Research on Secondary Cable Identification Based on the Principle of Electromagnetic Induction

Li Zhu Bao\textsuperscript{1}\textsuperscript{a*}, Jia Yan Yu\textsuperscript{1}\textsuperscript{b*}, Yu Wu\textsuperscript{1}\textsuperscript{c*}, Hao Wu\textsuperscript{1}\textsuperscript{d*}, Zhi Jun Tang\textsuperscript{1}\textsuperscript{e*}, Jun Cheng Wang\textsuperscript{1}\textsuperscript{f*}

State Grid Jiangsu Electric Power Co., Ltd. Maintenance Branch

\textsuperscript{a*}20201249047@nuist.edu.cn, \textsuperscript{b*}10385681@qq.com, \textsuperscript{c*}saltfishmail@sina.com, \textsuperscript{d*}19105037@qq.com, \textsuperscript{e*}29789531@qq.com, \textsuperscript{f*}422816108@qq.com, \textsuperscript{f*}304869298@qq.com

Abstract: When the operation and maintenance station performs cable maintenance, installation measures, etc., due to the lack of direct and effective tools, and the complicated wiring of the operation and maintenance station equipment, the wiring diagram is inconsistent with the actual situation, which brings risks to the removal of waste cables. As an indispensable safety tool in the power industry, the cable identification device is an important means to ensure the safety of maintenance personnel. In view of the current situation, this paper analyzes the electric field around the cable line of the operation and maintenance station, and simplifies the simulation of the line, and proposes a secondary cable identification device based on the principle of electromagnetic induction, which can quickly identify the target cable, which greatly improves the cable identification performance. Efficiency reduces the time for cable identification and improves safety.

1. Introduction
As China’s economy shifts from a stage of rapid development to a stage of high-quality and stable development, power cables have been widely used in power transmission and distribution in power systems, especially in operation and maintenance stations and urban distribution networks\textsuperscript{[1]}. Power cables are often laid in cable tunnels or cable trenches, and many cables with different voltage levels are often laid in parallel in a cable tunnel or cable trench\textsuperscript{[2]}. When the substation is carrying out protection technology transformation, when the cable in the cable trench needs capacity increase, transformation and line path change, it is necessary to correctly identify the target cable and find out the direction and function of the original cable before the demolition and transformation of waste cable can be carried out. At present, when dismantling and transforming used cables in substations, most of them use comparison cable signs, or choose to refer to drawings to identify secondary cables\textsuperscript{[3]}. When the old substation is carrying out the transformation of waste cables, due to the long age of the substation, the secondary cable signs are not standardized or the handwriting is blurred, the signs are missing, and a few cable signs are marked incorrectly, which makes the success rate of cable identification through cable signs low and serious waste of time. The cable laying situation in the substation is shown in Figure 1:

At present, the commonly used methods for identifying cables are the audio signal method and the pulse signal method, which are mainly aimed at the path finding method of adding signals under power outage conditions\textsuperscript{[4]}. However, in actual operations, many cables to be identified are running under power, which cannot fully meet the identification requirements for live cables. Therefore, how to identify live cables quickly and accurately has always been a difficult problem for cable frontline
workers to solve urgently.

Figure 1 Diagram of cable laying in cable trench

In response to the above problems, this paper proposes a secondary cable identification device based on the principle of electromagnetic induction\(^5\). Based on the principle of electromagnetic induction, a conductor in an electric field will generate induced charges in a changing electric field. By measuring the relationship between the potential of the induction electrode relative to the ground and the actual voltage on the power line, the actual voltage value of the power line can be obtained. The voltage level of the power line can realize the identification of the cable line.

2. Principle and basis of cable identification

2.1 Principle analysis

There is a special substance around the charged object. This invisible and intangible substance can transmit energy, which makes people begin to explore the magnetic field. Faraday gave the expression of electromagnetic induction phenomenon, the magnitude of induced electromotive force \( e \) is determined by the rate of change of magnetic flux through the coil:

\[
e = -\frac{d\Phi}{dt} = -\frac{d}{dt} \int B \cdot dS
\]

There are three main reasons for the change of magnetic flux:

(1) In a constant magnetic field, the relative movement of the conductor causes the magnetic flux of the closed loop to change. As shown in the figure, in a static magnetic field, the magnetic induction intensity \( B \) is constant, and the conductor \( ab \) moves to the right along the horizontal rail. A current that changes with time will be generated in the closed conductor\(^6\). The electromotive force \( e \) generated at both ends of the conductor \( ab \) is called motion electromotive force.

