Partial Discharges Pattern Classification in High Voltage Circuit Breakers

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Abstract. Partial discharge (PD) measurement is among the most important diagnostics methods of insulation systems in high voltage equipment, which makes it convenient to assess the insulation status. Partial discharge activities may stem from various defects, and correspondingly behave differently. Here, the PD patterns produced by 3 different laboratory models representing defects in High Voltage Circuit Breakers are recorded and analyzed. The research aimed at conducting PD tests with three apparatus including prefabricated defects. From the PD pattern data, statistical features were extracted and these features were reduced by linear discriminant Analysis (LDA). Adaptive neuro-fuzzy inference system (ANFIS) was used to train the fuzzy inference system (FIS). The trained FIS was then used to recognize the source of the PDs. Results show that ANFIS classification has a high success rate and highest average success rate at 110 kV reaches 95.83%.

1. Introduction
Partial discharge (PD) is an omen and the main reason of insulation deterioration in gas insulated switchgear (Circuit Breakers). Different types of defects in Circuit Breakers produce different partial discharge signs and the extents of damage to the Circuit Breakers are not the same. In this study, a novel method for recognition of the discharge source by means of an adaptive neuro-fuzzy inference system (ANFIS) is presented. The ANFIS uses a discharge fingerprint comprising 74 statistical parameters to discriminate PD defects[1].

Furthermore, the contribution of each feature to the classification is analyzed by linear 2 discriminant analysis (LDA). It shows that not all of the features have one and the same discriminatory power [2].

In other words, original features are transformed into new features without a loss of accuracy and thus an ANFIS classifier with a simplified structure can be obtained.

In this way, the total number of input features after the linear discriminant analysis was reduced to five. Then the samples are used to train and test the PD recognition. Finally, the performance of the ANFIS classifier is assessed.

2. Partial Discharge Measurement System
A set of PD measurement tests were performed in the laboratory, the rate of aging of insulation is changed markedly by applying an over voltage. Figure 1 presents test wiring method employed in herein. AC test voltage is applied between the high voltage winding and the ground. Circuit Breakers test equipment is grounded through a measurement device. The right half of the diagram displays the PD measurement circuit [3]. The test object was energized by a non-PD transformer with AC voltage as high as several kilo-volts.
When the voltage applied to the defect models rises over the threshold value of PD inception voltage (PDIV), PD phenomenon occurred at the electric weak point. PD current induced by discharges flowed through the test object and capacitor. Then the PD pulses can be detected. The PD signals were transmitted to the measuring device, which samples the signal, process the data. All measured analogs signal data were converted to digital data for storage in personal computer.

![Experimental setup for PD measurement](image)

Figure 1 Experimental setup for PD measurement

The high voltage part containing test model needs special care so that there is no source of partial discharge from measurement system. The high voltage part consists of step up transformer, a potential divider, coupling capacitance, and test object. A voltage from variable transformer is controlled from bench knob. AC high voltage test equipment increases test voltage gradually to carry out PD measurement. AC high voltage test equipment consists of two step-up transformers. Step-up transformers that connected in series can provide voltages up to 126kV.

In the voltage step-up procedure of the PD experiment, the high-voltage generator generated a rising-voltage from 6kV increasing by 10 kV for each 12 hours until an insulation breakdown. 40 electrical cycles data at a sampling rate of 20 MHz every five minutes were recorded in the A/D interface of the computer, which was carried out 144 times per day. The records were stored in a computer and PD’s signals and test voltage signals were also recorded simultaneously. Each record that includes voltage signals and current signal is difficult to process and store.

3. Partial Discharge Data Acquisition and Analysis

PD is a localized dielectric discharge that only partially bridges the insulation system between conductors, and that may or may not occur adjacent to a conductor[3]. PD occurs at the site of a defect and can cause the production of light, sound, heat or a chemical reaction. The variety of signals emitted during PD means that various methods exist to detect their occurrence ranging from electrical, acoustic, thermal, chemical and ultra-high frequency (UHF) monitoring. Therefore it is indispensable to detect their presence via nondestructive and reliable methods so as to obviate them. The statistical descriptors are mean, standard deviation, skewness and kurtosis. In addition, overall maximum magnitudes of positive and negative PDs and discharge phase region PD patterns are also calculated as features. Figure 2 and Figure 3 illustrate 3-D partial discharge pattern transformation.
The discharge phase region (DPR) denotes the range of phase windows where relatively dense PD signals appear. A discharge quantity in phase is defined as the sum of the discharge quantity at the same phase window for each measurement. In other words, the original 40x 600 matrix was converted to a matrix of 1x 600, which could then be plotted, as shown in Figure 4, and two clusters of PD were easily found to render DPR and DPR, representing the positive and negative cycle discharge phase regions, respectively. For the Nth measurement, the discharge phase region can be expressed as follows:

\[ DPR_N = DPR_N^+ + DPR_N^- \]  

Discharge phase region is illustrated each by two distributions: for the positive half of the voltage cycle and negative half of the negative cycle in Figure 4.

4. Dimensionality Reduction
Dimensionality reduction is an important task in machine learning, for it facilitates classification, compression, and visualization of high-dimensional data by mitigating undesired properties of
high-dimensional spaces. Over the last decade, a large number of new (nonlinear) techniques for dimensionality reduction have been proposed. Most of these techniques are based on the intuition that data lies on or near a complex low-dimensional manifold that is embedded in the high-dimensional space. New techniques for dimensionality reduction aim at identifying and extracting the manifold from the high-dimensional space.

LDA is a method for high-dimensional data analysis in the supervised learning paradigm as class labels are available in a data set. LDA has been successfully used as a dimensionality reduction technique to many classification problems, such as speech recognition, face recognition, and multimedia information retrieval. LDA aims to select discriminative features from the original feature set. And the basic idea of subspace learning is that the combination of the original features may be more helpful for learning.

LDA performs dimensionality reduction while preserving as much of the class discriminatory information as possible. It seeks to find directions along which the classes are best separated. It does so by taking into consideration the scatter within-classes but also the scatter between-classes. The computation of the LDA is described in detail in computing LDA.

LDA bears some resemblance to principal components analysis (PCA), in that a number of linear functions are produced (using all raw variables), which are intended, in some sense, to provide data reduction through rearrangement of information.

5. Conclusion
The PD defects classification system is composed of three major components. Based on the preprocessing stage, it is responsible for gathering the database for ANFIS from conducted PD tests rated at 110kV with apparatus including prefabricated defects. Phase-resolved PD datas are successfully evaluated and processed. The data gathered from the selected databases are connected to MATLAB software where the data are processed. The analysis system is based on feature extraction algorithm. This takes Linear discriminant analysis (LDA) as a medium to process the PD data. Feature extraction techniques are applied to the PD data and the characteristic points of interests are being extracted. These data provide meaningful information for the classification of PD defects. Those features are then used to model the ANFIS. ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using a backpropagation algorithm in combination with a least squares type of method. This allows the fuzzy systems to learn from the modeled data. The parameters associated with the Gaussian membership functions will change through the learning process.

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