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Received 2 July 2024
Revised 30 August 2024
Accepted 6 September 2024

Research on the monitoring system for induced voltage and ground current of 27.5 kV cable sheath in railways

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Abstract

Purpose – The purpose of this study is to address the deficiency in safety monitoring technology for 27.5 kV high-voltage cables within the railway traction power supply by analyzing the grounding methods employed in high-speed railways and developing an effective monitoring solution.

Design/methodology/approach – Through establishing a mathematical model of induced potential in the cable sheath and analyzing its influencing factors, the principle of grounding current monitoring is proposed. Furthermore, the accuracy of data collection and alarm function of the monitoring equipment were verified through laboratory simulation experiments. Finally, through practical application in the traction substation of the railway bureau on site, a large amount of data were collected to verify the stability and reliability of the monitoring system in actual environments.

Findings – The experimental results show that the designed monitoring system can effectively monitor the grounding current of high-voltage cables and respond promptly to changes in cable insulation status. The system performs excellently in terms of data collection accuracy, real-time performance and reliability of alarm functions. In addition, the on-site trial results further confirm the accuracy and reliability of the monitoring system in practical applications, providing strong technical support for the safe operation of high-speed railway traction power supply systems.

Originality/value – This study innovatively develops a 27.5kV high-voltage cable grounding current monitoring system, which provides a new technical means for evaluating the insulation status of cables by accurately measuring the grounding current. The design, experimental verification and application of this system in high-speed railway traction power supply systems have demonstrated significant academic value and practical significance, contributing innovative solutions to the field of railway power supply safety monitoring.

Keywords Railway 27.5 kV high-voltage cable, Online monitoring system, Grounding current, Induced potential

Paper type Research paper

This research was funded by the China Railway Wuhan Bureau Group Co., Ltd. under the 2023 Science and Technology Research and Development Plan (Second Batch) (Wuhan Railway Science and Information Letter [2023] No. 269), classification code 23GD07.

Railway Sciences
Vol. 3 No. 5, 2024
pp. 622-635
Emerald Publishing Limited
e-ISSN: 2755-0915
p-ISSN: 2755-0907
DOI 10.1108/RS-07-2024-0028

1. Introduction

With the rapid construction and development of high-speed railways in China, the use of 27.5kV cross-linked polyethylene (XLPE) single-core power cables has become increasingly prevalent (Wang, Li, Liu, Wang, & Liu, 2022). Serving as a specialized cable for electrified railways, this type of cable is extensively utilized in the traction power supply systems of high-speed railways due to its lightweight, simple manufacturing process, ease of installation, and superior heat resistance, as well as electrical properties (Li, 2019; Zhi, Lin, Li, Yuan, & Song, 2021). The cross-sectional view of the cable is depicted in Figure 1.

In the operation and maintenance management of high-speed railway high-voltage cables, timely fault repair is crucial for minimizing the impact on railway operations due to the concealed nature of these cables. According to fault statistics, 27.5 kV power supply line cable faults are usually caused by multiple factors, including construction quality, natural factors, overload, and overvoltage (Ma, 2015). Particularly in the early construction of railway passenger dedicated lines, the substitution of 35 kV cables, due to voltage mismatch, increased the risk of puncture during cable operation. Moreover, lax quality control during production and installation processes may lead to the installation and use of inferior products, further increasing the risk of faults. Cables also face issues of environmental and chemical corrosion during operation, which can lead to moisture penetration of the outer sheath, accelerate cable aging, and reduce insulation performance. Additionally, overload operation and overvoltage surges can cause additional damage to the cables, increasing the likelihood of faults (Zhong, 2016).

In recent years, a "bathtub curve" relationship has been observed between the service life and failure frequency of 27.5 kV power cables (Meng & Yi, 2021). Assuming external destructive factors are excluded, the failure rate of the cables exhibits a phased change. During the initial usage phase (1 to 5 years), the failure rate is relatively high due to quality issues in the manufacturing and installation process. Subsequently, in the mid-term usage phase (5 to 25 years), the performance of the cables tends to stabilize. Although aging is inevitable, it usually does not lead to the puncture of the insulation layer, resulting in a relatively lower failure rate. However, once the cables enter the late usage phase (beyond 25 years), the aging of the insulation layer becomes significantly more severe. Coupled with the expansion of electrical tree and water tree defects, stress relaxation in cable accessories, and the exacerbation of interfacial moisture issues, the failure rate soars dramatically, marking a high-incidence period for faults. This pattern underscores the importance of regular maintenance and timely replacement to ensure the reliability and safety of the power supply system in high-speed railways.

