the cable length to 2m, and the comparison test results are shown in Figure 12:

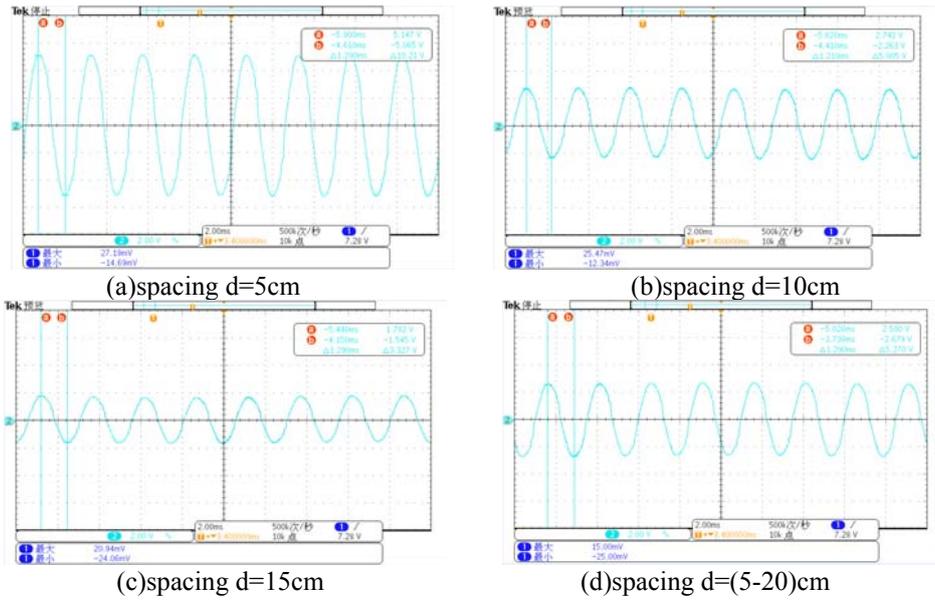


Figure 12. Test results with different d when $L=2\text{m}$:(a) spacing $d=5\text{cm}$;(b) Spacing $d=10\text{cm}$; (c) spacing $d=15\text{cm}$; (d) spacing $d=(5-20)\text{cm}$

The crosstalk simulation results of the 115V 400Hz AC cable to the bare wire are shown in Figures 13 and 14. It can be seen that the simulation results are basically consistent with the trend of the measured results. As the cable length increases, the crosstalk phenomenon becomes obvious, and under a fixed length, as the interval increases, the crosstalk phenomenon decreases.

