APPLYING ARTIFICIAL NEURAL NETWORKS TO THE DESIGN OF ABNORMAL DIAGNOSIS FOR POWER TRANSFORMERS

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ABSTRACT

It is not overstated that transformer is the heart of electrical system. A step-up transformer is used to reduce the power losses when the step-down transformer provides the various levels of voltage to the customers. Transformer is one of the most expensive and important electrical equipments installed in a power system. Any fault occurs in a main transformer will cause in the malfunction of whole power system. Those materials used in the interior parts of a transformer include insulated paper, stereotype paperboards, wood, dioxin resin, optical fiber, and insulation oil. The property of their insulation level could be deteriorated due to the change of ambient temperature and humidity in the long time operation. Thus, an inevitable fault may occur owing to the poor insulation.

This paper aims at discovering and analyzing those abnormal symptoms in the earlier stage and takes remedies in time. In addition to the periodic examination of the transformers, a regular testing of the isolation oil is the widely adopted technique to observe the operating situations and performance of the insulation oil inside the power transformers. The disadvantage of the above method is that it cannot grasp the dynamic state of transformer that a possible danger would take place anytime.

This paper presents a diagnostic system which includes a PC computer and an on-line gas detector to monitor a transformer located at Tainan Primary Substation in Taiwan. Through on-line monitoring the concentrations of the dissolved gases, the proposed diagnostic system offers a way to interpret the incipient fault causes. The artificial neural network (ANN) algorithm is employed to analyze the types of faults.

Keywords: transformer, on-line diagnostic system, dissolved gas analysis, artificial neural network

1. INTRODUCTION

The major function of voltage transformer is to change voltage for transformation or different grades of voltages for users, so its role is extremely important. As the inside insulating oil of a voltage transformer is destroyed with heat energy while resulting in burning or exploding electrically. Besides it needs to face the harmful substance and it will cause the chemical fire hazard at this moment, and it may cause the power system failure on a large scale area further. Then it causes social cost losses which is analogous to the degree. For the Utilities Electric Co., it supplies power that the quality and reliability of power supply will be queried; for customers, it will be also difficult to estimate damage when electrical power is lost. Therefore, if we can measure the system regularity, examine and know the trouble of it’s inside initial stage early before the unusual state of the voltage transformer is expanded further, and then we can arrange to shut down and enter the factory to maintain in schedule. It can not only merely save the social cost, but also improve the quality and reliability.

Gas analysis and trouble are diagnosed by [2] to dissolve the gas analytic approach in the voltage transformer oil (Dissolved Gas Analysis, DGA) the trouble is diagnosed in initial stage when it has already widely used in the voltage transformer at present. Because of the unusual operation of voltage transformer, insulating things that will generate heat more around a bit are resolved into the little member gas, unless the gas is produced too violent. The gas will be dissolved in the insulating oil fast [4], and these kinds of resolving the gas will be different to some extent as unusual position. One layer of analysis instruments of gas color can be analyzed oxygen (O2) by the oil sample, nitrogen (N2), carbon dioxide (CO2), hydrogen (H2), methane (CH4), ethylene (C2H4),
ethane (C2H6), acetylene (C2H2), carbon monoxide, they which are H2, CH4, C2H4, C2H6, C2H2, and CO, respectively are called the flammable gas. Dissolvent gas analytic approach by dissolving gas characteristic leads to the fact of the unusual possible reason to study and judge while being above-mentioned. Because it is not able to totally contain all kinds of trouble for dissolving its trouble inference result of analytic approach of gas, there are still weak points for regarding its analysis result as the reliable datum. In addition, it belongs to the taking off machine and one of the diagnosing methods to dissolve the gas analytic approach, if it regards the importing parameter as the content of gas or the composition ratio to distinguish. Besides it can be divided into the main gas analytic approach (Key Gas Method) and two kinds of digital analytic approaches. The main gas analytic approach is with the hydrogen (H2), methane (CH4), ethane (C2H6), ethylene (C2H4), acetylene (C2H2), and we take carbon (CO) flammable gas and the increase of flammable gas or increment rate of total amount as judging the different form basis at a stretch. If the increase of flammable gas is small and slow, it shows that the voltage transformer still belongs to normally. If the amount of growing up is great and fast, it shows that there exists the abnormal potential trouble inside. Such as diagnose for the voltage transformer should make other electric characteristics test, and shorten and fetch and send one kind of cycles of oil [5].

