An Electric Equipment Analysis Method based on Knowledge Reasoning

Xinjie Zhang\textsuperscript{1*}, Yao Wang\textsuperscript{2}, Run Lin\textsuperscript{3}, Yuze Zhang\textsuperscript{1}, Xu Li\textsuperscript{1}, Jian Wang\textsuperscript{1}

\textsuperscript{1}State Grid Tianjin Chengxi Electric Power Supply Branch, Tianjin, 300190, China
\textsuperscript{2}State Grid Tianjin Electric Power Company, Tianjin, 300010, China
\textsuperscript{3}Beijing Kedong Power Control System Co., Ltd., Beijing, 100085, China

*Corresponding author’s e-mail: 910877245@qq.com

Abstract. Facing the increasingly complex power grid architecture and high equipment failure risk, a comprehensive equipment condition analysis method based on knowledge reasoning is proposed in this paper, mainly using the large amount of characteristic information to realize the condition evaluation, fault detection and early warning. Firstly, it statistically analyzes the historical data, extracts the characteristic information of equipment health status and builds a knowledge mapping library of key factors for equipment-centered status analysis; secondly, it establishes an intelligent early warning library of equipment index data, and gets the probability of equipment defects and fault risks through induction-based knowledge reasoning method; finally, it gets the equipment status rating through logic and rule-based knowledge reasoning method and the closed-loop system of equipment status evaluation is established. The reasonableness of the evaluation method is verified by the examples, which realizes supervision operation status mining early warning, sensing equipment operation status in advance and reducing potential operation risk of power grid.

1. Introduction

The substation equipment condition analysis mainly uses the large amount of characteristic information contained in the substation equipment condition quantity to realize the condition evaluation, fault detection, defect diagnosis as well as reliability and service life analysis of key components, so that the power grid can respond to various equipment failures in a timely and proactive manner [1-2].

In the current production practice, the most widely used is based on the condition evaluation method specified in the guidelines. The equipment condition evaluation method comprehensively considers the possible performance of each transformer component in the event of a fault or defect, and scores the condition of each component of each device by matching different characteristic conditions. As different components have different degrees of influence on the normal operation of the equipment, the condition scoring method will eventually weight the component scores to obtain the total score of the transformer, and determine the current operating status and defect level of the transformer based on the total score [3-5].

The so-called knowledge reasoning is the process of inferring the unknown knowledge on the basis of the existing knowledge. By starting from known knowledge, new facts implied from it through the already acquired knowledge, or generalizing from a large amount of existing knowledge and promoting from individual knowledge to general knowledge [6-7].
At present, the knowledge reasoning technology has not been involved and applied in the electric power equipment condition evaluation business, so the present invention will use the knowledge reasoning technology to analyze the defects and fault conditions of the power grid equipment, and dig deeply into the correlation relationship and characteristic information between the knowledge; meanwhile, it will carry out the auxiliary logic or decision judgment, that is, based on the business logic map and data, it will adopt the power grid operation and condition, evaluation guideline and empirical knowledge, through which comprehensive analysis of equipment status is conducted and equipment status evaluation is obtained [8-10].

Through this study, a comprehensive equipment condition analysis method based on knowledge reasoning is formed to assist the supervision personnel to grasp the equipment operation in time, form the equipment risk warning, and lay the foundation for fault diagnosis and condition maintenance, so as to maintain the safety of the power grid.

2. Framework for constructing the analysis method

Comprehensive analysis of equipment status refers to the construction of an equipment-centered status analysis knowledge mapping library, the use of artificial intelligence methods to judge relevant data, a comprehensive qualitative and quantitative analysis of equipment operating status, the discovery of early symptoms of power equipment faults, the formation of equipment risk warning, and the laying of a foundation for equipment fault diagnosis and status maintenance. Figure 1 is the overall framework for the knowledge reasoning method.

![Figure 1. Figure of framework.](image)

3. Knowledge graph of key factors for condition analysis

Through statistical analysis of historical data, the characteristic information of equipment status can be chosen to sort out the equipment condition evaluation indexes from macro and micro, and the knowledge graph of key factors for condition analysis is built up, which centered on equipment.

