Scalable Computing: Practice and Experience, ISSN 1895-1767, http://www.scpe.org

Volume 26, Issues 2, pp. 699–707, DOI 10.12694/scpe.v26i2.3976

INFORMATION MONITORING OF TRANSMISSION LINE OPERATING ENVIRONMENT BASED ON INTERNET OF THINGS TECHNOLOGY

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Abstract. In order to solve the problem of real-time monitoring of transmission line status in smart grid construction, the author proposes an information-based monitoring method for the operating environment of transmission lines based on Internet of Things technology. This approach implements a monitoring system for transmission line status that leverages Internet of Things (IoT) technology, Passive Optical Network (PON) technology, and fuzzy expert diagnosis techniques. Extensive experimentation and field trials have yielded promising outcomes, facilitating the real-time monitoring of transmission line statuses and precise diagnostic assessments. The experimental results indicate that this system has shortened inspection time, reduced costs, and improved inspection accuracy. The accuracy can reach 99.9%, with high reliability. The accuracy and feasibility of the system have been verified, and it has the characteristics of comprehensive state information collection, stable network, high output accuracy, and simple deployment.

Key words: PON technology, Internet of Things, Fuzzy Analytic Hierarchy Process, Smart grid, Monitoring of transmission line status

1. Introduction. The Internet of things means the Internet connecting things. The Internet of Things technology enables objects to be intelligent and realize information communication and interaction between people and things, things and things by installing electronic tags (RFID), sensors, two-dimensional codes and other sensing devices on various objects, and then sharing the dynamic and static information of objects acquired by various sensing devices on the Internet [1-2]. The Internet of Things is not a new technology. On the basis of the existing Internet system, it is necessary to standardize and increase the means of perception and information processing, and extend Internet technology to objects. The Internet of Things technology has been widely applied in various fields related to national economy and people's livelihood (such as electricity, mobile communication, petrochemicals, etc.), and the power industry is one of the more widely used fields of Internet of Things technology, for example, online monitoring of transmission lines, intelligent substations, intelligent computer rooms, etc., the power Internet of Things covers various links such as power production, transmission, consumption, and management. Its industrial chain covers chips, sensors, terminal devices, information and communication networks, software applications, value-added services, and operation and maintenance. It is necessary to rely on the needs of power business to develop practical, serialized, and low-cost power Internet of Things products and systems, expand the industry application scope of Internet of Things products, improve product market share, and actively explore international markets [3].

Transmission lines are the power links with the largest and most widely distributed assets in the power grid, complex and harsh equipment operating environments, and frequent external factors. Due to the safety issues of transmission line equipment, such as high operating temperature of conductors, sag changes, wind bias discharge, gentle wind vibration, tower tilting, etc., most of them cannot be detected by the naked eye [4]. Therefore, it is urgent to install effective sensing equipment on transmission lines, achieve timely response to abnormal transmission line equipment through fault online monitoring systems, track and judge the operating status of transmission lines in real time, provide timely warning for line faults, and ensure the safe and stable

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operation of the power grid, applying IoT technology to the online monitoring system of transmission lines, obtaining equipment parameters of transmission lines, including wire tension, line temperature, grounding resistance, wire to ground distance, wire dancing frequency, pollution, tower pole stress, insulator wind deviation, etc, the parameters of various devices are transmitted to the data processing center through the Internet of Things gateway, and then advanced data analysis technology is used to process the data of various devices, determine whether there is a fault in the transmission line, and provide a basis for power grid safety decision-making [5-6]. With the increasing demand, scope, and types in the power supply market, the construction of supporting facilities for power transmission quality, power supply safety, and real-time monitoring of power lines is becoming increasingly strict. It is urgent to combine Internet of Things technology to build a multi element micro automatic meteorological station suitable for monitoring power lines and cables, to achieve microclimate observation, mobile meteorological observation posts, the seasonal ecological monitoring of power transmission line operational environments involves gathering meteorological data like temperature, humidity, air pressure, wind velocity, and precipitation (rain and snow). This data collection aims to enable the monitoring and early warning of meteorological conditions affecting power transmission line operations, timely formulate and implement preventive measures, and reduce the potential impact of meteorological factors on power transmission lines [7,8].

