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Research on Early Warning Technology of Power Transmission Lines

Wei Wang[1], Tao Guo[1], Lei Shi[1], Lianggang Xu[1], Chenfeng Xiang[1] and Long Zhu[2, *]

[1]Guizhou Power Grid Co. Ltd. Transmission Operation and Maintenance Branch, Gui Yang, 550000, China
[2]Wuhan Kell electric science and Technology Development Co., Ltd., Wuhan, 430072, China

*Corresponding author e-mail: zhulong_zyhd@163.com

Abstract. Against external force damage of transmission line has been a security problem need to be solved urgently. The paper analyzes the relationship between key characteristic quantity of line and the distribution regularities of spatial magnetic field by simulation, establishes dynamic mathematical model of the distance between vehicle manipulator and the high voltage wire, develops warning system against external forces of transmission line based on magnetic field measurement. Field test shows that through real-time measurement of the dynamic distance between vehicle manipulator and the high voltage wire, we can warn the external force damage accurately and timely, it provides an effective and reliable method to solve the trouble from external force damage of transmission line.

1. Introduction
In the process of power grid operation, external force destruction has been one of the main factors that threaten the safe operation of the power grid [1-2]. Especially in the construction of buildings under the transmission lines, large tower cranes and engineering vehicles can easily touch transmission lines, seriously affecting the safe and stable operation of transmission lines [3-4]. This paper extracts the magnetic field distribution characteristic information near the transmission line, establishes the distance inversion calculation model between the engineering vehicle and the transmission conductor, realizes the destruction of the external force of the working vehicle under the transmission line, and reduces the threat of external damage to the transmission line. This study provides a reference for the protection of external transmission lines against damage.

2. Early warning mechanism
The transmission line creates a magnetic field around the line [5]. When the boom of the engineering vehicle moves, it can measure the magnetic field near the flat tooth slot by using a magnetic sensitive element. The distance between the boom and the wire can be obtained by this magnetic field change.

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2.1. Spatial magnetic field distribution

Taking the typical high-voltage AC transmission lines designed by our country as an example, the calculation and analysis of its power frequency magnetic field, relevant parameters are considered in the following situations: ① Single circuit arrangement: Consider the typical IVI triangle arrangement and IVI horizontal arrangement. The minimum distance from the ground to the wire is 22m, and the load current is 3kA. ② Double loop arrangement: Consider the typical I series reverse phase sequence and vertical phase arrangement with the same phase, the minimum distance from the conductor to the ground is 21m, and the load current is 4kA.

The distribution of the magnetic field below the transmission line is shown in Fig. 1. The four curves (numbers 1, 2, 3, and 4) in the figure correspond to the magnetic field strengths of the four wire arrangements in the above two cases.

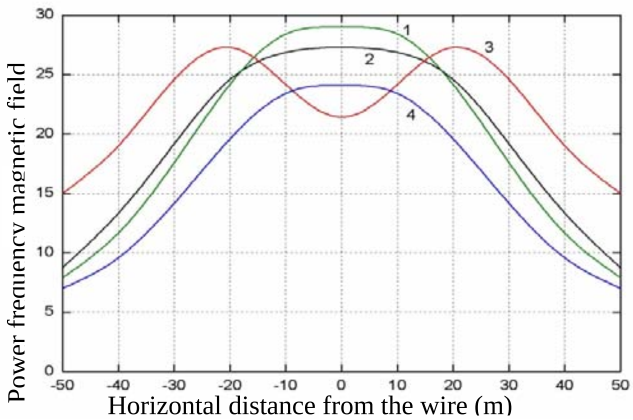

Figure 1. Horizontal distribution of power frequency magnetic field 1m away from ground

As can be seen from Figure 1, the magnetic field distribution of high-voltage AC transmission lines is mainly related to the line load current, spatial location, single-loop conductor arrangement, and dual-circuit phase sequence arrangement. Therefore, in the case of a certain layout and phase sequence, there is a one-to-one correspondence between the magnitude of the magnetic field and the line load current and spatial position. (The influence of metal objects on the distribution of the electromagnetic field of the circuit is very weak)

2.2. Dynamic distance back calculation model

As shown in Figure 2, assume that A, B, and C are three-phase transmission lines. The front end of the boom is located at point P. Since the diameter of the transmission line is much smaller than the distance from the measurement point to the line, a finite-current thin-wire model is used. The O. Sava law calculates the spatial magnetic field around the transmission line. The finite-current thin-wire model is shown in Figure 3.

