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Research Article

Distribution Network Disaster Early Warning and Production Decision Support System Based on Multisource Data

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Aiming at the problems of long warning time and low warning accuracy in the traditional distribution network disaster early warning and production decision support systems, a distribution network disaster early warning and production decision support system based on multisource data is designed. The forecast information is collected through the data collector, the wind load and lightning trip rate of the line are calculated, all of the information is integrated together for multisource data fusion processing, and the distribution network disaster early warning model is constructed in accordance with the system hardware, which is designed with a data collector, gateway, man-machine interface, fault analysis module, disaster early warning module, and expert decision support module. According to the system hardware and software design, the design of a distribution network disaster early warning and production decision support system based on multisource data is realized. The simulation results show that the system has high accuracy and a short warning time.

1. Introduction

In recent years, disastrous global weather has occurred frequently, resulting in rainstorm, hail, typhoon, haze, and other disastrous weather, which has an adverse impact on the normal operation of power equipment. For example, the ice disaster in northern Guangxi in 2008, the "weimasson" typhoon in Beibu Gulf in 2014, and the waterlogging caused by the rainstorm in Central Guangxi in 2019 not only caused the interruption of power supply for a large range of users but also bred potential power-related safety hazards [1]. Normal meteorological changes also have a great impact on power grid operation and power production activities. For example, outdoor high-voltage tests cannot be carried out in rainy weather. Heavy rain can cause water accumulation in the substation and rain leakage in the house, resulting in abnormal DC grounding or primary system grounding. In windy conditions, line wind deviation and galloping are easily caused, which leads to discharge tripping. Strong wind-borne floating objects are strung on a conductor, which will discharge in the event of precipitation and condensation. When the insulator is damp following pollution deposition, pollution flashover may happen. Increased load may be a result of high temperature. The likelihood of equipment overheating rises when a high temperature and heavy load are combined [2]. Another illustration would be windy weather, which has a significant impact on high-altitude operations and increases the risk of high-altitude operations due to loose ponding in pit foundations after rain, pole installation after rain, etc. With the improvement of the new generation Doppler weather radar network, the observation level of meteorological satellites has been continuously enhanced, the information transmission technology has been continuously upgraded, and the weather prediction ability of meteorological departments has also been greatly improved. However, the public meteorological service information provided by the meteorological department, whether in form, accuracy, scale, and timeliness, cannot meet the production needs of the power grid. The weather process early warning issued by the meteorological department is not described in detail; the description of the impact scope is relatively general; the start time and end time are not accurate; and the intensity distribution is not specific. It is the lack of guiding significance for the preprediction and postevaluation of the impact on power production [3]. The power grid enterprises' emergency plans for thunderstorms, gales, extreme heat, and other weather are currently subject to the superior documents, which are frequently behind schedule. Additionally, the preparation time for the disaster prevention and reduction measures implemented is insufficient and unfocused. The work arrangement is arbitrary and blind, and there are no reliable methods to assess the impact scope and degree of rainfall for special patrols following rain. There is often a major waste of personnel, vehicles, and other resources when a patrol is conducted after a serious disaster, before a small disaster, without a disaster, or never. Due to the large variety and quantity of distribution network equipment, the company has built a number of distribution network business management systems and generated a large amount of operation data. At present, it can basically support the work and business development of distribution network. However, due to the fragmentation of the business system, insufficient horizontal coordination between systems, and insufficient support for management and decision-making, it is unable to realize data collaborative integration and management penetration, lack of support for transparent management of the distribution network, accurate allocation of resources, and emergency disposal. Therefore, it is necessary to carry out research and application on key technologies of distribution network management decision-making, disaster prevention and early warning, and production decision support, build an information system for distribution network disaster early warning, monitor the analysis and auxiliary decision-making of the power grid, and improve the disaster prevention and disaster disposal capacity of the distribution network.