2. Literature Review. The Internet of Things (IoT) refers to a network that links various objects to the internet using information-sensing devices like RFID, GPS, infrared sensors, and laser scanners. These devices operate according to established protocols, facilitating intelligent functions such as identification, positioning, tracking, monitoring, and management of objects. The emergence of IoT technology as a next-generation information and communication technology has garnered considerable attention. Liu, L. et al. developed an online monitoring system for power fiber optic transmission networks utilizing IoT technology. The hardware components include sensors and microcontrollers, while the software aspects entail analyzing the system's functional requirements. They established a data acquisition module for power fiber optic transmission networks based on IoT, successfully implementing the system's software functions. Comparative experiments have verified the system's effectiveness in online monitoring, demonstrating significant potential for wider adoption[9]. Shen, Y. et al. employed wireless communication network technology for environmental monitoring in animal farms, devising a real-time reporting system aimed at continuously monitoring the health of animals[10]. Xu, X. et al. investigated remote monitoring of network public opinion within IoT applications. They focused on understanding campus public opinion dynamics and influencing its dissemination and direction. This exploration and research into online public opinion monitoring align with the objectives of smart campuses, and its theoretical advancement continues to evolve[11]. Innovatively integrating IoT technology, researchers have devised an image encryption transmission method tailored for power monitoring, capitalizing on the attributes of surveillance videos from stationary cameras. Experimental findings underscore the system's prowess across power monitoring image processing, encryption, and transmission, outperforming conventional algorithms by a significant margin [12].

The principal component analysis method is one of the widely used methods based on multi-dimensional statistical variable online monitoring technology. It is combined with Internet of Things technology to apply it to the online monitoring system of transmission lines. The basic idea is to first use Internet of Things technology to construct an information model of the normal operation status of the line, including monitoring statistical variables and thresholds, then, real-time collection of various parameters of the operating equipment of the transmission line is carried out, and they are projected onto the IoT information model. The statistical variable values are monitored at the online calculation point, and the presence of faults in the transmission line equipment is determined by comparing the online calculation values and threshold values. The author applied the combination of Internet of Things technology and LiDAR measurement technology to the online monitoring system of transmission lines, and achieved good results through practical application, proving the effectiveness of the method proposed by the author.

3. Method.

3.1. Internet of Things Technology. The system for monitoring the status of transmission lines, which combines IoT technology, mainly includes the application layer, transmission layer, and perception layer. In the transmission circuit section, including towers and transmission lines, intelligent sensors are equipped. These intelligent sensors collect equipment information on the line and micro meteorological information of the surrounding environment, which includes: Data on line icing, insulator contamination, line dancing, temperature, humidity, and more are gathered and sent to a monitoring agent via short-range wireless communication. Subsequently, this data is relayed to the Optical Line Terminal (OLT) at the substation through optical fiber, then further transmitted to a remote control center via a dedicated power network. Utilizing an expert diagnostic system, the current line status is accurately assessed, and results are disseminated to relevant departments for prompt action to prevent accidents [13,14].

3.2. Perception layer. Wireless sensor networks consist of numerous small nodes equipped with sensing, computing, and wireless communication capabilities, primarily designed for environmental monitoring rather than communication. These sensor nodes are strategically positioned in the monitored area to gather specific environmental data, which is then transmitted to aggregation nodes for further analysis[15]. The benefits of wireless sensor networks are manifold: they enable the acquisition of long-term, high-resolution environmental data at close range, a feat unattainable by conventional monitoring equipment; the computing and storage capacities of sensor nodes empower them to execute tasks like data filtering, compression, and application-specific processing; inter-node communication facilitates collaborative completion of intricate tasks such as target tracking; and finally, task reassignment capability allows for flexibility in altering the network's purpose as needed. The problems that wireless sensor networks need to solve include self-organization and self configuration of the network; Communication protocols; Distributed data management (data collection, storage, querying, retrieval, etc.); Specific data fusion processing for various applications; Energy conservation should be integrated into all designs. When designing the system, the main considerations include interference, power supply, transmission distance, and other issues. Intelligent wireless sensors will be deployed along transmission lines and towers to monitor both the condition of the lines and the surrounding environment. These sensors will collect data and transmit it to a central monitoring device, which acts as an agent overseeing the system's status. Communication between the sensor devices and the monitoring agent occurs via the ZigBee protocol.

