Evaluation method of fault indicator status detection based on hierarchical clustering

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Abstract. In order to solve the evaluation problem of fault indicator arrival detection and operation detection, an evaluation method of fault indicator status detection based on hierarchical clustering is proposed. Firstly, the evaluation model for status detection of fault indicator in distribution network is established. Then, through the fault indicator state detection single result table and the fault indicator operation state detection result table, the single equipment evaluation of fault indicator status detection is described in detail. Secondly, through the fault indicator state detection manufacture result table and the fault indicator state detection manufacture evaluation value, the manufacturer equipment evaluation of fault indicator status detection is described in detail. Finally, through the fault indicator state detection itemized result table and fault indicator state detection itemized evaluation value, the itemized equipment evaluation of fault indicator status detection is described in detail. The case analysis shows that the method is effective and feasible, can meet the actual needs of the site, and has positive significance.

1. Introduction

As an important part of intelligent maintenance, equipment status evaluation can be used to evaluate and analyse the arrival status and operating status of the equipment. It can screen the weak links of the equipment and eliminate the invisible faults of the equipment in the bud. It is one of the important means to improve the power supply reliability of the power grid [1-3].

As an important terminal equipment for feeder automation, fault indicators are widely used in current distribution networks due to their small size, low price, and live installation without power outages. However, in practical application, due to the uneven product quality, many installed fault indicators can not work effectively [4-6]. In addition to the changeable site environment, various problems caused the fault indicator to falsely report the signal when the power grid was operating normally, and the fault indicator missed the signal when the power grid was faulty. With the introduction of a large number of error signals, the result of fault judgment is often misjudged, losing its original meaning. Therefore, accurate evaluation of the fault indicator status is of great practical significance to better guide the arrival detection and operation maintenance.

Firstly, the evaluation model of the fault indicator status detection is established. Then through hierarchical clustering from three aspects of monomer, manufacturer, and sub-item, the status detection of the fault indicator is evaluated.

2. Evaluation model for status detection of fault indicator in distribution network

During the state detection of the fault indicator, due to the operating environment, operators and detection equipment, it can not be ensured that the results of each detection can correctly reflect the existing state of the fault indicator. Assume that the probability of the detection device's accurate
detection in the first detection is $P(1)$. In the second detection, the probability that the detection device accurately detects is $P(2)$. If the same information detected twice is used as the final result, considering the accuracy probability $P(U)$ in the two cases will be changed to $P(1)P(2)$, it is obvious that $P(U)$ will be less than $P(1)$ or $P(2)$.

In order to ensure the accuracy of the status detection, the information of the 3 detections can be used. According to the "2 out of 3" principle, the final result of the fault indicator detection is determined. The principle of "2 out of 3" means that the final detection results are represented by the same detection results twice in the three detections. Assuming that the probability of accurate detection by a single detection device is 98%, 1 means that the detection result is correct, and 0 means that the detection result is wrong. Then 8 cases are shown in Table 1.

| Condition | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-----------|---|---|---|---|---|---|---|---|
| 1         | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 2         | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| 3         | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 |
| $P_i$     | 0.000008 | 0.000392 | 0.000392 | 0.019208 | 0.000392 | 0.019208 | 0.019208 | 0.941192 |

It can be seen from Table 1 that according to the principle of "2 out of 3", the detection results in the first, second, third, and fifth cases are wrong, and the error probability is the sum of the probabilities in the four cases, that is, 0.001184. On the contrary, the probability of correct detection results is 0.998816. From the above analysis, it can be seen that the final test result determined according to the "2 out of 3" principle is more accurate than the single test result (0.98) and the two test results (0.9604).