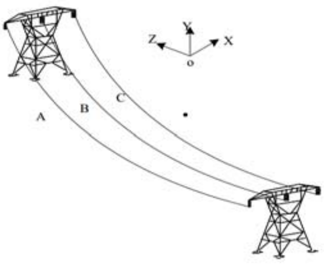

Figure 2. Dynamic distance back calculation model

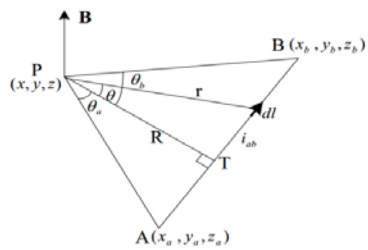

Figure 3. Magnetic field calculation model for a finite length current-carrying thin wire

Among them, AB is any current-carrying conductor segment in space, iab is the conductor current, R is the vertical distance from P to AB, and the X axis is established perpendicular to the line direction, the Z direction is along the direction of the line, and the Y direction is perpendicular to the ground. The axis's spatial coordinate system. According to the Bio-Sava law, the magnetic field generated at point P is:

$$\vec{B} = \frac{\mu_0 i_{ab}}{4\pi} \int_A^B \frac{\vec{dl} \times \vec{r_0}}{r^2} \tag{1}$$

Where $\vec{r_0}$ is the unit vector of the line element $\vec{dl}$ pointing to point P, μ_0 is the air permeability. Then there is a geometric relationship:

$$\left|\vec{dl} \times \vec{r_0}\right| = dl \cdot \cos\theta \tag{2}$$

$$dl = \frac{rd\theta}{\cos\theta} \tag{3}$$

$$r = \frac{R}{\cos\theta} \tag{4}$$

Substituting $\vec{dl}$ and r into formula (1) can be obtained:

$$B = \frac{\mu_0 i_{ab}}{4\pi R}(\sin\theta_a + \sin\theta_b) \tag{5}$$

In the rectangular coordinate system space:

$$\sin\theta_a + \sin\theta_b = \frac{AT}{PA} + \frac{AB - AT}{PB} \tag{6}$$

From the above, it can be seen that the coordinates of three points P, A, and B and the load current i_{ab}, the components of magnetic induction intensity B on the three coordinates can be determined by the vector $\overline{AB} \times \overline{PB}$. Any one phase conductor of a transmission line can be regarded as an infinite length wire composed of multiple current-carrying straight wire segments. According to the superposition theorem, the magnetic strength field at any point around the current-carrying wire can be obtained. Because the relationship between the position of P point and power frequency magnetic field is difficult to express with an explicit expression, but the genetic algorithm does not need to know the specific expression of the objective function, can solve large-scale, multi-parameter, any form of nonlinear inversion problems, so this article Genetic algorithms are used for solving calculations. According to the algorithm of genetic algorithm, the inverse problem of power frequency magnetic field in transmission lines can be expressed as:

$$\mathbf{B}_0 = F\ (i,\ R_{min}) \tag{7}$$

When the line current is constant, the power frequency magnetic field at a certain point near the power transmission line can be accurately calculated. Therefore, when the line current and the magnetic field strength are fixed, the spatial position of the P point can be calculated back. By obtaining the distance of the P point from the wire, it can provide an effective basis for the danger warning.

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2.3. Early warning grading standards

When large engineering vehicles are operating near transmission lines, the potential threat to the transmission lines is different when their booms are at different distances from the transmission lines; for the same separation distance, if the voltage levels are different, the threat is not the same. In combination with engineering practice, the alarm distances for different voltage levels were set, including the warning distance, the dangerous distance and the stopping distance, as shown in Table 1.