The insulating material belongs to the carbon hydride such as insulated paper, insulating oil within the voltage transformer. When the unusual phenomenon occurs, it will cause the relevant electric characteristic of the voltage transformer to produce and change. Besides, the high fever or electric arc emerge, and insulating things around will be resolved into the little member of gas such as the insulating oil or the insulating thing of solid that dissolves into insulating oil. It makes insulating the increase of oil gas, and gas analysis is taken to judge voltage transformer. The gas of oil analysis that diagnoses in advance for the trouble of the voltage transformer will fetch the oil kind and send to the relevant specific test unit in the domestic area, and the content of analysis from France (Gas Chromatography) and the kind of trouble with the gaseous phase floor will be obtained. The accuracy of this method is higher, but the shortcoming of fetching the oil once for each time will cause the empty window problem, and it is unable to grasp the effective trends of this voltage transformer. If we can change and understand the way that the original static behavior is passive at any time, the dynamic situation of the voltage transformer will be grasped while operating for a especially old one that was after overhauling or for potential persons who store in of weakness, and the gas is detected by the examining device which is picked and fetched through transmitting the materials remotely and the diagnostic program. It is feasible to construct the system of in the on-line oil [6].

The large scale of voltage transformer is equipped with electrically 87 differential electric relay protectors and with machinery 96B relays, 96D relays, 96P relays, 63Q relays. While breaking down within the voltage transformer, the relevant circuit breaker jump and take off fast and the trouble point will be isolated immediately or the unusual pressure within the voltage transformer will also be released to prevent the derivative accident, especially the fire accident. The electric voltage transformer of room appearance is defended by facilities, the oil pool, oil canal, broken stone ground, and fire equipment from the fire occurring in the room for the power system, automatically, but it is not able to guarantee fire free with having protection equipments not even better in case of careless omission [7].

The simple on-line combinational neural network method of monitoring system can assist diagnosing effectively. The content of gas composition in the oil that will be measured when there is a trouble exists the abnormal pressure trouble within the voltage transformer. In the following step, neural network methods will be applied to diagnosing and the tested proof will conducted with the real cases of the electric company's voltage transformer troubles in Taiwan. The proposed scheme is expected to achieve more than 90% of diagnosing accuracy with operating safety and reliability.

2. LITERATURE REVIEW

2.1 The Content of Oil Gas for Voltage Transformer

There is a little content of gas in the oil for the voltage transformer while running well and there is less one especially for flammable gas that is only below 0.1% for the total content of gas. The amount of gas will be fewer if new oil is adopted. According to the manual of the unit switchyard equipment safeguards [1] for Taiwan Power Company, the maintenance guidelines of variation devices stipulate the flammable total amount of gas (Total Combustible Gas, simplification TCG), other composed contents of gas, and the increasing trend that can be judged if exceptions occur or not. If the increase of flammable gas is small and slow, it shows that the voltage transformer is still normal, such as Table 1.
Table 2 illustrates the relations for all levels of voltage transformer and different thickness of gas, and this relation form is the flammable total amount of gas and reference criterion of the content of every composition gas in the most popular voltage transformer oil in the area of North America. This criterion not only states the grade of degree of weight of trouble, but also provides corresponding measures for the succeeding situations.

Table 1: The judgment table of normal measurement values.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>H2 (ppm)</th>
<th>CH4 (ppm)</th>
<th>C2H6 (ppm)</th>
<th>C2H4 (ppm)</th>
<th>CO (ppm)</th>
<th>TCG (ppm/annual)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69kV</td>
<td>125</td>
<td>350</td>
<td>250</td>
<td>150</td>
<td>1</td>
<td>350</td>
</tr>
<tr>
<td>161kV</td>
<td>100</td>
<td>150</td>
<td>150</td>
<td>100</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>345kV</td>
<td>7</td>
<td>100</td>
<td>50</td>
<td>1</td>
<td>1</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 2: Main flammable upper limit of thickness of gas (ppm).

