A Novel Defect Classification System of Cast-Resin Transformers by Neural Network under Acoustic Emission Signal

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Abstract: - Degraded insulating property of electric equipments will lead to serious accident and great loss for the utilities and customers. Partial discharge detection is an efficient diagnosis method to prevent the failure of electric equipments arising from degrading insulation. However, universal offline partial discharge detection could be performed only during shutdown of equipments. By using the principle of Acoustic Emission (AE) and real-time online detection functions, this paper analyzed partial discharge pattern for cast-resin transformers and conducted high-voltage test of pre-faulty transformers. Furthermore, it collected partial discharge AE signals with selected features and identified their faulty types using artificial neural network. The research results show that the average identification rate can reach as high as 92.5%.

Key-Words: - Neural Network, Partial Discharge, Acoustic Emission, Transformer.

1 Introduction

There is a growing demand on energy resources and power consumption with rocketing industrial and trade development. In addition to power supply, the stability of electric power shall also be improved accordingly. As the performance of power supply is closely related to electric equipments, it is possible to improve considerably the stability of power supply if real-time status of electric equipments is made available. Transformer is one of electric equipments most closely associated with power consumption. The lifespan of transformer depends upon the insulating strength of insulation materials. So, real-time awareness of the insulation state is helpful to prevent failure. At present, partial discharge detection has extremely high diagnosis accuracy for insulating medium. Thus, partial discharge detection is an important index to prevent equipment trouble [1-2].

In the event of equipment failure and local discharge, energy release will occur in tune with supersonic wave. If the supersonic wave can be analyzed and processed, it should be possible to identify the nature of failure, thus making breakthrough contribution to power detection. Any breakdown of running transformer will lead to dramatic loss and negative influence. In an attempt to prevent and identify occasional accident, degrading diagnosis and failure identification of transformer are urgently required based on a safe, real-time and accurate solution. Partial discharge detection is basically considered as a pulse phenomenon of energy release, and subsequent sound release is named Acoustic Emission (AE) from the perspective of supersonic wave. So, an ideal way to judge the performance of transformer is based on computer-aided AE method for partial discharge detection. The following are three highlights of AE methods in partial discharge detection for transformer: [3-6]

(1) On-line real-time supervision : AE can be detected on-line without switching-off, or any special arrangements.
(2) High safety : AE is detected in a contact-free manner, thereby helping to improve greatly the safety of maintenance personnel.
(3) Perfect trouble-shooting : In the case of new or unknown troubles of electric equipments, only AE data shall be required for future identification and prevention.

The major purpose of this paper is to set up a real-time online detection unit based on AE detection method, and also provide the end users with an approach to obtain the status of objects as well as relevant information and reference for failure prevention and diagnosis of any electric equipment. Based upon the transformers with discharge failure and a trouble-free transformer, this paper analyzed the data on the MATLAB platform and artificial neural network, and then identified the presence of or otherwise the nature of failure. To put it bluntly, "AE" represents supersonic wave of partial discharge within transformer.

2 Acoustic Emission Technology

Acoustic emission refers to natural phenomenon in many situations, such as earthquake, rock burst, thunder, crack of tree branches, fracture of glass or pottery, etc. In ancient times, the quality of pottery ware was identified with AE principle; at present, the maximum load of automobile components is tested with the same principle. The ASTM standard E610-82 gave a detailed description of AE as "Acoustic Emission is a transient elastic waves generated by the rapid release of energy form localized sources within a material." Therefore, this paper intends to apply AE principle to analyze partial discharge of transformers that is difficult to diagnosis by other method. The whole procedure for the proposed method is detail stated below.

2.1 Acquisition of AE Data

PD data, if obtained from simulation testing, may differ from those derived from empirical research. This study uses empirical experimentation, and employs tailor-made cast-resin transformers with designated defects. Five types of defects designed which include model A-qualified product, model B- improper solder on high-voltage side, model C- improper soft wire on grounding panel, model D and E- improper bubble within insulating material on low and high voltage side. To reduce interference from noise and to make a very high level of dependability, the experiment is conducted mainly in a control room and a magnetically shielded room. The conceptual diagram of equipment configuration is shown in Fig. 1, and the proposed process is in Fig. 2.