The evaluation indexes are divided into two parts: the key influencing factors extracting from the equipment condition evaluation guidelines and the key indexes determined by expert experience. Combing the above two type, the dimension of comprehensive equipment condition analysis is obtained. Table 1 shows the sources, types and data contents of the indexes.
Table 1. The sources, types and data contents of the indexes.

| Index Sources | Index type | Data Contents |
|---------------|------------|---------------|
| the key influencing factors from evaluation guidelines | Defect record | body, bushing, cooler, on-load and non-excitation tap changer, non-electricity protection and online supervision device. |
| Equipment maintenance | | maintenance content, interval with the previous maintenance, etc. |
| Alarm Information | | operating oil temperature, abnormal pressure release, cooling system fault, etc. |
| operating conditions | | short-circuit current, short-circuit times, transformer overload, transformer over-temperature, tap changer switching times. |
| The information combing expert experience | test reports | electrical test, oiling test, infrared temperature measurement, core grounding current, etc. |
| inspection records | | casing appearance, noise and vibration, oil leakage of the body, etc. |
| Geographic, meteorological conditions | | indoor/outdoor, temperature, humidity, surrounding environment, etc. |

The data is divided into structured data and semi-structured/unstructured data, which are implemented using ETL tools and distributed parallel processing framework, respectively. According to the knowledge of supervision business, the structure Schema design is carried out, including the definition of labels, entities (model entities, operational entities, label entities), and relations. Based on the schema of the graph Schema, the stock and incremental data are imported into the knowledge graph using model data, event rules, alarms, telemetry and other data, and the graph database is used for storage.

Neo4j graph database is used as the core storage component for the storage and query of the knowledge graph. The jdbc and Apoc components are also used to update the neo4j data using the Knowledge Graph Schema. According to the need, Cypher rule expressions are designed and provided to the application by rest service to open out the subgraphs of the schema query. The base schema stores public knowledge and can be continuously expanded for various types of business knowledge such as supervision schema and planning schema.

4. Intelligent early warning database of equipment index data

Based on knowledge graph, statistics of historical defects, calculates frequency distribution for attributes are classified and organized, which include defect level, equipment category, defect time, etc. Also, causes of defects and associated parameters are statistically analyzed, in order to set early warning thresholds for equipment supervision parameters. The fusion of equipment supervision, associated supervision parameters, warning thresholds, running time and other cross-sectional parameters establishes an intelligent early warning model for equipment supervision, and the intelligent early warning library for equipment index data.

In view of the complex reasons affecting the occurrence of defects in the power system, it is difficult to carry out defect prediction, time variables can be used instead of complex and variable factors, and time series method is used for trend warning.

Using $X$ to represent the observed values of time series variables, $T$ and $S$ to represent long-term trend factors and seasonal change factors, we can describe the $X=T+S$ multiplier model, apply the frequency distribution to separate $T$ and $S$, and apply the trend analysis method for forecasting.

The trend analysis method is to use existing data to find the inherent regularity of a certain statistical indicator, so as to obtain a more accurate forecast value of the indicator's future. That is, to obtain the
variation pattern of data from the sequence of indicator values \( \{x_1, x_2, x_3, \ldots, x_t\} \) and to predict the values of \( \{x_{t+1}, x_{t+2}, x_{t+3}, \ldots, x_{t+n}\} \).

Assuming that the collected index value series is \( \{y_1, y_2, y_3, \ldots, y_n\} \) and the collected time series is \( \{t_1, t_2, t_3, \ldots, t_n\} \) then the linear regression function is

\[
y = a + bt
\]

Using the least squares method to calculate the parameters \( a \) and \( b \).

\[
\begin{align*}
    b &= \frac{\sum_{i=1}^{n} t_i y_i - nt \bar{y}}{\sum_{i=1}^{n} t_i^2 - n \bar{t}^2} \\
    a &= \bar{y} - bt
\end{align*}
\]

Thus, \( \bar{t} = \frac{1}{n} \sum_{i=1}^{n} t_i \), \( \bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i \). The values of the parameters \( a \) and \( b \) can be estimated from the existing collected data, and the trend of the state quantities can be analyzed by substituting the value \( t \) at some future moment into the linear regression function. This method allows the analysis of data that will occur in the future and is suitable for data with relatively short data collection periods. Comparing the predicted data with the warning threshold gives a trend warning.

5. Equipment condition rating with logic and rules

The equipment condition rating is obtained by a logic and rule-based knowledge reasoning method. The logical reasoning uses a logical expression or a logical equation system to represent the knowledge judgment formulaically, and the conclusion is drawn by performing operations with, or, or, or, and, or other logical symbols. In the process of equipment state analysis, the typical application of logical symbolic reasoning is the parsing of state information, i.e., the logical parsing model of the state is established through the equipment and evaluation logic and association relationships stored in the knowledge base.

The rule reasoning belongs to deductive reasoning, which is a more accurate and explanatory reasoning method. Parts of the state evaluation guidelines, etc. in the state analysis will be written in a similar way to the generative rules. In the case of transformer condition evaluation, there are some restrictions such as "220kV and below", "330kV and above", etc. This kind of judgment is well suited for using generative rules to match queries from the a priori knowledge of the knowledge graph and then select the appropriate evaluation method. The evaluation rules and process are shown in Figure 2.

![Figure 2. Figure of the evaluation rules and process based on the knowledge graph.](image-url)
The logic and rules mainly exist in the equipment status evaluation guidelines, which are extracted by natural language processing methods. And the equipment condition ratings are classified as good, average, serious and critical in order.

