Reliability Analysis Method of Multi Area Fault Diagnosis and Location in Power Grid with Missing Information

Jun-ci Tang[1,2(✉)], Tie Li[1], Jun-bo Pi[2], Miao Wang[1], and Feng Jiang[1]

[1] State Grid Liaoning Electric Power Supply Co., Ltd., Shenyang 110000, China
tangjunci66888@163.com
[2] State Grid Corporation of China, Beijing 100031, China

Abstract. Aiming at the problem of poor positioning accuracy of traditional power grid fault diagnosis methods, this paper studies multi area fault diagnosis and positioning reliability analysis of power grid under lack of information. By analyzing the topology of the distribution network, the location of the fault points in the distribution network is quickly determined, and the fault treatment scheme is given; Based on the lack of information, the simplified structure and mathematical model of key equipment are introduced. The matrix is used to describe the switch state and topological relationship, and the fault diagnosis module based on information loss is designed by using the grid fault diagnosis algorithm based on matrix operation. It realizes the fast detection of multi area fault diagnosis and location, improves the reliability of the detection results, and provides convenience for fast fault location and processing.

Keywords: Lack of information · Power grid failure · Fault diagnosis · Fault location

1 Introduction

With the rapid development of power system, more and more distributed generation access to the distribution system, so the structure of distribution network is more and more complex. When the distribution network fails, accurately and efficiently finding out the fault point or area is the prerequisite for rapid isolation and power supply recovery as soon as possible, which is of great significance to improve the reliability of the distribution system [1]. In the power grid fault diagnosis, the lack of information technology is used to establish the relevant spatial topology and mathematical calculation model, which can make the fault diagnosis quickly and accurately locate the specific switchgear.

At present, the common fault location of power grid is mainly based on dispatching operation model. This model lacks necessary line simulation, does not provide line load transfer scheme, and the control of the line is completely based on the influence of natural on/off. Because the switch control status and the line relationship are not quantified, the problem solving lacks the relevant mathematical model support, The algorithm is inefficient when the structure of the line changes, and there is no

S. Wang et al. (Eds.): IoTCare 2021, LNICST 414, pp. 326–343, 2022.
https://doi.org/10.1007/978-3-030-94185-7_22

information about the hierarchical structure of the overhead line, and the description of the power grid structure is not intuitive. Based on the information missing technology, the multi area fault diagnosis and location reliability analysis method of power grid is optimized, and a series of processes such as fault diagnosis model are used to determine the fault point information, and a series of processes such as fault handling operation ticket are automatically generated to ensure the accuracy of fault diagnosis and location results.

For this reason, the relevant scholars have carried on the research and made some progress. In reference [2], a power grid fault diagnosis method based on PMU data and convolutional neural network is proposed. The characteristic gas value is transformed from decimal to corresponding binary, which is represented by two-dimensional data, and the two-dimensional data is used as the input of convolutional neural network to train the optimization model. The fault diagnosis accuracy of this model is high, but the accuracy of fault diagnosis is poor. In reference [3], a power grid fault diagnosis method based on superimposed sparse de-noising automatic encoder and Gru network is proposed. The superimposed sparse de-noising automatic encoder is used to reduce the dimension of the sequence, and the sparse feature expression of the data is obtained. The fault type is obtained by using the time-varying feature of the data extracted by Gru. This method can effectively extract high-dimensional data features and reduce the data dimension, but the accuracy of fault diagnosis is poor.

Aiming at the problems of the above methods, this paper puts forward the reliability analysis method of multi area fault diagnosis and location in power grid under the lack of information, uses the fault diagnosis model to determine the fault point information, and automatically generates a series of processes, such as fault processing operation order, to ensure the accuracy of fault diagnosis and location results.

2 Multi Area Fault Diagnosis and Location Reliability of Power Grid

2.1 Multi Area Fault Location Algorithm in Power Grid

Power grid fault start algorithm is used to detect the time of fault occurrence, and is a prerequisite for fault analysis, diagnosis and processing. The whole power grid fault diagnosis system in the application of the actual power grid, is unattended, real-time operation. The core of the fault start algorithm is the start criterion. When the dynamic data of the system meets the start criterion, the start signal is sent to the fault diagnosis system. An ideal starting criterion is that it can start quickly and reliably in case of system failure and has high starting sensitivity [2]. In normal operation state of power grid, including overload, frequency fluctuation and system oscillation, it will not start reliably. In the digital protection device, according to the different protection principles, the classical electric quantity startup criteria are divided into steady quantity startup criteria and sudden variable startup criteria, and the steady quantity startup criteria are mainly divided into excessive startup criteria and insufficient startup criteria [3]. The starting criterion of sudden variables is based on the calculation and comparison of the changes between the measured values before and after the fault. Generally, it has higher sensitivity than the starting criterion of steady-state variables. Therefore, the sudden variables are widely used as the starting conditions in the fault diagnosis system. According to the different types of electrical quantity, it can be divided into voltage sudden change starting criterion and current sudden change starting criterion [4]. The four sampling value method is used to extract the current sudden change to realize the judgment of fault starting conditions, as shown in formula (1)

