Assessment of Electrical equipment status in distribution network based on multi-source data fusion

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Abstract. In order to adapt to the lean maintenance and operation and maintenance requirements of the distribution network, and to improve the utilization of distribution network data, a method for identifying the operating status of distribution network equipment based on multi-source data fusion is proposed. First, the status identification and evaluation requirements of the network and equipment in the operation of the distribution network are analyzed. Then the multi-source data fusion principal is introduced, and the multi-source information sources of the distribution network equipment is explained. An identification method for the state of distribution network equipment based on association rules and entropy weight method fuzzy analysis is proposed, and the evaluation and identification process is given. Finally, the transformer equipment is taken as an example to verify the equipment status identification method proposed in this paper, and demonstrate the effectiveness of this method.

Keywords: multi-source data fusion; Electrical equipment status in distribution network; association rules; entropy weight method fuzzy analysis.

1. Introduction

Distribution network is an important system that the power system is directly connected with users. Its structure is complex, there are many states during operation, and it is prone to failure. The distribution network directly distributes electric energy to users, and its safe and stable operation directly affects the reliability of power supply. For distribution equipment, it is an important measure to arrange the maintenance plan reasonably and determine the running state of the equipment.

At present, there are many researches on the condition and maintenance of distribution network equipment. Literature [1] explains the risk assessment and condition assessment in the operation and maintenance of distribution network equipment. Literature [2] analyzes the operation maintenance and condition-based maintenance management of distribution network equipment. Literature [3] puts forward a method of automatic maintenance of distribution network equipment based on machine learning. Literature [4] studies the application of condition assessment and risk assessment system in distribution network equipment operation and maintenance. Literature [5] puts forward on-line state assessment of key equipment in distribution network based on multiple measures. Literature [6] analyzes the measures of condition-based maintenance and operation and maintenance management of
distribution network equipment. At present, the condition-based maintenance of distribution network equipment for multi-source data fusion needs to be deepened.

Therefore, this paper proposes a method of distribution network equipment state identification based on multi-source data fusion. In this paper, the operational risk of distribution network and the influence of network topology on distribution network structure are analyzed firstly, and then the sources of multi-information of distribution network equipment are explained by combining multi-information fusion technology. According to the multi-information fusion of association rules and entropy weight method, the equipment state evaluation model is established, and the equipment state analysis flow is given.

2. Distribution Network Equipment Status

2.1. Risk analysis of distribution network

In view of the current operation mode of distribution network, considering the failure of a single component, a switch refuses to operate to carry out network topology analysis, thus analyzing the risk of N-1 fault, which can be included in the subsequent safety early warning, auxiliary decision-making and safety check. The equipment risk assessment process is shown in the figure. Topology analysis, equipment risk failures and classification are needed. First, the installation location of the equipment with risks and failures should be determined according to real-time risk information. At the same time, the names of the failed equipment, the refusing switch, the risk equipment and the cause equipment should be specified. At the same time, it is necessary to compare the historical risk information with the implementation risk information. In normal operation mode, when the bus fails and the protection and circuit breaker act correctly, only the bus will be powered off, which will not cause the power outage of the line. Even if the switch refuses to operate, it will only cause the power outage of the equipment connected to the bus and the refusing switch, which will not cause the accident scope to expand. However, if the bus and switch are in the maintenance position and short-circuit fault occurs, the non-fault equipment may be cut off and the operation structure of the power grid may be changed. Therefore, the safe and stable operation of the power grid is threatened. At this time, the network topology connection relationship should be analyzed and the potential risk equipment should be identified by online identification, which is of great significance for dispatching operators to assess the power grid risk. The equipment risk analysis process is as follows: firstly, analyze the network topology, form a risk fault set, and conduct real-time safety assessment, auxiliary decision-making, and safety check before and within the day.

![Fig. 1 Evaluation process of distributed network equipment](image-url)
The function of equipment risk analysis is to analyze potential risk equipment such as equipment and switches in real time and online according to the operation mode of distribution network, combined with the topological structure and dynamic changes of distribution network, and provide corresponding early warning decision information, which is helpful to the safe and stable operation of power grid and enhance the refined management level of power grid.

Equipment analysis includes maintenance equipment, power grid connection mode, etc. Maintenance risks include bus maintenance, line maintenance, feeder terminal, switch maintenance, etc. The connection mode of the power grid is mainly aiming at the Topp mode of closed-loop design and open-loop operation of the distribution network. The change of topology structure is judged by the state of switches, and the range of faults is analyzed.