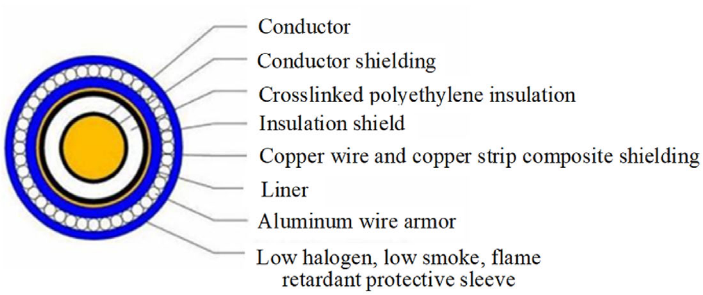

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Figure 1. Cross-sectional view of the 27.5 kV cross-linked polyethylene cable

In the forthcoming years, China's high-speed railway power cable systems are projected to confront significant challenges in maintaining operational reliability (Zhang, 2017; He, 2011). The current dearth of foundational cable information and operational monitoring data within railway operation departments has led to an urgent need for the diagnosis, screening, maintenance, insulation condition assessment, and enhancement of the operational reliability of aging cables. The absence of such data not only impedes the precise evaluation of the cable systems' health but also hampers the establishment and execution of preventive maintenance strategies. Consequently, to diminish the risk of potential incidents, railway operations urgently necessitate the deployment of a high-voltage cable grounding current monitoring system. This system will facilitate the collection of grounding current magnitudes, enabling a thorough assessment of the existing cable systems and the performance of essential maintenance tasks, thereby ensuring the ongoing reliability and safety of the high-speed railway's power supply infrastructure.

2. Principle of grounding current monitoring for high-voltage cables

Faced with the impending challenges to operational reliability of high-voltage cables in the forthcoming years, and given the current lack of online monitoring and alarm systems for such cables in China, this study introduces a principle for monitoring the grounding current of high-voltage cables. Initially, the paper conducts an analysis of the magnitude of the induced electromotive force within the cable sheath, identifying the factors that influence it. Subsequently, leveraging these factors, the paper proposes a principle for grounding current monitoring. This principle is essential for addressing the online monitoring needs of high-voltage cables, enabling the detection of operational anomalies and potential faults, and facilitating the implementation of preemptive measures to ensure the reliability and safety of high-voltage cable systems, which is particularly critical within the high-speed railway power infrastructure.

2.1 Induced electromotive force (EMF) in the sheath of high-voltage cables

Analyzing the AT power supply method of dual-line electrified railways, the 27.5 kV cable feeders of China's high-speed railways have four circuits in total, each consisting of a T line (+27.5 kV), an F line (−27.5 kV), and an N line (neutral position protection line). The induced electromotive force in the sheath of the high-voltage cable is divided into two parts: the self-induced EMF of the single-phase circuit and the influence EMF due to the current loop along the line, denoted as U_1 and U_2, respectively.

2.1.1 Self-induced EMF of a single-phase circuit. Analyzing a single cable circuit, a circuit formed by cables A and B is considered, as shown in Figure 2, where the distance between cables A and B is denoted as s. The current flowing through cable A is i_a, the current through

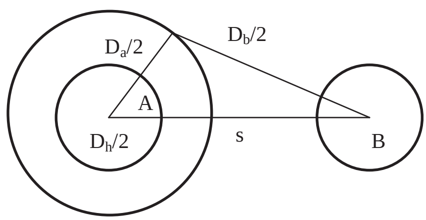

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Figure 2.
Schematic diagram of self-induced EMF in a single-phase circuit

cable B is i_b, with a frequency of f. The diameter of the cable sheath is D_h, and the diameter of cable A is D_a. The magnetic flux at a position x on the metal sheath of cable A, measured from the center, is given by $H_x = i_a/(2\pi x)$, and the magnetic field strength is $B_x = \mu i_a/(2\pi x)$.