$$\Delta i(n) = \| i(n) - i(n-N)| - |i(n-N) - i(n-2N)\| > I_{xt} \tag{1}$$

where i(n) is the instantaneous value of phase current sampling at n time (which can be measured by synchronous phasor measuring device). N is the number of sampling points in each fundamental frequency period of PMU phase current data. In the calculation of each i(n), four sampling values are used, covering the sampling span of two periods, so as to reduce the influence of frequency deviation and system oscillation on the current value to a certain extent. I is the threshold value of the starting criterion of the current sudden change, and the threshold value is also set to effectively avoid the normal fluctuation of the characteristic quantity in the actual power grid [5]. Because the location problem of fault section in distribution network belongs to 0–1 integer programming problem, the binary information missing optimization algorithm is adopted, that is, the binary number is used to express whether the fault section occurs or not, 0 represents no fault, and "1" represents fault [6]. For BPSO, the update formulas of velocity vector and position vector are as follows:

$$v_{im}^{T+1} = \omega v_{im}^{T} + a_1 r_1^T \left(P_{\text{best.im}} - x_{\text{iu}}^T\right) + a_2 r_2^T \left(G_{\text{bestim}} - x_{\text{im}}^r\right) \tag{2}$$

where $v_{im}^{T+1}, x_{im}^{T+l}$ is the velocity and position of the m bit of the T + 1 generation of information i, w is the inertia factor, a_1, a_2 is the acceleration factor, and $P_{\text{best}}, G_{\text{best}}$ is the optimal value of the information itself and the group over the ages:

$$\text{Sigmoid}\left(v_{im}^{T+1}\right) = \begin{cases} 0.98 & v_{im}^{T+1} > V_{\max} \\ \frac{1}{1+e^{-v}} & -V_{\max} < v_{im}^{r+1} < V_{\max} \\ -0.98 & v_{im}^{r+1} < -V_{\max} \end{cases} \tag{3}$$

In the process of optimization with information missing algorithm, the information keeps approaching the optimal value. When the convergence condition is satisfied, the more likely the fault section hypothesis is, the more information concentration, that is, the more times the information appears [7]. Therefore, it is proposed that the probability of each fault section set can be represented by the proportion of the occurrence times of each missing information, and the corresponding basic probability distribution function can be formed.

After a fault occurs in the distribution network, the distribution terminal installed at each section switch and tie switch can detect the fault current and upload the fault information to the master station. However, due to the bad working environment, communication impact and other reasons, information distortion or incomplete information often occurs in actual operation [8]. Based on this, a fitness function can be constructed to reflect the difference between the actual received fault information and the expected fault information, and then the BPSO algorithm is used to optimize the solution, and the multiple information corresponding to the minimum fitness function in the missing information and the times of its occurrence in the iterative process are recorded. The fitness function is used as the objective function for optimization:

$$F_1(R) = \text{ Sigmoid } \left(v_{im}^{T+1}\right) \sum_{j=1}^{N_2} \left|I_j - I_j^*(\mathbf{R})\right| + \omega \sum_{i=1}^{N_1} |\mathbf{R}(i)| \tag{4}$$

$$I_j^*(R) = \prod D_i - F_1(R) \tag{5}$$

The first traveling wave head transmitted from the received fault point is taken as the initial time to calculate the strongest positive jump point of voltage distribution along the line, and the fault point is determined by the location of the jump point. The calculation formula is as follows:

$$S_{\mathrm{i}} = I_j^*(R) \iiint L - S_{\mathrm{w}} \tag{6}$$

In the formula, S_{i} represents the distance between the fault point and the traveling wave bus; L represents the full length of DC line; S_{w} indicates the distance from the jump point to the test point. In order to calibrate the position of the fault point, the first derivative of voltage on the path can be calculated. The maximum positive value of the derivative corresponds to the position of the fault point. To calculate the voltage distribution on the path, the starting time should be calibrated, that is, the time when the initial traveling wave reaches the test point. Traveling wave fault location usually defines the time when the sampling value of voltage traveling wave exceeds a certain value as the initial time. The sampling frequency directly affects the accuracy of initial time calibration. When the traveling wave speed is the speed of light and the sampling frequency is 350 kHz, the maximum fault location error is within 300 m [9]. According to the above fault location principle, the voltage distribution along the line is calculated, and the corrosion fault point of HVDC transmission line is automatically diagnosed. The voltage distribution is the first voltage emission wave at a-terminal and the calculated voltage distribution on the path in the fault component network. Based on this, the principle of grid fault area screening is shown as follows (Fig. 1):

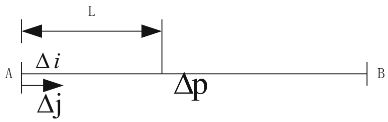

Fig. 1. Principle of power grid fault area screening

It can be seen from the figure that Δi and Δj represent the voltage component and current component of the corroded line fault point respectively; Δp is the voltage component of the fault point at L distance from A terminal. Under this condition, the voltage component Δp of fault point at t is calculated as:

$$\begin{aligned}\Delta p = & \frac{1}{2S_{\mathrm{i}}}\left[\Delta i\left(t-\frac{L}{V}\right)+\Delta j\left(t-\frac{L}{V}\right)C\right]e^{-\frac{rL}{c}} \\ + & \ \tfrac{1}{2}\left[\Delta j\left(t+\tfrac{L}{V}\right)-\Delta i\left(t+\tfrac{L}{V}\right)C\right]S_{\mathrm{i}}e^{\frac{rL}{c}}\end{aligned} \tag{7}$$