The fault indicator state detection information matrix (FSDI) is established to record the result information of a single fault indicator after three detections. The specific description is:

$$ FSDI = \begin{bmatrix} DI_{11} & DI_{12} & \cdots & DI_{1j} & \cdots & DI_{1n} \\ DI_{21} & DI_{22} & \cdots & DI_{2j} & \cdots & DI_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ DI_{31} & DI_{32} & \cdots & DI_{3j} & \cdots & DI_{3n} \end{bmatrix} $$

Wherein, each row represents the detection results of each sub-item of one detection. The $DI_{kj}$ ($k = 1, 2, 3$) is the result information of the $k$-th and $j$-th detection of the fault indicator. $j = 1, 2, 3, \ldots, n$. The $n$ is the number of sub-items detected by the fault indicator, and there are generally 10 types of sub-items detected. The $DI_{k1}$ is the result information value of the $k$-th short circuit fault alarm detection. The $DI_{k2}$ is the result information value of the $k$-th reclosing instantaneous fault detection. The $DI_{k3}$ is the result information value of the $k$-th reclosing permanent fault detection. The $DI_{k4}$ is the result information value of the $k$-th load fluctuation prevention false alarm detection. The $DI_{k5}$ is the result information value of the $k$-th transformer no-load closing inrush current anti-false alarm detection. The $DI_{k6}$ is the result information value of the $k$-th line closing load inrush current anti-false alarm detection. The $DI_{k7}$ is the result information value of the $k$-th heavy-load switching and anti-false alarm detection. The $DI_{k8}$ is the result information value of the $k$-th non-fault phase reclosing inrush current anti-false alarm detection. The $DI_{k9}$ is the result information value of the $k$-th telemetry accuracy detection. The $DI_{k10}$ is the result information value of the $k$-th live loading and unloading detection. If the detection result is correct, the $DI_{kj}$ is 1, otherwise it is 0.

### 3. Evaluation method of fault indicator status detection based on hierarchical clustering

The purpose of fault indicator detection and evaluation is to ensure that the quality of the equipment to be connected to the network is reliable, and the status of the equipment that has been running is stable. It can better guide future bidding, equipment function research and development, and equipment quality
improvement. Therefore, cluster analysis can be performed from three levels: single equipment evaluation, manufacturer equipment evaluation, and itemized equipment evaluation.

3.1. Single equipment evaluation of fault indicator status detection

The fault indicator state detection single result table (FDSR) is established to record the comprehensive result information of a single fault indicator after three tests. The specific description is as follows:

\[
FDSR = \left[ SR_1, SR_2, \ldots, SR_j, \ldots, SR_n \right]
\]

\[ SR_j = DI_{1j} + DI_{2j} + DI_{3j} \]

(2)

Wherein, the \( SR_j \) is the final result of the \( j \)-th detection of the fault indicator, and its value is between 0 and 3. According to the principle of "2 out of 3", the 0 means that the function is not correct after 3 tests, and the function is finally determined to be unqualified. The 1 indicates that the function is incorrect twice in three tests, and it is finally determined that the function is unqualified. The 2 indicates that the function is not correct once in three tests, and it is finally determined that the function is qualified. The 3 indicates that the function is correct in all three tests, and it is finally determined that the function is qualified and excellent.

The fault indicator operation state detection result table (FODR) is established to record the comprehensive result information of a single running fault indicator. The specific description is:

\[
FODR = \left[ OR_1, OR_2, \ldots, OR_j, \ldots, OR_n \right]
\]

\[ OR_j = \begin{cases} 1 & SR_j \geq 2 \\ 0 & SR_j < 2 \end{cases} \]

(3)

Where, the \( OR_j \) is the final result of the \( j \)-th operation detection of the fault indicator, and its value is between 0 and 1.

The fault indicator operation state detection single evaluation value (FOEV) is established to record the comprehensive evaluation value of a single running fault indicator. The specific description is:

\[
FOEV = \frac{100 \sum_{j=1}^{n} \alpha_j OR_j}{\sum_{j=1}^{n} \alpha_j}
\]

(4)

Where, \( \alpha \) is the impact factor of single function evaluation of fault indicator. Short-circuit fault alarm detection is the most important functional item of operation detection. The impact factor \( \alpha_1 \) of this item is 1.1, and the impact factor \( \alpha_2 \sim \alpha_{10} \) of other minor items is 0.1. The value range of FOEV is [0, 100]. Its value between [0, 55) indicates that the equipment is seriously unqualified, and it can no longer ensure that the short-circuit fault judgment is correct, and the equipment needs to be replaced as soon as possible. Its value between [55, 100] indicates that the equipment short circuit detection is qualified, and other detection items are unqualified. In order to use the existing equipment as much as possible, reduce the equipment replacement frequency and improve the efficiency, the equipment can be allowed to continue the network operation conditionally. Its value of 100 means that the equipment is fully qualified, all test items are qualified, and it can continue to run on the network.