The magnetic flux linkage ψ_{Ax} for cable A within the range from $x = D_h/2$ to $x = D_a/2$ with its metal sheath is given by Equation (3.1):

$$\psi_{Ax} = \int_{\frac{D_h}{2}}^{\frac{D_a}{2}} \frac{\mu i_a}{2\pi x} dx = \frac{\mu i_a}{2\pi} \ln\left(\frac{D_a}{D_h}\right) \tag{3.1}$$

The magnetic flux linkage ψ_{Bx} for cable B from the cable center to $D_b/2$ with its metal sheath is given by Equation (3.2):

$$\psi_{Bx} = \int_{s}^{\frac{D_b}{2}} \frac{\mu i_b}{2\pi x} dx = \frac{\mu i_b}{2\pi} \ln\left(\frac{D_b}{2s}\right) \tag{3.2}$$

Here, $i_a = -i_b$, in theoretical analysis, assuming $D_a \approx D_b \approx \infty$, we can derive the magnetic flux linkage ψ_A for the sheath of cable A as given by Equation (3.3):

$$\psi_A = \psi_{Ax} + \psi_{Bx} = \frac{\mu i_a}{2\pi} \ln\left(\frac{2s}{D_h}\right) \tag{3.3}$$

Subsequently, the induced EMF per unit length of the metal sheath affected by its own supply current, U_1, is given by Equation (3.4):

$$U_1 = 2\pi f \psi_A = \mu i_a f \ln\left(\frac{2s}{D_h}\right) \tag{3.4}$$

2.1.2 Influence EMF of the current loop along the line. In the operating mechanism of high-speed railway high-voltage cables, the EMF sensed by the metal sheath not only originates from the magnetic field generated by the current inside the cable but is also significantly affected by the parallel magnetic fields produced by adjacent facilities such as the upper and lower contact networks, power transmission lines, and power supply lines. When analyzing the upper power supply line cable, it is also necessary to consider the alternating magnetic fields excited by the currents in the adjacent lower contact network and power supply lines, and their mutual influence with the cable's own current magnetic field. This complex magnetic field interaction is crucial for the quantitative assessment of the induced EMF in the metal sheath, which in turn affects the electromagnetic compatibility and long-term operational safety of the cable.

The current flowing through the upper contact network is i_c, and the distance from the center of cable A is denoted as S_s. The current flowing through the positive feeder line is i_F, and the distance from the center of cable A is denoted as S_{sz}. The current flowing through the lower contact network is i_c', and the distance from the center of cable A is denoted as S_x. The current flowing through the lower feeder line is i_F', and the distance from the center of cable A is denoted as S_{xz}. The current flowing through the lower T line is i_T, and the distance from the center of cable A is denoted as S_T. The current flowing through the lower F line is i_{AF}, and the distance from the center of cable A is denoted as S_{AF}.

When analyzing the impact of the upper and lower contact network currents on the induced voltage of cable A, it is first necessary to analyze the impact of the induced magnetic flux on cable A by the upper and lower contact networks and feeders. The induced magnetic flux linkage ψ_{SA} at $x = S_s$ to $x = D_C/2$ due to the influence of the upper contact network on cable A can be obtained as:

$$\psi_{SA} = \frac{\mu i_C}{2\pi} \ln\left(\frac{D_C}{2S_s}\right) \tag{3.5}$$

The induced magnetic flux linkage ψ_{SZA} at $x = S_{sz}$ to $x = D_F/2$ due to the influence of the upper feeder line on cable A can be obtained as:

$$\psi_{SZA} = \frac{\mu i_F}{2\pi} \ln\left(\frac{D_F}{2S_{sz}}\right) \tag{3.6}$$

The induced magnetic flux linkage ψ_{XA} within the range from $x = S_x$ to $x = D_C'/2$ due to the influence of the lower contact network is given by:

$$\psi_{XA} = \frac{\mu i_C'}{2\pi} \ln\left(\frac{D_C'}{2S_x}\right) \tag{3.7}$$

Similarly, the induced magnetic flux linkage ψ_{XZA} within the range from $x = S_{xz}$ to $\mathrm{x} = D_F'/2$ due to the influence of the lower feeder line is:

$$\psi_{XZA} = \frac{\mu i_F'}{2\pi} \ln\left(\frac{D_F'}{2S_{xz}}\right) \tag{3.8}$$

