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A Review of Transformer Fault Diagnosis Based on Machine Learning and Dissolved Gas in Oil

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Abstract: Dissolved gas analysis in Oil (DGA) is a common transformer fault diagnosis strategy used to identify faults and monitor the status of oil-immersed transformers. It relates the concentration of various insulation degradation by-products dissolved in oil to the nature of the fault, and makes a judgment on the transformer fault category. The DGA standard provides a variety of interpretation methods for fault diagnosis and insulation life estimation. This paper reviews the principles of various traditional fault detection methods for dissolved gas in oil and points out their shortcomings. Aiming at the above problems, various fault detection methods combined with machine learning and dissolved gas analysis in oil are reviewed and summarized.

Keywords: Dissolved gas analysis in oil, power transformer, fault diagnosis.

1. INTRODUCTION

Oil-immersed power transformer is an important basic equipment in the power grid。The normal operation of the transformer is of great significance to the stable power supply of the power grid. Routine maintenance through condition monitoring extends the service life of these devices, and the condition of transformers can be monitored by evaluating their insulation. Although it is a normal process that insulation degrades with aging, external factors make insulation prone to premature aging, and factors such as overload, overvoltage, short circuit and mechanical stress will lead to accelerated aging. Therefore, from the point of view of reliability and economy, it is necessary to evaluate the state of oil-immersed power transformer.

Transformer fault diagnosis technology can be roughly divided into on-line method and off-line method. Offline methods mainly include: Dissolved gas analysis (DGA) in oil and TRANSFER Function technique (TFT); Online methods mainly include: Electrical detection method, ultrasonic detection method, infrared imaging detection method, pulsed current detection method, RIV detection method, optical detection method, micro water analysis, ULTRA-high frequency detection method, dissolved gas analysis in oil (dissolved gas analysis, DGA), oil temperature monitoring (OTM), acoustic partial discharge measurement (APDM), etc.

Gas chromatography is the most practical method to analyze the combustible gas in transformer oil. This method includes two processes: degassing from oil and measurement. Mineral oil is composed of about 2871 kinds of liquid hydrocarbons. Usually, only nine gases in insulating oil are identified: hydrogen (H2), oxygen (O2), nitrogen (N2), methane (CH4), carbon monoxide (CO), ethane (C2H6), carbon dioxide (CO2), ethylene (C2H4) and acetylene (C2H2). These gases are separated from oil and analyzed to prove their existence and content, which can reflect the fault type and severity of these gases. The gases produced by oil during normal aging are mainly carbon monoxide (CO) and carbon dioxide (CO2). When there is partial discharge in oil insulation (such as bubble breakdown in oil), the gases produced by oil cracking are mainly hydrogen (H2) and methane (CH4). When the fault temperature is not much higher than the normal operating temperature, the gas produced is mainly methane (CH4). With the increase of the fault temperature, ethylene (C2H2) and ethane (C2H6) gradually become the main characteristic gases; When the temperature is higher than 1000 ℃ (e.g. the arc path temperature is above 300 ℃), the gas produced by oil cracking contains more acetylene (C2H2). If the fault involves solid insulating materials, more carbon monoxide (CO) and carbon dioxide (CO2) will be produced.

For oil-immersed transformers, Dissolved Gas Analysis (DGA) in transformer oil is often used to diagnose and detect transformer fault types. Transformer insulation oil is mainly composed of a variety of hydrocarbons, transformer solid insulation material belongs to cellulose insulation material, the effect of electricity and heat will make the C-H bond, C-C bond, C-O bond fracture, and the formation of a small amount of hydrogen and hydrocarbons, Low molecular hydrocarbon gases such as hydrogen (H2), carbon monoxide (CO), carbon dioxide (CO2), methane (CH4), ethane (C2H6), ethylene (C2H4) and acetylene (C2H2).The gas is dissolved in the oil by convection and diffusion, and the concentration of the gas dissolved in the oil can reflect the state of the transformer. Accurate on-line DGA monitoring can therefore detect or diagnose any early faults occurring in the liquid or solid insulation of the transformer almost instantaneously, avoiding major faults, by monitoring the changes in the content of the gases mentioned above and determining the state and type of faults in the transformer in conjunction with the guidelines[1].

