Pattern Recognition of GIS defects based on Envelope characteristics of UHF signal

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Abstract: Partial discharge detection at UHF is one of the most effective methods for GIS diagnosis [1]. In this paper, five typical defect models and experiments in GIS have been carried out in laboratory. The envelope signals of UHF signal have been acquired based on UHF envelop detection circuit. The paper introduce the design of hardware including UHF envelope detection circuit and high-speed data sampling. The defect models and the process of model experiments were described too. Especially, A new method of pattern recognition was mentioned which analyses the characteristic parameters of the envelope signal at time-domain with BP neural network. The results indicate that the method used in this paper is effective.

Key words: GIS  UHF  envelope detection  BP neural-network  pattern recognition

1 Introduction

Partial discharge serves as both premonition and representation of degraded insulation of GIS and the cause of further degradation of insulation [4]. Therefore, detection of partial discharge is presently the most effective method for GIS insulation detection and diagnosis. Earlier insulation defects inside GIS can be discovered effectively through partial discharge detection so as to avoid further failure and improve the reliability of GIS. It can also compensate the deficiency of high voltage test.

Ultra High Frequency (UHF) Method is widely used for the online detection on GIS [2]. The UHF method receives high-frequency electromagnetic waves generated by partial discharge in GIS through UHF sensors. There are several data processing methods for failure identification including PRPD [3](Phase Resolved Partial Discharge), frequency-spectrum analysis [4], time domain waveform analysis [5], etc.

UHF envelope detection circuit was used in this paper to extract the envelope of UHF signal, and high-speed data collecting system was adopted for sampling. Defects classification of partial discharge can be carried out through extraction of finger-point features of time domain waveforms of the envelope signals and BP neural network.

Compared with real-time sampling method using wide-band oscilloscope, this method greatly reduced sampling velocity, data size and computational cost, and improved the efficiency of the defect diagnosis system.

2 Defects in GIS and Diagnosis

2.1 Defects in GIS

Defects may cause partial discharge in GIS which included free metallic particles, bad contact of conductive parts, needle on the conductor, air void in the insulator, metallic partial on the insulator and floating electrode [6-7]. Free metallic particles were possible to be produced in manufacture, assembly and running, and they had
the capacity of charge accumulation and can travel under the impact of AC electric fields. Their traveling and discharging possibilities were largely random. Sharp burr may appear on the surface of high-voltage conductors generally when under conditions of bad fabrication, damage or friction in installation. Both inner gaps formed in insulator manufacture and contraction coefficient difference between epoxy spacer and metallic electrode can lead to air void in insulator. Discharge caused by bad contact of conductive parts, especially by floating parts was considerably heavy and repeat. It is most likely that these insulation defects in GIS may cause partial discharge phenomenon in GIS, and partial discharge may erode insulating material and even lead to failure.

2.2 Partial Discharge Detection System

![Fig.1 Partial discharge Detection System for GIS at UHF](image)

The structure of partial discharge detection system was composed of built-in UHF sensor, wide-band amplifier, band-pass filter, GSM wave trap circuit, envelope extract circuit and high-speed data collection circuit, etc., as shown in Fig.1. The power of partial discharge signals received by the UHF sensor was from -80 dBm to -15 dBm. It was amplified by low noise, wide-band amplifier which gain was programmable. The maximum gain can achieve 50dB. The filter circuit comprises the band-pass filter and the GSM trap of 900MHz. The frequency of the band-pass filter was determined by the disturbance on testing site. And general disturbing signals on site include electric corona, FM broadcasting station, GSM 900MHz / 1800MHz, wireless LAN signals, etc. In the paper, a 300MHz-1500MHz filter and GSM trap of 900MHz was used to reduce most of the wireless disturbance as the mainly energy of UHF signal is between 300MHz to 1500MHz. The envelope detection circuit was composed of RF diodes and high-frequency capacitors, etc as shown in Fig.1.

The time for charging of the envelope detection circuit was required to be less than 1ns so as to reduce peak-value error. Due to their actual natural parameter limits, diode components has the equivalent on-resistance\(^6\) of 2.6kΩ in 10uA BIAS at room temperature. Then the equivalent integral time is 2.6ns for 1pF capacitance. Therefore, when the input of the detection circuit was GIS partial discharge UHF signals in non-continuous oscillation sine waves, there existed certain peak-value detection error. Experiment results shown the error is no more than 10% and can meet engineering requirements.

3 Defect Models Test

3.1 defect models test system

GIS partial discharge test system comprises: high-voltage power supply without partial discharge, GIS tank, GIS defect model, traditional partial discharge detecting instrument recommended in IEC0270, UHF measurement system, wide-band oscilloscope, etc. The test of defect models in this paper was accomplished on a 220kv GIS test system in a GIS manufacturer (as shown in Fig.2). Main equipment comprise: 550kv fully-sealed transformer booster, partial discharge test instrument, GIS cavity.
about 20m long, multifunctional meter, etc. The background partial discharge quantity of the system was about 1.1pC.

3.2 Data Analysis

Five defect models were installed in GIS respectively, and SF₆ gas was filled with 0.61Mpa pressure. Voltage was added step by step after ten minutes of stabilization. Discharge voltages applied in different defect models and partial discharge quantity measured by partial discharge instrument were shown in Table.1. According to the above data, both the discharge voltages and the quantities of partial discharge of different defect models are different.

<table>
<thead>
<tr>
<th>defect model</th>
<th>discharge voltage (kv)</th>
<th>partial discharge quantity (pc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>free metallic particle</td>
<td>38</td>
<td>2</td>
</tr>
<tr>
<td>needle on conductor</td>
<td>100</td>
<td>3.3</td>
</tr>
<tr>
<td>air void in the insulator</td>
<td>140</td>
<td>37</td>
</tr>
<tr>
<td>metallic partial on the insulator</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>floating electrode</td>
<td>133</td>
<td>30</td>
</tr>
</tbody>
</table>

Typical envelopes of UHF signals generated by partial discharges of different defects were shown in Fig.3(a)-Fig.3(e) respectively.

4 Defects Classification

From the experiment results, it is concluded that time-domain characteristics of partial discharge signals generated by the same defect model are almost consistent, and that is same as to the envelopes. Meanwhile, the time-domain characteristics of partial discharge signals generated by different defect models are different, that is same as to the envelopes. Therefore, characteristic parameters of envelope signals can be sampled, and pattern recognition or defects classification can be carried out by these parameters with neural-network algorithms[7-8].

4.1 Characteristic Parameters

Envelope shapes of partial discharge signals can be represented through time-domain characteristic parameters[9] which were listed in Table 2. The last two one in Table 2, skewness $s_k$ and kurtosis $k_u$, were defined as (3) and (4) respectively.

$$K_u = \frac{E(x_i - \mu)^4}{\sigma^4} \tag{3}$$

$$S_k = \frac{E(x_i - \mu)^3}{\sigma^3} \tag{4}$$

Where $x_i$ is number $i$ of sampling points, $\mu$ is the average value of $\{x\}$, $\sigma$ is the standard deviation.
Table 2: Typical characteristic parameters of five defects

<table>
<thead>
<tr>
<th>defect type</th>
<th>free metallic particles</th>
<th>needle on the conductor</th>
<th>air void in the insulator</th>
<th>metallic partial on the insulator</th>
<th>floating electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_h (\mu s) )</td>
<td>0.028</td>
<td>0.044</td>
<td>0.140</td>
<td>0.044</td>
<td>0.024</td>
</tr>
<tr>
<td>( t_r (\mu s) )</td>
<td>0.024</td>
<td>0.024</td>
<td>0.136</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td>( t_d (\mu s) )</td>
<td>0.108</td>
<td>7.624</td>
<td>0.600</td>
<td>0.232</td>
<td>0.144</td>
</tr>
<tr>
<td>( t_{50%} (\mu s) )</td>
<td>0.064</td>
<td>0.220</td>
<td>0.128</td>
<td>0.096</td>
<td>0.048</td>
</tr>
<tr>
<td>( t_{10%} (\mu s) )</td>
<td>0.136</td>
<td>7.668</td>
<td>0.740</td>
<td>0.256</td>
<td>0.168</td>
</tr>
<tr>
<td>( S_k )</td>
<td>10.2299</td>
<td>1.872</td>
<td>3.726</td>
<td>5.980</td>
<td>2.620</td>
</tr>
<tr>
<td>( K_u )</td>
<td>116.917</td>
<td>7.931</td>
<td>17.254</td>
<td>49.025</td>
<td>18.537</td>
</tr>
</tbody>
</table>

The seven characteristic parameters listed in Table 2 were used to describe the shape of the envelop of UHF signal. Moreover, the typical characteristic parameters of five defect models were presented in Table 2.

### 4.2 Classification Using BP Neural-Network

Pattern recognition or defects classification is important to the application of UHF PD detection. The neural-network method simulates the thinking process of the human brain, so it has very high intelligence. Back Propagation (BP) network, which adopts back-propagation training algorithm namely BP algorithm, is a multilayer feed-forward neural network used widely. BP is comprised of an input layer, an output layer and a middle hidden layer. Its essential idea is to adjust relevant weights to reduce the total network error to minimum. Through training and study of a certain number of samples, BP determines connection relevant-weights among layers, namely network parameters, through which it achieves pattern recognition of actual signal data. When the maximum of the absolute value of the error between the actual output and the desired output is smaller than specified error \( \delta \), the training ends.

The recognition results were listed in Table 3. As shown in it, the smaller the training error is, the longer the training time lasts. From table 3, it can be seen that recognition accuracy rate can be improved by reducing \( \delta \). Meanwhile, corresponding training time will grow. When \( \delta \) is smaller than a definite value, its influence on recognition results has been unimportant. Therefore, defining \( \delta \) as 0.001 is enough for the accuracy rate of recognition.

### 5 Conclusions

1) The feature of the envelop signals is different for different defects.
2) A method of time-domain analysis for envelope signals was proposed, and the characteristic
parameters have been selected.
3) Pattern recognition was achieved based on characteristic parameters of envelope signals and BP neural network. The test results indicate that the method is effective.

Reference