When analyzing the impact of the lower supply line currents on the induced voltage of the cable, the same method is applied to analyze the influence of the induced magnetic flux. The induced magnetic flux linkage ψ_{TA} within the range from $x = S_T$ to $x = D_T/2$ due to the influence of the lower T line is:

$$\psi_{TA} = \frac{\mu i_T}{2\pi} \ln\left(\frac{D_T}{2S_T}\right) \tag{3.9}$$

And the induced magnetic flux linkage ψ_{FA} within the range from $x = S_T$ to $x = D_T/2$ due to the influence of the lower F line is:

$$\psi_{FA} = \frac{\mu i_{AF}}{2\pi} \ln\left(\frac{D_{AF}}{2S_{AF}}\right) \tag{3.10}$$

By the aforementioned analysis and derivation, the total induced magnetic flux linkage ψ_2 along the line loop affecting cable A can be calculated as:

$$\psi_2 = \psi_{SA} + \psi_{SZA} + \psi_{XA} + \psi_{XZA} + \psi_{TA} + \psi_{FA} \tag{3.11}$$

Thus, the induced electromotive force per unit length U_2 produced by the current loop along the line in the metal sheath of cable A is:

$$U_2 = 2\pi f \psi_2 = \mu i_C f \ln\left(\frac{D_C}{S_s}\right) + \mu i_F f \ln\left(\frac{D_F}{S_{sz}}\right) + \mu i_C' f \ln\left(\frac{D_C'}{S_x}\right) + \mu i_F' f \ln\left(\frac{D_F'}{S_{xz}}\right) + \mu i_T f \ln\left(\frac{D_T}{S_T}\right) + \mu i_{AF} f \ln\left(\frac{D_{AF}}{S_{AF}}\right) \tag{3.12}$$

Given tha $i_c = -i_F$, $i_c' = -i_F'$, $i_T = -i_{AF}$, $D_C \approx D_F \approx \infty$, $D_C' \approx D_F' \approx \infty$, $D_T \approx D_{AF} \approx \infty$, the equation of U_2 can be simplified to:

$$U_2 = \mu i_C f \ln\left(\frac{S_{sz}}{S_s}\right) + \mu i_C' f \ln\left(\frac{S_{xz}}{S_x}\right) + \mu i_T f \ln\left(\frac{S_{AF}}{S_T}\right) \tag{3.13}$$

In summary, the total induced EMF per unit length U in the metal sheath is:

$$U = U_1 + U_2 = \mu i_a f \ln\left(\frac{2s}{D_h}\right) + \mu i_C f \ln\left(\frac{S_{sz}}{S_s}\right) + \mu i_C' f \ln\left(\frac{S_{xz}}{S_x}\right) + \mu i_T f \ln\left(\frac{S_{AF}}{S_T}\right) \tag{3.14}$$

2.2 Principle of ground loop current monitoring

The magnitude of the induced EMF per unit length in the metal sheath of the high-voltage cable affects the grounding method of the cable. Taking a common cable model on the market as an example for calculation and analysis, the metal sheath diameter D_h = 55.5 mm, the center-to-center distance of the single-phase circuit cable s = 62.5 mm, f = 50 Hz, $\mu = 4\pi \times 10^{-7}$ H/m. According to the design documents, S_s = 9.3 m, S_{sz} = 9.5 m, S_x = 14.2 m, S_{xz} = 18.1 m, S_{AF} = 15.2 m , S_T = 15.26 m. assuming the maximum current passing through the railway traction substation is 1,350 A, then $i_a = i_T$ = 450 A, $i_c = i_c'$ = 1,350 A.

Based on the analysis of Section 3.1, the induced EMF U per unit length on the metal sheath of the single-core cable can be obtained as:

$$U = \mu i_a f \ln\left(\frac{2s}{D_h}\right) + \mu i_C f \ln\left(\frac{S_{sz}}{S_s}\right) + \mu i_C' f \ln\left(\frac{S_{xz}}{S_x}\right) + \mu i_T f \ln\left(\frac{S_{AF}}{S_T}\right) \tag{3.15}$$

Substituting the above parameters into Equation (3.15), U is found to be 0.0452 V/m. According to the GB 50217-2007 standard (GB 50217-2007, 2007), the induced voltage at any point not directly grounded should not exceed 50 V. It can be calculated as 50/0.0452 = 1.106 km. When the length of the 27.5 kV high-voltage cable does not exceed 1.106 km, a single-end grounding method can be used.

