Development and Application of XLPE High Voltage Cable Grounding Circulation Online Monitoring System

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Abstract. The grounding current increases and the outer sheath heats up seriously, which will greatly reduce the operating heat capacity of the cable and affect the stable operation of the cable. Therefore, detecting the grounding current of the cable accessory is of great significance for monitoring the operation of the cable. In order to improve the operational monitoring level, the ground loop online monitoring system began to be gradually applied in the power system. In this paper, based on the operating environment of XLPE high-voltage cable, the structure design of the on-line monitoring system of grounding circulation is analysed. The examples of online monitoring system are given. The advantages and disadvantages of the monitoring system are discussed in combination with the operating experience.

1. Introduction

With the rapid development of China's economy and the continuous improvement of urban modernization level, power cables, as an important equipment in urban power grids, are developing at an extremely fast rate, with an average annual growth rate of 35%¹-³. At present, the development trend of cable technology is to increase the transmission capacity of the line by increasing the voltage level, increasing the cable section and increasing the line current capacity. As the demand for electricity increases, the proportion of high-voltage and ultra-high-voltage cables is gradually increasing⁴.

However, the fast-growing cable lines also place high demands on equipment operating units. According to the cable test statistics, the cable failure occurred due to the damage of the outer sheath caused by external force damage accounted for 58%. In the inter-operation of the cable, once the outer sheath of the cable is damaged by external force, chemical corrosion, lightning overvoltage or system overvoltage, the insulation of the sheath is damaged or even grounded at one or more points, which will damage the metal sheath of the high voltage cable. The grounding system causes the imbalance of the induced electromotive force of the metal sheath of the cable, which leads to a large circulation of the metal sheath and the earth. The additional line loss increases and the cable temperature increases. This will endanger the main insulation and shorten the normal operation of the cable line. Lifetime affects the safe operation of the line.
Based on this, the research team combined with the local cable operating environment, proposed to develop the "cable grounding loop online monitoring system", through real-time monitoring of the cable terminal and the grounding loop at the cable joint, to master and judge the insulation state of the cable sheath. This paper discusses the online monitoring system in combination with the actual operation of the transmission cable, and provides monitoring examples after the system is running, in order to provide reference and reference for the further development of the grounding circulation online monitoring system.

2. Technical background
At present, the 110kV cable above the main operation adopts a single-core structure. In operation, an induced voltage is generated on the metal sheath, and a high induced potential is formed at both ends of the cable. It is necessary to adopt a suitable outer sheath grounding measure to sense the induced voltage limited to a safe voltage range. According to different cable lengths, two outer sheath grounding methods are mainly used.

2.1. Single-ended protection grounding
This type of grounding is mainly suitable for the case where the length of the cable loop is short. The structure is as shown. One end of the outer sheath is directly grounded, and the other end is grounded through a sheath protector. When the line is in normal operation, the sheath protector is considered to be insulated from the ground, and the outer sheath does not form a circulation, and the current is small. When the line flows overcurrent, a large overvoltage is induced on the outer sheath. At this time, the sheath protects the breakdown and forms a loop to release the energy and prevent the sheath from being damaged.

Fig. 1 The schematic diagram of single-ended protection grounding

2.2. Cross-connect grounding
When the cable length is long, the crossover interconnection is mainly used to limit the overvoltage of the outer sheath. Its structure is shown in the figure. This type of grounding is mainly suitable for the case where the length of the cable loop is short. The structure is shown in Figure 2. One end of the outer sheath is directly grounded.

Fig. 2 The schematic diagram of the cross-connect system

3. The basic structure of the online monitoring system
The system is built in a modular way, consisting of five modules: power module, responsible for the power supply of each device; sensor module, collecting ground current; data processing module, processing and transmission of data; wireless transmission module, responsible for the inside of the
trench Data hopping and public network transmission; terminal, historical waveform and data analysis. The functions of each module are described below.

3.1. Power Module

The system adopts open-loop high-voltage power-taking device. Compared with the conventional induction power-receiving method, the device adopts an open-loop magnetic core, and the magnetic circuit is not closed, which effectively avoids magnetic saturation and eddy current conditions, and is more stable and hotter than conventional equipment. Great improvement has been made. The basic structure is shown in Figure 3.

![Open loop high voltage induction power take-off device](image)

Fig.3 Open loop high voltage induction power take-off device

Considering the harsh operating environment of the cable, the waterproof performance of the power take-off device reaches the IP68 level, ensuring long-term stable operation in a humid environment.

3.2. Sensor

The sensor is mainly responsible for the cable load current, the ground current data collection on the ground cable, and the signal is transmitted to the data processing and transmission module. The current sensor in the system adopts a flexible mutual inductance coil, the coil does not contain a magnetic saturation component, the linearity is good, the calibration is easy, the transient reaction capability is outstanding, the current range to be measured is large, and the phase difference error is less than 0.1 degree, and the phase difference error is less than 0.1 degree. The coil insulation voltage is >1000V, and the high-voltage bushing insulation voltage can reach 10kV, no danger of secondary open circuit and overload danger.

The basic parameters of the current sensor are shown in Table 1.

| Range                  | 30A     | 300A    | 3000A   |
|------------------------|---------|---------|---------|
| Current peak-to-peak value during use | 45A peak | 450A peak | 4500A peak |
| Current rms value during use | AC 0.5~30A | AC 5~300 A | AC 50~3000A |
| Specified range of effective values | AC 0.5~30A | AC 1~300A | AC 5~3000A |
| Output/input ratio | 33.3 | 3.33 mV/A | 0.33 mV/A |
| Voltage output signal accuracy | ±0.5% |               |         |
| Ammeter display accuracy | ≤±1%±5 words of range | | |
| Phase shift (50Hz) |          | ≤0.1°    |         |
| Waveform output linearity (10% to 100% of range) | | ≤ ±0.5% of reading | |
| Residual current (noise, I = 0) | | ≤0.5A RMS | |
| Load impedance | | ≥10kΩ | |

Tab.1 The indicators of current sensor
3.3. Data Processing and Transmission Module

This module is mainly responsible for data processing and transmission of received sensor signals. The data processing part is mainly responsible for collecting sensor data and storing historical data. The main structure of the data processing and transmission module is shown in Figure 4.

![Fig. 4 Data processing and transmission module](image)

The data collected by the sensor is input to the microcontroller through photoelectric conversion, A/D conversion. Then through the single-chip microcomputer, the data is sent to the jump point of the wellhead through the coaxial cable.

The microprocessor uses the C8051 microcontroller in this project, mainly considering its high-speed operation, high-speed real-time input and output, and multi-interrupt response. Facilitate subsequent module upgrades. The 8051 MCU has an 8-bit I/O port with good expansion performance. The C8051 has an 8-channel 12-bit ADC with a conversion rate of up to 100 KS/s. In addition, there is a programmable gain amplifier PGA for amplifying the input signal and improving A/D conversion accuracy.

The main program of the acquisition system is compiled in C language. The main flow chart is shown in Figure 5.

![Fig. 5 Acquisition system flow chart](image)

3.4. Data Monitoring System

The data monitoring system mainly uses virtual instruments, which are composed of computers and application software. When data anomalies occur, the joint geographic information, grounding current and other related information of the abnormal data are sent to the owner of the device through the GPRS public network.

The photos after installation are as follows.
4. Status of online monitoring system operation

4.1. Remote online monitoring system operation accuracy

The four lines were installed with a ground loop online monitoring system for 10 months. Table 2 shows the actual measurement and monitoring values of the site after a 110kV cable line A installation monitoring system.

| Current (A)       | Field measurement | Remote monitoring |
|-------------------|-------------------|------------------|
| Load current      | Field measurement | Remote monitoring |
|                   | A    | B    | C    | A    | B    | C    |
| Load current      | 218  | 219  | 225  | 216  | 216  | 219  |
| Ground current    | 8.9  | 14.4 | 7.1  | 8.7  | 13.5 | 8.2  |

It can be seen that the values obtained by using the remote online monitoring device are basically the same as the field measurements. The system has high accuracy.

4.2. Monitoring examples

The outer sheath of the cable is affected by external force damage, chemical corrosion, lightning overvoltage or system overvoltage, resulting in damage to the sheath insulation or even grounding at one or more points to form a ground loop, so that the ground current of the outer sheath rises rapidly. At this point, the monitoring system will record the circulation value, set the ground current value to be greater than 10% of the load current, the system will alarm, and send the relevant information to the owner of the equipment.

The groundwater level in the test area is high, the water in the pipe trench is serious, and the water level in some pipe trenches has not passed through the grounding box. If the grounding box is not tightly sealed, the grounding system will be destroyed after entering the water, forming a circulation, causing the grounding current to be too large. Table 3 shows the current data of the joint grounding box of a 110kV cable line B.

| Phase       | A    | B    | C    |
|-------------|------|------|------|
| Load current| 105  | 117  | 106  |
| Ground current| 2.1  | 14.7 | 15.7 |

It can be seen that the ground current value has exceeded the load current by 10% and the system issues an alarm message. The staff checked the fault grounding box and found that the inside of the grounding box was rusted seriously.
4.3. Problems exposed during operation
Poor signal is the biggest obstacle to the promotion of current ground loop online monitoring system. Some joint wells are far away from the wellhead, and data transmission in the trench may need to pass multiple levels of hopping, which ultimately leads to poor signal, and the terminal cannot accept signals or data loss.

5. Conclusion
(1) The ground loop online monitoring system can effectively monitor the ground current data. The monitoring results are basically consistent with the on-site measurement data.
(2) The ground loop online monitoring system can realize 24-hour uninterrupted real-time online monitoring. It is guaranteed that the outer sheath of the cable will be found in the first time. At present, the operating experience shows that the grounding tank has better monitoring effect.
(3) The poor wireless signal in the trench is the biggest obstacle to the popularization and application of the monitoring system. Due to the part of the joint well, the cable joint is far away from the wellhead, making it difficult to transmit signals in the trench. It may need to pass multiple stages of hopping, resulting in no signal and other problems in some joints.

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