Real-time Evaluation System of Monitoring Equipment State Based on the Integration of Subjective and Objective

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Abstract. Equipment operation monitoring is an important means to ensure the safe operation of power grid, and the operation status of power equipment will directly affect the operation security of power grid, so it is necessary to evaluate the equipment status in real time. In this paper, a subjective and objective evaluation system based on AHP and entropy weight method is proposed, which integrates the operation information and model information of power grid equipment and defines the indicator system of multi-dimensional analysis. The results show that this method has a very good guiding role in ensuring the real-time evaluation of equipment and the auxiliary decision-making of regulation and control.

1. Introduction
Equipment is the basic element of the power grid. The operation status of equipment is related to the safe operation level of the power grid. If the operation of equipment is not reasonable, it may cause equipment damage, equipment performance degradation, forced outage and other risks. With the operation of power system, due to the non-linear effect between the components in the system, the system will gradually enter into a self-organized critical state [1, 2, 3], at this time, any small local disturbance may lead to grid accidents.

From the perspective of the operation and inspection personnel, the equipment status evaluation is based on the results of operation inspection, maintenance, overhaul, preventive test and live test (online monitoring), etc., to analyse and evaluate the status indicators reflecting the health status of the equipment, so as to determine the status level of the equipment. For the equipment monitoring personnel, they need to pay attention to the operation of the equipment at all times. However, due to the lack of effectiveness of the evaluation of the operation inspection equipment status and the difference between the evaluation perspective and that of the monitoring personnel, the evaluation results cannot be fully applied in the field of equipment monitoring [4, 5].

This paper analyses the status of current equipment status evaluation, and puts forward a real-time evaluation method of monitoring equipment status based on meeting the requirements of real-time monitoring and control of monitoring equipment. Through the case of actual power grid system, it shows that the real-time evaluation method of the equipment can support the assistant decision-making of monitoring and control personnel, dispatching personnel and operation and inspection personnel, and guide the optimization and adjustment of power grid operation mode.

2. Current Situation of Equipment Status Evaluation
The equipment evaluation of the operation inspection unit is divided into three categories: lean management evaluation, annual status evaluation and dynamic evaluation. Lean management evaluation is a comprehensive inspection and evaluation of substation equipment acceptance, operation and maintenance, detection, maintenance, counter measure implementation and operation.
and inspection management, to find out the weak links of equipment and operation and inspection management in an all-round way, and to continuously improve the level of lean management of substation and equipment operation reliability. The annual state evaluation is a comprehensive professional inspection, live line detection, online monitoring, routine test, diagnostic test and other technical means. According to the guidelines for state evaluation of power grid equipment, the annual state evaluation is organized and carried out in a centralized way every year. Dynamic evaluation is the evaluation carried out after the change of the important state quantity of the equipment. The main categories are the first evaluation of new equipment, defect evaluation, evaluation after experiencing bad working conditions, evaluation after live detection abnormality and evaluation after maintenance. The lean evaluation cycle is three years, and the annual state evaluation is in the first half of each year. The dynamic evaluation with the best timeliness can only take place in specific circumstances, so the evaluation cycle is long, and the timeliness is far from meeting the needs of equipment monitoring.

3. Real-time Evaluation System

In order to realize the real-time status evaluation of the equipment, based on the status evaluation results of the inspection equipment, the supporting data of the equipment monitoring system is quoted, and based on the analysis results of the monitoring big data platform, the monitoring equipment is evaluated in real-time from multiple dimensions through the analysis of the historical data and the mining of the historical experience. The results are used to support scheduling optimization control, monitoring professional management and equipment management.

3.1. Selection of Evaluation Indicators

Based on the requirements of power grid equipment monitoring and object-oriented analysis, this paper constructs five dimensions of equipment control, equipment operation defects, equipment operation conditions, equipment remaining life and equipment abnormal operation mode to evaluate the equipment in real time. The equipment control dimension explains the monitoring degree and control degree of the equipment by the equipment monitoring personnel. The quoted indicators include frequent signal reversal indicator, signal not reset indicator, signal failure indicator, signal inhibition indicator, signal blocking indicator, remote control failure indicator, etc. The equipment operation defect dimension describes the number of critical, serious and general defects existing at the time of evaluation. The dimension of equipment operation condition describes the situation of equipment overload, over temperature and voltage over limit. The dimension of equipment remaining life is based on the evaluation results of operation inspection status, and the basic physical remaining life of equipment is preliminarily evaluated. The abnormal operation dimension of the equipment describes the switching operation, reconstruction and expansion, maintenance test, equipment defect elimination, etc. of the equipment when it is evaluated.