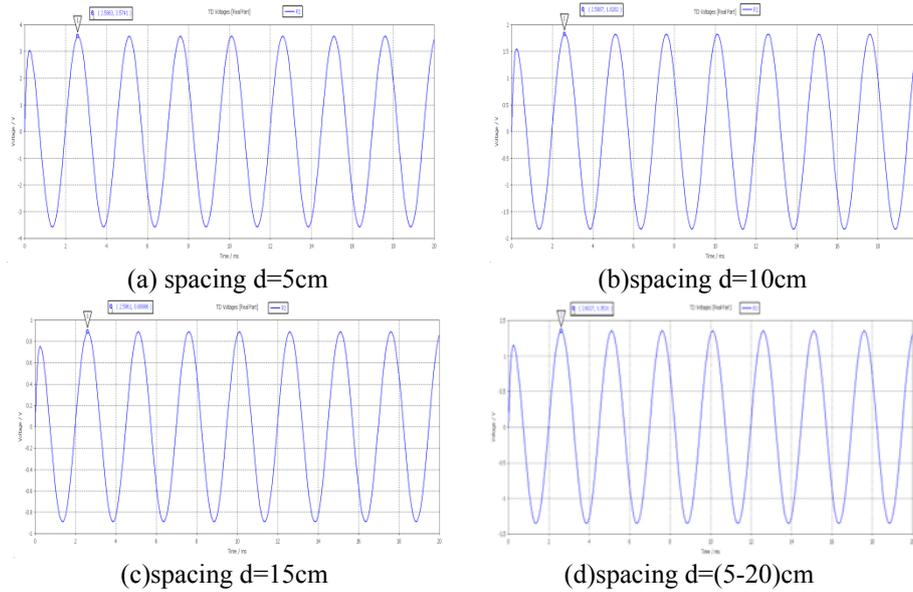


Figure 13. $L=1\text{m}$, 115V 400Hz to bare wire crosstalk simulation results

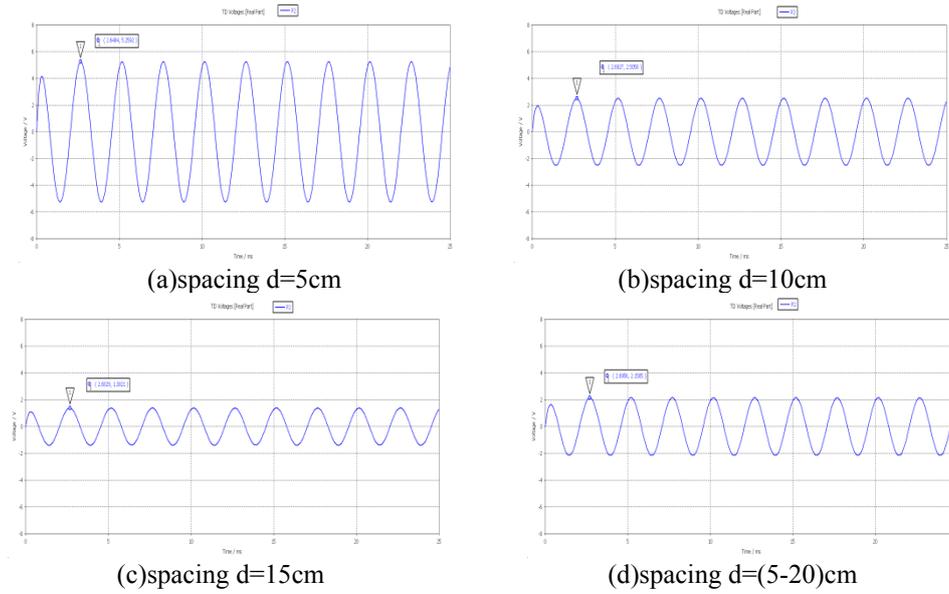


Figure 14. L=2m, 115V 400Hz to bare wire line crosstalk simulation results

After the cable length increases, the trend is basically same, and the coupling phenomenon is more obvious than L=1m. The result of crosstalk under different lengths is shown in Table 2:

Table 2. Comparison of different length L crosstalk test and simulation result

length	result	d=5cm	d=10cm	d=15cm	d=(5-20)cm
L=1m	Test(peak-to-peak)	6.9V	3.5V	1.7V	2.7V
	Simulation(peak-to-peak)	7.14V	3.64V	1.76V	2.7V
L=2m	Test(peak-to-peak)	10.2V	5V	3.3V	5.3V
	Simulation(peak-to-peak)	10.4V	5V	2.76V	4.4V

AC 220V 50Hz to Bare Wire

Fix the cable length to L=1m, switch the excitation power supply to 220V 50Hz through the programmable power supply, and use RVV 2*1.5 as the excitation cable. The test result is shown in Figure 15:

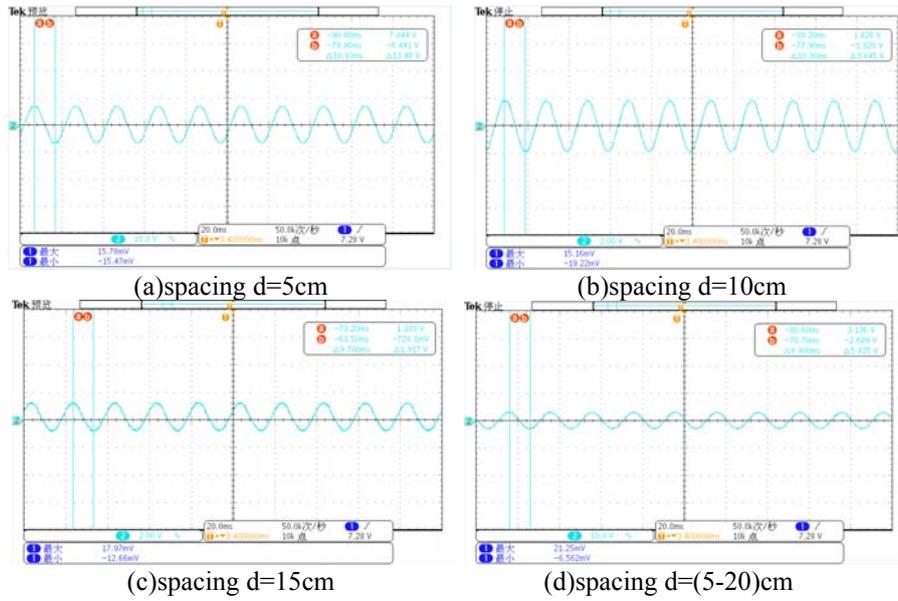


Figure 15. 220V 50Hz to bare wire crosstalk test results

Similarly, the cable length is fixed to $L=1\text{m}$ and the excitation port signal is set to 220V 50Hz. The simulation result is shown in Figure 16:

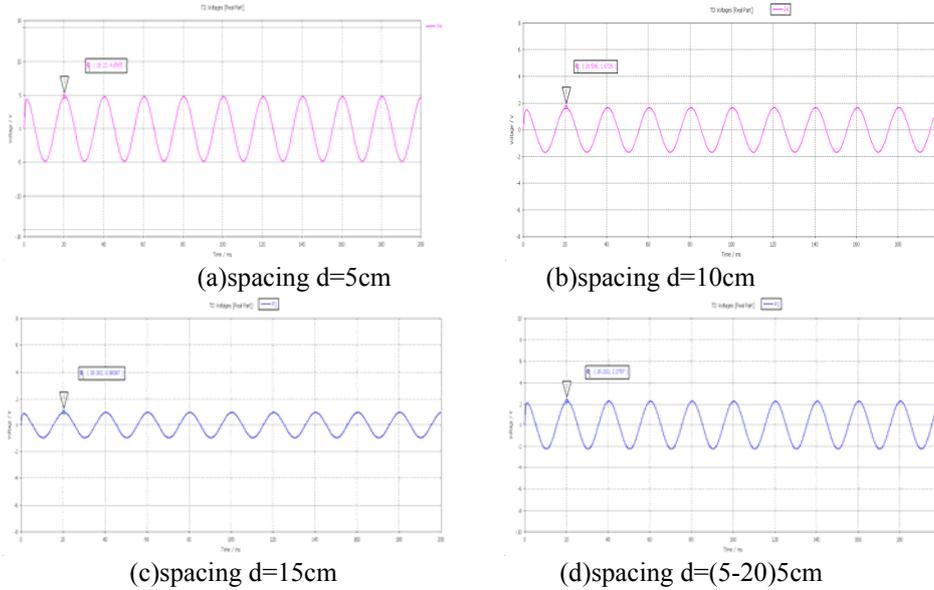


Figure 16. 220V 50Hz to bare wire crosstalk simulation results

It can be seen that the test results are basically consistent with the trend of the simulation results. As the interval increases, the crosstalk phenomenon is weakened.

Table 3 Comparison of different length L crosstalk test and simulation results

result	d=5cm	d=10cm	d=15cm	d=(5-20)c m
Test (peak-to-peak)	13.5V	3.6V	1.9V	5.8V
Simulation (peak-to-peak)	9.6V	3.34V	1.96V	4.54V

AC 380V 50Hz to Bare Wire

The excitation power supply is switched to 380V 50Hz through the programmable power supply, and RVV 4*1.5 is used as the excitation cable. The test result is shown in Figure 17:

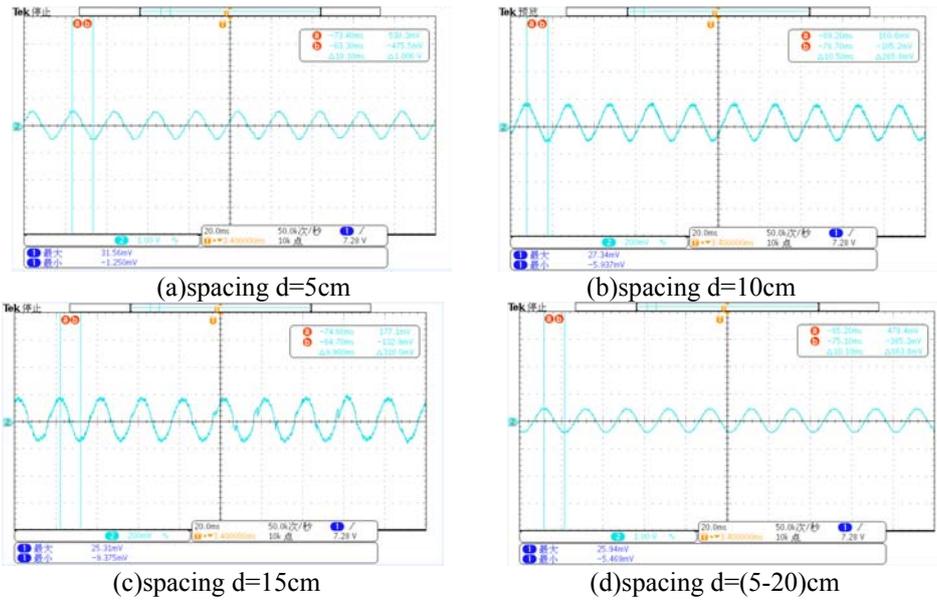


Figure 17. 380V 50Hz to bare wire crosstalk test results

Three excitation ports are used to achieve 380V 50Hz three-phase power supply. The simulation results are shown in Table 4 and Figure 18.