<table>
<thead>
<tr>
<th>State</th>
<th>H2</th>
<th>CH4</th>
<th>C2H6</th>
<th>C2H4</th>
<th>CO</th>
<th>TCG</th>
</tr>
</thead>
<tbody>
<tr>
<td>State 1</td>
<td>101-700</td>
<td>121-400</td>
<td>35</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State 2</td>
<td>101-700</td>
<td>401-1000</td>
<td>36-50</td>
<td>51-100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State 3</td>
<td>710-1800</td>
<td>&gt;1000</td>
<td>51-60</td>
<td>101-200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Main flammable upper limit of thickness of gas (ppm).

<table>
<thead>
<tr>
<th>State</th>
<th>C2H2</th>
<th>CO</th>
<th>CO2</th>
<th>TCG</th>
</tr>
</thead>
<tbody>
<tr>
<td>State 1</td>
<td>65</td>
<td></td>
<td></td>
<td>720</td>
</tr>
<tr>
<td>State 2</td>
<td>66-100</td>
<td>351-570</td>
<td>2500-4000</td>
<td>721-1920</td>
</tr>
<tr>
<td>State 3</td>
<td>101-150</td>
<td>571-1400</td>
<td>4001-10000</td>
<td>1921-4630</td>
</tr>
</tbody>
</table>

2.2 Causes of Abnormal Power Transformer

The trouble is caused by the winding component and the exception of firm determination within the voltage transformer, because they adopt a large number of various types of insulating materials and were damaged under long-time operation and attacked by the unusually high invasion of dashing wave of voltage of external world. In order to guarantee the voltage transformer running well in time, it is necessary to understand the unusual reason of voltage transformer, to control the inclination of grasping degradation of the voltage transformer, and to take precautions instantaneously. There are three main kinds of unusual phenomenon such as being overheated, discharging, and wearing out, for the voltage transformers, and they can be classified as follows:

1. Overheated phenomenon:
   If the temperature is less than 65 degrees Centigrade for the electric voltage transformer rises warmly, and its oil under the state is too warm to exceed 90 degrees Centigrade and then it will run well under 105 degrees Centigrade for the winding. However, the temperature may reach 1000 degrees Centigrade for a partial overheated part, and it will damage and destroy the insulating part seriously [8]. It is very difficult to be detected according to the measurement methods at present, and the only way is to analyze the content of gas in the oil.

2. Discharge:
   In the unusual state of voltage transformer, it is the most serious and dangerous phenomenon for discharge. Due to the high temperature produced by discharge, the harm is most serious for the voltage transformer. It may cause burning or exploding incident if the discharge has been lasting for a period. There are some issues related discharge and described as follows:
   (1) The discharge phenomenon and energy magnitude: according to releasing amount of energy, the discharge phenomenon can be divided corona (Corona) discharge (low energy), lines (Streamer) discharge (medium energy), flash over discharge, or break-down discharge (high energy), and arc discharge (extra high energy).
   (2) Position of discharge: The places often occur among the regular contacts of metal, winding, unshakable in one's determination, insulating cardboard, insulating oil and the outer cover of voltage transformer.
   (3) Reasons of discharge: (a) External high-current, such as short-circuit accident, resulting in winding distortion. (b) Such as lightning surge damage caused by casing. (c) Bad design or construction of transformer assembly, some component shortage gap. (d) OLTC failure, selector switch (Selector Switch) have become the load. (e) Earthquakes, so that displacement of transformer components, resulting in insufficient insulation.

3. Degradation (worn out):
   When the power transformer, after a long period of operation. Due to rain, moisture, air and temperature will affect the insulating material degradation (worn out), resulting in failure. If we can prevent the deterioration, transformer operation can be safe.
   (1) Degradation phenomenon Category: There are insulating paper degradation and the deterioration of insulating oil.
   (2) The reason of insulation paper degradation: (a) result of heat, moisture and oxygen effect in
that the cellulose decomposition, the tensile strength decreased. (b) High moisture. (c) Transformer overload, so that the long-term overheating in the coil.

2.2 Online Simple Gas Detection methods:
The structure of this system is mainly formed by brass fittings sensor module and I/O modules. The working principle is dissolved in insulating oil in the combustible gas through selective permeability membrane to the electrochemical gas sensor, with the external incoming oxygen generated current; The current signal through the load resistor, its voltage drop to determine the concentration of gas; In other words, the speed of response of the electric current signal in the flammable gas of direct radio, when reflect the speed fast, then the electric current signal is measured greatly, the relative voltage drop is also larger, so the gas is large in thickness. This gas detecting device only detects and examines the hydrogen, carbon monoxide, acetylene, and ethylene.