When the test sample (cast-resin transformer) generates partial discharge and AE phenomenon, the voltage value obtained from sensor will be transmitted to amplifier and then AE data capture card for A/D conversion. Finally, the digital data pattern is got and stored in database.

2.2 AE Definition and Parameter Setting

In AE measurement system, AE-related characteristic utilization and noise processing often dictates the performance of AE measurements. If AE system only concentrates on maximum sampling rate without considering other issues, the data may contain many noise and rebound AE signals, making it impossible to identify the problem of partial discharge. In such case, the relevant AE parameters, AE characteristics, noise interference and rebound wave processing shall be taken into account for optimized setting and utilization.

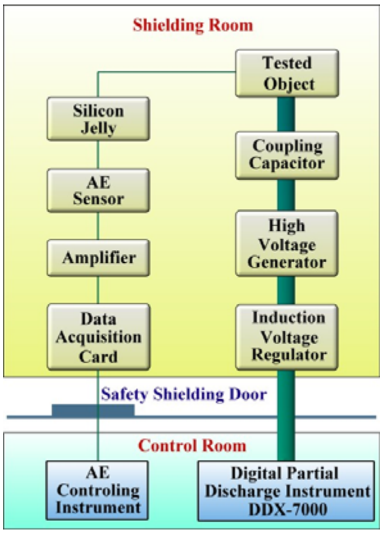

Fig. 1. Diagram of PD Measurement Structure for AE

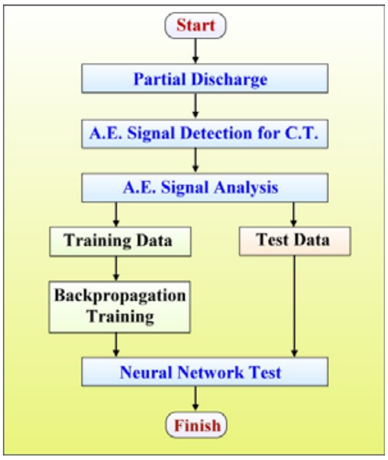

Fig. 2. Flowchart of the proposed PD Defect Classification Process

(1) Definition of Waveform Sampling

Rebound wave is a most challenging issue in identification of AE data, since it has characteristics similar to original AE waveform. This paper attempts to address the rebound interference using waveform characteristic filtering method, and analyzed AE waveform with three commonly defined parameters to obtain a complete waveform.

A. PDT (Peak Definition Time)

The time from signal generation to the peak hour of detection system is shown in Fig. 3. It aims to confirm Rise Time of signal. This parameter has immediate influence upon Rise Time (Rise) and peak of entire AE wave. Three parameters for waveform sampling definition may differ owing to the influence of test objects.

B. HDT (Hit Definition Time)

The value captured within this time range is deemed as a complete waveform signal as shown in Fig. 3. A complete AE data waveform can be defined from PDT and HDT, and the time interval set by HDT is closely related to the quantity of waveform data.

C. HLT (Hit Lockout time)

No signal capture is performed within this time range, as shown in Fig. 3. This parameter aims to cut down the interference of rebound wave, and has influence upon the data acquisition speed or quantity of data.

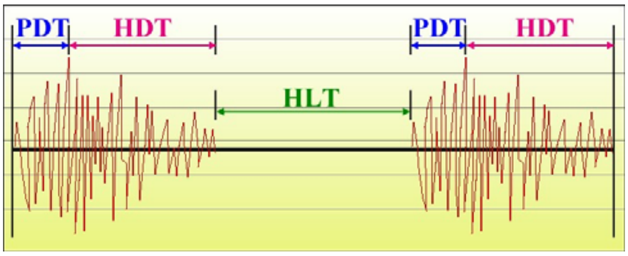

Fig. 3. Drawing of Acoustic Emission Wave Definition

(2) Consideration on Materials

Three waveform sampling definitions are mainly intended to address the interference of rebound wave. However, the wave speed of AE signals differs from different materials. So, the property of materials shall be considered in order to optimize the effects of PDT, HDT and HLT. Initial setting values of PDT, HDT and HLT are based on the recommended values of PAC. In this paper, cast-resin transformer is a non-metal composite material; the PDT, HDT and HLT are set as 30us, 200us, and 300us respectively.