The main algorithms of state checking of distribution network equipment are network topology analysis theory and protection action logic simulation. Network topology and wiring analysis, mainly according to the status of switches and other logic elements in the power grid and the connection relationship of various devices, analyzes the bus and network models that have an effect on power grid calculation. Nodes connected by closed switches, that is, physical points of equipment connection established during network modeling, form bus nodes for calculation, which is characterized by equal voltages of all physical nodes contained in bus nodes.

Lines and transformers connected to physical nodes are called branches, and equipment connected between two buses and load generators connected to these physical nodes are called injection quantities. The power grid equipment connected together through the road becomes an island, and if it contains both generators and loads, it is called a living island; On the contrary, it is a dead island. The number of live power grids is usually the number of subsystems. Usually, the system in normal operation has only one live island. If there is more than one live island in a power grid, the system is in a disconnected operation state.

The topological structure of power grid is divided into whole network topology and partial network topology. When each risk fault is set automatically, partial network topology is adopted for analysis in time, and only the changed switches are classified. Because the whole network topology of the system needs to search all the devices in the system, it takes a long time to identify such devices.

An electrical island is an isolated power transmission, distribution and consumption system. When the system fails, the system is often divided into several sub-islands. By analyzing the electrical sub-islands, it can be judged that the equipment is in various operating states. By searching the network connection mode, we can determine the network connection mode, set the relevant middle switch or side switch failure according to the connection mode, and determine the protection action logic according to the connection mode. The risk equipment generated by network topology analysis is formed into an expected accident set, which can be used for real-time stability assessment, auxiliary decision-making and prior safety check.

2.2. Distribution network equipment status and multi-information fusion

There are many kinds of distribution equipment, which are widely distributed, and the models, specifications, scales and quantities of the equipment are different according to the situation. Distribution equipment mainly includes distribution transformers, circuit breakers, feeder lines, etc. The operating parameters and state of electrical equipment are mainly expressed by the state quantity of the equipment, which directly or indirectly represents the technical indicators, performance indicators and operating parameters of the equipment under various operating conditions, and is used to reflect the overall performance of the equipment. When the state quantity of equipment changes, the corresponding operation and performance changes of the equipment can be obtained through corresponding programs and algorithms, and then the maintenance plan of the equipment can be determined according to the safety and importance of the state quantity itself to the equipment.
Multi-information fusion technology is aimed at the collaborative utilization of information from different aspects, so as to make comprehensive utilization of multi-level, multi-level, multi-dimensional information, with the aim of obtaining target state estimation and trend estimation. Multi-information fusion technology mainly includes the space-time dimension of information, information synthesis and information complementation.

Aiming at the multi-information fusion of distribution network, it mainly involves the fusion of fuzzy, definite, synchronous, asynchronous, digital and non-digital information; In the process of information integration, there are also different processing and processing schemes for multiple information, and the methods selected according to big data and information processing technologies are also different; Complementarity of information is the complementarity of different levels in function, structure and data storage of multi-equipment information in distribution network. It can be seen from this that information fusion aims at making full use of multiple information, and performs multiple complementary and redundant operations on the observed information in time or space dimension, thus forming an omni-directional and multi-angle interpretation or description of the observed object.

In the process of multiple information fusion, there will be a variety of indicators, which are independent of each other. Fuzzy analysis can describe the objective relationship between a single information source and a collection of information sources to a great extent. Fuzzy integral is a nonlinear function defined on the basis of fuzzy analysis. Fuzzy integration does not need traditional analysis, and the factors between methods are independent of each other, so it can be widely used in the process of multivariate information fusion analysis with certain correlation but partial independence. Traditional fuzzy analysis needs to quantify or qualitatively analyze the input information, but the distribution network components are widely distributed and have many types, so the corresponding quantitative and qualitative analysis is difficult. In the evaluation process, real-time dynamic data, historical data and operation and maintenance data of equipment are needed. There is a certain correlation among these three types of data, and at the same time, the indicators and targets of these data are different.

Fig. 2 Status of distributed network equipment
3. Multi-source Information Fusion based on Association Rules and Entropy weight method

3.1. Association rule
Association rule analysis is used to analyze the correlation of different elements in the same event, that is, to find the subset of elements in all events and attributes and their interaction relationship. The confidence level of association rule $A \rightarrow B$ is conditional probability $P(B | A)$, as follows:

$$C(A \rightarrow B) = P(B | A) = \frac{P(A \cup B)}{P(A)}$$ (1)

Then the confidence level of a comprehensive state quantization value $A_i \rightarrow B$ can be obtained by the above formula, namely:

$$C(A_i \rightarrow B) = \frac{P(A_i \cup B)}{P(A_i)} = \frac{\sigma(A_i \cup B)}{\sigma(A_i)}$$ (2)

The individual confidence level in each comprehensive state is calculated by the above formula, and then the confidence levels in the same comprehensive state level are compared to obtain the weight under the confidence level, and the initial weight can be determined.

$$\omega_i = \frac{C_i}{\sum_{m=1}^{M} C_{m_i}}$$ (3)

$\omega_i$ is the initial weight; $C_i$ is the confidence level of comprehensive state quantity $i$; $m_i$ is the number of individual factors in the comprehensive state quantity.

3.2. Grey relational analysis
The basic principle of grey relational analysis is to judge whether different sequences are closely related according to the geometric shapes of sequence curves. Grey relational analysis is a widely used analysis method, which reflects the distance relationship between the evaluation object and the standard object through the correlation coefficient. The larger the correlation coefficient, the better the evaluation object is. The correlation analysis method has no hard index for the amount of data, and can
obtain reliable analysis conclusions on the premise of less computation, which has certain practicability [7].

Let the comparison matrix and reference matrix be as follows:

\[ x_i = \{x_i(1), x_i(2), \ldots, x_i(n)\} | i = 1, 2, \ldots, m \]  
\[ y_j = \{y_j(1), y_j(2), \ldots, y_j(n)\} | j = 1, 2, \ldots, t \]  

(4)  

(5)

Then the grey correlation coefficient of point k is as follows:

\[ \xi_{ij}(k) = \frac{\Delta_{\min} + \rho \Delta_{\max}}{\Delta_{ij}(k) + \rho \Delta_{max}} \]  

(6)

In which:

\[ \Delta_{\min} = \min_{j} \min_{k} |x_i(k) - y_j(k)| \]  

(7)

\[ \Delta_{\max} = \max_{j} \max_{k} |x_i(k) - y_j(k)| \]  

(8)

\[ \Delta_{ij}(k) = |x_i(k) - y_j(k)| \]  

(9)

In the above formula, \( \rho \) is the determination coefficient, which is generally a value between 0 and 1. By calculating the average correlation coefficient, the grey correlation coefficient between two series can be obtained.

\[ R_{ij} = \frac{1}{n} \sum_{k=1}^{n} \xi_{ij}(k) \]  

(10)

Firstly, the first index value sequence is designated as the reference sequence, and the correlation degree between other sequences and gray is analyzed. And then select the next reference sequence until all of them are finished. Finally, the upper triangular matrix is obtained, and each non-zero element is the grey correlation degree:

\[ r_{nm} = \begin{pmatrix} r_{12} & r_{1m} \\ r_{2m} & \end{pmatrix} \]  

(11)

"Association" means that the index value of association degree is greater than the threshold value, so it is necessary to normalize the grey association matrix. Threshold is defined as the maximum correlation degree of all independent index pairs, namely:

\[ \beta = \max r_{ij} \]  

(12)

Where \( \beta \) is the threshold.

Correlation degree can characterize the correlation between them. If the same information or similar information appears, it is necessary to eliminate the overlapping information between them. Then the updated grey correlation weight is:
3.3. Measurement and evaluation based on entropy weight method

The determination of index weight is mainly divided into subjective weighting and objective weighting. Entropy method is the most widely used method to determine weight objectively.

According to m States of distribution network equipment, each state has n factors, forming an m×n order data matrix \( A' = \begin{bmatrix} a'_{1} & a'_{2} & \cdots & a'_{n} \end{bmatrix}_{m \times n} \), where \( a'_{j} \) represents the jth factor value in the ith state.

After standardization treatment, \( A = \begin{bmatrix} a_{1} & a_{2} & \cdots & a_{n} \end{bmatrix}_{m \times n} \) is obtained. The entropy of the j index is:

\[
E_{j} = \alpha \cdot \sum_{i=1}^{m} b_{ij} \ln b_{ij} \quad j = 1, 2, \cdots, n
\]

(14)

Type in \( \alpha = -\frac{1}{\ln m} \), \( b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \).

When \( b_{ij} = 0 \), \( b_{ij} \ln b_{ij} = 0 \).

The entropy weight of the jth index is:

\[
\omega_{j} = \frac{1 - E_{j}}{\sum_{j=1}^{n} (1 - E_{j})}
\]

(15)

Among them \( \omega_{j} \in [0,1] \), and \( \sum_{j=1}^{n} \omega_{j} = 1 \).

Thereby obtaining the weight \( W = \{\omega_{1}, \omega_{2}, \cdots, \omega_{n}\} \) of each index.

According to the evaluation index set of quantity measurement x, the evaluation vector of index can be obtained, and then the evaluation matrix of uncertain measurement can be obtained.

The final equipment state evaluation matrix is calculated as follows:

\[
\mu_{n} = W \cdot \mu_{QxR}
\]

(16)

W is the weight obtained by entropy weight method; \( \mu_{QxR} \) is the evaluation matrix of index uncertainty measurement.

3.4. Distribution network equipment status analysis process

The analysis flow of equipment index and equipment status based on multivariate information fusion method is shown in the following figure. Firstly, sample data to be measured is selected to form a sample matrix, and the sample matrix is normalized. Then calculate the weight and weighted correlation degree of the main indicators. Sort the correlation degree and combine it with fuzzy method to determine whether the equipment status is normal, abnormal, alarm or accident.
The qualitative analysis of evaluation indexes of equipment running status is shown in the following table.

| State   | Health condition description                                      |
|---------|------------------------------------------------------------------|
| Normal  | Running in good condition, the equipment is safe                  |
| Abnormal| There is abnormal operation condition, and there is certain possibility of failure |
| Alarm   | The equipment is in poor running condition, and an alarm signal appears, indicating that there are major defects |
| Fault   | The equipment is very unsafe and has a very serious fault, so it should be repaired immediately |

4. Example Simulation

4.1. System description
In this paper, taking four transformers of distribution network as examples, the status of distribution network equipment based on multi-information fusion is analyzed, which is recorded as A, B, C and D respectively. For transformers, the index types are as follows [8].
In this paper, the historical data of transformer in literature [9] is selected for analysis.

4.2. Example analysis
According to the above data, the initial weight of equipment status is calculated:

\[ h = \begin{bmatrix} 0.112 & 0.186 & 0.148 & 0.217 & 0.205 & 0.132 \end{bmatrix} \]

Then, the weight is calculated by grey relational analysis.

\[ \omega = \begin{bmatrix} 0.115 & 0.195 & 0.133 & 0.177 & 0.218 & 0.162 \end{bmatrix} \]

Taking transformer A as an example, the evaluation matrix is calculated and the following results are obtained:

\[
\begin{bmatrix}
0.42 & 0.55 & 0.01 & 0.01 \\
0.97 & 0.01 & 0.01 & 0.01 \\
0.97 & 0.01 & 0.01 & 0.01 \\
0.81 & 0.23 & 0.02 & 0.01 \\
0.01 & 0.01 & 0.54 & 0.26 
\end{bmatrix}
\]

\[ \mu_{Q,R} = \begin{bmatrix} 0.7186 & 0.1274 & 0.0914 & 0.0475 \end{bmatrix} \]

According to the fuzzy theory, the classification vector matrix is obtained:

\[ w = \begin{bmatrix} 0.14 & 0.26 & 0.26 & 0.19 & 0.15 \end{bmatrix} \]

Therefore, the final \( \mu_1 \) is:

\[ \mu_1 = \begin{bmatrix} 0.7186 & 0.1274 & 0.0914 & 0.0475 \end{bmatrix} \]

Tab.2 Results of status

| State     | A    | B    | C    | D    |
|-----------|------|------|------|------|
| Health degree | 71.52| 16.32| 54.94| 43.28|

Finally, the analysis results show that four transformers A, B, C and D are in normal, fault, abnormal and alarm states respectively.

For other equipment in the distribution network, after determining the evaluation index and historical data, it can be analyzed according to the method proposed in this paper to get the equipment status.

5. Summary
In this paper, the operational risk of distribution network and the influence of network topology on distribution network structure are analyzed firstly, and then the sources of multi-information of distribution network equipment are explained by combining multi-information fusion technology. According to the multi-information fusion of association rules and entropy weight method, the equipment state evaluation model is established, and the equipment state analysis flow is given. Finally, the comprehensive evaluation of transformer equipment status is carried out, and the evaluation results of its operation status are obtained, which shows the effectiveness and rationality of this method, and can provide reference for the implementation of condition-based maintenance.
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