A distribution network disaster early warning system based on geographic information systems is designed in literature (GIS) [4]. The system is composed of the data acquisition module, data analysis module, data preprocessing module, and disaster early warning module. The distribution network data is collected through the data acquisition module, including geographic information data, meteorological data, and power grid data. The data preprocessing module fuses the gathered distribution network data, and the processing outcomes are input into the disaster early warning module for distribution network catastrophe early warning. The literature [5] develops the distribution network disaster early warning system based on the operation state, analyses the distribution network operation state, builds the load rejection risk index system of the power supply capacity after the distribution network fault based on the operation state, obtains the load rejection risk index, and uses the Monte Carlo state sampling method to calculate the load rejection risk and develop the distribution network. However, the above two systems take a long time to carry out distribution network disaster early warning, resulting in low early warning efficiency. Document [6] designs a distribution network disaster early warning system based on the whole process. The system is divided into three functional modules. The first module is the data acquisition module, which is responsible for collecting distribution network disaster prevention and dispatching data; the second module is the operation status monitoring module, which mainly monitors the collected distribution network disaster prevention and dispatching data; and the third module is the early warning module. Carry out early warning on the monitored data, formulate an emergency repair plan, and complete the design of the distribution network disaster early warning system in the whole process through three modules. The literature [7] develops a distribution network disaster early warning system based on image monitoring, designs system hardware through an image acquisition unit, communication unit, and early warning unit, monitors distribution network sites, collects distribution network overhead line site images, analyses distribution network overhead line disaster impact degree based on the collected image, provides early warning, and completes system software design. Although the above two systems have realized the design of distribution network disaster early warning system, the early warning accuracy is low and the early warning effect is poor.

In view of the problems existing in the above system, this paper carries out the research on the distribution network disaster early warning technology integrating multisource data, establishes the distribution network disaster early warning and production decision support system, realizes the management transformation of "predisaster early warning and prevention, disaster emergency management, and postdisaster emergency repair decision", and provides in-depth analysis and auxiliary decision-making for distribution network disaster prevention.

2. Design of the Distribution Network Disaster Early Warning and Production Decision Support System Based on Multisource Data

2.1. Overall System Framework. The distribution network disaster early warning and production decision support systems are designed in this study using two system hardware and software components. The data collector, gateway, man-machine interface, fault analysis module, disaster early warning module, and expert decision support module are all parts of the system hardware [8]. The overall frame design is shown in Figure 1.

2.2. System Hardware Design

2.2.1. Design of the Data Collector. The data collector is the primary system data collecting instrument in the early warning of distribution network disasters and production decision support processes. Control of the ad chip during data collector design is dependent on FPCA. After CPS transmits the clock signal to FPCA, it uses a variety of data processing techniques to acquire the ad chip trigger command [9]. In addition, the sampling measurement value is added to the collector to realize the efficient data collection.

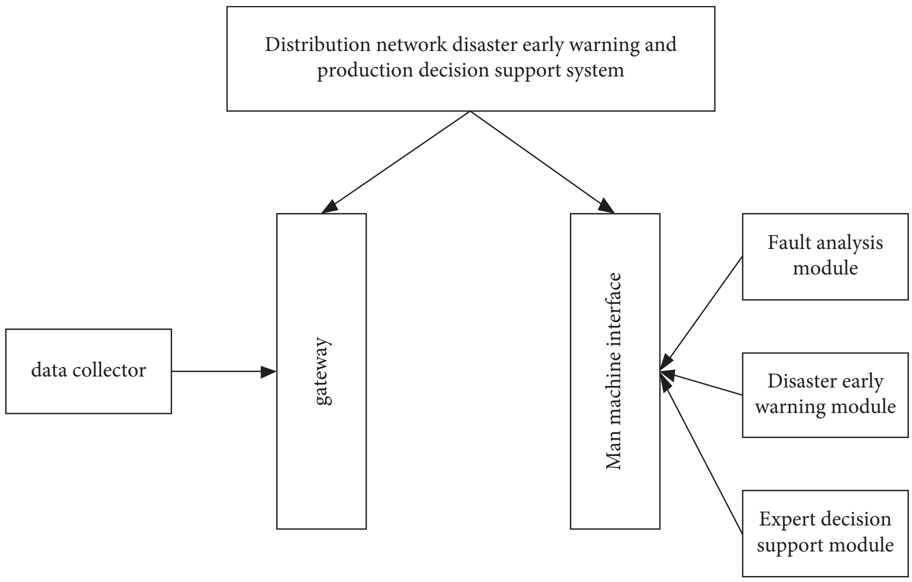

Figure 1: Overall system framework design.