(3) Processing of Other Noise

Since error identification may occur under noise interference, noise processing shall be required in either of the following ways:

A. Processing of contact surface noise

Contact surface filtering: by virtue of air-tightness (degree of coupling) medium (silicone grease) different from the test samples, AE signal is acquired without being influenced by air.

B. Processing of background noise

Critical filtering: Threshold is set based on a fixed critical value. In this paper, Threshold of noise filtering is set if no AE signal is recorded during the pressure test of trouble-free cast-resin transformer, namely, if AE signal is recorded in the computer, electric discharge occurs prior to failure of test samples. The test begins with 6db (1db added every time), and no AE signal is recorded until 30db, which is set as the Threshold of test.

2.3 Feature Selection

The feature values are selected according to (a) feature value of the same nature with little difference, (b) feature value of different natures with identifiable difference. Therefore, four feature values are taken as the identification data in this paper: Rise Time, Count, Duration and RMS. These values are represented in a statistical way as shown in Fig. 4:

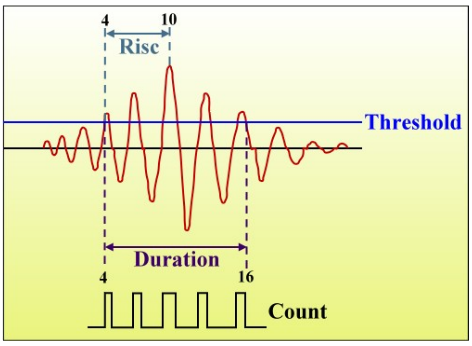

Fig. 4. Explanatory Drawing of Feature Value

(1) Rise Time

The time from generation of AE signal to the peak value of AE signal. It is assumed that the time to threshold value is 4, and the time to peak value is 10, as shown in Fig. 4. In this test, Rise Time of AE wave is 10-4=6 uS, so feature value of Rise is 6.

(2) Duration

The time from beginning to the end of a complete AE signal, such that the magnetite is bigger than threshold value and then fallen below it. It is assumed that the time to critical value is 4, and the time to peak hour is 16, as shown in Fig. 4. In this test, Rise Time of AE wave is 16-4=12 uS, so feature value of Duration is 12.

(3) Count

The extraction number of AE wave conforming to the threshold value. As shown in Fig. 4: the number of exceeding threshold value of AE wave is 5, so Count is 5 in this test.

(4) RMS

The root mean square value of AE wave signal transmitted into computer capture card.

After AE signal is obtained, it is also impossible to identify if numerous data are not analyzed to obtain feature value. So, acquisition of feature value is the key to data processing. This paper uses fixed mode threshold to filter the background noise and judge the characteristic representation. A passive sensor is triggered by external pulse, and data is directly stored into a memory. The filtering methods include: threshold filtering, frequency filtering, sound characteristics filtering and contact surface filtering methods. Finally, four feature values Rise Time, Count, Duration and RMS are selected.

3 Implementation

In the past, heavy-duty electric equipments were often detected during the scheduled shutdown, which was a time-consuming process against performance of power supply. In such case, a real-time online detector will extend significantly the service life of electric devices, but also improve dramatically the performance of power supply to meet the growing demand. Hence, this paper intends to detect and identify partial discharge for fault diagnosis of cast-resin transformers based on AE sensing theory.

Aiming the testing object, the testing specification is cast-resin transformers EWF-20DB shown in Fig. 5 and Epoxy resin is the main material. The Rated maximum voltage is 23kV, the impulse voltage withstand is 125kV, the primary current value is 60/30A, and secondary current value is 5A. This testing involved five tailor-made transformer models which is model A- qualified product as shown in Fig. 6, model B- improper solder on high-voltage side, model C- improper soft wire on grounding panel as shown in Fig. 7, model D and E- improper bubble within insulating material on low and high voltage side as shown in Fig. 8. Therefore the particular defect must be made before cast-resin in manufacture procedure.