Construction and installation of this device is very simple, more economical, and easy maintenance of its advantages. Because of its detection of the displayed value is the total amount of combustible gas (TCG) item. When the total amount of flammable gas exceeds a set value the system will issue a warning. Maintenance personnel must take the oil sample sent to laboratory testing and diagnosis. Because there is no amount of each component of the combustible gas, it is impossible to begin troubleshooting.

2.3 Introduction to Neural Network
A neural network uses a large number of simple artificial neurons to imitate the living beings. The neural network uses the artificial neuron to make simple simulation for the biological neuron. Through association form and information transmission between the neuron, various kinds of human know feeling, memory, pondering over ability, and even the states of the emotion and mood [9]. The operation can be in the brain or surface. The scientist applies neural network to computer software development. On the setting-up of one kind of neural networks in the theory and development of the way, the back-propagation network (BPN) is most adopted, and belongs to the supervising type of the network [10]. The network component includes neuron (Neuron), the unit (Units). The processing information that consists of the node (Nodes) and the minimizing error function dealing with the unit to concentrate and organize in groups, is called layer (Layer). There are three treatment layers for the BPN: input layer, hidden layer, export layer. Each of networks has one input layer. There is one or a lot of hidden layers, which join each other adjacent one while dealing with the nodes of layer to transmit to the next one and one exported layer.

The operation of neural networks is divided into two stages: training stage, simulation stage. During the training stage, the weight value is to determine network that is leaning towards right value [11]. The simulation stage is to determine the prediction outputting value of the network or verify the accuracy of the network. After the materials input into the network and are transmitted to the hidden layer by the node, the information is spread with different weights. The information would be calculated with the weights and then export the signal to the output layer finally. When the network trains, one layer of simulation result of output of every training circulation, will be compared with a group of known results (trains the goal). The difference between the two will be passed back in the network and the simulation will improve this network behaves. The whole procedure is made up by the inputting, spreading into the network, judging the error of training and passing the connection weight in order to be adjusted of the error among the nodes back by the materials etc.. The whole operation is to produce the knowledge to the materials through training and to transmit knowledge through testing and then to correct the circulation that produces the acceptable knowledge. This acceptable knowledge is namely the weight value included in every node and leans towards right value [12].

2.4 Power Transformer Anomaly Criterion
Digital analysis is the oil of certain elements in the dissolved gas conversion ratio of 20% of the patterns, such as CH4/H2, C2H2/C2H4. Based on data with relevant experience, and further the scope for different ratios of gas mix ratio, giving a corresponding codes (such as 0, 1, 2). Then according to occur in the composition codes respectively and set out the faults belong to the combination of patterns. The well-known digital analysis methods would be Rogers’s improved method and IEC analysis.

Through the above dissolved gas analysis method for fault diagnosis process, the power transformer fault diagnosis expert practical experience is often playing a very important role. In other words, using dissolved gas analysis method for fault diagnosis process needs to tie in with the opinions of experts to get the integrity and reliability of the diagnosis. In addition, in the laboratory of the oil containing dissolved gas
sampling for measurement and analysis process, the gas data collected will also be noise or error situation.

3. ARCHITECTURE METHODOLOGY

In this paper, proposed monitoring and fault diagnosis system mainly consists of type of personal computer, online oil, gas detectors and associated interfaces, software, etc... Through a modem connection with the remote PC can be remotely download and monitoring. Monitoring and diagnosis of fault type part of the program is to combine real-time data. Reference to the benchmarks of Taiwan Power Company, Japan Electric Association for Research and ANSI/IEEE, first make a preliminary monitoring, and then use back-propagation neural network for fault type diagnosis.

3.1 Simple Detector Description

Taiwan Power Company is currently adopting this simple type detector in large transformer, its construction as shown in Fig. 1. For the single-hole oil-entry, insulating oil due to thermal gas-film chip resistors in the probe part of the flow of heating oil in the combustible gases hydrogen (H2), CO, C2H2, and C2H4 spread through the film between the film and fuel cells. Each molecule of hydrogen fuel cell cathode reaction will have two electrons and two hydrogen ions, while the surrounding oxygen gas and hydrogen ions in the anode to produce water and complete the cell reaction. Then the reaction of other gases into water and carbon dioxide, flammable gas were put on a probe reaction converted into electricity. In fact hydrogen content of 100% and other gases are in accordance with the formula CO: 15%, C2H2: 8%, and C2H4: 1% calculation.