The analog channels of the data collector are set to 8, and the input current and input voltage of each channel are 0–10 A and 0–350 V, respectively.

2.2.2. Gateway Design. This study builds the raspberry gateway architecture illustrated in Figure 2 based on the Internet of Things architecture of Linux, taking into account the connection of various hardware devices in the distribution network catastrophe early warning and production decision support system. The primary hardware needed for gateway design is a CPU, DDR, and flash chip, according to the network architecture diagram [10]. Flash chips play the role of hard disk. Sx1278 RF chip is selected in this paper, and the system memory function depends on the DDR module. During the working process of the monitoring and early warning system, the application program and main files are placed on the flash chip.

Because the sx1278 RF chip is transparent to the transmission of operation data of distribution network equipment, in order to improve the communication distance of operation data of distribution network equipment, Lora spread spectrum technology is adopted in this paper to expand the working frequency band of data transmission by about 50 MHz, so as to ensure that the transmission of operation data of network IT hardware can better resist external interference [11].

2.2.3. Man-Machine Interface Design. The GIS platform can present the analysis results and early warning outcomes through the human-machine interface and has robust geographical analysis and display capabilities. An effective man-machine interface for distribution network disaster early warning is provided by the GIS platform. Planners and domain experts can effectively participate in each early warning and planning process through the GIS platform; that is, human intelligence can be organically integrated into the early warning and planning process [12].

2.2.4. Design of the Fault Analysis Module. Due to various geographical locations, natural disasters occur frequently, especially extreme weather such as typhoon, lightning, hail, rain, and snow and strong convective weather, which cause great harm to the safe and stable operation of distribution networks, resulting in the failure of distribution network [13]. Therefore, the fault analysis module is designed to analyze the faults of the distribution network under natural disasters and provide theoretical basis for expert decision support. The fault analysis process is shown in the Figure 3.

2.2.5. Design of the Disaster Early Warning Module. Through the distribution network disaster early warning module which analyzes the abnormal situation of the distribution network, it will intelligently alarm when the safety state of the distribution network is abnormal [14]. Additionally, it involves the processes of measuring abnormal conditions, sending SMS warnings, controlling detecting conditions, looking for alarm data, etc. Setting the appropriate short message transmission device is required to finish the SMS alarm notification [15]. The disaster early warning module is divided into two parts: abnormal detection condition management and abnormal alarm information query, which correspond to three different submodules. The disaster early warning module is shown in Figure 4.

When the submodule has the measurement function of the background of the current distribution network, it can enable the staff to more comprehensively grasp the hidden state of the current distribution network risk and clarify whether there are corresponding abnormal situations. Through the functional design of this part, the staff can find some abnormal alarm information in time, master the required data and information, and bring more references to subsequent decisions [16].