Fig. 5 Experimental tailor-made cast-resin transformer

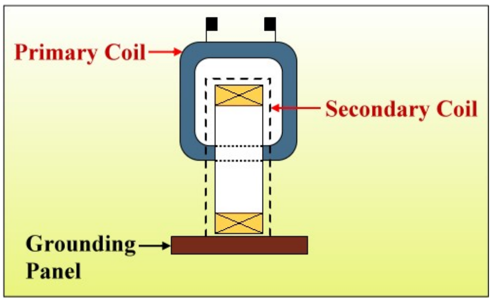

Fig. 6. Qualified Product

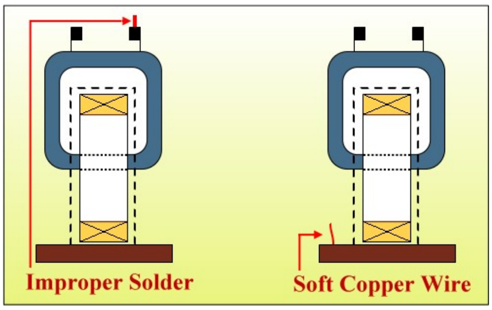

Fig. 7. Improper Solder on High-Voltage Side and Improper Soft Wire on Grounding Panel

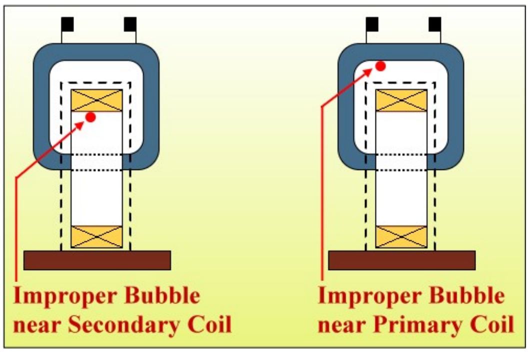

Fig. 8. Improper Bubble within Insulating Material on Low and High-Voltage Side

3.1 Test of Partial Discharge

Fig. 9 illustrates the experiment procedure. High voltage controller, via switch control panel, orders high voltage generator to generate a high voltage, which delivers 34.5kV, 1.5 times as high as the maximum voltage of the transformer, within 50 seconds, and holds for 1 minute and subsequently drops to 23kV in 20 seconds. At the point, the detector starts to gauge PD for a session of 2 minutes. 20 minutes after the detecting finishes, the transformers recuperate and the next stage of the experiment unfolds. It is for the purpose of exciting PD that 34.5kV is held for one minute. Voltage drops to 23kV in order for PD to continue and for the PD detector to gauge and record. Each experiment renders a set of data. There are five kinds of discharge models; each model is experimented on 30 times. Firstly, test the qualified products, and set the critical value without signal and other four with AE signal. Then, acquire AE data according to four faults. This experiment produces 120 sets of data, 80 and 40 of which is for training and for testing.

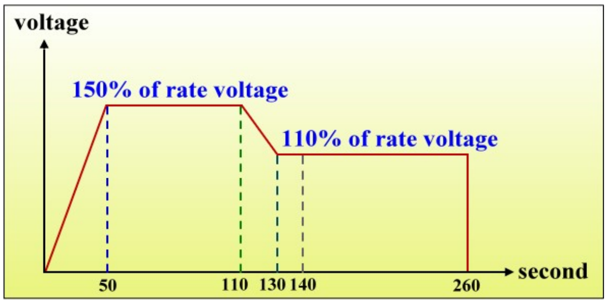

Fig. 9. Explanatory Drawing of Voltage Test Procedure

3.2 Apply to Artificial Neural Network

(1) Setup of Artificial Neural Network

In this paper, back-propagation artificial neural network is used for identification on MATLAB platform with high-speed mathematical operating capability for numerous data [7-10]. The neural network architecture has three layers (input layer, hidden layer and output layer), while the learning rule is based on gradient steepest descent method. Rather than the number of neuron in hidden layer, the neuron of input and output layer are decided by the users. To this end, it is required to make a reference of the following empirical equation for the number of neuron in hidden layer:

Number of neuron in hidden layer
=(number of neuron in input layer
+number of neuron in output layer) / 2.