3.3. Network layer. The network layer serves as a conduit for transferring data collected by the perception layer to the application layer. Traditional data transmission systems rely on wireless public networks like GPRS and 3G, but their speed and bandwidth limitations hinder efficient transmission of large data volumes in smart grids. However, with the introduction of OPGW (overhead ground wire composite optical cable) in transmission lines, optical fiber communication has become feasible. PON technology, particularly EPON, emerges as a mature and practical solution for optical communication. Within this system, EPON technology is employed to relay real-time monitoring data. PON comprises three main components: OLT, ODN, and ONU. OLT equipment is situated in the substation, while ODN and ONU are positioned on the line towers. In this setup, the ONU acts as a state monitoring agent device, responsible for collecting and aggregating data from intelligent sensors. Communication between the status monitoring agent device and the intelligent sensors is wireless, with options including ZigBee or WiFi. At the same time, considering the on-site environment and the difficulty of obtaining power, it is required that the status monitoring agent device must be able to adapt to outdoor work with low power consumption, generally requiring a power consumption of less than 5W. The power supply method should be solar panel power supply, and there should also be battery energy storage to prevent prolonged cloudy and rainy weather. The data communication architecture is shown in Figure 3.1.

3.4. Application layer. At the application layer, a fuzzy expert diagnostic system is employed. Developing expert systems entails integrating extensive expert knowledge and feature vectors. Transmission line status information encompasses four key aspects: fundamental details, operational management data, disaster alerts, and environmental monitoring data. This data is fed into the fuzzy expert system for analysis and decision-making[16]. Steps for establishing a fuzzy expert system:

1. Build a multi-level structural model as needed.
2. Create a fuzzy consistent judgment matrix to assess the relative importance of elements and derive a set of weights. This matrix represents pairwise comparisons among elements to gauge their significance

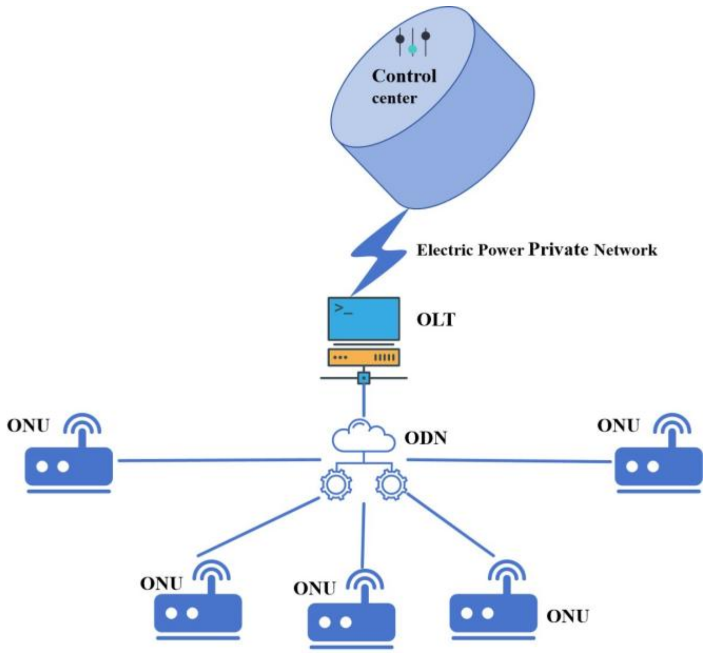

Fig. 3.1: Communication Network Model

$a_1, a_2, \cdots, a_n$ be:

$$F = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & f_{nn} \end{bmatrix} \tag{3.1}$$

In the formula, f_{ij} represents the membership degree of the i-th element in the layer that has a fuzzy relationship with the j-th element. The larger f_{ij}, the more important a_i is than a_j. When f_{ij}=0.5, it indicates that a_i is equally important as a_j.