The length of 27.5 kV cables on China's high-speed railways generally does not exceed 1 km. After the above analysis, it can be known that the 27.5 kV cables on high-speed railways generally adopt a grounding method with one end grounded and the other end grounded through a protective device (Yang, Zhu, Dong, Lu, & Li, 2016), as shown in Figure 3. The grounding protection device can effectively prevent circulation current between the metal shielding layer and the ground, preventing the cable from overheating. When the induced voltage exceeds the safety threshold set by the protector, the protector will guide the overvoltage current to the ground, thus protecting the metal shielding layer and avoiding the risk of the cable's outer sheath being punctured.

When current is conducted in a single-core cable, an alternating magnetic field is produced in the surrounding space, which couples with the magnetic flux of the cable circuit, thereby inducing electromagnetic induction. This phenomenon causes the metal shielding layer and the armor layer of the cable to induce electromotive force, the magnitude of which is jointly affected by the amplitude of the current inside the cable, the geometric arrangement, and the longitudinal length. When the outer sheath of the high-voltage cable is damaged, the shielding layer or the armor layer may form grounding points at both ends, thereby generating a significant loop current phenomenon in these conductive layers. The magnitude of this loop current can be used as a key indicator to assess the insulating performance of the cable's outer sheath. By monitoring the grounding current of the high-voltage cable's shielding layer and armor layer in real-time and online, not only can the damage and faults of the cable's outer sheath be effectively diagnosed and located (Zhang, Li, & Chen, 2009; Xin, 2013; Yang *et al.*, 2016; Xu, 2021), as shown in Figure 4, but it also has important practical significance for preventing cable faults and ensuring the stable operation of the power system. This monitoring method provides a scientific and effective means to ensure the safety and reliability of the high-voltage cable system.

3. Grounding current monitoring system for high-voltage cable

The grounding current monitoring system for high-voltage cables in high-speed railways is of key significance for real-time monitoring of the cable insulation condition and ensuring the safety of railway operations. The system design includes both hardware and software aspects: the hardware part focuses on the selection and design of current sensors and acquisition terminals to ensure the accuracy of data collection; the software part focuses on optimizing data transmission and the functional design of the user interface to improve data processing efficiency and user experience. The development of this monitoring system is crucial for improving the operation and maintenance management level of high-speed railway cables.

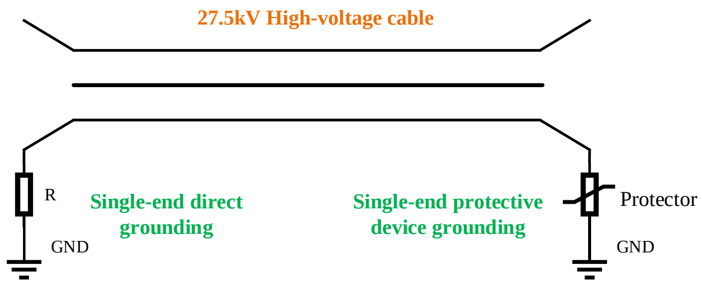

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Figure 3. One end directly grounded, the other end grounded through a protector

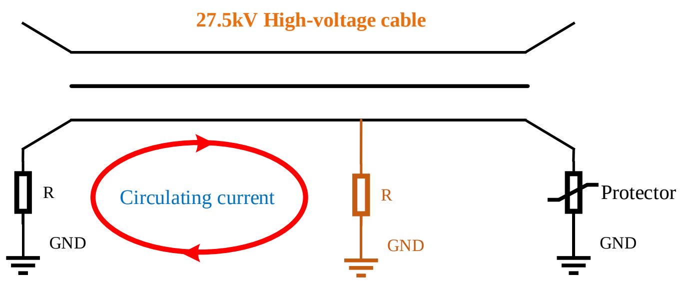

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Figure 4. Loop current situation when the cable is damaged

3.1 Overall design scheme

The grounding current monitoring system for high-voltage cable adopts a distributed collection method, deploying sensors along the railway line to achieve real-time collection of the grounding current of high-voltage cables. The collected data is synchronized to the central data terminal through the data transmission system for aggregation and analysis. The system hardware is responsible for data collection and transmission, while the software provides data visualization and early warning mechanisms. The design goal of this monitoring system is to enhance the monitoring capability of the railway power supply system to improve the safety of railway transportation.

3.2 Hardware design scheme

3.2.1 Collection system of grounding current monitoring system for high-voltage cable. Considering that high-voltage cables are mostly located in remote areas along the railway line, and local power supply facilities are relatively scarce, the power supply module design of this monitoring system must have independent power supply capability. The module integrates three power supply methods: solar power, cable power extraction, and direct current/alternating current power supply, to ensure stable operation in different environments. Under conditions of sufficient sunlight, the system prioritizes power supply through solar panels, and if the installation site has stable power supply conditions, the system can also choose direct current or alternating current power supply for power (Li, 2016, 2017, 2018; Zhao & Li, 2019).

In terms of hardware design, the current sensor is installed on the grounding lead wire of the cable's shielding layer and armor layer to achieve precise monitoring. Considering the convenience of installation and the continuity of line operation, a split-type sensor that does not require the existing cable to be dismantled is preferred. In addition, given that some monitoring points are located in outdoor environments, the sensor must have good waterproof performance. Therefore, this study selected the split-type waterproof current transformer model KHCTFS451L to meet the needs of outdoor monitoring. The overall structure of the hardware equipment is shown in Figure 5, showing the composition and layout of the system's hardware.

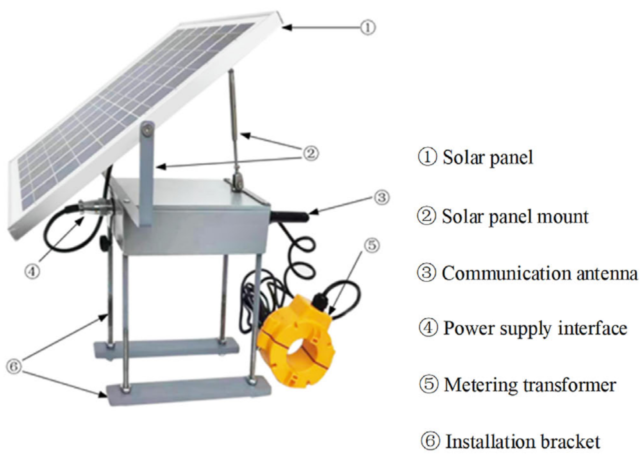

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Figure 5. High-voltage cable grounding current monitoring system collection system

3.2.2 Transmission system of grounding current monitoring system for high-voltage cable. The grounding current monitoring system for high-voltage cable adopts LoRa wireless communication technology, and the LoRa gateway router is shown in Figure 6. By integrating the LoRa module into the acquisition terminal, efficient wireless data transmission is achieved. The data collected by the current sensor is processed by the front end and then transmitted on the 433 MHz frequency band through the LoRa module, ensuring communication reliability in open environments. Subsequently, the LoRa gateway router converts the signal into a 4G signal and further transmits the data to the remote server. The LoRa module is easy to integrate, friendly for programming, and can provide stable data transmission within the line of sight, making the entire monitoring system easy to deploy and maintain in complex outdoor environments, showing good operability and stability.

3.3 Software design scheme

3.3.1 Data collection and filtering of grounding current monitoring system for high-voltage cable. The front-end collection module is connected to the current transformer to accurately capture the current signal, and the signal is adjusted through filtering circuits and operational amplifier circuits to eliminate noise and amplify the signal. Subsequently, the data sampler converts the conditioned analog signal into a digital signal, and digital signal processing technology is used for compression and encoding to optimize the transmission efficiency and accuracy of the data. Finally, the micro-controller (MCU) drives the LoRa module to efficiently send the processed digital signal to the server, ensuring that the entire process from current signal collection to data transmission is both accurate and efficient.

3.3.2 Display function of grounding current monitoring system for high-voltage cable. The design of the display part of the grounding current monitoring system for high-voltage cable focuses on interface design, database design, and early warning design. The interface design aims to provide an intuitive user interaction experience, which can not only clearly display the monitoring area and line information, such as specific high-speed railway lines and traction substations, but also dynamically present the collected current data in the form of waveform diagrams. In the two-dimensional coordinate system of the time axis and current value, these data are collected by distributed acquisition terminals and sent to the software system for real-time visualization display through the transmission system.

The core goal of the database design is to efficiently collect, store, and manage the data obtained by the system from various acquisition terminals. This design ensures that data can be conveniently called and analyzed during the data presentation and processing process.

Figure 6.
LoRa gateway router

Source(s): Authors' own work

The early warning design focuses on providing real-time monitoring status feedback for the maintenance team. When cable insulation faults, equipment abnormalities, or other potential problems are detected, the system will automatically trigger an early warning mechanism, clearly marking the fault point through the interface, ensuring that maintenance personnel can respond quickly and take necessary maintenance measures to minimize the impact of the fault.

4. Experiments results and field trials

4.1 Experimental results

In terms of hardware design, current sensors are respectively installed on the shielding layer and armored grounding wire of high-voltage cables to achieve real-time monitoring of the grounding current of high-voltage cables. Each monitoring system can monitor one high-voltage cable, and the monitoring distance is determined by the length of the cable. Considering the convenience of installation and the continuity of line operation, open sensors that do not require dismantling of existing cables are preferred. In addition, considering that some monitoring points are located in outdoor environments, sensors must have good waterproof performance. Therefore, this study selected the KHCTFS451L open-ended waterproof current transformer to meet the needs of outdoor monitoring. The overall hardware device structure is shown in Figure 7 (a), which illustrates the hardware composition and layout of the system.

To verify the data collection and alarm functions of the cable grounding current monitoring device, the current output was gradually increased from 0 to exceed the current threshold. The current threshold was set to 4 A, as shown in Figure 8, which shows the current collection waveform display on the computer side, where the current was gradually increased from 0 to 4.49 A. From Figure 7 (b), it can be seen that when the current reached 4.49 A, the system issued an alarm for excessive current value, verifying the current collection data display function and the threshold exceeded alarm function of the software on both the mobile terminal and the computer side.

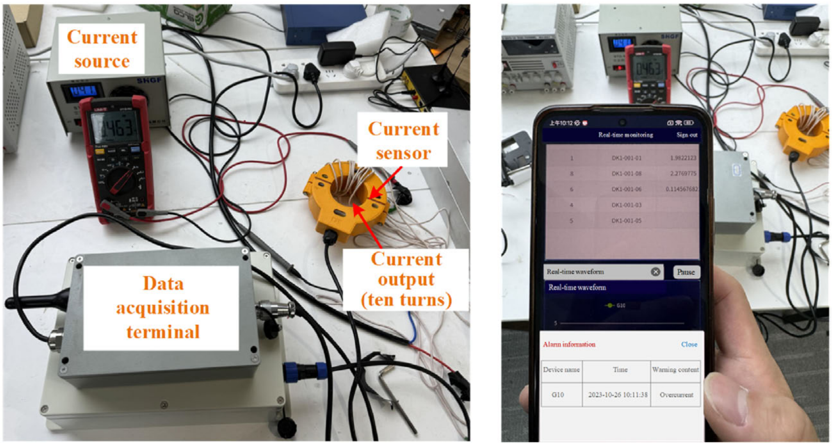

Photo of high-voltage cable grounding current monitoring experiment
(a)

Threshold exceeded alarm (displayed on the mobile terminal)
(b)

Source(s): Authors' own work

Figure 7.
High-voltage cable grounding current monitoring experiment diagram

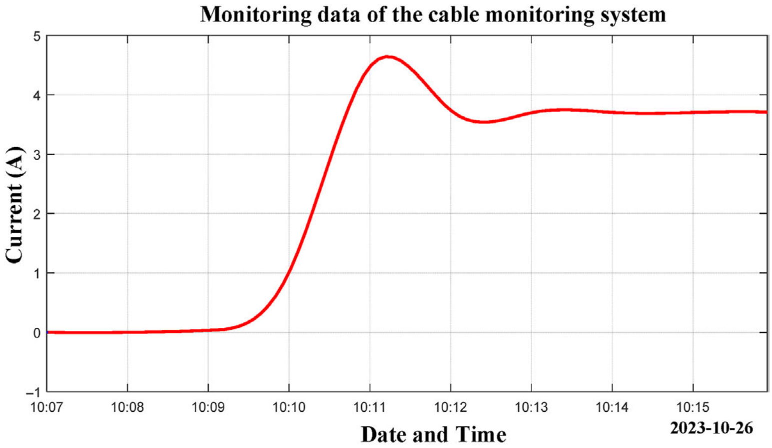

Figure 8.
Waveform diagram of high-voltage cable grounding current experiment

Source(s): Authors' own work

4.2 Field trials

In order to further explore the stability and reliability of the grounding current monitoring device for high-voltage cable in practical applications, and to obtain field data for subsequent data analysis and system optimization, the research team specially went to the traction substation of the railway bureau for on-site installation and testing, as shown in Figure 9. Monitoring devices were installed at key positions in the traction substation, and the grounding current of the cables was systematically collected and recorded.