As shown in this empirical equation, there are 4 neurons in the hidden layer in this research. To make sure if proper number of neuron is 4, this paper also conducted a few accuracy tests, and showing that 4 is a desirable number of hidden neurons.

(2) Training of Artificial Neural Network

The convergence of artificial neural network is judged through the iteration error that specified. If the iteration error can be reached among 3000 times of iterations, the iteration process is stopped, and the network training is successful, otherwise, network training is unsuccessful if the range of error isn't reached after 3000 times of convergence. In such case, re-adjust the setting of the training process will be needed. The whole training process chart is shown in Fig. 10.

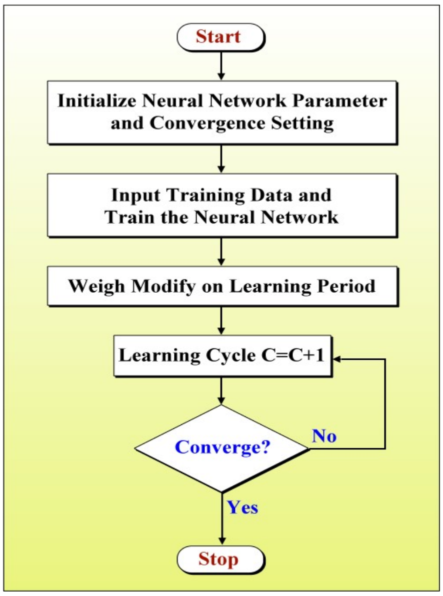

Fig. 10. Training Process Chart of Artificial Neural Network

(3) Setup of Training Group and Test Group

50 data samples are selected randomly from 4 types of failures, each of which is divided into two groups. The former 30 data samples are used as training data of artificial neural network, and latter 20 data samples as test data. As a whole, there are 120 training data and 80 test data. Also, Initial value of weights is randomly set in order to prevent the output value from becoming localized optimal solution. Four groups of training objects are set below:

1 0 0 0 = improper bubble within insulating material of low-voltage side
0 1 0 0 = improper soft wire on grounding panel
0 0 1 0 = improper solder of high-voltage side
0 0 0 1 = improper bubble within insulating material of high-voltage side

3.3 Simulation Results

The research results from artificial neural network are described below:

Accuracy for bubbles within insulating material of high-voltage side:
18/20→ 90%
Accuracy for bubbles within insulating material of low-voltage side:
19/20→ 95%
Accuracy for soft wire on grounding panel:
18/20→ 90%

Accuracy for solder of high-voltage side:
19/20➔ 95%

Average accuracy: 92.5%

4 Conclusions

This paper has developed a experimental procedure for partial discharge (PD) recognition of cast resin transformers. This procedure distinguishes itself in its practicality, and can be extended to other electrical equipments. In addition, study of BPN application to PD pattern recognition from transformers proves itself valid. In a magnetically shielded room, the recognition rate can as high as 92.5% accuracy. The research results are of importance for reference in field detecting. Nonetheless, there is a way to work before this procedure can be considered field practical. Our to-do list states that more typical PD patterns need to be collected from other kinds of defective tailor-made transformer models and more appropriate filter techniques need to be devised, in sound consideration of application context. Only by going through the list can we be assured of reliable recognition and endow the PD techniques with an on-line application era.

By using AE detection and partial discharge technologies, this paper made failure simulation tests of electric equipments in cooperation with back-propagation artificial neural network, showing an average identification rate up to 92.5% for entire identification system. The strongest advantage of AE detection is that, online detection is made possible without switching-off, nor any special arrangements. And, the maintenance personnel can implement detection in a contact-free manner, thereby helping to minimize their risk. Thus, AE detection is an ideal method to detect the faults of electric equipments.

5 Acknowledgment

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