3.2. Manufacturer equipment evaluation of fault indicator status detection

The fault indicator state detection manufacture result table (FDMR) is established to record the comprehensive result information of the same manufacturer's fault indicator after three detections. The specific description is:
\[
FDMR = [MR_1, MR_2, \ldots, MR_i, \ldots MR_m] \\
MR_i = \min FDSR_i = \min [SR_{i1}, SR_{i2}, \ldots, SR_{iw}]
\]

Wherein, the \( MR_i \) is the final detection result of the manufacturer's \( i \)-th fault indicator. \( i = 1, 2, 3, \ldots, m \). The \( m \) is the total number of fault indicators of the same manufacturer. The \( FDSR_i \) is the fault indicator state detection single result table of the \( i \)-th fault indicator. The \( SR_{ij} \) is the final result of the \( j \)-th detection of the \( i \)-th fault indicator. Based on the principle of prudence, the minimum value in \( FDSR_i \) is taken to represent the final detection result of the fault indicator.

The fault indicator state detection manufacture evaluation value (FMEV) is established to record the comprehensive evaluation values of all indicators of the same manufacturer. The specific description is as follows:

\[
FMEV = 70(\frac{x + 2y + 3z}{3m}) + 30FM
\]

\[
FM = \begin{cases} 
1 - \frac{e^{m-y-z}}{e^m} & y + z \neq m \\
1 & y + z = m 
\end{cases}
\]

Wherein, the \( x \) is the number of devices whose final detection result of the fault indicator \( MR_i \) is 1. The \( y \) is the number of devices whose final detection result of the fault indicator \( MR_i \) is 2. The \( z \) is the number of devices whose final detection result of the fault indicator \( MR_i \) is 3. The \( FM \) is the impact evaluation value of the number of detection equipment. The value range of FMEV is [0,100]. The larger the value, the better the quality of the manufacturer’s fault indicator. The 0 means that all fault indicator detections of the manufacturer are unqualified. The 100 means that all fault indicator detections of the manufacturer are all excellent.

3.3. Itemized equipment evaluation of fault indicator status detection

The fault indicator state detection itemized result table (FDIR) is established to record the detection result information of all the fault indicators in the same batch with different sub-functions. The specific description is:

\[
FDIR_j = [IR_{j1}, IR_{j2}, \ldots, IR_{jh}, \ldots IR_{jw}]
\]

Wherein, the \( FDIR_j \) is the detection result information of the \( j \)-th item in the same batch fault indicator detection. The \( IR_{hj} \) is the detection result of the \( j \)-th function of the \( h \)-th fault indicator detection. Its value is the same as \( SR_{j} \) in the \( FDSR. h=1, 2, 3, \ldots, w \). The \( w \) is the number of fault indicators detected in the same batch.

The fault indicator state detection itemized evaluation value (FIEV) is established to record the comprehensive evaluation value of an item after the detection of all indicators in the same batch. The specific description is as follows:

\[
FIEV_j = \frac{1}{w} \sum_{k=1}^{w} IR_{kj}
\]

Wherein, the \( FIEV_j \) is the equipment evaluation value of the \( j \)-th functional status detection item of all fault indicators in the same batch. Its value is between \([0, \ 3]\). The larger the value, the better the equipment status of the item. Its value between \([0, \ 2]\) means that the fault indicator of most
manufacturers is unqualified for the sub-function detection. It is a ubiquitous quality problem, and the quality level of the entire industry needs to be improved or industry standards revised. Its value between [2, 3] means that the fault indicators of most manufacturers of this sub-function detection are qualified. The quality of the equipment is relatively mature, and industry standards can be appropriately upgraded as needed.