3.1.1. Equipment control indicator. The indicator is used to support monitors to evaluate the remote monitoring and control strength of the equipment, then analyze and confirm the remote signaling, telemetry, remote control and other alarm information sent to the main station from the sub station, and monitor the operation of the auxiliary monitoring system, such as video hot spot monitoring system, automatic voltage control system, fault recording system, etc.

3.1.2. Equipment operation defects indicator. The indicator refer to all abnormal phenomena that affect the safe operation of power grid or the health level of equipment in operation or standby equipment and facilities [6-9]. Equipment defect management is an important measure to ensure the safe operation of power grid. Based on the classification of equipment defects, the critical defects, serious defects and general defects of the equipment are counted, which are used to support the evaluation of the operation status of power equipment.

3.1.3. Equipment operation conditions indicator. The indicator is used to reflect the information that the important remote measurement exceeds the upper and lower limit of the alarm, that is, the measurement values that may affect the operation status of the power grid equipment, such as the
active power, reactive power, current, voltage, transformer oil temperature and section current, operating overvoltage, external short circuit, over excitation, etc., are important information that needs real-time monitoring and timely processing.

3.1.4. Equipment remaining life indicator. The indicator is to determine the status and future development trend of the equipment through regular measurement of the equipment, timely analysis of the data obtained, and to realize the prediction of the operation status of the equipment through long-term monitoring. This indicator is supported by the status evaluation of operation inspection.

3.1.5. Abnormal operation mode of equipment indicator. The abnormal operation mode of the equipment refers to the special operation mode of the equipment, including the condition that the equipment is in the maintenance state, the equipment is in the interval transformation, and the switching operation is required.

3.2. Construction of Evaluation System
According to the selected evaluation indicators, the indicator system is constructed, which is composed of core first level indicators and expandable second level indicators. The first level indicators include equipment control indicator, equipment operation defect indicator, equipment operation condition indicator, equipment remaining life indicator and equipment abnormal operation mode indicator. Based on the first level indicators, the second level indicators are respectively extended to support the result evaluation of the first level indicators.

| First Level Indicators                          | Second Level Indicators                                      |
|-----------------------------------------------|-------------------------------------------------------------|
| equipment control indicator                   | frequent reversal indicator                                 |
|                                               | signal not reset indicator                                  |
|                                               | remote control failure indicator                             |
|                                               | signal inhibition indicator                                 |
| equipment operation defect indicator           | critical defects indicator                                  |
|                                               | serious defects indicator                                   |
|                                               | general defects indicator                                   |
| equipment operation condition indicator        | oil temperature overloading indicator                       |
|                                               | voltage off-limit indicator                                 |
|                                               | active power off-limit indicator                            |
| equipment remaining life indicator             | remaining life indicator                                    |
| equipment abnormal operation mode indicator    | switching operation indicator                               |
|                                               | reconstruction and expansion indicator                      |
|                                               | eliminate defects indicator                                 |

4. Indicator Weight Setting
In this paper, AHP and entropy weight methods are used to confirm the weight of evaluation indicator. Analytic hierarchy process is a kind of subjective weighting method, which is to decompose a complex multi-objective decision-making problem into multiple objectives or criteria as a system, and then decompose it into several levels of multiple indicators. Through the fuzzy quantitative method of qualitative indicators, it calculates the single level and total level, and optimizes the decision-making of multiple schemes as the objective. The entropy weight method is a kind of objective weight method, which uses the information entropy to calculate the entropy weight of each index according to the variation degree of each index, and then gives the objective weight of each index [10, 13].
4.1. AHP Method

Based on the evaluation index system, a hierarchical analysis structure is constructed, including the target layer, criteria layer and scheme layer [11-13]. The model structure is shown in the following figure:

Figure 1. AHP structure.