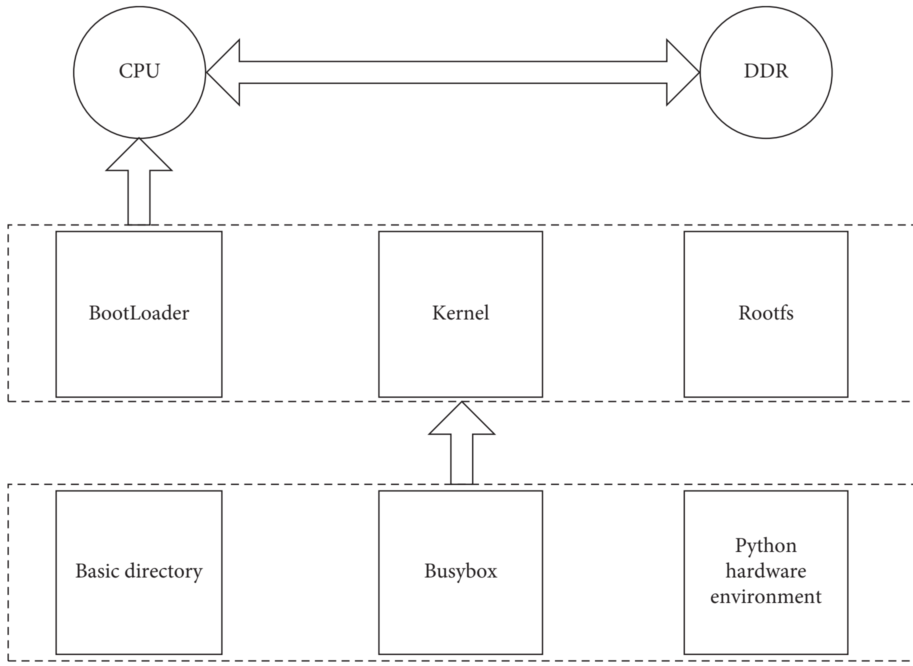

Figure 2: Gateway architecture.

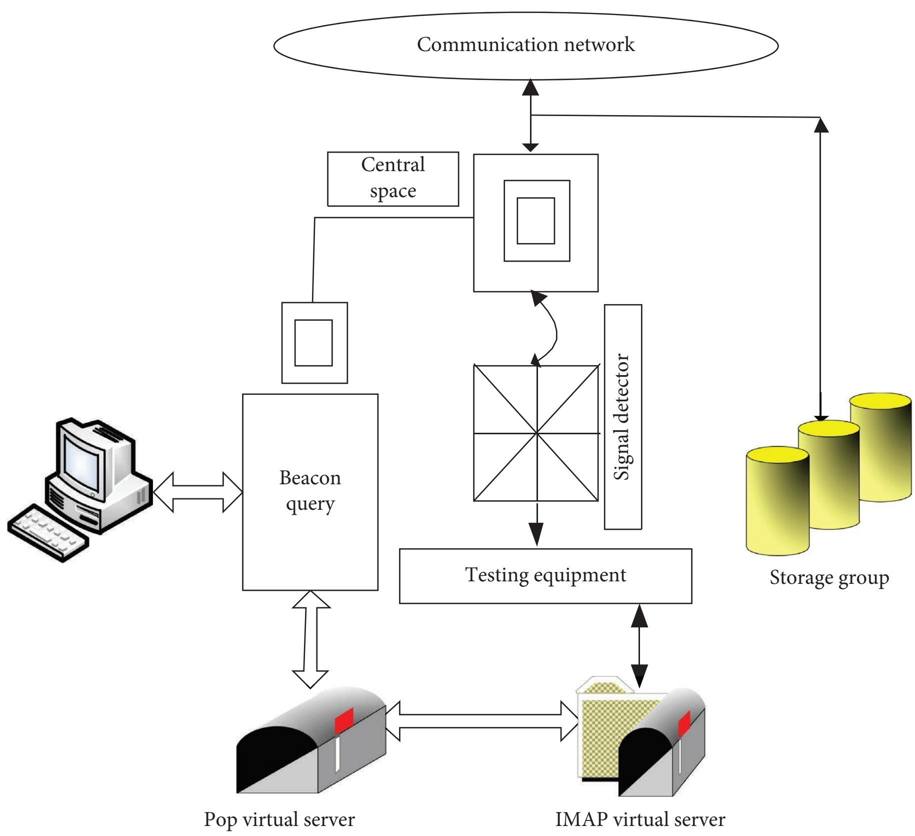

Figure 3: Fault analysis process.

2.2.6. Design of Expert Decision Support Module. The central component of the production decision support system that ensures the coordinated operation of all sections is the expert decision module. A thorough analysis and decision-making process are carried out, a distribution network disaster early warning scheme is created, and the findings are saved in the database utilising a variety of information connected to distribution network disaster early warning and knowledge