In the formula: r is the resistance per unit length of transmission line; C is the traveling wave impedance of transmission line; V is the traveling wave velocity. According to the law of refraction and reflection of traveling wave, the fault point can be diagnosed automatically. When a fault occurs at a certain position of the line, the voltage distribution on the path needs to be calculated. If the voltage component of the section is greater than the total voltage value, it means that the part of the line is faulty, otherwise it is normal [10]. Although the calculated voltage distribution on the path is false at the fault point, the voltage traveling wave is fully refracted at the bus, and it is refracted at the fault point, so the transmitted wave at the opposite end will not change greatly in the propagation process, that is, there is the strongest positive jump at the fault point, and the distance between the jump point and the opposite end is the fault point distance, Fault location can be achieved by using the distribution characteristics of traveling wave voltage [11, 12, 13].

When the fault occurs in different areas, different alarm information will be uploaded. The recognition framework and its basic probability distribution can be obtained from the alarm information. Then the fault section set which can best explain the uploaded information can be obtained by fusing multi-source information with evidence theory, which is the final diagnosis result. In summary, the flow chart of the fault section location method based on multi-source information fusion proposed in this paper is shown in the Fig. 2.

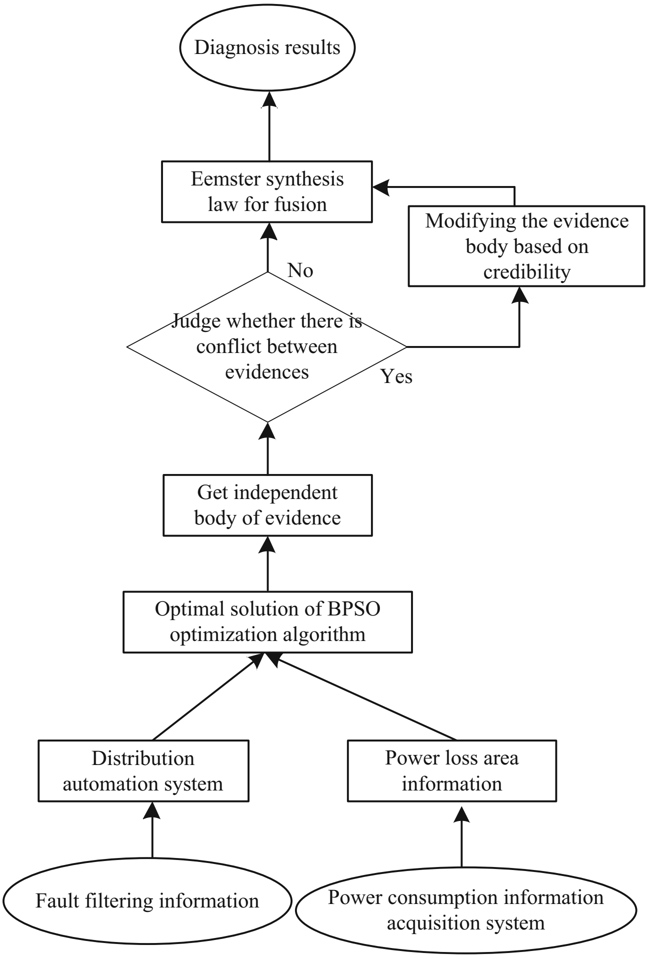

Fig. 2. Distribution network fault location process

The proposed algorithm obtains fault over-current information of distribution automation terminal from distribution automation system and abnormal voltage information from power consumption information acquisition system.

2.2 Fault Diagnosis of Distribution Network

There are many algorithms about fault type discrimination and fault phase selection, but most of them inevitably use sequence component to diagnose fault type more accurately. For example: according to whether there is a zero sequence component, it can distinguish whether it is grounded short circuit or ungrounded short circuit. According to whether there is a negative sequence component in the measured current, it is necessary to distinguish between two-phase short circuit fault and three-phase fault. It can be seen that the sequence component obtained by symmetrical component method has obvious advantages and importance in power grid fault analysis and diagnosis. Corresponding to the single-phase short-circuit grounding fault, it has the characteristics of positive sequence current, negative sequence current and zero sequence current, which can be represented by the composite sequence network diagram of positive sequence, negative sequence and zero sequence series. Similarly, for other types of faults, different boundary conditions in the form of sequence components will also be obtained. The main characteristics of distribution network missing information fault categories can be summarized as follows (Table 1):

Table 1. Main characteristics of distribution network missing information fault category