Suppose that there are n factors in a certain layer, \( X = \{x_1, x_2, ..., x_n\} \), based on the influence degree of the layer on a certain criterion (or target) in the upper layer, the proportion of the two factors in the layer relative to a certain criterion is determined, and a paired comparison matrix is formed. Through the consistency test of the matrix, if the consistency requirements are not met, the pairwise comparison matrix needs to be adjusted; for the pairwise comparison matrix satisfying the consistency requirements, confirm the normalized eigenvector of the largest eigenvalue \( W = [w_1, w_2, ..., w_n] \) as the weight of its indicator \( w_j \).

4.2. Entropy Weight Method

Entropy weight method is a kind of objective weight method[10]. According to the variation degree of each index, it uses information entropy to calculate the entropy weight of each index, and then gives each index more objective weight.

The flow of the algorithm is as follows:

The first step is to build the initial analysis matrix \( R = (r_{ij})_{m \times n} \) based on the historical operation data and operation inspection results of the evaluated objects in a certain area.

\[
R = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]  

(1)

Where \( m \) is the number of evaluated equipment, \( n \) is the number of evaluation indexes, and \( r_{ij} \) represents the evaluation value of the i-th equipment under the j-th index.

In the second step, the initialization matrix is dimensionless:
If \( j \) is a positive indicator,
\[
\hat{r}_{ij} = \frac{r_{ij} - \min(r_{ij})}{\max(r_{ij}) - \min(r_{ij})}
\]
(2)

If \( j \) is a negative indicator,
\[
\hat{r}_{ij} = \frac{\max(r_{ij}) - r_{ij}}{\max(r_{ij}) - \min(r_{ij})}
\]
(3)

Where, \( \min(r_{ij}) \) represents the minimum value of the value in column \( j \); \( \max(r_{ij}) \) represents the maximum value of the value in column \( j \). In this paper, the positive index method is used to form a new matrix \( \hat{R} = (\hat{r}_{ij})_{m \times n} \).

\[
\hat{R} = \begin{bmatrix}
\hat{r}_{11} & \hat{r}_{12} & \cdots & \hat{r}_{1n} \\
\hat{r}_{21} & \hat{r}_{22} & \cdots & \hat{r}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\hat{r}_{m1} & \hat{r}_{m2} & \cdots & \hat{r}_{mn}
\end{bmatrix}
\]
(4)

The third step is to calculate the probability of the index value of the \( i \)-th equipment under the \( j \)-th index \( p_{ij} \):
\[
p_{ij} = \frac{\hat{r}_{ij}}{\sum_{i=1}^{m} \hat{r}_{ij}}
\]
(5)

That is, the proportion of the \( j \)-th index in the \( i \)-th evaluation equipment.

The fourth step is to calculate the information entropy of the \( j \)-th index \( e_j \):
\[
e_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij}
\]
(6)

Where \( k = \frac{1}{\ln m} \), if \( p_{ij} = 0 \), then \( p_{ij} \ln p_{ij} = 0 \).

The fifth step is to calculate the entropy weight of the \( j \)-th index \( w_j \):
\[
w_j = \frac{1 - e_j}{\sum_{j=1}^{m} (1 - e_j)}
\]
(7)

4.3. Confirm the Combination Weight

\[
w_j = \frac{w_j w_j}{\sum_{i=1}^{m} w_i w_j}
\]
(8)

Because of the characteristics of two kinds of methods, that is, the subjectivity of AHP and the objectivity of entropy weight method. When the weights of AHP and entropy weight method are in the same order, using the weights of entropy weight method as the final weights of each evaluation index can effectively eliminate the subjectivity of index weights; when the weights of the two methods are in different order according to the importance of evaluation indexes, By using the eclectic analysis method of equation (8), the advantages of entropy weight method and analytic hierarchy process (AHP) are integrated, which makes the determination of weight in multi index comprehensive evaluation more reasonable.
5. Experimental Results

5.1. Determining Subjective Weight Based on AHP
In order to facilitate the analytic hierarchy process, 10 local supervisors of a provincial power grid company are used as expert teams to set the relative weight of the first level indicators involved in the evaluation system. Based on the influence of the second level indicators on the first level indicators, the proportion of the two factors in the second level indicators relative to the first level indicators is determined, and a paired comparison matrix is formed.