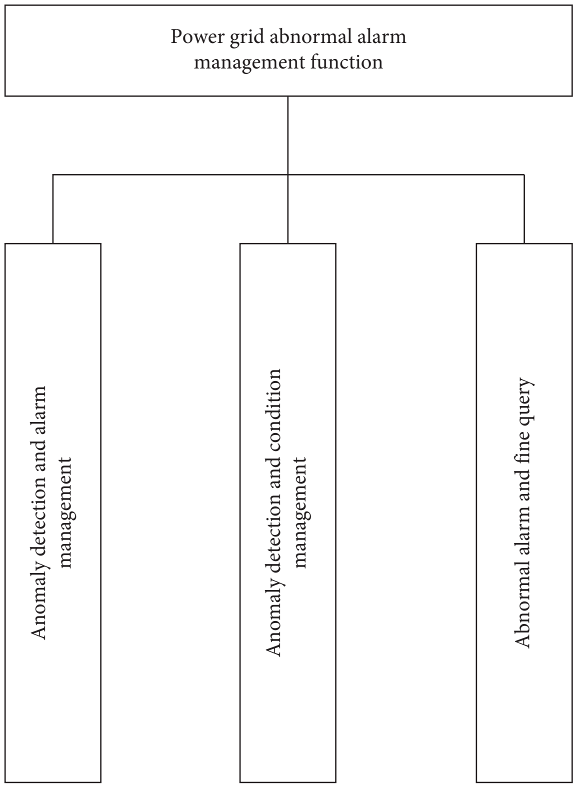

Figure 4: Disaster early warning module.

in the knowledge base [17]. Through message transmission to coordinate the relationship between various databases and information transmission between them. The structure of the expert decision support module is shown in Figure 5.

2.3. System Software Design

2.3.1. Distribution Network Multisource Data Acquisition. Meteorological disasters affecting the safe operation of distribution network include lightning, galloping, wind, icing, pollution flashover, and geological disasters [18]. In this paper, the prediction information is collected through the data collector, as shown in Table 1.

Through the above analysis, it can be seen that wind and lightning are frequent meteorological disasters at present. Therefore, this paper studies under the conditions of wind and lightning meteorological disasters to calculate the line wind load and lightning trip rate [19].

(1) Wind Load. The influence of wind load on the outage rate of distribution lines is mainly reflected in: (1) medium speed and stable wind acts vertically on distribution lines, causing line vibration; (2) the higher the distribution tower is, the more seriously it is affected by the wind load. The line and tower are prone to tower-line coupling and galloping.

The subtraction operation is realized by adding an expression to simulate the relationship between wind load and climate intensity and distance in climate:

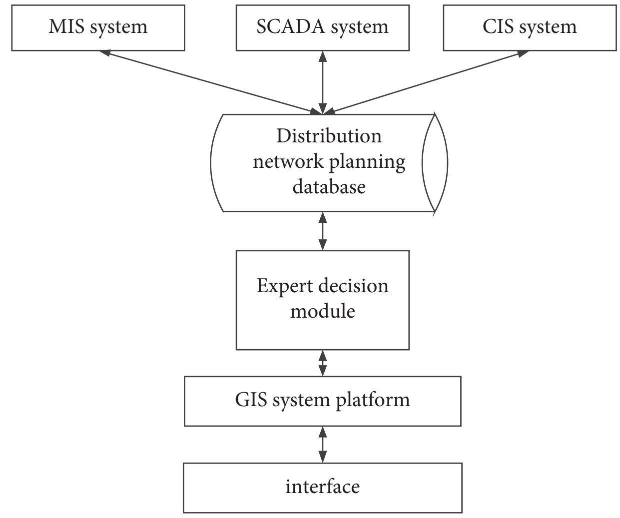

Figure 5: Structure diagram of the expert decision support module.

$$w_\beta(t) = \sin\beta(t)(x_i, y_i), \tag{1}$$

where $\beta(t)$ represents the included angle between a section of distribution line (x_i, y_i) and wind direction, and $w_\beta(t)$ represents the influence of wind direction on the wind load of distribution line. When $\beta(t) = 90^\circ$, that is, when the wind direction is perpendicular to the distribution line, the distribution line bears the maximum wind load [20].

Suppose that a certain section of the distribution line between coordinate points (x_m, y_m) and (x_n, y_n) also bears coordinate (μ_n, μ_n) in the climate, and the included angle of vector $\gamma = (x_m, y_m)$ and vector $u = [(x_m, y_m), (x_n, y_n)]$ changes between $0 \sim \pi$.