The first section of this paper introduces the background of transformer fault diagnosis based on DGA. The second section analyzes and summarizes the traditional detection methods. The third section analyzes and summarizes the methods based on machine learning. The fourth section is the summary of the whole paper.

2. TRADITIONAL FAULT DIAGNOSIS METHOD BASED ON DGA

Traditional transformer diagnosis method is mainly to get several key features by the DGA technology of gas composition and content and qualitative and quantitative analysis[2], and combined with DL/T722-2014 "guidelines for the transformer oil dissolved gas analysis, and judgment in the realization of power transformer fault diagnosis, the traditional diagnosis methods mainly include the characteristic gas method, three ratio method, and etc.

Oil immersed transformer is the most common type of transformer in power system at present. With the increase of the service life of the transformer, the internal faults of the transformer are inevitable. Transformer insulating oil is usually composed of a variety of hydrocarbons. When encountering faults such as discharge or overheating, the carbon carbon bond and hydrocarbon bond in the compound will crack, producing H2 and a series of low-carbon hydrocarbon gases.

In addition to transformer oil, the carbon carbon bonds, hydrocarbon bonds, and carbon oxygen bonds contained in solid insulators such as cellulose molecules in transformer insulating paper will be cracked under the fault of discharge or overheating to form Co, CO_2, H_2O, and hydrocarbon gases. The type, concentration and proportion of fault gas produced by different types and degrees of faults are different, so the type and content of dissolved gas in insulating oil can be detected to reflect the insulation state and fault type of oil immersed transformer. Therefore, the detection technology based on dissolved gas analysis (DGA) in oil has been widely valued by scholars at home and abroad.

Oil gas separation device is an important unit in the transformer on-line detection system, which is responsible for separating the fault gas from the transformer insulating oil. It is the premise of DGA. The result of oil-gas separation will directly affect the concentration of the extracted fault gas, and then affect the quantitative detection result of the extracted fault gas. Therefore, the result of oil-gas separation will have a decisive impact on the reliability of the whole system.

Therefore, it is necessary to study the relevant technologies of oil-gas separation, clarify the factors that affect the results of oil-gas separation, find better oil-gas separation technology, and improve the accuracy of oil-gas separation results, so as to help the operation and maintenance personnel control the insulation state of the transformer more accurately, contribute to the preventive maintenance of the transformer, and ensure the safe and stable operation of the transformer.

2.1 Characteristic gas method.

With the continuous operation of oil-immersed transformer, as well as the influence of heat and electric energy, the main components of transformer internal insulation oil and paper will gradually aging and decomposition. Gases produced during the aging and decomposition process are dissolved in the insulating oil. These gases mainly include low molecular hydrocarbons, carbon dioxide and carbon monoxide. If the transformer in the continuous operation of different types of discharge phenomenon and overheating fault, the gas content generated by the aging decomposition process will also increase. If the failure continues to worsen without resolution, the gas produced by decomposition can dissolve in the insulating oil. The composition and content of fault gas are closely related to the type and degree of fault[3], so the fault type of transformer can be determined according to the composition of gas. The biggest advantage of characteristic gas method for transformer fault type judgment is its strong pertinence. Besides, its advantages also include intuitiveness and convenience. However, this method lacks the concept of quantity[4], requires expert experience, and does not consider the differences between individual transformers, which is a basic diagnosis method.

2.2 2.2 Characteristic ratio method.

The characteristic ratio method is to calculate the values of C_2H_2/C_2H_4, CH_4/H_2 and C_2H_4/C_2H_6, and compare the three ratios with the code table, corresponding to the different fault types obtained. In reference[5], a preliminary explanatory theory for detecting early faults using dissolved gases, hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), and acetylene (C_2H_2) is presented. According to these theories, only four of the various ratio combinations obtained from dissolved gases in oil provide information relevant to faults. The ratio of dissolved gas content in oil is also related to faults. In view of transformer faults that may occur in the near future, the combination and range of gas ratio are determined. These faults can be roughly divided into overheating faults, partial discharge faults, partial discharge and coexistence of overheating faults. Using characteristic gas ratios to account for these failures reduces the reliance on detailed statistical procedures and minimizes maintenance costs.

This paper introduces the traditional fault diagnosis methods based on DGA and the different methods used for fault classification. It then Outlines the problems with traditional methods, including large or small ratios, unrecognized ratio combinations, mixed fault zones, and inability to detect co-existing faults. To solve these problems, the researchers provided a solution by using artificial intelligence technology.

