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Study on Pattern Recognition of Partial Discharge Stage in Switchgear Using TEV Amplitude-Number Chart

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Abstract. Partial discharge is one of the main causes of insulation condition assessment. Transient earth voltage (TEV) method is widely used in partial discharge detection of switchgear. This article simulated the actual fault defects in the switchgear. A TEV sensor was designed to measure the TEV signal generated by internal partial discharge. The amplitude and number of triggers of the TEV signal pulse were counted. A method for TEV amplitude-number chart was proposed. The similarities of spectra at different voltages were compared and the support vector machine (SVM) algorithm for verification was used. The results show that the matrix similarity comparison method and support vector machine algorithm can be used to analyze the amplitude-number chart of TEV pulse under different voltages. The partial discharge stage can be recognized by using TEV amplitude-number and the state of the switchgear can be predicted.

1. Introduction

The 10 kV and 35 kV metal-enclosed switchgear, which is widely used in substations, is the most direct equipment for distribution networks and users. Various types of insulation defects of the switchgear will cause partial discharge which accumulates to a certain extent will cause a breakdown. And affect the power system [1]. Therefore, monitoring the partial discharge stage can predict the fault well and carry out reasonable maintenance work to ensure the safe and reliable operation of the equipment and system.

At present, the partial discharge detection methods for the switchgear mainly include ultra-high frequency (UHF) method, infrared thermal imaging detection method, pulse current (EAR) method, transient earth voltage (TEV) method and ultrasonic (AE) detection method, etc. Many colleges and companies have proposed a series of mature theories and models [2-6]. The above literatures all use the partial discharge phase-amplitude chart or time and frequency domain analysis measured by sensors to perform pattern recognition on partial discharge of the switchgear. However, it is difficult to obtain the reference phase when measuring in the field. It will reduce the effectiveness of pattern recognition.

In this paper, the actual artificial fault in switchgear was simulated. A TEV sensor was designed to measure the TEV signal generated by internal partial discharge. The article proposed a TEV amplitude-number chart method. The matrix similarity comparison method and support vector
machine (SVM) algorithm were used to analyze the chart under different voltages. Without the reference phase condition, it can realize the pattern recognition of the partial discharge stage and make a pre-judgment on the state of the switchgear. Therefore, the inspectors can overhaul the equipment before serious failures occur.

2. Basic principles of TEV detection

2.1. Principle of TEV generation
When the closed high-voltage electrical equipment is partially discharged due to internal insulation defects, the partial discharge pulse can generate electromagnetic waves with frequencies up to several hundred megahertz. The electromagnetic wave energy propagates in all directions inside the switchgear. Due to the shielding layer is discontinuous, the electromagnetic wave energy can propagate to the outer surface of the switchgear and propagate to the space. The electromagnetic wave will induce the current on the outer surface. Different transient voltage pulse signals are formed at different positions [7-8].

2.2. Basic Principles of TEV Detection Technology
When the partial discharge occurs in the insulation part of the switchgear, electromagnetic waves propagate from the discharge source through the gap on the outer surface. The partial discharge duration is generally only a few nanoseconds. Place a capacitive coupling sensor on the outer surface can measure parameters of the discharge pulse. The working principle of the detection is shown in Figure 1.

![Figure 1. Diagram of TEV test principle](image)

3. Experimental platform and discharge model design

3.1. TEV measurement system composition
The test measurement system consists of a TEV sensor, power number high voltage test console, power supply equipment, PC and software, which can collect and record partial discharge data records of the switchgear. The TEV detector has a built-in filter amplifying circuit and an acquisition circuit. It converts the partial discharge activity to a TEV amplitude pulse signal in units of mV.

3.2. Experimental platform construction
The article used UniGear ZS1 12kV switchgear to obtain the partial discharge TEV information. The discharge model was set internally. The voltage was applied by the test transformer. The TEV sensor was closely attached to the outer surface, and the signal was transmitted from the coaxial cable to the TEV monitor to collect the discharge data. The field experiment platform is shown in Figure 2.
3.3. Discharge model and experimental process design

The insulation defects on the contact box of the circuit breaker were manufactured. The discharge model designed is shown in Figure 2(c). Two contact boxes’ bottom were drilled 5 small holes and respectively installed in phase A. According to the previous research and experiments, this experiment started from the initial voltage of 11kV. The input voltage of the primary side was raised by 1kV every 24 hours. The data was collected every 5 minutes.

4. TEV amplitude-number chart analysis and pattern recognition

4.1. Similarity comparison method

The TEV detection instrument used in this paper can display and record the amplitude and number. After the data was processed in Excel, it was expressed in the form of pulse amplitude-number chart. The abscissa of the chart was the excitation pulses. The ordinate was the corresponding pulse amplitude. Some TEV amplitude-number charts are shown in Figure 3. It is difficult to see the difference between different charts by direct observation. Therefore, the statistical information comparison method was used to analyze data.