3. Sum fuzzy matrices by row:

$$W_i = \sum_{h=1}^{n} f_{ij}, i = 1, 2, \cdots, n \tag{3.2}$$

4. Perform the following mathematical transformation on W:

$$W_{ij} = \frac{w_i - w_j}{2n} + 0.5 \tag{3.3}$$

Obtain the weight matrix:

$$F = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix} \tag{3.4}$$

5. The weight set $A = (A_1, A_2, \cdots, A_n)$ of the elements in the fuzzy consistency judgment matrix W represents the weight allocation of each factor. The sum of the elements in each row of the fuzzy

consistency matrix (excluding the diagonal element) indicates:

$$L_i = \sum_{j=1}^{n} W_{ij} - 0.5, i = 1, 2, \cdots, n \tag{3.5}$$

The total without diagonal elements is:

$$\sum_{j=1}^{n} L_i = \frac{n(n-1)}{2} \tag{3.6}$$

In the formula, n is the order of the matrix.

Since L_i represents the importance of indicator i relative to the upper level objectives, normalizing L_i can obtain the weights of each indicator:

$$A_i = \frac{L_i}{\sum_{j=1}^{n} L_i} = \frac{2L_i}{n(n-1)} \tag{3.7}$$

6. Determine the set of solutions $M = (M_1, M_2, \cdots, M_n)$, where n is the number of solutions. Mapping each element in the structure to M can determine a fuzzy relationship R.

$$F = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \tag{3.8}$$

In the formula, r_{ij} represents the importance of a single factor i in scheme j.

3.5. System functions and components. The transmission line operation environment monitoring system based on LiDAR measurement technology mainly consists of a spatial data management display module, inspection data processing module, and terrain and landform change analysis module (see Figure 2). Among them, the spatial data management display module realizes the management display of ledger data, inspection data (video images, point cloud data, etc.), and basic spatial data. The inspection data processing module integrates the independently developed IMOS cloud point cloud processing software, which is used to process laser point cloud data collected during inspections, obtain basic data for terrain and landform change analysis, and display terrain image maps. The analysis module of terrain and landform changes is the core part of the system function, which is used to analyze point cloud data and obtain the impact of environmental changes on transmission lines [17].

3.6. Working principle and process. The transmission line operation environment monitoring system based on LiDAR measurement technology is supported by high-precision point cloud data and high-definition image data collected. The raw data is filtered, classified, and extracted using the IMOS-cloud point cloud processing software to obtain result data. Combined with POS (Point of Sale, Flight Position, Sensor Attitude Information) data and image data, DEM (Digital Elevation Model), DOM (Document Object Model) and other result data are generated. The processing and analysis process is shown in Figure 3.3. The main steps are introduced below [18].

3.7. Calculation of distance between ground features and conductors. Process the generated laser point cloud data using the IMOS-cloud point cloud processing software and store it as a las file based on single span partitioning. The calculation process for the distance between objects and wires is as follows:

1. Determine the distance between buildings such as houses and trees within the passage and each point of the conductor (that is obtain a rectangular range of specified distances on both sides of the tower).
2. Classify and extract ground points and feature points (crossing objects, buildings, vegetation) from point cloud data for calculation.

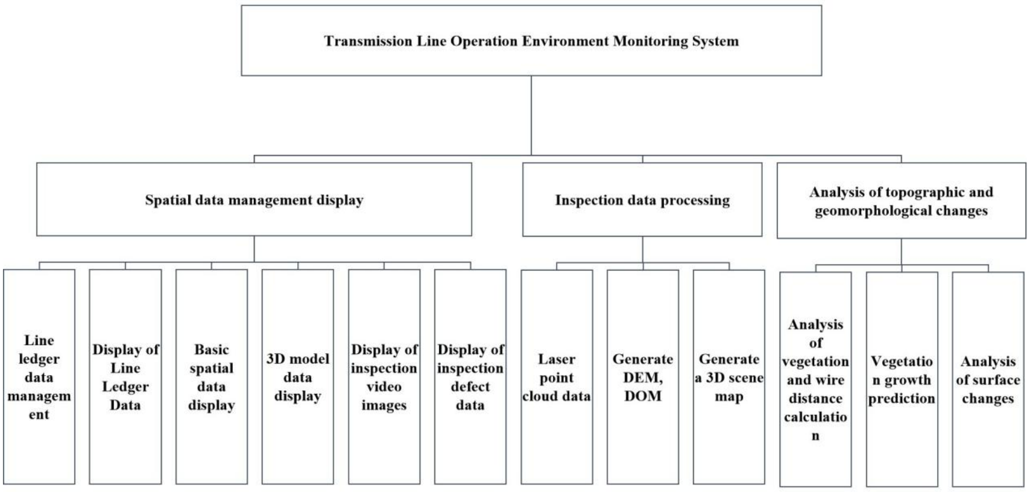

Fig. 3.2: Composition of Transmission Line Operation Environment Monitoring System

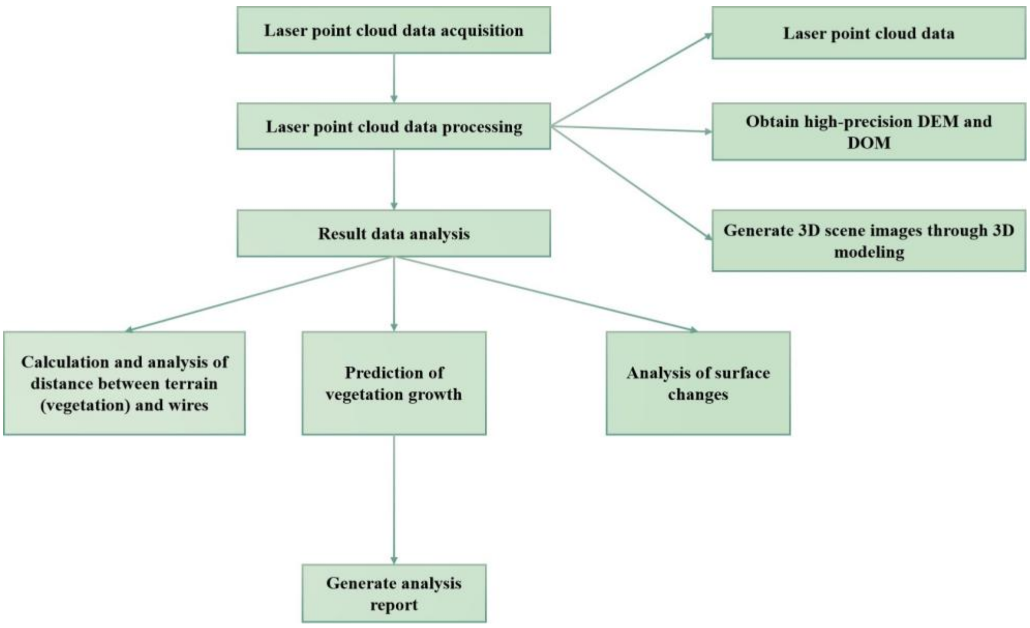

Fig. 3.3: Processing and Analysis Process of Transmission Line Operation Environment Monitoring System

3. Construct irregular triangular meshes on the classified point sets using the Crust algorithm.
4. Obtain the highest point in each triangular grid, and then establish a horizontal circular area with the highest point as the center and the set safe distance as the radius. Filter out the power line points that are horizontally projected within this circular area, and calculate the distance between each point and the highest point. If it is less than the safe distance, it indicates a safety hazard, and record the spatial information of the hazard points.

Table 4.1: Grid data corresponding to the first collection of DEM

Number	Longitude x/(°)	Latitude y/(°)	Altitude z/m
1	109.902078	40.506983	981.30
2	109.902078	40.507008	981.22
3	109.902006	40.507034	981.15
4	109.902016	40.507061	981.58
5	109.902015	40.507087	981.40
6	109.902025	40.507113	981.37

3.8. Prediction of vegetation growth curve. Due to the gradual growth of vegetation over time, tree flash faults can occur when the distance between vegetation and conductors within the transmission line corridor is less than the safe distance, affecting the safe and stable operation of the transmission line. The prediction of vegetation growth curve only considers the relationship between tree height and time; The grey algebraic curve model proposed on the basis of the grey model is suitable for predicting linear and nonlinear processes with low growth rates. Therefore, this system introduces this model to predict the growth of trees. Due to the fact that the vegetation in the transmission line corridor is mainly dominated by poplar trees, the tree growth model is obtained based on the height values of poplar trees at different age stages when establishing the model; Then, the tree height value obtained from each inspection record is fed into the prediction model to obtain the height prediction value for a certain period of time in the future, calculate its distance from the wire, generate a vegetation growth change curve, and provide warning information [19].

3.9. Analysis of topographical changes. Terrain change detection is the process of comparing information data from different periods in the same area to identify differences and understand the changes in terrain. DEM is a solid ground model that represents ground elevation in the form of an ordered numerical array. The DEM structure of a regular grid is simple and computationally concise, allowing for quick comparative calculations.

1. Firstly, the data space registration of different phase DEMs is used to unify them into the same coordinate system. Then, stacking and comparison are performed, and the elevation difference is calculated. After removing errors, the areas where the terrain has changed can be identified. The area of the changed areas is calculated, and the spatial information of the changed areas is recorded.
2. After image classification, the comparative method is used to classify image data from different periods. Pixels are compared one by one to determine the position of changes, and the trend of changes in the horizontal direction is found to obtain three-dimensional terrain change information [20].
3. Calculate the inclination and base height of nearby towers using point cloud data, and compare them with existing tower information to determine the impact of terrain changes on the towers. If the change area is located below the transmission line, it is necessary to calculate whether the net clearance distance of the transmission wires in the change area is within the safe range to determine whether it will affect the wires.

4. Results and Discussion. Convert the DEM data obtained from the original data collected during inspection and the corresponding data from the same area to rectangular grid data, as shown in Tables 4.1 and 4.2. By overlaying and subtracting DEM, the location of subsidence or protrusion on the ground was determined. After profile analysis (as shown in Figure 4.1), it was found that the terrain had protrusions, resulting in a distance less than the safe distance from the conductor.

During the patrol inspection, 13 trees endangering the superelevation safety distance of the line, 6 hidden dangers of the passage, 3 desert terrain changes, 1 river crossing width and 1 mudflat landform were found; Simultaneously calculating the settlement of nearby tower foundations, tower inclination, and predicting the growth cycle of trees, as well as other terrain change parameters, can provide early warning of their impact, shorten inspection time, reduce costs, and improve inspection accuracy. The accuracy can reach 99.9%, with high reliability.

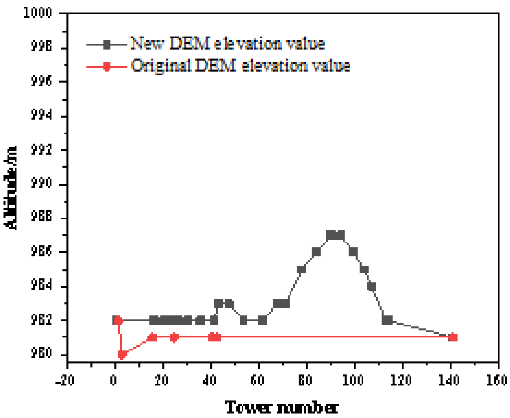

Fig. 4.1: Terrain Change Profile

Table 4.2: Grid data corresponding to the second collection of DEM

Number	Longitude x/(°)	Latitude y/(°)	Altitude z/m
1	109.902086	40.506994	981.32
2	109.902096	40.507016	981.24
3	109.902105	40.507044	981.15
4	109.902113	40.507077	981.56
5	109.902123	40.507096	981.40
6	109.902135	40.507128	981.37

5. Conclusion. The author proposes an information-based monitoring of the operating environment of transmission lines based on Internet of Things technology. Online monitoring is an important means to ensure the safe operation of the power grid and improve its transmission capacity. Due to the fact that most equipment safety issues on transmission lines cannot be detected with the naked eye, there is an urgent need to build an online fault monitoring system. The Internet of Things technology involves deploying a large number of sensing devices (such as smart sensors, electronic tags, RFID modules, etc.) to include all key equipment parameters of transmission lines in the monitoring scope. By establishing a unified information model at the sensing layer, it is compatible with data sensing formats from different manufacturers, after data preprocessing and storage by the aggregation controller, the data is transmitted to the power grid through a unified communication protocol. At the application layer, the principal component analysis method is used to analyze the real-time monitoring data. By setting appropriate alarm thresholds, it is determined whether there is a fault in the transmission line. The author's research did not involve the study of a unified information model and unified communication protocol for the Internet of Things. The next step of research will mainly focus on obtaining a unified information model suitable for parameter perception of transmission line equipment.

Acknowledgement. Management Technology Project of State Grid Power Space Technology Co., LTD. : Deepening Application Research of 3D System based on laser scanning Data (5100/2022-44005B)

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Edited by: Bradha Madhavan
Special issue on: High-performance Computing Algorithms for Material Sciences
Received: May 18, 2024
Accepted: Jun 25, 2024