As the hierarchical model is incomplete, the comparison matrix is constructed for the criterion layer and the comparison matrix is constructed for the sub nodes of the criterion layer.

Based on the hierarchical evaluation model structure, the criterion layer is constructed, which includes the power equipment supervised by 10 local dispatching units of the provincial power grid company, including 2476 transformers, 1306 units, 5698 buses, 2930 lines, 3467 capacitors and 380 reactors, th

The weight results are as follows:
\[
\begin{bmatrix}
1 & 5/4 & 5/4 & 5/3 & 5 \\
4/5 & 1 & 1 & 4/3 & 4 \\
4/5 & 1 & 1 & 4/3 & 4 \\
3/5 & 3/4 & 3/4 & 1 & 3 \\
1/5 & 1/4 & 1/4 & 1/3 & 1
\end{bmatrix}
\]

\[
\begin{align*}
w_A &= \{0.2654, 0.2123, 0.2123, 0.2502, 0.0598\}; \\
w_{B1}' &= \{0.2, 0.2, 0.3, 0.3\}; \\
w_{B2}' &= \{0.5119, 0.3378, 0.1502\}; \\
w_{B3}' &= \{0.2632, 0.2105, 0.2632, 0.2632\}; \\
w_{B4}' &= \{0.5377, 0.1948, 0.2675\};
\end{align*}
\]

5.2. Determination of Objective Weight Based on Entropy Weight Method
Based on the power equipment supervised by 10 local dispatching units of the provincial power grid company, including 2476 transformers, 1306 units, 5698 buses, 2930 lines, 3467 capacitors and 380 reactors, the initialization analysis matrix is constructed based on the evaluation index system, and the weight results are as follows:
\[
\begin{align*}
w_{B1}'' &= \{0.1456, 0.1624, 0.3462, 0.3458\}; \\
w_{B2}'' &= \{0.2015, 0.2961, 0.5024\}; \\
w_{B3}'' &= \{0.2738, 0.3409, 0.1111, 0.2741\}; \\
w_{B4}'' &= \{0.3122, 0.2249, 0.4629\};
\end{align*}
\]

5.3. Confirm the Evaluation Score of Each Equipment Based on the Combination Weight
Based on the weight determined the AHP method and the entropy weight method, according to the formula (8), the weight of each secondary index is obtained as follows:
\[
\begin{align*}
w_{B1} &= \{0.1082, 0.1206, 0.3858, 0.3853\}; \\
w_{B2} &= \{0.3702, 0.3589, 0.2708\}; \\
w_{B3} &= \{0.2191, 0.3410, 0.2196, 0.2196\}; \\
w_{B4} &= \{0.1667, 0.3335, 0.4998\};
\end{align*}
\]

Furthermore, through the historical operation data and detection data of equipment, the evaluation of various equipment can be realized, and the operation evaluation of substation and power grid can be realized based on the evaluation results of equipment. Taking the transformer as an example, through the analysis of 2476 transformers in the province, the results of the evaluation based on the voltage level are shown as follows
Figure 2. Transformer score results.

The grid evaluation results are as follows:

Figure 3. Grid score results.

Through the evaluation results of equipment and power grid operation, it can be seen that high-voltage equipment has relatively high scores due to equipment safety requirements and equipment maintenance level; at the same time, based on the evaluation scores of power grid, the operation and maintenance level of equipment and equipment health status in each region can be preliminarily evaluated, so as to realize the prediction of personnel carrying capacity and personnel regulation capacity.

6. Conclusions
The real-time state evaluation of monitoring equipment makes up for the non-timeliness of the evaluation method of operation inspection equipment, which lays a foundation for adjusting the operation mode, timely discovering the defects of power grid equipment and the weak links of power grid operation. The real-time evaluation method of equipment state based on the synthesis of AHP and entropy weight method improves the subjectivity of AHP and the objectivity of entropy weight method. It is a kind of remedy for both methods, and has strong applicability for the multi index comprehensive evaluation method. The test results show that the method can calculate the evaluation score of power grid equipment in real time, and use the score in the important reference index of power grid monitoring, so as to provide reliability guarantee for improving the safe operation of power grid.

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