The grounding current intensity of the high-voltage cable is closely related to the size of the current passing through the cable, showing obvious dynamic change characteristics. By comparing and analyzing the cable current data recorded by the railway bureau (as shown in Figure 10) with the current values captured by the grounding current monitoring system of high-voltage cable (as shown in Figure 11), it can be clearly observed that the trends of the two are highly consistent. This phenomenon not only reveals the sensitivity and

Figure 9.
Field installation diagram of high-voltage cable grounding current monitoring

Source(s): Authors' own work

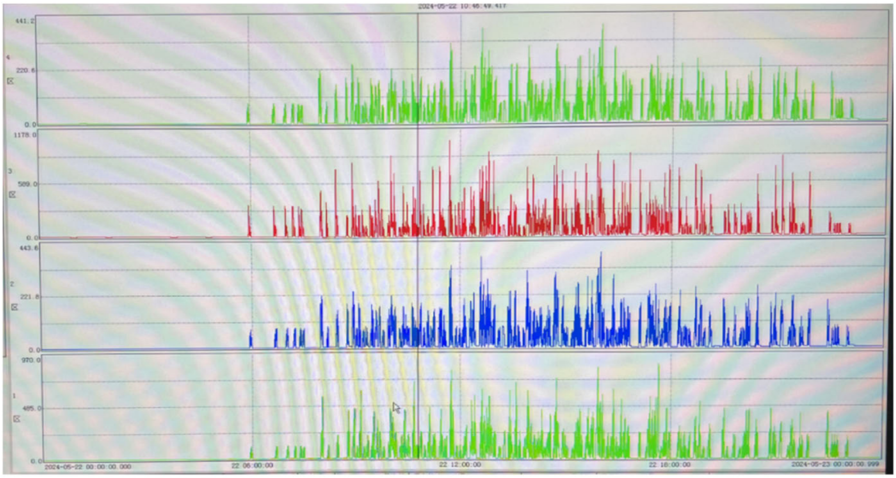

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Figure 10.
Cable current passing through the traction substation

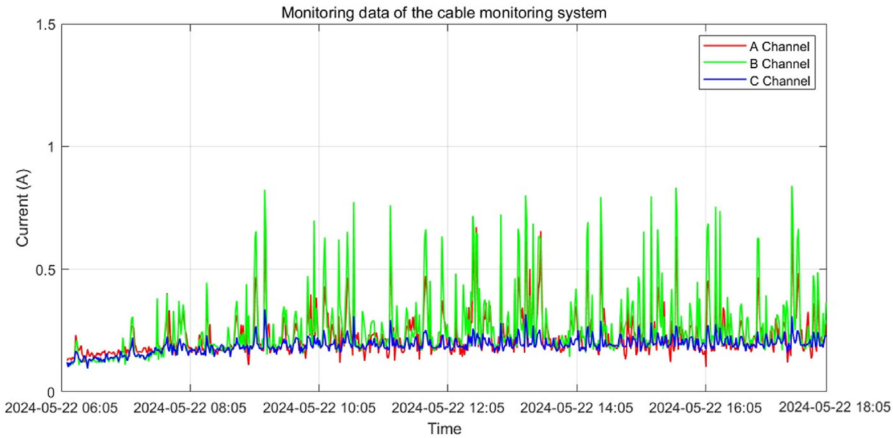

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Figure 11.
Monitoring data of the cable monitoring system

responsiveness of the grounding current monitoring system to changes in cable current but also further verifies the accuracy and reliability of the monitoring system in practical applications.

5. Conclusion

In summary, this article studies the grounding current monitoring technology for 27.5 kV high-voltage cables, designs a monitoring device that reflects the insulation condition of the cable by monitoring the grounding current, and conducts experimental verification. The research results can be summarized as follows:

(1) This article studies an analysis method based on the induced electromotive force of high-voltage cable sheaths to determine the grounding method for high-voltage cables with a length less than 1 km. Based on this method, an insulation state monitoring method suitable for single ended grounding of cables was developed, and a high-voltage cable grounding current monitoring device suitable for railway operation was designed.

(2) The reliability of the cable grounding current monitoring system developed in this paper in terms of data acquisition accuracy and alarm function has been verified through laboratory simulations and field experiments. It can effectively monitor and respond to changes in cable grounding current, help operation and maintenance personnel reduce inspection and maintenance workload, and provide strong technical support for the safe operation of high-speed railway traction power supply systems. However, actual implementation needs to consider economic feasibility and management feasibility, and further improve the system and relevant management methods of the railway bureau.

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