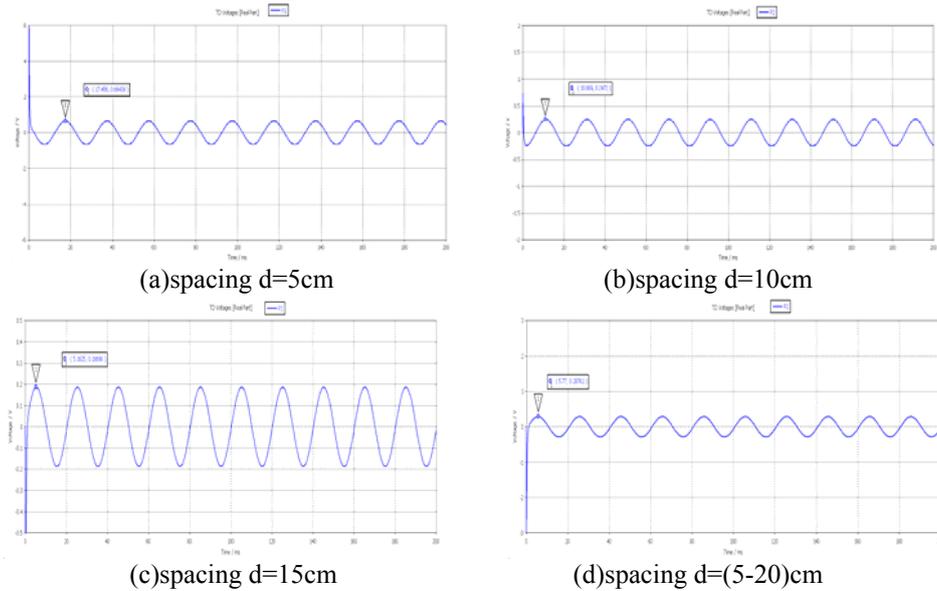


Figure 18. 380V 50Hz to bare wire crosstalk simulation results

Table 4 Comparison of different length L crosstalk test and simulation results

	d=5cm	d=10cm	d=15cm	d=(5-20)cm
Test (peak-to-peak)	1.32V	0.48V	0.36V	0.56V
Simulation (peak-to-peak)	1V	0.27V	0.31V	0.86V

It can be seen that the simulation results are basically consistent with the measured results, and it can be seen that the coupling of the DC cable is the strongest under the 115V 400Hz excitation, whether it is test or simulation, indicating that the excitation signal frequency is higher at this time. Strong, so the interference received by the coupling cable is also greater. The coupling phenomenon is obviously weakened under the excitation condition of 380V 50Hz. It is presumed that the phase difference of the three phase lines in the three-phase power supply mode causes the interference

signals coupled on the coupling cable to overlap each other, resulting in a smaller final test and simulation result.

Conclusion

In this paper, crosstalk between different types of power cables is studied by means of actual measurement and simulation for common power cables. By changing the parameters of the cable and the excitation source, the influence of various parameters on the crosstalk of the power cable was studied.

According to the research and analysis in this paper, the source line crosstalk is related to the cable coupling length, the line spacing and the excitation power signal. The increase of the coupling length, the decrease of the cable spacing or the increase of the frequency of the excitation signal will lead to the intensification of the cable crosstalk and crosstalk. The voltage waveform is a superimposed AC voltage signal based on a DC voltage, and the crosstalk frequency is approximately the frequency of the AC signal.

By changing the power cable and excitation source parameters, this paper summarizes the following conclusions.

1) Crosstalk between AC and DC power cables, other parameters remain unchanged, and when the cable length or cable height from the ground or the metal plate area is changed, the influence on the amplitude of the crosstalk voltage is small;

2) When changing the cable spacing, the amplitude of the crosstalk voltage is greatly affected. The closer the cable spacing is, the larger the amplitude of the crosstalk voltage is;

3) changing the frequency of the alternating signal, the frequency of the crosstalk signal changes with the change of the frequency of the alternating signal, and the amplitude of the crosstalk voltage increases simultaneously with the increase of the frequency of the alternating signal;

The power cable, power excitation source, load end test and simulation modeling methods given in this paper can provide reference for modeling other complex cable systems. The crosstalk conclusion of the power cable obtained in this paper can provide a theoretical reference for the design and laying of cables in practical engineering.

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