Type of short circuit	Main features	Composite order network
Three phase short circuit	Only positive sequence components, etc	/
Two phase short circuit	The positive sequence current and negative sequence current of non fault phase are equal	Parallel connection of positive and negative sequence
Two phase short circuit grounding	The non fault phase current is 0	Positive, negative and zero sequence parallel connection
Single phase short circuit	The three sequence currents of the fault phase are equal	Positive, negative and zero sequence series connection

The fault location based on voltage sag information is based on the different position fault, the short-time voltage sag value produced at each node of the system is different. Based on this, it is assumed that each node has a fault in turn, and the fault current at the fault point can be obtained by using the voltage sag value and system impedance. If the node is the real fault point, the current should be consistent with or almost the same with the actual fault current value. Therefore, it can be judged whether each node is a real fault node. After the distribution network fails, it is equivalent to adding an injection current meter at the fault point to divide the distribution network in the fault into two parts, as shown in Fig. 3:

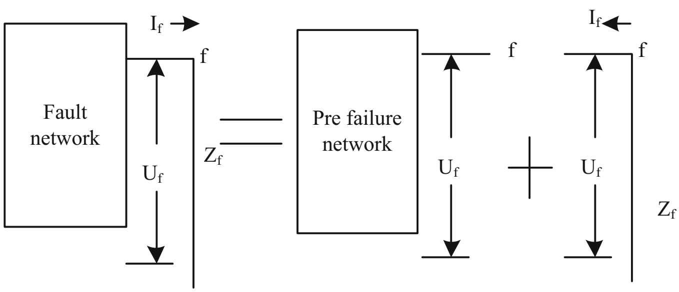

Fig. 3. Fault component missing information diagnosis

When the distribution automation terminal at the key position is missed or misreported, the fault location method of traditional single information source will often lead to misjudgment. For example, when the distribution terminal in the fault section fails to report or the adjacent downstream distribution terminal misalarm, it will get the wrong conclusion whether using matrix algorithm or artificial intelligence algorithm. This is the inherent defect of fault section location by using fault overcurrent information alone, and the multi-source information fusion can solve this problem well. It is assumed that there is a fault on Sect. 11, but FTU on Section II fails to upload the flow information to the control center of the main station due to communication reasons, that is, the fault over-current information field is 100100010000000, and the load point information field called by ceias is 0000010. In this case, the fault section set and its basic probability distribution obtained by BPSO algorithm are shown in the Table 2.

Table 2. Section diagnosis results in case of loss of fault information of key position

possibility	Fault section set	M1	M2	Fusion results	K value
1	8	0.6772	0.0000	0.5032	0.1276
2	10	0.1381	0.0000	0.0415	
3	11	0.1305	0.9221	0.6946	
4	12	0.0287	0.0000	0.0086	
5	4,8	0.0260	0.0000	0.0079	
6	3,9	0.0000	0.0227	0.0159	
7	4,9	0.0000	0.0191	0.0135	
8	9,11	0.0000	0.0183	0.0128	
9	8,11	0.0000	0.0183	0.0128	

When there are multiple distribution automation terminals that fail to report or misreport, the accuracy of traditional section positioning method is not high, and the optimization algorithm is often used to solve the problem, which often needs iteration many times to obtain the final result. The voltage value at any node in the network can be divided into two parts, the normal component and the fault component are

$$\mathbf{U}_i = \Delta p \mathbf{U}_i^{01} - Z_i \mathbf{I}_f \tag{8}$$

Suppose there is a fault in Sect. 13, but the terminal at the head end of Sects. 8 and 12 does not upload the over-current information to the master station control center due to equipment reasons, that is, the actual uploaded fault over-current information is 100100010, and the load point information field called by CEIAS is 00100. The fault section set and its basic probability allocation M1 and M2 obtained by BPSO algorithm are shown in the Table 3.

Table 3. Diagnosis results of multiple distribution automation terminals with information loss

possibility	Fault section set	M1	M2	Fusion results	K value
1	4	0.4586	0.0000	0.1459	0.0751
2	4,9	0.4152	0.0000	0.1342	
3	9	0.0367	0.0000	0.0112	
4	4,12	0.0326	0.0315	0.0348	
5	4,13	0.0315	0.0000	0.0095	
6	13	0.0000	0.8503	0.5953	
7	9,12	0.0000	0.0587	0.0398	
8	12	0.0000	0.0369	0.0259	
9	8,13	0.0000	0.0358	0.189	

The intelligent fault location depends on the fault information fed back by the monitoring center. According to the operation status of the master station before and after the fault, it makes a comprehensive judgment to determine the fault area. After the fault occurs in the distribution network, the distribution automation feeder terminal unit collects the corresponding current waveform and uploads it to the master station for data monitoring. After receiving the feedback information, the switch displacement information on the circuit breaker will control the start of fault location software.

Since genetic algorithm can't directly convert parameters into data, it is necessary to encode parameters into binary digital strings. The genetic operation only operates on the digital string, while the fault location of distribution network should be 0/1 coded according to the requirements of genetic algorithm. The fault of current equipment flowing through the fault line is set to 1, and the fault of current equipment flowing through the fault line is set to 0. By analyzing the status of feeder terminal unit in distribution automation, it is determined whether the switches in each area can be started normally, which reflects the relationship between each element and switch in distribution network. For a single power supply circuit, the switching function can be defined as:

$$F(\mathrm{x}) = \mathbf{U}_i \left[1 - \sum_{m=1}^{\mathrm{m} \neq \mathrm{n}} x(m) \right] \| x(m+1) \| \tag{9}$$

In the formula: $F(\mathrm{x})$ is the switch function; $x(m)$ indicates the state value of the m element downstream of the switch; G is the number of elements downstream of the switch. The fitness function is constructed as follows:

$$k(\mathrm{x}) = \sum_{j=1}^{h} |\mathrm{f}(\mathrm{x}) - F(\mathrm{x})| \tag{10}$$

where $k(\mathrm{x})$ is the fitness value in space; $\mathrm{f}(\mathrm{x})$ is the real state of the switch. Fault location is calculated by searching the minimum difference between the actual state value and the derived state value in $k(x)$ space, which is the minimum solution of the formula. According to the above content, the specific flow of fault intelligent positioning system is shown in the Fig. 4.

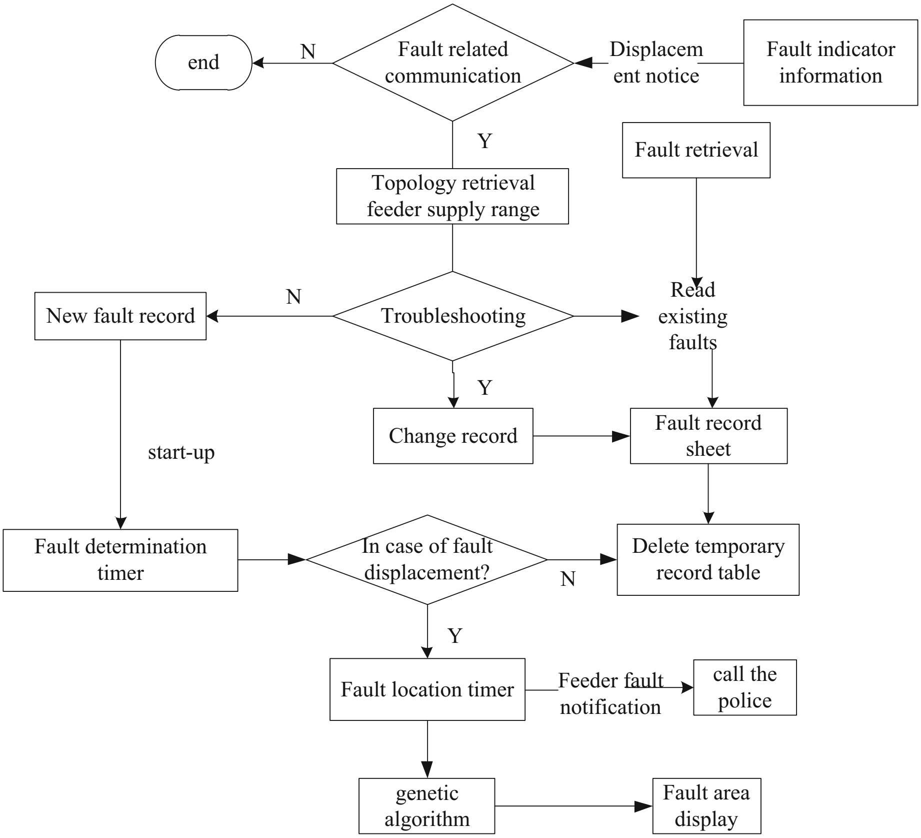

Fig. 4. Intelligent fault diagnosis process of multi area power grid

The power system of distribution network is a complex system, and there are uncertainties between data and signal. Genetic algorithm can improve the uncertainty of data. Combined with the specific implementation process shown in the figure, the function design of system central station is completed to ensure the effect of multi area fault intelligent diagnosis.

2.3 Reliability Optimization of Fault Diagnosis and Location in Power Grid

During the operation of power grid equipment, lidar will scan a set of point data sets in radar coordinate system. The relevant target information points are extracted from the point data set, including scan point, start point and end point. The purpose of feature extraction is to find fault location information points in all information points.

After scanning point data set $(a_{\mathrm{i}}, \theta_{\mathrm{i}})$, most of the feature points are invalid due to reflection, so it needs to be preprocessed. The specific steps of pretreatment are as follows:

Filter point $a_{\mathrm{i}} > D_T$ data in all point data sets to obtain effective point set $\left(a_{\mathrm{j}}, \theta_j\right)$;

Calculate the distance $a_{\mathrm{j,j+1}}$, $a_{\mathrm{j,j+1}} = \left|a_{\mathrm{j}} - a_{\mathrm{j+1}}\right|$ between the two points in the relative concentration of effective feature points;

According to the formula, we can judge whether a_{j} and $a_{\mathrm{j+1}}$ belong to the same effective subset W_{i}:

$$a_{\mathrm{j,j+1}} \leq A_0 + D_{\min} \cdot \frac{\tan\alpha\sqrt{2(1-\cos\beta)}}{k(\mathrm{x})\cos\frac{\beta}{2} - \sin\frac{\beta}{2}} \tag{11}$$

Among them, $D_{\min} = \min\left\{a_{\mathrm{j}}, a_{\mathrm{j+1}}\right\}$; β is the angle resolution of lidar; α and A_0 are system parameters. Based on this, α is further calculated as follows:

$$\begin{aligned} v &= \sqrt{a_{\mathrm{j}}^2 + a_{\mathrm{j+1}}^2 - 2a_{\mathrm{j}}a_{\mathrm{j+1}}\cos\beta} \\ \alpha &= \frac{\pi-\beta}{2} - \arcsin\left(\frac{a_{\min}\sin\beta}{v}\right) \end{aligned} \tag{12}$$

In the formula: v represents the distance between adjacent feature points, and the measured distance values of these two points are a_{j} and $a_{\mathrm{j+1}}$ respectively. If $a_{\mathrm{j,j+1}}$ satisfies the formula, then we need to put $\left(a_{\mathrm{j}}, \theta_j\right)$ into the effective subset W_{i} and $\left(a_{\mathrm{j+1}}, \theta_{j+1}\right)$ into a new effective subset $W_{\mathrm{i+1}}$. We can judge $a_{\mathrm{j+1,j+2}}$ until the effective point data is completely judged and identified. Based on the power grid fault diagnosis method based on PMU data, a power grid fault diagnosis system based on PMU data is designed and developed by using VC + + 6.0. The diagnosis process is shown in the Fig. 5.

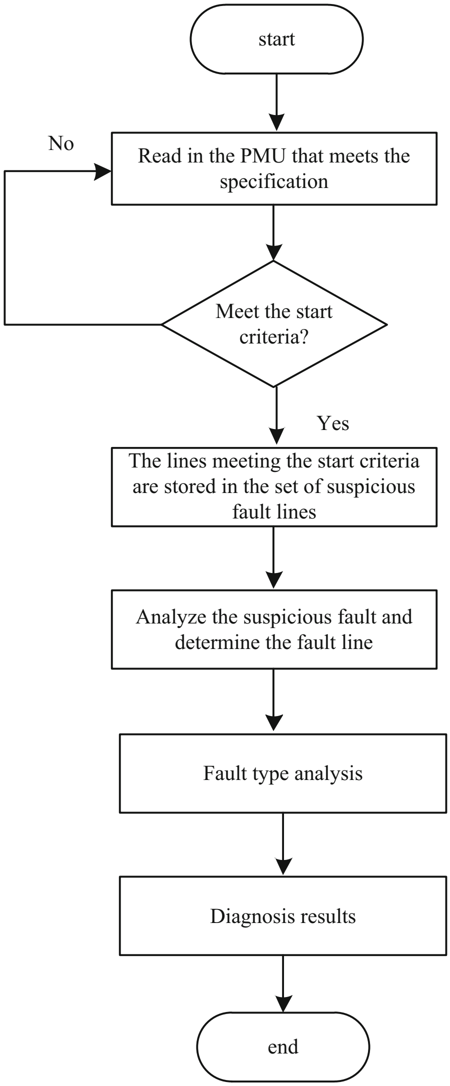

Fig. 5. Process optimization of fault location and diagnosis in power grid.

As shown in the figure above, the power grid fault diagnosis method developed in this paper will start from the data, monitor and refresh the received synchronized phasor data in real time, calculate and analyze them, and judge whether they are fault start criteria. If it is satisfied, it is considered that the system may have a fault, and the set of lines meeting the start criteria is stored in the set of suspicious fault lines. Then, the fault location analysis of the lines in the suspicious line fault set is carried out based on their respective data, and the fault lines are quickly selected and stored in the fault line set. The data of the fault line is extracted, and the characteristics of its electric quantity change are analyzed to diagnose the fault type and fault phase. Finally, a fault diagnosis conclusion including fault occurrence time, fault component, fault type and fault is output. According to the coordinates of the substation equipment in the global coordinate system, the positioning workflow is designed. The specific steps are as follows:

① Power on self check;

② Send get_ Health request;

③ Check whether the data receiving time-out, if the time-out, the broadcast communication error; If there is no timeout, proceed to the next step;

④ Check whether protective shutdown is selected. If it is stopped for the first time, it is necessary to send a reaet request and return to step 2 with a delay of 5 ms. If the machine is shut down for many times, troubleshooting is needed. If there is no downtime, send scan request;

⑤ Receiving ranging data;

⑥ Whether the waiting time is out of time. If it is out of time, it is necessary to deal with the fault and check whether the scanning equipment is running normally. If there is no timeout, it is necessary to preprocess the ranging data;

⑦ Check if the scan is finished? If it is, it needs to send a stop request to obtain the specific location of the fault. If not, wait until the scan is complete.

According to the positioning workflow, the relevant fault characteristics are extracted and the substation equipment is controlled in real time, so as to realize the fault location and accurate diagnosis of the substation equipment, and improve the reliability of fault location and diagnosis results.

3 Analysis of Experimental Results

In order to improve the reliability of this method, the experimental verification analysis is carried out. Taking the ungrounded system of 20 kV power grid in a certain area as the experimental environment, the experiment is built in Matlab environment, in which the hardware environment is Intel Core 3-5501g memory and the operating system is Windows 8. Suppose that a large number of network communication nodes are distributed at 2000 m in the optical fiber environment × 2000 m uniform array area, written according to the requirements of C++, can add multiple functions of Microsoft, including the system running through the whole windows program, user interface and file operation. The experimental parameters are shown in the Table 4.

Table 4. Experimental parameter setting

Parameter	Remarks
Optical fiber communication frequency band	3 kHz–8 kHz
Carrier frequency time width	3 ms
Normalized initial frequency of data mining	0.15 Hz
Number of sampling points	256
SNR range	−15 dB–15 dB

According to the experimental environment and parameter setting results, the experimental content is analyzed. Take the first line and the sixth line, i.e. line 1 and line 6, as an example, input line 1 and line 6 into “address input”, i.e. x10001 and x6001. Click the three-phase current button to collect the three-phase current and zero sequence current of the line, as shown in the Table 5.

Table 5. Experimental data acquisition

Control area	The first line			Route 6		
Address input	X10001			X60001		
Configuration setting	21			21		
Phase current	A	B	C	A	B	C
	1.2	4.5	3.7	1.1	3.6	5.6
Zero sequence current	3.15 A			3.0A		
Reply message	44321085613134979622341646416748856201123365448525525555F5655W15241G12121121QQ111			443210856131345698974146484131258479945468845555 + 55454545F5655W15241G12121121QQ111		

It can be seen from the table that the three-phase current and zero sequence current values viewed from the reply information are the original three-phase current data collected from the interface of the master station control center. The simulation model of 500 kV transmission line is built by pscadbmtdc software. The transmission line adopts distributed parameter model, the length of the transmission line is L = 200 km, and the measuring point is located at the M end. The sampling frequency is 1 MHz. The grounding fault is set at the far end and near end of the transmission line Mn respectively, and the fault point is represented by F. In order to simulate the real application environment of the location method, noise is added to the extracted transient traveling wave (Fig. 6).

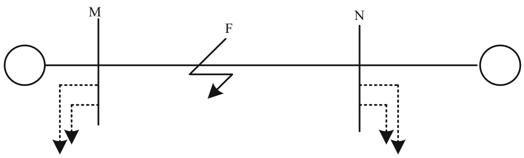

Fig. 6. Transmission line simulation model

Based on the above model, the structure parameters of network equipment are further standardized, as shown in the following Table 6.

Table 6. Structure of power grid equipment

Bus structure	I	II	III	IV
M-end reflection coefficient	<0	<0	>0	>0
N-terminal reflection coefficient	<0	>0	<0	>0
M-terminal bus type	Class I	Class I	Three classes of initials	Three classes of initials
N-terminal bus type	Class I	Three classes of initials	Class I	Three classes of initials

When the bus is a class II bus, there is no reflection wave when the traveling wave reaches the class II bus because the wave impedance is constant. In addition, from the practical application point of view, the class II bus is almost absent, so the case of class II bus is not considered in the simulation example. In order to simplify the analysis process, the influence of traveling wave from adjacent bus can be ignored. The following experiments are carried out to solve the problem diagnosis technology of flexible DC transmission line. The length of the experimental line is 1000 km, and the grounding fault in the positive direction of current occurs at 400 km away from the rectifier side, and the fault time is 2.0S. Based on this, the experimental contents are compared and analyzed (Fig. 7).

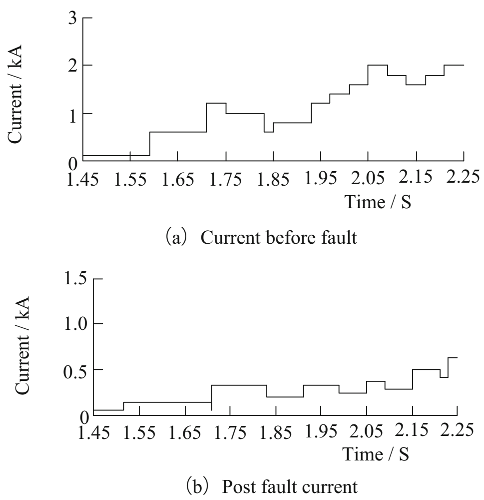

Fig. 7. Current diagnosis results before and after fault

According to this point, the rationality of diagnosis technology is compared and analyzed, and the specific comparison content is as follows. The traditional diagnosis technology and automatic location based on traveling wave voltage distribution characteristics are analyzed, and the results are shown in the Figs. 8 and 9.