Since the wind direction is always perpendicular to the vector γ, $\beta(t)$ varies between $0 \sim \pi/2$, that is,

$$\beta(t) = \begin{cases} \dfrac{\pi}{2} - \alpha\alpha \leq \dfrac{\pi}{2}, \\ \\ \alpha - \dfrac{\pi}{2}\alpha > \dfrac{\pi}{2}. \end{cases} \tag{2}$$

(2) Lightning Trip Probability. There are many factors affecting protection tripping, among which the most important factor is a lightning stroke. Therefore, to study the relationship between lightning stroke and protection tripping, lightning stroke tripping factors must be extracted from many influencing factors, and the expression is as follows:

$$D = D_W + D_M + D_P, \tag{3}$$

where D_W is the influencing factor of the lightning strike, D_M is the influencing factor of equipment, and D_P is the factor of human misoperation. The latter two factors are represented by a simple linear relationship:

Table 1: Collection of forecast information.

Early warning objects	Meteorological information content	Spatiotemporal resolution
Thunder	Basic elements: rainfall; characteristic parameters: thunder cloud height and direction, radar echo intensity, echo top height, vertical cumulative liquid water content, lightning current amplitude	1 km × 1 km; 0.5 h~4 h, 10 min by 10 min
To dance wind disaster	Basic elements: precipitation, temperature, relative humidity, wind speed, wind direction; meteorological events: rime, rime, freezing rain, icing	1 km × 1 km; 0 h ~ 24 h, 1 min by 1 min
Icing pollution flashover	Basic elements: wind speed and direction; meteorological events: system gale, squall line wind, typhoon	1 km × 1 km; 0 h~24 h, 15 min by 15 min
Geologic hazard to dance	Basic elements: rainfall, temperature, relative humidity, wind speed, wind direction; meteorological events: rime, rime, freezing rain	1 km × 1 km; 0 h ~ 24 h, 1 min by 1 min
Wind disaster micing	Basic elements: temperature, humidity, air pressure, precipitation, wind speed, wind direction; meteorological events: fog, haze, sandstorm, drizzle	3 km × 3 km; 0.5 h~4 h, 1 min by 1 min
Pollution flashover	Basic elements: rainfall; meteorological events: rainstorm and typhoon	3 km × 3 km; cumulative rainfall of LH, 3 h, 6 h, 12 h and 24 h

Table 2: Early warning level of wind bias discharge.

Wind bias discharge probabilities	Early warning level
$80\% \le P_{WSD}$	Grade I (red)
$60\% \le P_{WSD} < 80\%$	Grade II (orange)
$40\% \le P_{WSD} < 60\%$	Grade III (yellow)
$20\% \le P_{WSD} < 40\%$	Grade IV (blue)
$0\% \le P_{WSD} < 20\%$	No alarm

Figure 6: Topography of the N60 tower and its surroundings.

$$D_M = at + b,$$
$$D_P = ct + d, \tag{4}$$

where t represents time (days), a, b, c, d represents coefficient, and the above parameters are estimated by the least square method. Substituting the obtained a, b, c, d into the above formula, we can get that D_M is the equipment impact probability and D_P is the human misoperation probability. The lightning impact probability D_W can be obtained by subtracting D_M, D_P from the total impact probability D.

2.3.2. Distribution Network Multisource Data Fusion Processing. Deliver the cluster head node the combined information you combined for fusion processing, and the cluster head node will send data packets to the sink node. Due to the nodes' density and excessive acquisition frequency, more duplicated information is generated during this process, which clogs the distribution network, raises the packet loss rate, and lengthens network delays. Therefore, the data fusion processing should be carried out on the data.

The data fusion algorithm can be analyzed using time correlation and spatial correlation. Time correlation refers to the high similarity between data caused by acquisition frequency, so it can be fused. The collector node's acquisition frequency can be manually adjusted; however, if it is set too high, there will be an excessive amount of comparable data. The real-time performance is not good, and too low an early threshold will prevent real-time monitoring of the field data. As a result, we can perform data fusion processing by setting the secondary threshold, which states that when the difference between the data and the value collected at the previous time is greater than a certain value (primary threshold), the data will be sent as normal data; otherwise, it won't be sent. When the secondary threshold is exceeded and the data continues to change, it will be sent to the disaster early warning module as abnormal data via the emergency channel.

