Research and Application of Online Monitoring and Early Warning System for Converter Transformer

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Abstract. In order to make up for the deficiency of the current monitoring methods for converter transformer and its accessories, an intelligent monitoring system for the operation parameters and environment of the converter transformer is designed based on the monitoring of the converter transformer. The current monitoring means are expanded and the key operation parameters and operation environment monitoring information of the converter transformer are further integrated. Statistical analysis method and DBN neural network are used to analyze the running state of the converter and realize the condition monitoring and evaluation of the converter and its accessories. The operating status of equipment is effectively perceived and analysis and decision-making basis for carrying out condition maintenance are provided.

Keywords: converter transformer, intelligent monitoring, internet of things, analysis of defect.

1. Introduction
The 800kV converter station is the core node of the power grid. Once a major failure occurs, it may cause serious consequences such as grid disconnection and large-scale blackouts in the city. Therefore, it is important to ensure the safe and stable operation of the equipment in the substation. The converter transformer is the core equipment in the converter station, which runs at full load and high temperature for a long time. Once a fault occurs during operation, it may cause serious accidents such as DC tripping or even explosion and fire. The daily inspection and maintenance work of the converter transformer is an important daily work to ensure the safe and stable operation of the equipment. Through the patrol inspection of the converter transformer, its operating conditions can be grasped, and the defects of the equipment can be found and eliminated in time to prevent the occurrence of major accidents[1][2]. At present, there are a large number of converter transformers in UHV converter stations, heavy manual inspection workload, many interference factors, long inspection cycles and blind spots in inspections. Therefore, it is necessary to add intelligent monitoring systems and analysis methods to make up for the shortcomings [3] [4].

In view of the above problems, on the basis of analysis of the existing monitoring system of converter transformers, this paper proposes a unified monitoring transformation plan for online monitoring of converter transformers based on WiFi wireless transmission, which is installed in a ±800kV converter...
station. Through online collection of the temperature of key parts of the converter transformer, the SF6 pressure of the wall bushing, the number of actions of the arrester, the temperature and humidity in the secondary screen cabinet, and other operating parameters of the converter. Various data collected by different sensors are sent to unified cloud platform, and save it in the database. Online analysis and processing of the collected data through the background host, displaying the historical transformation trend of the operating data, and generating an alarm in time when the data exceeds the alarm value, assisting the operating personnel in online analysis and decision-making on the operating conditions of the converter transformer.

2. Architecture

The types of parameters that need to be monitored in the converter transformer are complicated. The data of Online monitoring of converter transformer is analyzed, including dissolved gas in oil, partial discharge, bushing insulation, SF6 gas, core ground current, winding deformation, transformer vibration spectrum and other state variables [5]. The above-mentioned monitoring volume has been able to cover many objects, but it is still insufficient for some situations.

For example, in a ±800kV converter station, the converter transformer does not have the actual conditions for installing partial discharge and winding deformation due to the long operation time. According to the actual situation of the converter transformer site, the data to be monitored include: Converter transformer bushing SF6 pressure, main transformer internal oil chromatogram, infrared temperature measurement of bushing, body, oil pillow and radiator, iron core ground leakage current, clamp ground leakage current, cooling fan vibration, main transformer noise. According to the judgment of operation and maintenance experience, as an important secondary control device for the converter transformer, the condensing problem of the control cubicle is very serious. Therefore, the online monitoring data of the converter transformer adds the temperature and humidity in the control cubicle to timely monitor the condensation situation in the control cubicle.

Therefore, this paper puts forward a transformation plan for online monitoring and unified monitoring of converter transformers based on WiFi wireless transmission. Data transmission adopts wireless mode. After the WIFI in the station is collected, the data is uploaded to the storage server in the station through optical fiber or network cable. The mobile phone in the station is connected to the WIFI base station to access the server in the station. The WIFI base station is installed on the roof of the main control building and is connected to the cloud server in the main control room through a network cable.

![Fig. 1 The Intelligent monitoring system framework for converter transformer.](image)

2.1. Data collection

A monitoring system is installed in the A-phase, B-phase and C-phase three-phase single-phase single converter transformer area of a 2Y/△ high-end converter transformer of a converter station.
The missing data on site includes: SF6 pressure of converter transformer casing, infrared temperature measurement of casing, body, oil pillow, radiator, cooling fan vibration, and main transformer noise. According to the actual installation of sensors on site, the online monitoring system collects as described in Table 1.

| Table 1. Data Collected By Additional Sensors |
|----------------------------------------------|
| Converter variable part | data | Collection method |
|-------------------------|------|-------------------|
| casing                  | surface temperature | Infrared thermal image |
| Oil pillow              |                   |                   |
| Body                    |                   |                   |
| Cooler                  |                   |                   |
| SF6 pressure gauge for casing | SF6 pressure | Visible light camera |
| Oil level gauge for oil pillow | Oil level |                   |
| Control Cubicle         | Temperature and humidity | Temperature and humidity sensor |
| Cooling fan             | Vibration and noise | Vibration noise sensor |