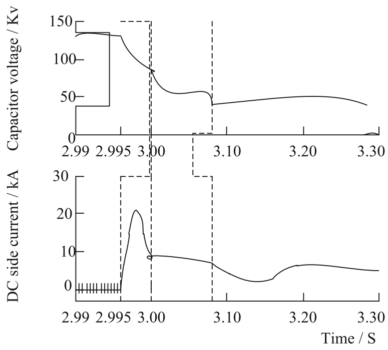

Fig. 8. Fault location results of traditional method

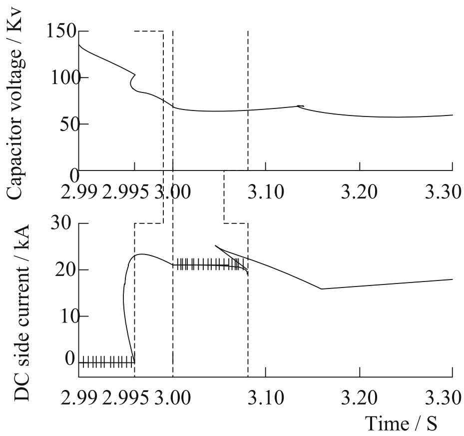

Fig. 9. Fault location results of this method

The capacitor voltage obtained by traditional diagnosis technology is also inconsistent with the DC circuit obtained by traditional diagnosis technology based on traveling wave voltage distribution characteristics. Furthermore, the diagnosis errors of traditional diagnosis technology and automatic diagnosis technology based on traveling wave voltage distribution characteristics are compared and analyzed, and the results are shown in Table 7.

Table 7. Comparison and analysis of diagnosis error of two technologies

Times	Traditional technology	This paper introduces the technology
1	0.6	0.2
2	0.7	0.1
3	0.8	0.1
4	0.6	0.05
5	0.5	0.1

It can be seen from the table that: under these five experimental conditions, the automatic diagnosis technology based on traveling wave voltage distribution characteristics has relatively small diagnosis error compared with traditional technology, which can better improve the reliability of fault diagnosis and location, and fully meet the research requirements.

4 Concluding Remarks

More and more distributed generation connected to distribution system has become the development trend of power grid in the future, but the existence of distributed generation will affect the size and direction of fault current, so the traditional fault diagnosis method of distribution network is no longer applicable. The fault diagnosis method of distribution network based on fault power direction criterion and information missing makes full use of both upload and measured fault information to ensure the accuracy and effectiveness of fault diagnosis of distribution system with distributed generation and improve the speed of fault diagnosis. In the complex situation of information loss or distortion, this method can still accurately determine the fault area of distribution network, which meets the needs of modern distribution network fault diagnosis.

Acknowledgement. This paper is supported by the “Research and demonstration application of key technologies of intelligent control robot assistant (SGTYHT/19-JS-215)”, the project of headquarters management science and technology of State Grid Corporation of China.

References

1. Hassan, Z., Amir, A., Selvaraj, J., et al.: A review on current injection techniques for low-voltage ride-through and grid fault conditions in grid-connected photovoltaic system. Sol. Energy **207**(47), 851–873 (2020)
2. Ding, X., Zhu, X., Li, X., et al.: Research on power grid fault diagnosis method based on PMU data and convolutional neural network. In: 2020 IEEE 4th Conference on Energy Internet and Energy System Integration (EI2). IEEE (2020)
3. Ling, Z., Yan, P., Chen, F., et al.: Power grid fault diagnosis method based on stacked sparse denoising auto-encoder and GRU network. J. Phys. Conf. Ser. **15**(42), 41–56 (2020)
4. Kruse, J., Schafer, B., Witthaut, D.: Predictability of power grid frequency. IEEE Access **8** (1), 149435–149446 (2020)
5. Kortenbruck, J., Premgamone, T., Ortjohann, E., et al.: Asymmetrical grid control with power electronic regulator in distribution level. IET Renew. Power Gener. **14**(15), 2830–2839 (2020)
6. Yang, H., Meng, C., Wang, C.: A probability first memetic algorithm for the dynamic multiple-fault diagnosis problem with non-ideal tests. Memetic Comput. **12**(2), 1–13 (2020)
7. Gashteroodkhani, O.A., Majidi, M., Etezadi-Amoli, M., et al.: A hybrid SVM-TT transform-based method for fault location in hybrid transmission lines with underground cables. Electr. Power Syst. Res. **170**(5), 205–214 (2019)

8. Saffarian, A., Abasi, M.: Fault location in series capacitor compensated three-terminal transmission lines based on the analysis of voltage and current phasor equations and asynchronous data transfer. Electr. Power Syst. Res. **187**(3), 106457 (2020)
9. Wu, F., Sun, J., Zhou, D., et al.: Simplified Fourier series based transistor open-circuit fault location method in voltage-source inverter fed induction motor. IEEE Access **8**(1), 83953–83964 (2020)
10. Khoramabadi, H.R.S., Keshavarz, A., Dashti, R.: A novel fault location method for compensated transmission line including UPFC using one-ended voltage and FDOST transform. Int. Trans. Electr. Energy Syst. **30**(1), 1–31 (2020)
11. Ebrahim, M.A., Aziz, B.A., Nashed, M., et al.: A novel Hybrid-HHOPSO algorithm based optimal compensators of four-layer cascaded control for a new structurally modified AC microgrid. IEEE Access **9**(1), 4008–4037 (2021)
12. Tian, S., Li, Z., Li, H., et al.: Active control method for torsional vibration of DFIG drive chain under asymmetric power grid fault. IEEE Access **8**(6), 155611–155618 (2020)