Spatial correlation analysis means that due to the dense nodes, the similarity of the data collected between adjacent nodes is very high. Therefore, to fuse the redundant information, the idea of the average value can be used to reduce the redundancy of data, such as temperature, humidity, wind, and other parameters. Due to the close location, the collected data are similar, and the repetition rate is high. Therefore, the average method is adopted to reduce the redundancy of data, remove the highest and lowest values from the data collected by nodes in each cluster, and then calculate the average value as follows:

$$T = \frac{1}{n-2}\left(\sum_{i=1}^{n} T_i - T_{\min} - T_{\max}\right). \tag{5}$$

If there are 10 nodes in a cluster, including 1 cluster head node and 9 noncluster head nodes. Each collector node must be transmitted to the cluster head node. If data fusion is not carried out, the node needs to transmit data for each period. After data fusion, only one data is needed, which greatly reduces bandwidth traffic, data collision, packet loss rate, and delay. Firstly, it is assumed that the data collected by the sensor meets the normal distribution, and then the standard deviation S of n data is calculated.

If the data fusion coefficient of the sensor node is λ, the length of the data packet received by the sensor node is k_{rec}, and the length after data fusion is k_{trans}, then:

$$\lambda = \frac{k_{\text{rec}}}{k_{\text{trans}}}. \tag{6}$$

Fuse the data of N, and the length of each data is $x + a$, then:

$$k_{\text{rec}} = M * (x + a),$$
$$k_{\text{trans}} = N * x + N * a, \tag{7}$$

where x is the data length, and a is the packet header length. When $1 < M < N$, it indicates that some data have been fused. When $M = 1$, it indicates that the fusion effect is the best at this time, and multiple data packets are fused into one data packet. When $M = N$, there is no data fusion. It can be seen that when the fusion effect is better, the received packet length is smaller, so the fusion degree coefficient λ is smaller.

2.3.3. Early Warning Model Construction. According to the above multisource data fusion processing results of the distribution network, a distribution network disaster early warning model is constructed. Firstly, the clear value is set as Q, the current output value is x_1, the current input value is x_2, the synthesis coefficient is e, the distribution network line is I, and the line number is i. The TS type synthesis method is used to calculate the synthesis of the distribution network current input value and output value, and the clear value is obtained. The expression is as follows:

Table 3: Experimental environment settings.

Software names	Version information
Development platform	My eclipse ide integrated development platform
Java platform	Java EE
GPRS module	M590 GPRS wireless communication module. The GPRS module of the monitoring device directly adopts the equipment information provided by the equipment supplier
Programing language	Java, JSP, HTML, Javascript, SQL
Database	MySQL enterprise server (enterprise edition)
Web server	Tomcat 7.0.52
SSM version	Springmvc 5.0.6 Spring 5.0.6, Mybatis 3.4.5
Web browser	Ie90 and above kernel version

Table 4: Release format of wind disaster early warning.

Alert numbers	Release time	Early warning line	Early warning content	Early warning level	Early warning prescription
2021-5-7-001	2021-5-7 20 : 00	220 kV XX line XX tower	Wind bias discharge probability 73.78%	Grade II orange	23 : 00–02 : 00

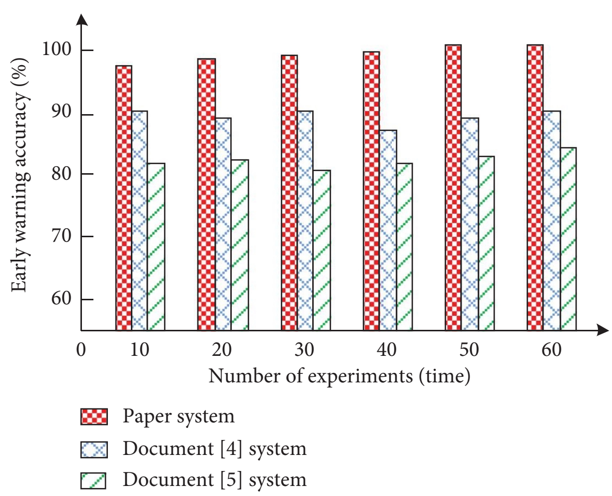

Figure 7: Distribution network disaster early warning accuracy of three systems.