- The on-line temperature monitoring subsystem of the converter transformer can dynamically monitor the operating temperature of the key parts of the converter transformer, collect temperature data for real-time storage, and have functions such as trend analysis and dynamic early warning.
- The SF6 pressure online monitoring subsystem of the converter transformer can realize online monitoring of the SF6 pressure of the converter transformer casing, obtain SF6 meter photos through the camera, and identify the SF6 meter readings in the pictures through artificial intelligence algorithms.
- The temperature and humidity online monitoring subsystem of the secondary screen cabinet of the converter transformer can realize the online monitoring of the temperature and humidity of the secondary screen cabinet, the collected data can be dynamically stored, and it has the functions of trend analysis and fault diagnosis.
- The operation of the converter transformer cooling fan is monitored by industrial control, the noise and vibration data of the converter transformer fan, such as vibration displacement, speed, acceleration, are collected by installing noise and vibration sensors, and abnormal operating conditions are identified through algorithms.

2.2. Communication Methods
The types of converter transformer data collected include maps and values. Each of the infrared maps is about 1M, and the high-definition visible light maps are about 3~5M. Three converter transformers transmit data every hour, and the total amount of data transmitted is about 50M, the data transmission volume is large, so the data transmission method requires a fast communication rate, a long transmission distance, and a strong signal diffraction ability. Comprehensive comparison of the transmission stability, transmission rate, transmission range, cost and other characteristics of different network connection technologies such as ZigBee, NB-loT, Lora, and WiFi [6] [7] [8] [7], as described in Table 2.

| Table 2. Comparison of Communication Methods |
|----------------------------------------------|
| communication methods | ZigBee | Lora | NB-loT | WiFi |
|----------------------------------------------|
| cost | Lower | lowest | Lower | Lower |
| Communication distance | 10~100m | <300m | 5~10kM | <200m |
| Transmission rate | <250kb/s | <256kb/s | <250kb/s | >2Mb/s |
| Communication frequency band | 2.4GHz | 470MHz~518MHz | 433MHz~912MHz | 2.4GHz |
| Wall penetration | weak | Strong | Strong | Strong |
| eSIM card | N | N | Y | N |
| Anti-noise performance | Good | Good | Good | Good |
Through the comparison of communication methods in Table II, it is found that WiFi has the highest transmission rate, long transmission distance, and strong transmission ability through walls and bypassing obstacles, which can form a local area network in the converter station. Other communication methods have shortcomings in the commutation variable data collection scenario:

- Although the NB-IoT technology has a long transmission distance, it needs to insert an eSIM card, and the data enters the server background through China Mobile, China Unicom or China Telecom operator network. In the occasions where data is highly confidential, such as converter stations, it does not comply with data security management regulations.

- In most wireless sensor networks, Zigbee and LoRa technologies with low power consumption and local network transmission are used more frequent, but Zigbee and LoRa technologies have complex networking, low transmission rate, and limited ability to pass through obstacles, which are not compatible with converter stations.

In summary, the use of WiFi technology to achieve intra-converter network networking, data will not go out of the station. The characteristics of convenient networking, low cost, wide wireless coverage and a high transmission rate of 54Mbps, which meets the application scenarios of converter transformers collecting maps and values.

3. Analysis of Defect

3.1. Methods of statistical analysis

Sort out the monitoring data, environmental monitoring data, and historical equipment defect records related to the converter transformer status, use monitoring data or environmental data as clues, the coupling relationship between key parameters and equipment status is explored and a multi-dimensional state evaluation index system is formed by using correlation analysis, clustering, deviation analysis and other methods, and the multi-dimensional evaluation are realized by utilizing the vertical (time) and horizontal changes of the equipment parameters to accurately and timely predict the operating status of the converter transformer based on the key feature parameters corresponding to different equipment. Figure 2 shows the multi-dimensional analysis architecture of converter station equipment based on operational monitoring and environmental monitoring data.

![Fig. 2 Multi-dimensional analysis framework](image-url)

A monitoring information model is established based on the monitoring data of Key parameters of equipment operation, environmental data and historical status data, the criterion for abnormal equipment status is identified by using cluster analysis method, whether the equipment status is abnormal is judged through the changes of vertical (time) and horizontal status data by using multivariate statistical analysis methods, and discover potential faults in time. State assessment methods based on horizontal and vertical comparison include:

- Judge whether there is an abnormality by comparing the daily maximum, daily minimum, daily average with the threshold.
- Judge whether there is an abnormality by comparing the monthly fluctuations of the daily maximum and minimum with the threshold.
Judge whether there is an abnormality by comparing and analyzing the predicted value and the measured value.

The operation and maintenance defect data of different defect types of different equipment types and models are obtained through the standardized information collection model. On this basis, clustering analysis of the status of the family equipment for the defects of the auxiliary equipment of the converter transformer, and identifying the family characteristics. Count the number of occurrences of certain types and types of defects of different equipment manufacturers, and timely push equipment early warning information according to the set early warning rules to realize centralized monitoring and management of the defect operation and maintenance of converter stations.

