Design of lightning monitoring and fault identification algorithm for overhead distribution lines based on internet of things

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ABSTRACT

As an important part of the (DMS), the operation state of distribution lines is related to the operation safety of the DMS. Lightning is a natural transient weather phenomenon with high voltage, high current and strong electromagnetic radiation in nature, and it is also one of the more common natural disasters, which has become the primary factor of distribution line tripping. In this article, an algorithm for lightning monitoring and fault identification of overhead distribution lines based on the Internet of Things (IOT) is proposed. According to the distribution characteristics of wavelet energy spectrum under different lightning strikes, the response characteristics and fault identification criteria are constructed. The simulation results verify the real-time and reliability of the online monitoring data transmission of the lightning monitoring system for overhead distribution lines. The method in this article can avoid the influence of lightning impact corona and reflected wave at the end of the line on the accuracy of the algorithm by reasonably selecting the judgment threshold and the monitoring point of current traveling wave, which has high practical value. Through the statistical analysis of various monitoring data of the system, the operation and management department of distribution line can grasp the changes of key operation state of the line in time and lay a solid foundation for the condition maintenance of distribution line.

Keywords: Distribution line; lightning monitoring; fault identification; internet of things

1. INTRODUCTION

As an important part of the DMS, the operation state of distribution lines is related to the operation safety of the DMS. With the growth of the national economy, the demand for electricity is rising, and the scale of the DMS is gradually expanding, so it is more and more difficult to patrol the distribution lines and take safety precautions [1]. Because of its wide distribution range, distribution lines are often threatened by various complex geographical and climatic environments, which makes the fault of distribution lines always one of the most important factors affecting the safe operation of DMSs [2]. Lightning is a natural transient weather phenomenon with high voltage, high current and strong electromagnetic radiation in nature, and it is also one of the more common natural disasters. It has become the primary factor of distribution line tripping and seriously affects the safe and stable operation of DMS [3]. The formation of line lightning damage is mainly caused by the flashover of line insulation under the action of lightning overvoltage. When the flashover is transformed into a stable power frequency arc, the protection action can be caused and the circuit breaker will trip [4]. Under the interference of high frequency of lightning current, several existing transient protections may misjudge. Therefore, whether lightning interference can be correctly identified is one of the key problems that must be solved in the practical application of traveling wave protection and transient protection. Establishing a convenient, practical, fast and accurate lightning monitoring and early warning system in areas with frequent lightning activities can not only predict lightning accidents before they occur, but also provide auxiliary decision-making for the power industry to formulate distribution lines for reference, which is of great significance to effectively reduce the harm of lightning accidents in DMSs [5].

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Strengthening lightning protection of distribution lines can not only reduce the quantity of lightning trips caused by lightning strikes on distribution lines, but also help the safe operation of electrical equipment in substations, which is an important link to ensure the reliability of power supply in DMSs [6]. With the continuous expansion of DMS capacity and a large quantity of equipment, it is more and more difficult to monitor the real-time operation status of distribution lines. Even under certain conditions, detection requires a lot of manpower, and power supply units are overwhelmed, and some line equipment is installed in places that are difficult for maintenance personnel to reach, so real-time data cannot be obtained [7]. In this case, the contradiction between the operation state of distribution lines and the unknowability of potential faults and the safe and stable operation of large DMSs is becoming increasingly prominent [8]. Leal et al. installed Rogowski coils on the low-voltage terminal of the line insulator string and the ground wire bracket of the tower to monitor the lightning current. By comparing the magnitude and polarity of the current in five coils, the fault of counterattack and shielding failure can be judged [9]. Souza et al. used waveform consistency coefficient to identify lightning stroke fault, but the determination of its threshold value still needs theoretical support [10]. Wang et al. choose neural network classifier to identify according to the signal energy distribution, but the training speed of classifier is slow and it is easy to fall into local minimum [11]. Operation data show that lightning strike is one of the main causes of high voltage distribution line failure [12]. Therefore, it is of great theoretical value and practical significance to judge the frequency and location of lightning strike faults and identify lightning strike faults and common short circuit faults. This article presents an algorithm for lightning monitoring and fault identification of overhead distribution lines based on IOT.

2. METHODOLOGY

2.1 Smart grid characteristics

In the traditional DMS, the power generation side is a flexible source, and the user side belongs to an uncontrollable source. Through the construction of smart grid, the flexibility of power generation enterprises can be significantly improved, and then the power production side and consumption side of the DMS can be regulated in real time. Even in the case of uncontrollable power supply, the balance between power production and consumption can be maintained. Because the distribution line needs to monitor a relatively large amount of information, and the surrounding environment is complex, which is not conducive to the direct transmission of a large amount of information, it is need to form a quantity of small sensor networks in a certain area, and then collect the data of these networks through aggregation nodes for overall transmission. Therefore, the underlying sensor network also has the functions of perception, collection and anti-interference in different environments. IOT is to realize the interconnection of things to things, people to things and people to people. IOT has the characteristics of comprehensive perception, reliable transmission and convenience. The growth of IOT provides technical support for on-line monitoring and asset management of power transmission and transformation equipment.

Due to the existence of components and equipment whose operation status changes at any time, smart grid must be monitorable. Through the regulation and control of the above equipment, the changes are analyzed in time, which can provide certain guarantee for the stable operation of the system. Distribution lines have the characteristics of wide geographical distribution, complex geographical environment and changeable climate, so it is need to comprehensively obtain the information of equipment, environment, wires, towers and other equipment through IOT technology for comprehensive processing and judgment. Comprehensive information perception provides the basis for all-round monitoring and intelligent management of distribution lines [13]. With the growth of society, people's demand for electricity is increasing gradually. In some areas, the main line of DMS needs to pass through areas with complex terrain, and the operation of DMS has to bear greater risks due to the harsh environment. In some cases, the failure to grasp the terrain of the operating environment leads to DMS accidents. Therefore, in order to improve the security of the DMS system, it is need to collect climate indicators, and then prevent the corresponding disasters.

The communication network is divided into three layers. The first layer is the sensor network layer, which consists of sensors, online monitoring terminals and wireless routers. The second layer is the optical fiber communication layer, which uses the optical fiber in the optical fiber composite overhead ground wire on the distribution line as the communication path to transmit the monitoring data to the monitoring center. The third layer is communication network and Beidou satellite navigation system. The monitoring data of sensor network is transmitted through multi-hop transmission through routing nodes, and the network is the first choice. The network architecture of high voltage distribution line based on IOT technology is shown in Figure 1.

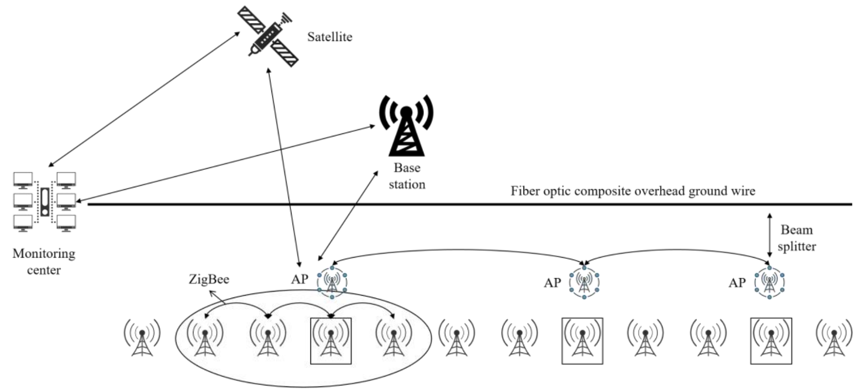

Figure 1. Network architecture of high-voltage distribution line based on IOT technology

In order to ensure the efficiency of information collection, data fusion technology is used to combine useful information more effectively while gathering and processing information [14]. Therefore, the mobile network communication layer, to a certain extent, strengthens the scope of network transmission and improves the timeliness of information transmission. Through video compression, the video recorded by the camera can be compressed, and then transmitted to the monitoring system through the wireless network. With the help of the computer, the line manager can monitor the towers and lines, thus realizing remote monitoring. In order to improve the performance of video surveillance, people have developed high-definition image sensor and wireless network technology, which makes video surveillance more widely used. Using IOT technology, multi-sensors are deployed on overhead distribution lines to monitor galloping, micro-weather, wind vibration, conductor icing and conductor temperature of conductor wireless sensors, thus completing real-time online monitoring of power lines.