Table 1. Alarm distance parameters

Voltage level (kV)	110	220	330	500
Stop Zone (m)	5.0	6.0	7.0	8.5
Danger Zone (m)	6.0	7.0	8.0	9.5
Attention Zone (m)	7.0	8.0	9.0	10.5

Corresponding to the distances in Table 1, according to the distance between the booms of the large-scale engineering vehicles and the transmission lines, the area near the conductors is divided into four zones: stop zone, danger zone, attention zone and safety zone. The corresponding warnings in these four regions are as follows:

1) Stop area: In this area, the operator is required to stop the operation;

2) Danger Zone: When the boom is in this area, a preset sound and light alarm device will issue a warning signal to remind the operator to exit the area;

3) Attention area: When the boom is in this area, the preset alarm device sends a prompt message, causing the operator's attention and paying attention to the operating range.

3. Experimental verification

3.1. Early Warning Monitoring System

The current measuring device is arranged on the wire and measures the load current of the flow wire in real time, which provides a basis for the calculation of the magnetic field distribution of the power transmission wire. The magnetic field measuring device is installed on the arm of the large vehicle last night and is used to measure the size of the magnetic field at the position of the working arm. Based on the above magnetic field distribution and the size of the magnetic field at the jib position, the distance from the jib to the wire can be inversely measured. In combination with the distance parameters in Table 1, the alarm device judges the area of the hazard level out of the jib and gives the corresponding alarm information. The above components transmit data through radio frequency communication, as shown in Figure 4.

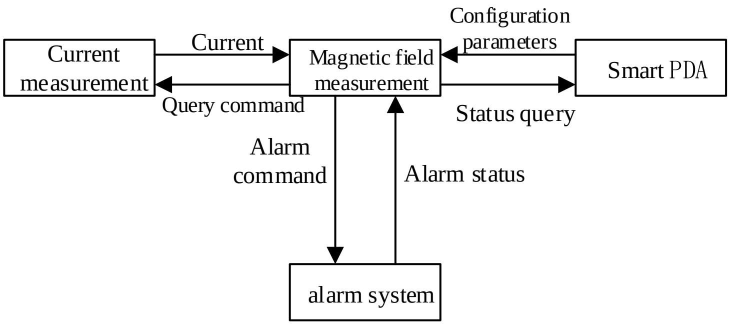

Figure 4. Structural diagram of preventing external force destruction monitoring system based on magnetic field measurement

A 220kV double-circuit overhead transmission line was selected for testing. An excavator was used as a test construction vehicle. The magnetic field measuring device was installed on the working arm. The alarm device was installed in the excavator's working chamber and the current measuring device was installed on the wire.

3.2. Test Results

In the course of testing, alarm conditions of alarm devices under different load conditions were recorded. At the same load current, the excavator performs simulations from different locations under the wire. Table 2 shows the alarm conditions for the three load currents 60A, 80A and 100A.

Table 2. Test data of excavator construction near the wire

Number	Invasion	Test item	60A	80A	100A	Distance from the wire	Alarm status
1	Below	Current	59.13A	79.17A	99.04A	7.3m	No alarm
		Magnetic strength	402	599	841		
2	Below	Current	59.77A	79.47A	99.56A	6.3m	Voice alarm
		Magnetic strength	470	750	1090		
3	Below	Current	59.45A	79.49A	99.88A	4.6m	Sound and light alarm
		Magnetic strength	820	1350	2045		
4	Below	Current	59.63A	79.85A	99.78A	3.5m	Sound and light alarm
		Magnetic strength	2020	3460	5280		
5	Side	Current	59.53A	79.95A	99.85A	3.6m	Sound and light alarm
		Magnetic strength	2190	1530	940		

The above test results show that the method proposed in this paper can realize the early warning of large-scale engineering work vehicles in the area near the wire, and can reduce the external damage caused by large-scale work vehicles on the transmission line in the construction site.

4. Conclusion

Large-scale construction vehicles operate near transmission lines and pose a great threat to the operation of transmission lines. In this paper, the magnitude of the magnetic field of the jib position of the work vehicle is used to measure the distance of the hangtag from the wire. Field test tests show that the method is feasible and can accurately alarm according to pre-divided hazard zones and alert operators to reduce the external damage of the transmission line. This method is applicable to the simple layout of single-circuit and double-circuit wirings. For a relatively large number of transmission loops, the magnetic field distribution in the vicinity of the conductor is relatively complex, and the method in this paper may be limited.

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