3.2 Application of Neural Networks to Establish Detection System

Software system architecture and control rules are in order to achieve real-time diagnosis of transformer on-site analysis function abnormalities. This paper analyzes the software program is divided into simple online diagnostic monitoring devices and Neural diagnostic two procedures, its structure process shown in Fig. 2.

3.3 Diagnosis of Fault Type

Transformer fault diagnosis is used widely by the public and very high accuracy of diagnosis of neural network methods. A result of neural network input and output can express the relationship between variables. i. The greatest advantage is that does not require complicated mathematical calculations, as long as the use of pre-defined sample data entry to training can be used as fault types of transformer diagnosis. This article uses the most widely used back-propagation neural network.

Back-propagation neural network is to apply the basic principles of the Gradient Steepest Descent Method theory. Its operation process is divided into two stages: The first stage is the learning phase: By learning algorithm would repeatedly enter the correct sample and constantly adjust the weights of the network nodes, so that the network output value and target value approximation.

The second stage is the recall phase: Network at this stage to accept outside input, and in accordance with the computing algorithm, after the results sent by the output layer.
3.4 Neural Network Diagnostics Architecture

Neural network input layer data is used in Japan Electric Power Research digital method that is C2H2/C2H4, CH4/H2 and C2H4/C2H6 ratio as input. The output would be high-temperature overheating, the overheating temperature, low temperature overheating, arc discharge and partial discharge of five types of failure. Therefore, to adopt three layers network architecture: input layer has three neurons, output layer has three neurons, hidden layer has four neurons, and its structure as shown in Fig. 3.

![Fig. 3: Neural network diagnostics architecture.](image)

4. RESEARCH ANALYSIS AND RESULTS

4.1 First Fault Diagnosis

In this study with the diagnosis of the operation, first of all uses simple online monitoring system as a preliminary monitoring program to determine the composition or the total online transformer flammable gas is an exception. If judged as normal then the completion of the first phase of operations; If judged as abnormal or more than set the reference value, in addition to issuing warnings, then entering the second phase of the neural network system as the malfunction diagnosis.

4.2 Neural Network Diagnosis Fault

Neural network methods are widely used in power transformer fault diagnosis. Because neural networks have through training programs to learn failure patterns and the hidden nature of the gas between the types of features. Therefore, neural networks can be applied to transformer fault diagnosis analysis.

Application of neural network methods in fault diagnosis of power transformers first collects the failure information offline. The use of neural networks to learning and training, when the training is completed, just enter the data of gas in transformer oil into the network at virtually no cost at any time that is able to obtain diagnostic results, so it is suitable for real-time environment for online diagnosis.

4.3 Abnormal Transformer Results

Since the Taiwan Power Company has been collecting the diagnosis and determine the transformer dissolved gas to various data, as the neural network training and learning materials. Input layer enter the ratio of C2H2/C2H4, CH4/H2, C2H4/C2H6 as input. The output layer is to use high temperature overheating, the overheating temperature, low temperature overheating, arc discharge and partial discharge five kinds of fault type as its output. Such as Japan Electric Association in fault diagnosis as shown in Table 3, and so will receive a very high diagnostic accuracy.

<table>
<thead>
<tr>
<th>C2H2/C2H4</th>
<th>CH4/H2</th>
<th>C2H4/C2H6</th>
<th>Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>0</td>
<td>L.T</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>1</td>
<td>M.T</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>H.T</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Arc Discharge</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>Partial Discharge</td>
</tr>
</tbody>
</table>

4.4 Diagnosis and Outcome of Neural Networks

The use of neural networks in the diagnosis must obtain the effective sample and choice of programming tools. Only trained neural network function value can be obtained for diagnosis. It is to adopt the suit procedure of Network Toolbox [3] in MATLAB to originally study and train. Since MATLAB nntool BOX has a comprehensive program interface with a simple command. It is very convenient.

4.5 Learning and Training

Training samples were collected for 30 groups of definite fault type in input/output pairs. Using 5000 as training samples, and the remaining 25 groups as a test, is expected to train the convergence curve as shown in Fig. 4.

![Learning and Training](image)
Fig. 4: Convergence curve.

REFERENCES:


