Operation Situation Assessment of Intelligent Distribution Station Based on Internet of Things

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Abstract. In order to solve the problem of online monitoring and early warning evaluation of intelligent distribution station, an operation situation assessment of intelligent distribution station based on internet of things is proposed. A multi-source data information matrix is established for the distribution station, and describes the temperature information, humidity information, water intrusion information, smoke information, switch telemetry information, and switch remote control information of the intelligent distribution station within a period of time before the current time. The distribution station multi-source information matrix is quantitatively evaluated through the distribution station multi-source evaluation matrix. Then, the distribution station multi-source evaluation matrix is quantitatively integrated for each column to generate a distribution station multi-source single evaluation matrix. Finally, based on the weighted average method, the distribution station multi-source single evaluation matrix is integrated to generate the distribution station operation situation evaluation index to describe the overall operation situation assessment of intelligent distribution station. The feasibility of the proposed method is verified by the example analysis, which can meet the actual needs of the field project.

1. Introduction

As an important part of intelligent maintenance, the operation status assessment can evaluate and analyze the real-time and historical operation status of power grid, predict and analyze the future operation situation of power grid, screen the weak links of power grid, and eliminate the hidden faults in the embryonic state. It is one of the important means to improve the reliability of power supply in the power grid [1-3].

At present, the evaluation of operation status is mostly concentrated in the field of power equipment, and mostly based on electrical quantity. Distribution stations, such as switching stations, ring network rooms, ring network boxes, distribution rooms, box substations, etc., are the placement containers of distribution equipment. Their operation status is affected by environmental temperature, humidity, concentration of toxic gases, water invasion, current, voltage, remote control of switches and other environmental information and electrical information. Based on the development of IoT(Internet of Things) technology, all kinds of information and data in the intelligent distribution station can be transmitted to the monitoring master station system by means of optical fiber, wireless and carrier communication, so as to realize on-line operation state evaluation, analysis and early warning of the intelligent distribution station. It effectively improves the level of intelligent maintenance.
At present, the research on the operation status assessment of intelligent distribution station is seldom seen in the newspapers. The reference [4] proposed a transformer operating state assessment method based on multi-information fusion. The reference [5] proposed an operation status assessment method of high voltage circuit breakers based on credibility theory. The reference [6] proposed a practical method for comprehensive state assessment of distribution networks based on improved radar charts. The reference [7] proposed a distribution transformer state assessment method based on real-time operational data mining. Based on the widely distributed electrical quantity acquisition terminals in medium voltage distribution network, the above methods evaluated the operation status of distribution network equipment and network from many aspects, such as equipment layer and network layer.

However, none of the above methods has evaluated the operation status of distribution stations. In order to reduce the inspecting workload of operation and maintenance personnel, find the defects of distribution stations and equipment in time, and carry out intelligent maintenance in a planned and purposeful way, it is necessary to mine and analyze a large number of environmental analogue and electrical data collected in the distribution station, and quantitatively evaluate the operation status of the intelligent distribution station.

In this paper, the operation situation assessment model of the distribution station is first established, and then the operation status of the distribution station is quantified based on the operation situation assessment model. Finally, based on the operation assessment results of the distribution station and the weighted average method, the overall operation situation of the distribution station is comprehensively evaluated.

2. Operation situation assessment model of distribution station

Figure 1 shows the multi-source data fusion diagram of the intelligent distribution station. The temperature information, humidity information, water intrusion information, smoke concentration information, current overload information, and switch remote control failure information in the distribution station are collected by different sensors, and the data is collected and compressed by the concentrator and communicated through optical fiber, wireless or carrier. The data is transmitted to the secure access zone I. Finally, the data is accessed through the secure access zone to the DMS (Distribution Management System) in the distribution control area. After the data fusion by the DMS system, the evaluation and analysis are carried out through the intelligent distribution station operation situation assessment software.

![Figure 1. Data fusion diagram of intelligent distribution station.](image)

A Distribution Station Multi-Source Information Matrix (SMIM) is established to record the temperature, humidity, water entry, smoke, switch telemetry and switch remote control information in the distribution station for a period of time before the current time. The SMIM is described in detail as follows:
Wherein, The first column is the internal environmental temperature information of the distribution station, the second column is the internal environment humidity information of the distribution station, the third column is the internal water intrusion information of the distribution station, the fourth column is the internal smoke concentration of the distribution station, the fifth column is the switch current overload information of the distribution station, and the sixth column is the remote control failure information of the distribution station switch.

\( MI_{i1} \) is the environmental temperature value of distribution station in the current sampling period, and \( MI_{i1} \) is the environmental temperature value of distribution station in the \( i \)-th sampling period before the current time \((^\circ C), i = 1, 2, \ldots, m\). \( MI_{i2} \) is the environmental relative humidity of distribution station in the current sampling period, and \( MI_{i2} \) is the environmental relative humidity of distribution station in the \( i \)-th sampling period before the current time (%). \( MI_{i3} \) is the water level of the distribution station in the current sampling period, and \( MI_{i3} \) is the water level of the distribution station in the \( i \)-th sampling period before the current time (cm). \( MI_{i4} \) is the smoke concentration of distribution station in the current sampling period, and \( MI_{i4} \) is the smoke concentration of distribution station in the \( i \)-th sampling period before the current time (% FT). \( MI_{i5} \) is the number of all current-exceeding switches in the current sampling period, and \( MI_{i5} \) is the number of all current-exceeding switches of the distribution station in the \( i \)-th sampling period before the current time. \( MI_{i6} \) is the number of all remote control failures of the distribution station in the current sampling period, and \( MI_{i6} \) is the number of all remote control failures of the distribution station in the \( i \)-th sampling period before the current time.

The data in SMIM can be sampled in 30 minutes to 2 hours, usually in 1 hour. The sampling interval can be taken from 5 minutes to 15 minutes, usually 10 minutes. Therefore, the range of sampling data point \( m \) can be 3-12, generally 6.

3. Operation situation assessment method of intelligent distribution station

The operation situation assessment of intelligent distribution station belongs to the category of artificial intelligence, which is greatly influenced by people's subjective consciousness. In order to reduce the influence of human factors, this paper uses the logic operation method and the weighted average method to quantitatively evaluate the environmental data and electrical data inside the station.

3.1. Operational situation assessment data quantification

A Distribution Station Multi-Source Evaluation Matrix (SMEM) is established to quantitatively evaluate the temperature, humidity, water intrusion, smoke, switch telemetry and switch remote control information at each sampling time before the current time of the distribution station. The specific description is:

\[
\text{SMEM} = \begin{bmatrix}
ME_{i1} & ME_{i2} & ME_{i3} & ME_{i4} & ME_{i5} & ME_{i6} \\
ME_{i1} & ME_{i2} & ME_{i3} & ME_{i4} & ME_{i5} & ME_{i6} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
ME_{i1} & ME_{i2} & ME_{i3} & ME_{i4} & ME_{i5} & ME_{i6} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
ME_{i1} & ME_{i2} & ME_{i3} & ME_{i4} & ME_{i5} & ME_{i6}
\end{bmatrix}
\]

Wherein, \( ME_{i1} \) is the environmental temperature assessment value of distribution station in the current sampling period, and \( ME_{i1} \) is the environmental temperature assessment value of distribution station in the \( i \)-th sampling period before the current time, \( i = 1, 2, \ldots, m \). \( ME_{i2} \) is the environmental temperature assessment value of distribution station in the current sampling period, and \( ME_{i2} \) is the environmental temperature assessment value of distribution station in the \( i \)-th sampling period before the current time, \( i = 1, 2, \ldots, m \).
relative humidity assessment value of distribution station in the current sampling period, and $ME_{13}$ is the environmental relative humidity assessment value of distribution station in the $i$-th sampling period before the current time. $ME_{16}$ is the water intrusion assessment value of the distribution station in the current sampling period, and $ME_{15}$ is the water intrusion assessment value of the distribution station in the $i$-th sampling period before the current time. $ME_{14}$ is the smoke concentration assessment value of distribution station in the current sampling period, and $ME_{13}$ is the smoke concentration assessment value of distribution station in the $i$-th sampling period before the current time. $ME_{15}$ is the current overshoot assessment value in the current sampling period, and $ME_{16}$ is the current overshoot assessment value of the distribution station in the $i$-th sampling period before the current time. $ME_{16}$ is the remote control failure assessment value in the current sampling period, and $ME_{15}$ is the remote control failure assessment value of the distribution station in the $i$-th sampling period before the current time.

$$
ME_{1i} = \begin{cases} 
1 - \frac{MI_{1i}}{V_{\text{Tup}}} & MI_{1i} < V_{\text{Tup}} \\
0 & MI_{1i} \geq V_{\text{Tup}} 
\end{cases}
ME_{12} = \begin{cases} 
1 - \frac{MI_{12}}{V_{\text{Hup}}} & MI_{12} < V_{\text{Hup}} \\
0 & MI_{12} \geq V_{\text{Hup}} 
\end{cases}
(3)
$$

Wherein, $V_{\text{Tup}}$ is the upper limit of temperature anomaly alarm of distribution station ($^\circ$C), which can be adjusted according to different regions and seasonal changes. $V_{\text{Hup}}$ is the upper limit of relative humidity anomaly alarm of distribution station ($\%$), which can be adjusted according to different regions and seasonal changes.

$$
ME_{13} = \begin{cases} 
1 - \frac{MI_{13}}{V_{\text{Wup}}} & MI_{13} < V_{\text{Wup}} \\
0 & MI_{13} \geq V_{\text{Wup}} 
\end{cases}
ME_{14} = \begin{cases} 
1 - \frac{MI_{14}}{V_{\text{Lup}}} & MI_{14} < V_{\text{Lup}} \\
0 & MI_{14} \geq V_{\text{Lup}} 
\end{cases}
(4)
$$

Wherein, $V_{\text{Wup}}$ is the upper limit of the water level abnormal alarm of the distribution station (cm). $V_{\text{Lup}}$ is the upper limit of the smoke concentration abnormal alarm of the distribution station ($\%$FT).

$$
ME_{15} = \begin{cases} 
1 & MI_{15} = 0 \\
0 & MI_{15} > 0
\end{cases}
ME_{16} = \begin{cases} 
1 & MI_{16} = 0 \\
0 & MI_{16} > 0
\end{cases}
(5)
$$

Wherein, when the number of current overshoot switches is greater than 0, the logic value of current overshoot evaluation is 0, and vice versa is 1. When the number of switch failures is greater than 0, the logic value of remote control failure evaluation is 0 and vice versa is 1.

3.2. Operation situation assessment method

A Distribution Station Multi-source Single Evaluation Matrix (SMSM) is established to evaluate the temperature information, humidity information, water invasion information, smoke information, switch telemetry information and switch remote control information for a single comprehensive quantitative assessment in a period of time before the current time. The specific description is:

$$
SMSM = [MS_1 \ MS_2 \ MS_3 \ MS_4 \ MS_5 \ MS_6]
(6)
$$

Wherein, $MS_1 (j = 1, 2, 3, 4, 5)$ represents a single-phase comprehensive quantization evaluation of the $j$-th column element in the matrix SMEM. When the number of non-zero elements in $ME_{ij}$ exceeds a certain value $V_{ll}$, the value is:

$$
MS_j = \frac{1}{m} \sum_{i=1}^{m} ME_{ij} \quad MS_6 = \begin{cases} 
1 & \sum_{i=1}^{m} ME_{6i} = 0 \\
0 & \sum_{i=1}^{m} ME_{6i} > 0
\end{cases}
(7)
$$
When the number of non-zero elements in $ME_{ij}$ does not exceed the value $V_{LL}$, its value is zero. $V_{LL}$ is the limit value of the continuous occurrence of related information overrun events in the distribution station for a period of time. The value can be $\lambda$ times of $m$, and the value range of $\lambda$ is 0~1.