According to the statistical analysis from the aforementioned experimental results, the lowest amplitude was set to 1 and followed subtracted the lowest amplitude. Finally 200 pulse amplitudes were taken, and the upper limit of the number of pulses were set to 100 times. The data’s number less
than 10 times of amplitudes under each group of voltages was removed. After the initial processing, a magnitude-number matrix of 200×100 was established for each set of voltages. The number of matrix rows indicated the amplitude of the discharge pulse, and the number of columns represented the number. Finally the whole chart was converted into 200×100 matrix of class elements 0 and 1 composed. After converting the amplitude-number chart of any two groups of voltages into a matrix, the similarity of different chart can be analyzed more accurately by comparing the same number of 0 and 1. The similarity calculation formula is:

\[
\sigma = \frac{\sum_{i=1}^{200} \sum_{j=1}^{100} (A_{ij} - \bar{A})(B_{ij} - \bar{B})}{\sqrt{\sum_{i=1}^{200} (A_{ij} - \bar{A})^2 \sum_{j=1}^{100} (B_{ij} - \bar{B})^2}}
\]

(1)

In the formula, \(A\) and \(B\) are matrices at different voltages respectively, \(i\) and \(j\) are the numbers of rows and columns of the matrix respectively, \(\bar{A}\) and \(\bar{B}\) are the mean values of the matrices \(A\) and \(B\).

According to formula (1), the results are shown in Table 1 and Table 2. Comparing the similarity of each group, it is found that the partial discharge was divided into three stages. The first stage is 11-16 kV, the second stage is 17-25 kV, and the third stage is 26-27 kV. The similarity of each group except the first group can reach more than 80%. The data in each stage has a high degree of similarity. From the comparative analysis of each group in different stages. It is found that the similarity difference of each group is relatively large. The similarity of the first stage and the second stage is 23%. The similarity between the third stage and other stages is less than 10%. The analysis of the data shows that the amplitude dimension of the first two stages is stable within 45. The third stage is larger than the first two stages. The range of data is expanded and the coincidence point is reduced making similar degree reduced. It can be preliminarily believed that the method of spectral similarity can be used to compare and analyze the current experimental results. It performs well in pattern recognition of different stages of partial discharge under different voltages. With the expansion of experimental pressure range, the database capacity will increase and the number of effective chart. The quantity can further improve the accuracy of the data.

| Stage 1 | Voltage (kV) | 11 | 12 | 13 | 14 | 15 | 16 | - | - | - |
|---------|--------------|----|----|----|----|----|----|---|---|---|
| \(\bar{\sigma}\) | 0.73 | 0.84 | 0.82 | 0.81 | 0.83 | 0.85 | - | - | - |
| Stage 2 | Voltage (kV) | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| \(\bar{\sigma}\) | 0.78 | 0.87 | 0.82 | 0.85 | 0.86 | 0.81 | 0.88 | 0.83 | 0.83 |
| Stage 3 | Voltage (kV) | 26 | 27 | - | - | - | - | - | - | - |
| \(\bar{\sigma}\) | 0.72 | 0.72 | - | - | - | - | - | - | - |

Table 1. The average similarity of different voltage spectra

Table 2. The average similarity of different voltage spectra of the three stages

| \(\bar{\sigma}\) | Stage1 | Stage2 | Stage3 |
|---------------|--------|--------|--------|
| Stage1        | 1      | 0.23   | 0.05   |
| Stage2        | 0.23   | 1      | 0.08   |
| Stage3        | 0.05   | 0.08   | 1      |

4.2. SVM algorithm

SVM is a machine learning algorithm based on statistical learning theory. It can improve the generalization ability by seeking the minimum structural risk. There is a great advantage in dealing
with the less and non-linear data of partial discharge data, which can obtain good statistical laws. The basic principle is to map data samples in low-dimensional space to high-dimensional space, making them linearly separable. And then it will find the optimal classification surface to maximize the classification between positive and negative classes.

80% of the data of 11-16 kV, 17-25kV, and 26-27kV were used as the training data input. The tag type is known, and the remaining 20% was used as the predicted data with unknown tag type, the output is shown in Figure 4.

![Figure 4. SVM analysis result](image)

In Figure 4, the SVM displays the real classification and the predicted classification label of the test data simultaneously. The overall classification accuracy rate is 90%, and the third stage classification accuracy rate is 100%. There is a big change between the third stage and the first two. The prediction results of the first phase and the second phase are crossed, but the classification accuracy rate is also above 80%, which can well classify and identify the discharge phase. The accuracy of SVM depends largely on the size of the sample data. As the data continues to improve and complement, the classification effect will be better.

5. Conclusion
Based on TEV amplitude-number chart, the article proposes the matrix similarity comparison method and SVM algorithm to analyze under different voltages. And the state of the switchgear is defined. They perform well in pattern recognition of the discharge stage. SVM algorithm has better classification effect. The intensity of the partial discharge and insulation state can be identified. So an early warning will be issued before the breakdown of the switchgear. The inspectors can check and repair the switchgear timely to avoid greater damage to the system.

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