Figure 2 The induced electromotive force generated by a moving conductor in a magnetic field

(2) The closed conductor loop remains unchanged, and the magnetic field changes. At this time, an induced current will be generated in the closed conductor, and the resulting electromotive force is called induced electromotive force. Since the loop does not change, the magnitude of the induced electromotive force is only related to the time \( t \). At this time, the first-order partial conductance of the magnetic induction intensity time is shown in the following formula:

\[
e = -\frac{d}{dt} \int B \cdot dS = -\frac{d}{dt} \int B \cdot dS
\]
\[
\begin{align*}
    & = - \int \left[ \frac{\partial B}{\partial t} \cdot dS + B \cdot \frac{\partial (dS)}{\partial t} \right] \\
    & = - \int \frac{\partial B}{\partial t} \cdot dS
\end{align*}
\]

(3) The magnetic induction intensity changes with time, and the loop also changes. At this time, the induced electromotive force \( e_1 \) generated when the two circuits are unchanged and the motional electromotive force \( e_2 \) when the magnetic induction intensity is constant are as follows:

\[
e = e_1 - e_2
\]

At this time, the second term of the above equation \( e_2 \) can be rewritten as:

\[
- \int \frac{\partial B}{\partial t} \cdot dS = - \int B \cdot \frac{\partial (dS)}{\partial t} = \int (v \cdot B) \cdot dl
\]

It can be concluded from the above formula that the induced electromotive force can be superimposed and extended to any closed loop in space. As long as the magnetic flux in the loop changes, the electromotive force will be induced in the closed loop. A changing electric field will induce a changing magnetic field, and a changing magnetic field will induce a changing electric field. This interdependent and restrictive relationship between electric and magnetic fields forms the phenomenon of electromagnetic induction.

2.2 Transmission model of cable line

The analog charge method uses a set of discrete virtual charge points to equate the uneven current flowing in the actual conductor, so that the electric field generated by the analog charge and the electric field generated by the current in the actual conductor have the same boundary conditions, and then all the points are solved. Match point potential.

The cable line uses alternating current for electric energy transmission. The magnetic fields generated by the alternating current rotate and superimpose or cancel each other, and adjacent lines will also generate alternating magnetic fields to superimpose, which makes the electromagnetic environment of the cable line more complicated [7]. If three-dimensional it is very difficult to calculate the space magnetic field. The wavelength \( \lambda \) of the cable line is 6*10^6m, which is much longer than the length of the cable line itself. Therefore, the induced current generated by the alternating magnetic field is ignored, and the eddy current effect caused by the magnetic field on the surface of the conductor is ignored.

When applying the analog charge method for analysis and calculation, certain conditions need to be met. The following simplifications are made here:

(1) The cable line is regarded as infinitely long, and the cable lines are arranged at equal intervals;

(2) Ignore the distortion effects of lightning conductors, ground wires, insulators and fittings on the electric field;

(3) The influence of magnetic field is not considered;

(4) The electric field is regarded as a two-dimensional field;

3. Device design

3.1 Hardware design

3.1.1 Overall design

The cable identification device designed in this paper uses a single-chip microcomputer as the control chip, which mainly includes signal acquisition module, filtering and amplification module, A/D conversion module, single-chip module, alarm module, wireless communication and human-computer interaction module, etc. The overall structure of the system as shown in Figure 2:
The signal collected by the sensor is transformed and processed, and the harmonic is eliminated through the filter circuit. The output voltage signal is $mV$ level. It needs to be amplified before it can be sampled by the A/D module of the single chip microcomputer. The sampled results are sent to the host through the wireless module, and the host will judge after receiving them. The identified results are output through acoustic and optical signals, and display the collected electric field value.

### 3.1.2 Filter circuit

Due to the large amount of electromagnetic interference in the measurement environment, the signal output by the sensor will contain a lot of noise, which will cause signal distortion in severe cases and affect the accuracy of the measurement. This requires a filter circuit to filter out the useless signals as much as possible. Composition, leaving a useful signal. The cable identification device designed in this paper is mainly used to measure the power frequency voltage of the cable line. The cut-off range of the frequency is set to 1000 Hz, so a low-pass filter is selected. Among the common low-pass filters, the frequency amplitude characteristics of the Butterworth filter are relatively flat, especially in the low frequency band, which is approximately a straight line, which meets the requirements of the designed cable identification device.

The simplest filter is an $RC$ low-pass filter, which consists of a resistor and a capacitor. After the $RC$ filter, a voltage follower circuit is added to form a first-order active low-pass filter as shown in Fig. 3.

### 3.1.3 A/D conversion

The output signal of the sensor has analog signals such as voltage, current, pressure, temperature, and the processor (such as a single-chip microcomputer) can only recognize the digital signal logic 0 and 1. These analog signals cannot be directly collected by the single-chip microcomputer, and need to be converted into what the single-chip microcomputer can do. The calculation can be performed after the recognized digital signal, which requires an analog-to-digital conversion circuit (Analog to Digital Convert) to achieve.

The A/D module used in this article is the built-in A/D module of the STM32F103 single-chip microcomputer, with a resolution of 12bit, a reference voltage of 3.3V, and an input analog voltage of
0-5V. The working principle of this A/D converter is shown as in Fig. 4.

![A/D Converter Working Principle](image)

The STM32F103 has a built-in 16-channel 12-bit A/D converter, providing 4 modes (single, continuous, voltage comparison, timer automatic), and the conversion rate is 1MHz, 500kHz, 125kHz, 31.25kHz. The external address of the A/D conversion control register ADC_CTL is 0xD0. Considering the real-time change of the measurement position, the continuous conversion mode is used, and the control bit ADC_CNTNU_CV is set to 1.

3.1.4 Button design
The button is the input function that realizes the human-computer interaction. When the single-chip microcomputer is required to produce certain specific actions, you can press the preset button, and the single-chip computer detects that the level of the circuit connected to the button has changed and sends out the corresponding instruction. To achieve specific functions.

There are 4 buttons in the device design, respectively K1, K2, K3 and K4. Among them, K1 is the button reset, which is used when the system needs to be initialized; K2 is used to start measurement. When K2 is pressed, the single-chip microcomputer sends the data sent by the sensor Carry out A/D conversion; K3 is used to test the alarm circuit, which will drive the buzzer and light up the diode after pressing; K4 is the switch button, which can be turned on/off after long pressing.

3.2 Software design
The functions to be realized by this device are as follows:

1. It can display the sensor data after processing;
2. According to the results of the data, judge whether it is the target cable, and if the conditions are met, an alarm will be issued;
3. The key can realize the corresponding human-computer interaction function.

3.2.1 Main program design
Long press the switch button, the single-chip microcomputer is powered on, enters the initialization program, and performs self-checking on each module. When the start measurement button is pressed, the A/D conversion module starts to work, converts the voltage signal of the sensor into a digital signal and sends it to the single-chip microcomputer. The microcontroller analyzes the data and sends the data to the host for processing. The driver generates the corresponding waveform and generates the data. If the data is displayed as a target cable, the microcontroller will execute the alarm program, drive the buzzer, and make the LED lights flash alternately.

3.2.2 Data processing
When the measurement button is pressed (set ADC_PD=0, the control register ADC_SINGLE_CVT in the analog-to-digital conversion is set to 1, and the A/D conversion is started. After the conversion is completed, an interrupt time is generated. Because there are 2 sensors, it is necessary to turn on the continuous conversion mode (ADC_CNTNU_CVT=1), and turn on the analog/digital conversion
comparison function (EN_ADC_CMP=1). After the input is converted, it is compared with the preset threshold in the comparison buffer (ADC_CMP_V). When the input value is greater than (When ADC_BIG=0) or less than (ADC_BIG=1) setting value, an interrupt signal will be generated to the MCU to execute the corresponding function.

3.2.3 Judgment process
When the voltage values of the two sensors are collected, the single-chip microcomputer first performs the difference calculation on the sensor values, and compares the calculated difference with the preset threshold. If the difference is less than the preset value, it is judged that there is no target cable. Terminate the calculation; when the difference is greater than the preset value, go to the next step. Compare the value of sensor 1 with the threshold of the target cable. If it is greater than the threshold, the electrification condition is met, execute the electrified program, and terminate the operation; if it is less than the threshold, enter the next step. Compare whether the value of sensor 2 meets the electrified threshold, if so, execute the electrified procedure; otherwise, execute the no electrified procedure, and the procedure ends.

4. Device test
Through the construction of the system hardware circuit and the debugging of the software program, in order to demonstrate the reliability of the device, measurements will be carried out in the substation environment to verify the performance of the device. The main test content is to select the cable line of the substation, measure the surrounding environment without interference, check the reliability of the device and determine the reliable range of identification, and combine the experimental data to summarize the reliability of the device.

The measurement area is located directly below the cable line, and the distance from the cable is in the range of 0 cm to 20 cm. Take the ground directly below the middle phase as the origin, and set 1 measuring point on the left and right, a total of 3 measuring points. Each measuring point measures the value of the distance of 0 cm, 5 cm, 10 cm and 15 cm at the same time. Due to the measurement error of the sensor, the unit data is rounded. The measurement data is shown in Table 1.

Table 1 Measurement data

| Measuring point coordinates (cm) | Measuring value 1 (V/cm) | Measuring value 2 (V/cm) | Difference (V/cm) |
|----------------------------------|--------------------------|--------------------------|-------------------|
| (-1, 0)                          | 3.04                     | 2.61                     | 0.43              |
| (-1, 5)                          | 2.61                     | 2.16                     | 0.45              |
| (-1, 10)                         | 2.17                     | 1.72                     | 0.45              |
| (-1, 20)                         | 1.73                     | 1.30                     | 0.43              |
| (0, 0)                           | 2.97                     | 2.51                     | 0.46              |
| (0, 5)                           | 2.52                     | 2.07                     | 0.45              |
| (0, 10)                          | 2.09                     | 1.66                     | 0.43              |
| (0, 20)                          | 1.68                     | 1.24                     | 0.44              |
| (1, 0)                           | 3.07                     | 2.62                     | 0.45              |
| (1, 5)                           | 2.63                     | 2.21                     | 0.42              |
| (1, 10)                          | 2.21                     | 1.75                     | 0.46              |
| (1, 20)                          | 1.78                     | 1.33                     | 0.45              |

According to the data in the table, the device is reliable and the best measuring distance is in the range of 5 cm.

5. Conclusion
The cable identification device designed in this paper is easy to operate, has a high safety factor, and has broad application prospects and market demands. The feasibility and practicability of the equipment
are verified through the trial application of the actual cable operation on site. The equipment has extremely high accuracy and adaptability, which can further improve the safety and efficiency of power engineering construction and cable general survey, and provide great help to avoid misjudgment of identifying cables.

This article mainly completes the following tasks:

1. The electromagnetic environment around the transmission line was studied, and the cable line was simplified according to the analog charge method and a mathematical model was established; according to the field strength distribution characteristics of the transmission line space, a non-contact cable identification method was explored, and verified that the method is indeed feasible in the experiment.

2. Filter and amplify the voltage signal from the sensor and send it to the single chip microcomputer for A/D conversion and analysis. Determine whether it is the target cable according to a certain algorithm process. If so, send an audible and visual alarm to improve the maintenance personnel.

References

[1] Gao Guihua. Design of non-contact ultra-high voltage electroscope based on field strength distribution [D]. Xidian University, 2014.

[2] Yang Pengfei, Wen Xiaolong, Ni Xiaoming, Peng Chunrong. Research on the spherical shell-type non-contact AC test device[J]. Journal of Electronics and Information, 2021, 43(06): 1637-1643.

[3] Tan Yumiao. Research and realization of non-contact high voltage DC electroscope[D]. Chongqing University of Technology, 2018.

[4] Chen Jiandong, Wang Dongpeng, Fan Daoting, Chen Tao, Dong Hualiang, Li Changxin, Yu Bing. Design of a non-contact high-voltage detection device [J]. Electronic Technology, 2017, 46(05): 33-35+29.

[5] Huang Qin. Research on the Algorithm of Intelligent Video Early Warning System for Transmission Line Breakdown Prevention [D]. South China University of Technology, 2020.

[6] Gu Yijun, Mo Haibo, Liang Tao, Wang Gonghan. Distributed optical fiber sensing technology-based monitoring system for preventing external damage to distribution lines[J]. Rural Electrification, 2020(10): 38-43.

[7] Hong Bo, Zhang Chenxi, Wang Xu. Monitoring and early warning system for high-voltage cable protection against external damage based on Michelson interference and image recognition[J]. Zhejiang Electric Power, 2021, 40(03): 79-84. Qi Dongchun, Chen Xinghua, Zhu Yiwen, Zhang Qi. A new type of wind-resistance cable net for narrow suspension bridges and wind-resistance cable element for its calculation[J]. Structures, 2021, 33:

[8] Hu Yujing, Hu Wei, Yang Wen, Wu Junjie, Chang Yan, Yin Fucheng, Xie Yi. The corrosion analysis and prevention of secondary cable joints used in outdoor terminal boxes of substation in humid environment[J]. IOP Conference Series: Earth and Environmental Science, 2021, 621(1):

[9] Sun Zhongyu, Xu Bingyin, Wang Wei, Chen Heng, Liu Yang, Wei Xinch. Modeling and Simulation of Cable Fault Pulse Current Ranging System[J]. Automation of Electric Power Systems, 2021, 45(04): 142-147.

[10] Jiang Yixin, Chen Feng. Development of a live secondary cable identification instrument[J]. Information and Communication, 2017(02): 282-283.