$$Q = \sum_{i=0}^{I} \left(\frac{x_1}{x_2} - e \right). \quad (8)$$

Set F as the set, gather the Q calculated above into it, and regularize it to meet the construction requirements of the early warning model. The expression is as follows:

$$F(Q) = \sin Q - \cos e. \quad (9)$$

Set the distribution network disaster early warning value as K, the distribution network line distance as s, the early warning time as t and the early warning frequency as f, then the constructed distribution network disaster early warning model is as follows:

$$K = \left(s - \frac{\sqrt{t}}{Q} \right) \times f. \quad (10)$$

Considering that there is a margin in the design of the maximum wind deflection angle, and the wind speed value is also increased according to the predicted weakening rate during the probability sampling of predicted wind speed, the early warning threshold value of wind deflection discharge probability is set as $P_{\mathrm{WSD}} = 20\%$, which can be dynamically adjusted according to the early warning effect in practical application. The power industry generally adopts red, orange, yellow and blue to represent the risk level. In this paper, the early warning level of wind bias discharge is also divided into red, orange, yellow and blue, as shown in Table 2.

3. Simulation Experiment Analysis

In order to verify the effectiveness of the distribution network disaster early warning and production decision support system based on multisource data in practical application, an N60 tower of the 220 kV transmission line in an area is selected as the experimental object for a simulation experiment analysis. N60 tower and surrounding terrain are shown in Figure 6.

Table 5: Distribution network disaster warning time of three systems (s).

Number of experiments (time)	Paper system	Document [4] system	Document [5] system
10	4.23	12.50	22.60
20	4.36	12.60	23.50
30	4.55	12.80	23.90
40	4.63	13.50	24.60
50	5.20	13.90	24.90
60	5.63	14.60	25.10
70	5.92	14.70	25.80
80	6.12	15.20	25.90
90	6.13	15.90	26.50
100	6.58	16.80	27.90

The experimental environment settings are shown in Table 3.

Due to the frequent occurrence of strong winds of force 8~9 in this area, the system designed in this paper is used for wind disaster early warning for the N60 tower of 220 kV transmission line in this area. The format of early warning releases is shown in Table 4.

According to Table 3, the distribution network disaster early warning and production decision support system based on multisource data designed in this paper has a good effect on wind disaster early warning. In order to verify the effectiveness of this system, the distribution network disaster early warning and production decision support system based on multisource data designed in this paper, the GIS-based power meteorological disaster monitoring and early warning system designed in document [4], and the distribution network disaster early warning system designed in document [5] are used to compare and analyze the distribution network disaster early warning accuracy. The comparison results are shown in Figure 7.

According to Figure 7, the precision of distribution network disaster early warning and production decision support systems based on multisource data designed in this paper can reach 100%, and the early warning effect is good. The precision of distribution network disaster early warning by literature [4] and literature [5] is only 90% and 85%, respectively It shows that the distribution network disaster early warning and production decision support system based on multisource data designed in this paper has the highest accuracy.

The production decision support system based on multisource data, literature [4] early warning system, and the literature [5] early warning system designed in this paper are used to compare and analyze the distribution network disaster early warning time in order to further confirm the effectiveness of this system. The comparison results are shown in Table 5.

According to Table 4, the distribution network disaster early warning and production decision support system based on multisource data designed in this paper has the shortest early warning time and the highest early warning efficiency within 6.58 s.

4. Conclusion

This study develops a distribution network catastrophe early warning and production decision support system based on multi-source data since the traditional system takes a long time to carry out distribution network disaster early warning and the early warning accuracy is low. Software and hardware make up the system. The data collector, gateway, human-machine interface, fault analysis module, disaster early warning module, and expert decision support module are all included in the hardware. The software includes the steps of data acquisition, data fusion processing, and early warning model construction. The multisource data of the distribution network is collected through the data collector, and the collected data are fused. The distribution network disaster early warning model is built based on the processing findings, and the wind bias discharge early warning level is segmented. The simulation findings demonstrate the high distribution network disaster early warning accuracy and efficiency of the production decision support system based on multisource data, which paves the way for the secure operation of the distribution network.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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