Using the weighted average method, the Distribution Station Operation Situation Evaluation Index (SOEI) is used to describe the overall operation of the intelligent distribution station in a period of time, specifically:

$$SOEI = \begin{cases} 0 & MS_{h} = 0 \\
\frac{1}{100} \sum_{h=1}^{6} \beta_{h} MS_{h} & MS_{h} \neq 0
\end{cases} \quad (8)$$

Where, $h=1, 2, 3, 4, 5, 6$; $\beta_{1}$ is the temperature information evaluation coefficient of the distribution station, the value range is 0.15~0.25, generally 0.2; $\beta_{2}$ is the evaluation coefficient of humidity information of the distribution station, the value range is 0.05~0.15, generally 0.1; $\beta_{3}$ is the evaluation coefficient of water intrusion information of the distribution station, the value range is 0.15~0.25, generally 0.2; $\beta_{4}$ is the evaluation coefficient of the smoke concentration information of the distribution station, the value range is 0.05~0.15, generally 0.1; $\beta_{5}$ is the evaluation coefficient of the telemetry information of the distribution station, the value range is 0.15~0.25, generally takes 0.2; $\beta_{6}$ is the evaluation coefficient of the remote control information of the distribution station, the value range is 0.05~0.15, generally 0.1; the sum of each evaluation coefficient is 1.

When the value of any element in $MS_{h}$ is 0, the comprehensive logical quantitative evaluation value of the single item information in the distribution station is 0, indicating the temperature, humidity, station water level, smoke concentration, and overcurrent switch of the distribution station. If the number is equal to the upper limit, it is a major defect and needs to be repaired in time. The value of SOEI ranges from 0 to 100. The closer to 0, the worse the operation situation of the distribution station is, and it needs to be repaired in time. The closer to 100, the healthier the operation situation of the distribution station is.

4. Case analysis

As shown in Table 1, it is the information collection data table of the current distribution station S1 and S2 at the current time, 10 minutes ago, 20 minutes ago, 30 minutes ago, 40 minutes ago and 50 minutes ago.

The temperature, humidity, water level, smoke concentration, the number of off-limit current switches and the number of remote control failure switches are shown in Table 1. The default values are adopted for each parameter unit.

| Name          | 0m | 10m | 20m | 30m | 40m | 50m |
|---------------|----|-----|-----|-----|-----|-----|
| Station       | S1 | S2  | S1  | S2  | S1  | S2  |
| Temperature   | 34 | 75  | 32  | 72  | 31  | 70  |
| Humidity      | 45 | 40  | 45  | 40  | 46  | 38  |
| Water         | 0.1| 0   | 0.1 | 0   | 0   | 0   |
| Smoke         | 0.2| 21  | 0.3 | 19  | 0.2 | 18  |
| Current       | 0  | 2   | 0   | 2   | 0   | 0   |
| Remote        | 0  | 0   | 0   | 0   | 0   | 0   |

According to the method described in this paper, the information matrix SMIM is established for intelligent distribution station S1 and S2, and the matrix SMEM is generated from information matrix.
SMIM. At the same time, single quantitative evaluation is made for SMEM, and SOEI is generated for intelligent distribution station. The specific evaluation results are shown in Table 2.

Table 2 Evaluation results of distribution station operation condition

| Name | MS1  | MS2  | MS3  | MS4  | MS5  | MS6  | SOEI  |
|------|------|------|------|------|------|------|-------|
| S1   | 0.4333 | 0.3381 | 0.9889 | 0.9865 | 1   | 1   | 81.55 |
| S2   | 0   | 0.4333 | 1   | 0   | 0   | 1   | 0     |

It can be seen from Table 2 that for the intelligent distribution station S1, the temperature, humidity, station water level, smoke concentration, number of overcurrent switches, number of remote control failure switches, etc. have not exceeded the limit, and its comprehensive evaluation is 81.55 points. It indicates that the intelligent distribution station is in good condition. In the distribution station S2, there are 3 individual items with a score of 0, indicating that the temperature and smoke concentration in the intelligent distribution station are seriously exceeded, and there are multiple switch overcurrent phenomena, indicating that a serious fault occurs inside the distribution station. It needs to be repaired in time.

5. Conclusion

This paper establishes a multi-source data information matrix for the distribution station, and describes the temperature information, humidity information, water intrusion information, smoke information, switch telemetry information, and switch remote control information of the intelligent distribution station within a period of time before the current time. The distribution station multi-source information matrix is quantitatively evaluated through the distribution station multi-source evaluation matrix. Then, the distribution station multi-source evaluation matrix is quantitatively integrated for each column to generate a distribution station multi-source single evaluation matrix. Finally, based on the weighted average method, the distribution station multi-source single evaluation matrix is integrated to generate the distribution station operation situation evaluation index to describe the overall operation situation assessment of intelligent distribution station.

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