2.2 Lightning monitoring and fault identification algorithm for overhead distribution lines

The edge intelligent terminal intelligently analyzes and processes the video and sensor data, uploads it to the cloud system when an abnormality is detected, and provides the video data before the abnormality occurs for analysis. When it is normal, it uploads the data periodically, and the cloud system can also start the real-time data upload function for real-time monitoring. In order to realize three-dimensional perception, intelligent monitoring and intelligent inspection of power distribution line status, the intelligent module of edge intelligent terminal is preliminarily analyzed and judged, and the intelligent module in cloud makes comprehensive judgment by using regional monitoring data to improve the accuracy of early warning. When lightning strikes the incoming line of substation, the fault traveling wave will be transmitted to the substation, which may lead to the action of lightning arrester. When non-fault lightning strikes and common short-circuit faults occur, the good nonlinear characteristics of lightning arresters make the amplitude of electric current on the grounding line passing through the lightning arresters smaller, while the amplitude of current traveling waves is smaller when lightning strikes.

When lightning strikes the ground near the line, the electromagnetic field causes induction lightning to occur on the three-phase conductor of the overhead line at the same time. Its amplitude on the three-phase conductor is close, its polarity is the same and its waveform is similar. The calculation of induced lightning overvoltage on overhead lines is a complex process, which mainly includes the determination of the temporal and spatial distribution characteristics of lightning current, the calculation of electric field generated by lightning current and the calculation of induced voltage generated by the coupling of electric field and conductor. The formula for estimating the amplitude of induced lightning overvoltage on overhead lines is:

$$U_{\max}(d) = k_{\mu} I_0 e^{k_0 + k_0 \ln d + k_1 \ln^5 d} \tag{1}$$

Where $k_u \approx k_2 h$ and h are the height of the conductor from the ground; d distance from lightning strike point to conductor; The coefficients k_0, k_1 and k_2 are determined by the characteristics of lightning current. No matter whether it is induced lightning overvoltage or direct lightning overvoltage, many high-frequency signals will be generated on the line. Wavelet multi-scale analysis is used to propose identification criteria for these high-frequency signals.

Considering the fact that the video monitoring image in the actual distribution line channel has not changed in a large amount of time, in order to save transmission bandwidth and calculation resources and effectively use limited resources to monitor the whole line, a combination of regular and real-time monitoring, front-end and cloud monitoring is adopted, and moving target detection is used as a trigger for intelligent analysis of the system to monitor the distribution line channel in real time. Describe the decomposition process of wavelet packet to distribution line operation signal;

$$W_{2n}(t)=\sum_k h_k w_n(2t-k) \tag{2}$$

After wavelet packet decomposition, the characteristics in each frequency band can be obtained. Because when a distribution line fails, the signal energy near the fault position is relatively large, and the signal energy far away from the fault position is relatively small, therefore, the fault characteristics can be extracted by changing the signal energy in the relevant frequency band:

$$E_{3\phi}=\int\left|S_{3j}(t)\right|^2 dt=\sum_{k=1}^{n}\left|x_{jk}\right|^2 \tag{3}$$

Where x_{jk} is the amplitude obtained after reconstructing the distribution line signal S_{3j}. Because the signal energy in each frequency band will be changed after the distribution line fails, the signal energy change is reconstructed as a feature vector:

$$R=\left[E_0^{'},E_1^{'},\ldots,E_7^{'}\right] \tag{4}$$

When the fault is serious, the signal energy in the relevant frequency band will also increase, which increases the amount of calculation. Therefore, normalization is needed:

$$I_j \frac{E_j^{'}}{\sqrt{\sum_{j=0}^{7}\left|E_j^{'}\right|^2}} \tag{5}$$

The eigenvector of the normalized distribution line fault is described as:

$$I=\left[I_0,I_1,\ldots,I_7\right] \tag{6}$$

The traditional electromagnetic current transformer is used to measure the current on high voltage distribution lines, but the traditional current transformer has a series of problems such as magnetic saturation, narrow frequency band and ferromagnetic resonance, and its application is more and more limited. When an object enters the channel, the depth recognition model of the edge intelligent terminal is triggered to detect and recognize the image. If foreign body intrusion is identified, the identification information and image information will be reported to the cloud for further analysis and processing. By dividing the lightning warning level, a good lightning warning effect can be obtained, and the system will remind the service object as early as possible. Because the threshold value of electric field intensity of blue warning is relatively low, it can provide time guarantee for users to arrange production reasonably.