3.2. Methods of intelligent diagnosis based on DBN

The DBN deep belief network contains multiple hidden layers and is a probabilistic generation model superimposed by multiple RBMs. RBM is an energy-based generative model, including visible layer $v$ and hidden layer $h$. Its overall energy is defined as

$$
E(v, h | \theta) = -v^T W h - b^T v - a^T h - \sum_{i=1}^{m} \sum_{j=1}^{n} W_{ij} v_j - \sum_{j=1}^{n} b_j v_j - \sum_{i=1}^{m} a_i h_i
$$

(1)

Where $v$ represents the state vector of the node in the visible layer, $h$ represents the state vector of the node in the hidden layer, $m$ and $n$ are the number of nodes in the visible layer and the hidden layer respectively, $W$ represents the connection weight matrix, $\theta$ is the parameter of the network model, where $a$ and $b$ respectively represent the bias value vector of the hidden layer node and the visible layer node. Apply the Contrastive Divergence (CD-k) algorithm to determine the value of the parameter $\theta=\{W,b,a\}$ in RBM. By training the DBN network layer by layer, the optimal parameters of each layer are obtained, and the output data of the current layer is used as the input data of the next RBM network layer, and the training is carried out in sequence to finally obtain the initial parameters of the DBN.

In this paper, the DBN algorithm is used to identify the defects of the converter transformer. According to the historical fault data of the converter transformer, combined with the actual operation and maintenance experience, the continuous characteristic index $X=\{a_1, a_2, \ldots, a_m\}$ that characterizes the operation status of the converter transformer and the fault location classification set $Y=\{y_1, y_2, \ldots, y_n\}$ are selected, each category uses binary coding, and finally a labeled fault location sample set $U=\{X_1, X_2, \ldots, X_m, Y\}$ is constituted.

In the formula, $a_1, a_2, \ldots, a_m$ represents $m$ continuous feature quantities, and $y_1, y_2, \ldots, y_n$ represents the classification of $n$ fault locations.

Continuous characteristic quantity $X=\{SF6$ pressure, hydrogen, ethane gas content, acetylene gas content, partial discharge, oil level, oil temperature, iron core ground current, clamp ground current, vibration signal\}. According to the historical fault data statistics of the converter transformer and the summarized common fault types [9], the fault type of the converter is used as the output of the converter fault prediction, corresponding to different monitoring changes, the converter fault prediction is carried out. The output codes are shown in Table 3.

**Table 3. Codes of Converter Transformer Fault Type**

| Fault type          | Corresponding code |
|---------------------|--------------------|
| Normal              | (1,0,0,0,0,0,0)    |
| Winding failure     | (0,1,0,0,0,0,0)    |
| Core failure        | (0,0,1,0,0,0,0)    |
| Oil failure         | (0,0,0,1,0,0,0)    |
| Casing failure      | (0,0,0,0,1,0,0)    |
| Tap changer failure | (0,0,0,0,0,1,0)    |
| Cooling system failure | (0,0,0,0,0,0,1)    |
Determine the number of neurons in the input layer and the number of neurons in the output layer of the DBN model according to the input data type and output defect category, and use the training set with fault classification labels to train the DBN model layer by layer without supervision, and finally a diagnosis model is formed.

4. Implementation of System

4.1. On-line monitoring of converter transformer temperature
Infrared temperature monitoring and historical data display. The dynamic monitoring of the operating temperature of key parts of the converter transformer is realized, the collected temperature data can be stored in real time, and the historical data trend analysis function and temperature limit alarm function are realized.

Obtain infrared temperature measurement information of key components of different equipment through multiple infrared temperature sensing devices, combine basic equipment information, environmental monitoring information, and identified temperature information to establish an infrared temperature image database (as shown in Fig.3). The detection data is classified into defects. Using temperature method, temperature rise method, comparative method, relative temperature difference method, and typical case library of infrared spectrum to comprehensively determine whether the equipment is operating abnormally. The temperature warning process is shown in Fig.4.

![Infrared temperature image database](image1)

![Temperature warning process](image2)

4.2. Other online monitoring systems
Temperature and humidity monitoring of converter transformer control cabinet: the temperature and humidity data of the secondary screen cabinet is returned to the system background by installing a
temperature and humidity sensor inside the control cabinet, the collected data can be dynamically stored, and the functions such as trend analysis and fault diagnosis are realized.

Vibration condition monitoring of converter transformer cooling fan: Monitor the vibration conditions of the cooling fan, and judge the working status of the converter transformer cooling fan through the abnormal recognition of vibration displacement, speed, and acceleration.

5. Conclusion
This paper analyzes and researches the intelligent monitoring system of the converter transformer, and through online collection of the operating parameters of the converter transformer such as the temperature of key parts of the converter transformer, the SF6 pressure of the wall bushing, the temperature and humidity in the secondary screen cabinet, and the vibration conditions of the converter fan, various data collected by different sensors are sent to a unified server through the Internet of Things, and stored in the database. Carry out multi-dimensional analysis and data over-limit alarms using different data in the system, realizing online intelligent monitoring of converter and variable operating conditions, effectively perceiving the operating status of equipment, and providing analysis and decision-making basis for carrying out condition maintenance.

Acknowledgements
Fund Project: Science and technology project of China Southern Power Grid EHV Transmission Company (010100KK52180003).

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