For the established indicator data trend warning, check and analyze as samples to fill the intelligent warning library, and continuously improve the intelligent warning library day by day. Through result verification, the reasonableness of the evaluation results is determined, and when the evaluation results do not match with the equipment status, the model is corrected, thus forming a closed-loop system for equipment status evaluation.

6. Case Analysis and Result
With the above method, the main transformer oil temperature data is analyzed, which includes three parts: data preparation, algorithm processing and resulting outputs. Figure 3 shows the whole process of main transformer oil temperature data analysis.

By correlating the main variable measurement data, main transformer-related defect data, meteorological data, etc., we can obtain the main transformer operating condition data. Then, merging, filling, invalid data elimination, feature extraction, etc., the processed data is modeled by decision tree algorithm, and the model is continuously optimized and corrected by test data, and finally the optimized and perfected model is output.

After getting the model, input the real-time oil temperature data for prediction analysis, get the actual measured value of oil temperature, predicted value of oil temperature, maximum value of actual and predicted oil temperature deviation, maximum value of actual oil temperature, and combine with the maximum limit value of oil temperature measurement, limit value of oil temperature deviation and limit value of oil temperature deviation slope obtained from the experiment, make diagnosis analysis of oil temperature of main transformer, and output the operation status result of main transformer through judgment logic, including: telecommunication The result of the operation status of the main substation is outputted through the judgment logic, including: remote signal misfiring, normal status and warning status.

Figure 3. Figure with the analysis process of main transformer oil temperature data.
7. Conclusions
This paper provides a comprehensive analysis method for equipment status based on knowledge reasoning, which improves the ability of equipment status risk assessment, as well as the ability of dispatcher fault research and diagnosis. Besides, it has made several improvements in the following aspects:

Firstly, an equipment-centered knowledge mapping library of key factors is constructed for condition analysis. It contains equipment condition assessment indexes from macroscopic and microscopic aspects, which can reflect equipment characteristic information and health status.

Secondly, an intelligent early warning library of equipment index data is established. Basing on the indexes and inductive reasoning method, equipment defects and fault probabilities can be obtained quickly and accurately.

Finally, equipment condition ratings are realized by knowledge reasoning, considering both logic and rules. Furthermore, a closed-loop system for equipment condition evaluation is established, and the reasonableness of the evaluation results is determined through result verification.

The reasoning method of knowledge graph carries out comprehensive analysis of the state of power equipment, identifies power grid safety hazards and prevents equipment fault defects, which is conducive to deepening condition maintenance and aiding decision-making and maintaining power grid safety.

Acknowledgments
As a stage achievement, this work was only supported by Science and Technology Project of State Grid Tianjin Electric Power Company (No. KJ21-1-6).

References
[1] Li L, Zhang D, Xie LJ, et al. (2013) A condition assessment method of power transformers based on association rules and variable weight coefficients. J. Proceeding of the CSEE, vol.33(24). pp. 152-159+22.
[2] Liang L, Yu L. (1991) The complement of An improved analytic hierarchy process. J. Systems Engineering, vol.9(3). pp. 64-65.
[3] Zhang P, Qi B, Li WP, et al. (2019) A differentiated evaluation method of transformers considering the part and its performances. J. Proceeding of the CSEE, vol.39(20). pp. 6138-6146.
[4] Ma ZG, Ni RY, Yu KH, “Recent advances, key techniques and future challenges of knowledge graph,” J. Chinese Journal of Engineering, vol. 42(10). pp. 1254-1266, 2020.
[5] Shi ZC, Zheng JX, Zhou TB. (2020) Study on knowledge graph construction of equipment monitoring and alarming information based on semantic analysis. J. Zhejiang Electric Power, vol. 39(8). pp. 83-87.
[6] Guan SP, Jin XL, Jia YT, et al. (2018) Knowledge reasoning over knowledge graph: A survey. J. Journal of Software, vol. 29(10). pp. 2966-2994.
[7] Li ZX, Ren SY, Wang HM, Shen K. (2019) Knowledge reasoning method based on unstructured text-enhanced association rules. J. Computer Science, vol. 46(11). pp. 209-215.
[8] Tang YC, Liu TT, Liu GY, et al. (2019) Enhancement of power equipment management using knowledge graph. In: Proceedings of the 2019 IEEE Innovative Smart Grid Technologies-Asia (ISGT Asia). Chengdu, China.
[9] Jiang Yiwen, Li Lee, Li Zhiwei, et al. (2019) An information mining method of power transformer operation and maintenance texts based on deep semantic learning. J. Proceedings of the CSEE, vol. 39(14). pp.4162-4171.
[10] Zhou ZH. (2016) Machine learning. Tsinghua University Press, Beijing.