3. RESULT ANALYSIS AND DISCUSSION

The continuous growth of monitoring technology provides a technical basis for the application of online monitoring in various fields. Therefore, when developing the monitoring system, we should pay attention to the expansion of the whole system architecture. High-performance data acquisition terminal is responsible for automatic data sampling and processing, saving and transmitting all kinds of data and environmental information collected by the equipment, and realizing the maintenance and adjustment of its own working state. It packages all collected data and sends them to the monitoring master station through the communication module. If the system can be divided into multi-layer architecture, it can better ensure that the whole system can allocate tasks according to user requirements, which greatly improves the applicability and flexibility of the system. The deviation curve of main fault characteristics of distribution lines is shown in Figure 2.

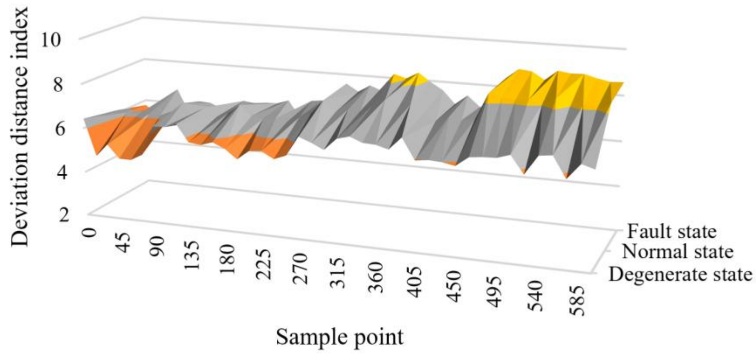

Figure 2. Preliminary selection of fault characteristic deviation curve

The proposed lightning monitoring and fault identification algorithm for distribution lines manages the distribution resources at a smaller granularity, and improves the utilization of cloud resources and energy consumption. The running system uses the trained intelligent model to intelligently process business data. Deploy the trained intelligent models in the edge intelligent terminal and the cloud platform respectively, and carry out intelligent data analysis and intelligent image recognition.

The learning model has self-learning function, and the intelligent model is trained regularly by using the massive data accumulated in the operation of the system. After the new model is updated, the system will update the local running system model and update the intelligent model of the edge intelligent terminal synchronously, so as to continuously improve the accuracy of intelligent analysis and identification of the model. Figure 3 shows the comparison of the monitoring accuracy of the algorithm.

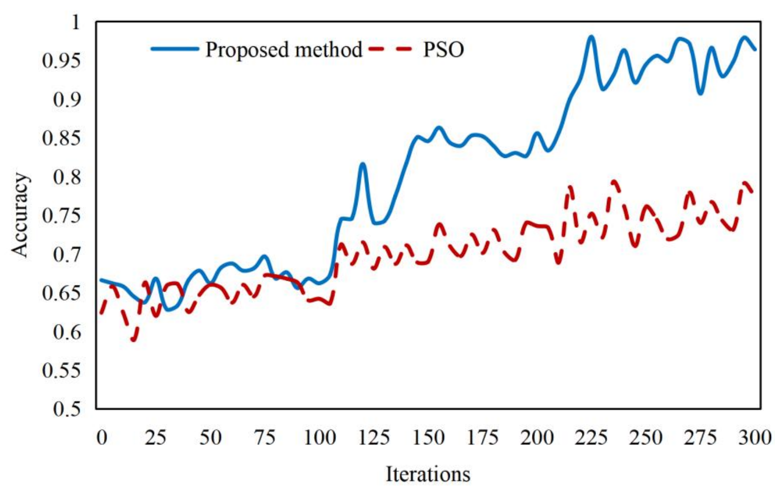

Figure 3. Comparison of monitoring accuracy of the algorithm

It can be seen that with the increase of the quantity of experiments, the monitoring accuracy of this algorithm is stable at about 95%. In order to optimize the key technologies of distribution lines as a whole and improve the quality of distribution line planning, the equipment of distribution lines must be regularly maintained and maintained, and at the same time, the loss of equipment should be reasonably controlled so that the equipment can maintain a good running state.

Because the lightning monitoring and early warning system of distribution lines comprehensively calls the data resources of multiple business application systems, the multi-thread step-by-step technology is used to complete the data acquisition function, that is, an independent monitoring thread is opened for each business resource acquisition module, which automatically captures the latest meteorological data and automatically updates the system information of the DMS. The false alarm rate of different distribution line fault identification algorithms is shown in Figure 4. The detection time of different distribution line fault identification algorithms is shown in Figure 5.

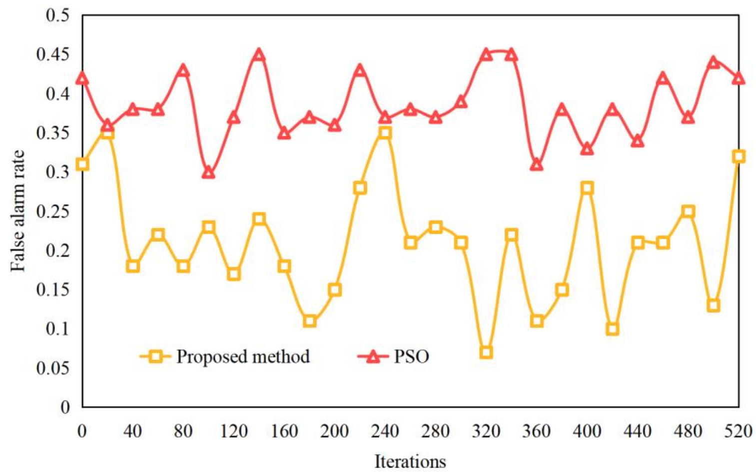

Figure 4. False alarm rate of different algorithms

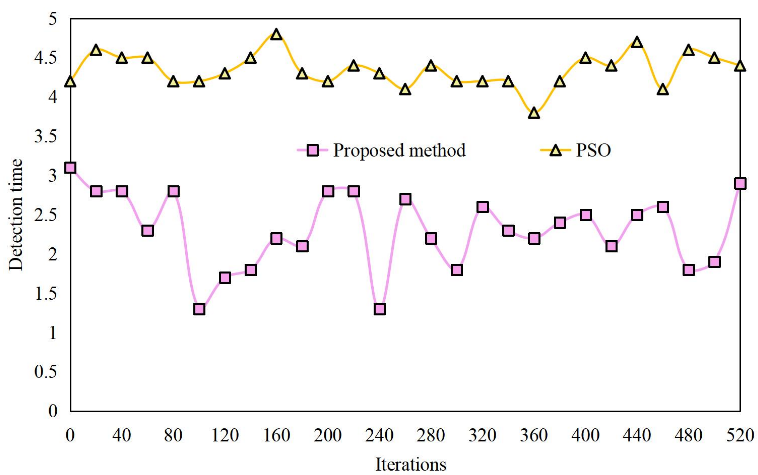

Figure 5. Detection time of different algorithms

From Figure 4 and Figure 5, it is not difficult to find that the lightning monitoring and fault identification algorithm for overhead distribution lines based on IOT proposed in this article has obvious advantages compared with the propagation algorithm in false alarm rate and detection efficiency. The algorithm has better fault tolerance, can adapt to the fault location of multi-point simultaneous short-circuit faults, can achieve higher and more accurate short-circuit fault location of distribution lines, and provides reliable guidance for accurate and rapid inspection of actual distribution line faults.

4. CONCLUSION

Because of its wide distribution range, distribution lines are often threatened by various complex geographical and climatic environments, which makes the fault of distribution lines always one of the most important factors affecting the safe operation of DMSs. Establishing a convenient, practical, fast and accurate lightning monitoring and early warning system in areas with frequent lightning activities can not only predict lightning accidents before they occur, but also provide auxiliary decision-making for the power industry to formulate distribution lines for reference, which is of great significance to effectively reduce the harm of lightning accidents in DMSs. In this article, an algorithm for lightning monitoring and fault identification of overhead distribution lines based on IOT is proposed. According to the distribution characteristics of wavelet energy spectrum under different lightning conditions, the response characteristics and fault identification criteria are constructed. The results show that the algorithm has better fault tolerance, can adapt to the fault location of multi-point simultaneous short-circuit faults, can achieve higher and more accurate short-circuit fault location of distribution lines, and provides reliable guidance for accurate and rapid inspection of actual distribution line faults. The system intends to collect the key parameters that affect the operation of the distribution line in normal operation state and potential fault state around the clock, monitor the main operation state of the distribution line in real time, and automatically analyze its operation state, so that the management and maintenance of the distribution line are targeted.

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