4. Case analysis

There are 15 sets of fault indicators in a certain region, belonging to manufacturers A, B and C. The fault indicators are detected according to the principle of "2 out of 3". The detection items include 10 basic functions, and the correct detection times of each fault indicator are shown in Table 2.

| Equ | Man  | Function 1 | Function 2 | Function 3 | Function 4 | Function 5 | Function 6 | Function 7 | Function 8 | Function 9 | Function 10 |
|-----|------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-------------|
| 1   | A    | 3          | 2          | 2          | 2          | 2          | 2          | 3          | 3          | 3          | 2           |
| 2   | A    | 3          | 3          | 2          | 2          | 2          | 3          | 3          | 3          | 3          | 3           |
| 3   | A    | 1          | 2          | 2          | 2          | 3          | 3          | 0          | 0          | 1          | 1           |
| 4   | A    | 2          | 3          | 3          | 3          | 3          | 3          | 2          | 2          | 2          | 2           |
| 5   | A    | 2          | 2          | 2          | 2          | 3          | 3          | 3          | 3          | 3          | 3           |
| 6   | A    | 0          | 0          | 0          | 0          | 1          | 2          | 1          | 2          | 1          | 2           |
| 7   | A    | 3          | 3          | 3          | 3          | 3          | 2          | 2          | 2          | 2          | 3           |
| 8   | A    | 3          | 3          | 3          | 3          | 3          | 3          | 3          | 3          | 3          | 3           |
| 9   | B    | 2          | 2          | 2          | 2          | 2          | 3          | 3          | 3          | 3          | 3           |
| 10  | B    | 2          | 2          | 3          | 3          | 3          | 3          | 3          | 3          | 3          | 3           |
| 11  | B    | 3          | 3          | 3          | 3          | 3          | 3          | 3          | 3          | 3          | 3           |
| 12  | B    | 3          | 2          | 2          | 2          | 2          | 1          | 1          | 2          | 2          | 2           |
| 13  | B    | 2          | 2          | 3          | 3          | 3          | 3          | 2          | 2          | 2          | 2           |
| 14  | C    | 2          | 2          | 2          | 2          | 2          | 2          | 2          | 2          | 2          | 2           |
| 15  | C    | 1          | 2          | 3          | 2          | 2          | 3          | 3          | 0          | 3          | 3           |

The single equipment evaluation of fault indicator status detection is shown in Table 3. The fault indicators 3, 6, 12, 15 are all unqualified, and the other fault indicators are all qualified, especially the fault indicators 8 and 11 have excellent detection results.

| Equ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|-----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| Eva | yes | yes | no | yes | yes | no | yes | good | yes | good | no | yes | yes | no | no |

The manufacturer equipment evaluation of fault indicator status detection is shown in Table 4. Manufacturer B’s equipment evaluation is the highest with 76.117 points, manufacturer C’s evaluation is the lowest with 42.297 points, and manufacturer A’s evaluation is in the middle of 67.842 points.

| Equ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|-----|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| MER | 2 | 2 | 0 | 2 | 2 | 0 | 2 | 3 | 2 | 2 | 2 | 3 | 1 | 2 | 2 |
| Man | A | B | C |    |    |    |    |    |    |    |    |    |    |    |    |
| FMEV | 67.842 | 76.117 | 42.297 |    |    |    |    |    |    |    |    |    |    |    |    |
The itemized equipment evaluation of fault indicator status detection is shown in Table 5. The functions of most manufacturers in this batch are qualified. The highest evaluation value of function 10 is 2.53, which means that all manufacturers are basically qualified in the function detection. The lowest evaluation value of function 1 is 2.13, which means that many fault indicators of this function are unqualified. This function is the main function of fault indicators, and manufacturers need to further improve the quality.

| Equ | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| FDIR| 2.13| 2.2 | 2.33| 2.27| 2.33| 2.4 | 2.27| 2.27| 2.2 | 2.53|

5. Conclusion
The evaluation model for status detection of fault indicator in distribution network is established. Based on this model, cluster analysis is performed from three levels: single equipment evaluation, manufacturer equipment evaluation, and itemized equipment evaluation. The detailed calculation formulas of various evaluations are given. The case analysis shows that the method is effective and feasible, can meet the actual needs of the site, and has positive significance.

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