3. APPLICATION OF MACHINE LEARNING IN FAULT DIAGNOSIS

Machine Learning is a method that enables a computer to automatically summarize rules from some data and obtain a prediction model, and then use the model to predict unknown data. It is an approach to artificial intelligence and an interdisciplinary discipline that integrates statistics, probability theory, approximation theory, convex analysis, computational complexity theory and so on. Machine learning is a way to give a machine the ability to learn so that it can do things that direct programming cannot. But in a practical sense, machine learning is a way of using data, training models, and then using models to make predictions. The "training" and "prediction" processes of machine learning can correspond to the "induction" and "prediction" processes of human beings. Through such correspondence, we can find that the idea of machine learning is not complicated, but only a simulation of human learning and growth in life. Because machine learning is not based on results formed by programming, its processing is not causal logic, but correlation conclusions drawn through inductive thinking.

Machine learning has deep connections to pattern recognition, statistical learning, data mining, computer vision, speech recognition, natural language processing and other fields.

In terms of scope, machine learning is similar to pattern recognition, statistical learning and data mining. At the same time, the combination of machine learning and processing technology in other fields has formed interdisciplinary disciplines such as computer vision, speech recognition and natural language processing. Therefore, when talking about data mining in general, it can be equivalent to talking about machine learning. At the same time, what we call machine learning applications should be universal, not limited to structured data, but also images, audio, etc.

Machine learning is the calculation method of artificial intelligence, including Logistic, SVM, decision tree, Bayesian method and so on.

Representation learning is the study of how to get a good representation in machine learning, so as to make the subsequent model learning easier. Shallow auto eccoding machine is one of the methods.

Literature[6] presents a Dynamic Adam and dropout based deep neural network (DADDNN) for fault diagnosis of oil-immersed power transformers, this method can effectively solve the data extraction availability, better problem such as local optimum, gradient disappeared, but because of too little data samples, Lack of validation of model stability. Kefei Zhang et al. [7] used the BP neural network to conduct DGA analysis, calculate the uncoded ratio of dissolved gas in oil, and input it into the BP neural network to mine the connection between data information and transformer operation state and judge transformer operation state. In order to improve the accuracy of fault diagnosis, scholars put forward a variety of combined diagnosis models, that is, a variety of single diagnosis models are combined according to certain rules and principles. Zhang Di et al. [8] proposed an explainable bi-level machine learning method for oil-immersed power transformer fault diagnoses, consisting of a binary imbalanced classification model and a multi-classification model. Xiaoxin Wu and others [9] proposes a deep parallel diagnostic method for transformer dissolved gas analysis (DGA). improve the accuracy of the model for transformer fault diagnosis. At the same time, the model can accept data sets of different lengths as input, which makes the generalization performance of the model stronger. In literature[10], unsupervised training is carried out on unlabeled sample data through k-step comparison divergence to optimize each restricted Boltzmann machine of the fault diagnosis model, and the parameters of the fault diagnosis model are adjusted by supervised algorithm. Finally, the power transformer fault type is determined by Softmax regression. This method can effectively solve the problems of data extraction availability, better local optimization and gradient disappearance. Deep belief network (DBF) has also been used to improve the classification accuracy of DGA data and has demonstrated high accuracy. The deep structure of the network can cover the obvious features of the DGA sample space. The input of DBF model is 9 gas concentrations, 3 of which are critical gas ratios, and the remaining 6 are critical gas ratios and fault gas concentrations[11].

4. THE SUMMARY

This paper reviews fault diagnosis techniques based on DGA. The traditional DGA methods (characteristic gas method and ratio method) are simple, economical and effective. However, all of these methods have the problem of unhandled numerical values and uncertain diagnosis results, such as the ratio combination in the ratio method is not available, different conventional methods display inconsistent results for the same fault data, conventional methods have inflexible boundaries and cannot detect concurrent faults, etc. As an emerging algorithm in machine learning, machine learning model provides an automatic feature learning process, which can replace manual feature selection in traditional fault detection and diagnosis. And the research of machine learning in the field of fault diagnosis is just starting, and it will become the development trend in the field of fault diagnosis in the future.

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