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Partial Discharge Comprehensive Fault Decision of 0.4KV/10KV Power Transformer Based on PSD-PSO Algorithm

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Abstract: In order to ensure the stability of power grid, 0.4kV/10kV power transformer PD on-line monitoring system is studied in this paper. With the help of pulse current detection method, the PD propagation characteristics can be precisely located by the power spectrum density (PSD). In order to have a good weight distribution of PSO and the statistical analysis problem, PSD-PSO algorithm is introduced in this paper. And the comprehensive fault decision based on PSD- PSO algorithm is studied in this paper. At last the simulation results show that the proposed method can improve the accuracy and the real- time performance of fault diagnosis via power transformer.

Keywords: 0.4KV/10KV power transformer, comprehensive fault decision, partial discharge, particle swarm optimization (PSO), power spectrum density (PSD).

1. INTRODUCTION

As an important part of transmission and distribution equipment, power transformers play important roles in power grid. Moreover, the overall deterioration of insulation level of power transformers is an important reference index for stable running and economic operation of a power system .In view of the present situation that the periodical inspection and repair cycle cannot perform the inspection and repair scientifically and reasonably, the insulation level of power transformers cannot be kept stable during the long-term online operation. In order to ensure the stability of power grid, it is indispensable to reinforce the monitor and diagnosis of the transformer insulation. Partial discharge (PD) during insulation is considered as a major cause of insulation degradation in transformers attaching importance due to the safety and reliability of running transformers. Many researchers pay much more attention to the study of fault diagnosis of power transformers [1-4].

With the fast development of sensing technology, computer technology and information processing technology, modelling analyzing and knowledge reasoning based on Rough set and ANN network have been studied [5-7], esp. comprehensive application of internal fault diagnosis technology of transformer has been applied in industries [8, 9]. ANN network, expect system and fuzzy set theory etc. play a promising role in condition monitoring and fault diagnosis in power grid equipments. In order to deal with weight distribution of PSO and the statistical analysis problem, the comprehensive fault decision based on PSD-PSO algorithm is studied in this paper. According to the problems existed in field 0.4kV/10kV power transformer PD on-line monitoring system, this paper researches on the PD propagation characteristics based on the detection method of pulse current method (PCM).

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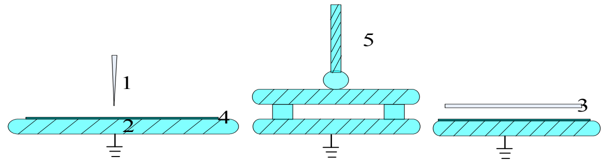
2. PD TEST AND PROPAGATION CHARACTERISTICS DETECTION METHODS

Auto-recognition to discharge types in on-line PD monitoring system could be used to find out internal partial defects and the relevant discharge development degree in time, and thus the equipment is prevented from the coming faults. In general, electromagnetic radiation, high frequency pulse, dielectric loss voice, lighting and heating emission can be monitored with the profile of PD in power equipments. And there are several PD propagation characteristics methods discussed earlier. Electric and non-electric methods are to diagnose and correct the problem situations for large power transformer, such as pulse current method (PCM), dielectric loss method (DLM) and electromagnetic radiation method (ERM) have been studied in the past decade. According the IEC standards, PCM is the recommended detection method for PD propagation characteristics.

2.1. PD Models and Experimental Devices

According to the internal insulation PD in the transformer and the PD propagation characteristics, there are three PD models designed in this paper, which are shown in Fig. (**1**), namely point discharge in transformer oil (P1), solid Insulation of power transformer (P2), and surface discharge in transformer oil (P3). The PD signals are measured by PCM. Test PD detection schematic diagram and experimental devices are shown in Figs. (**2**) and (**3**).



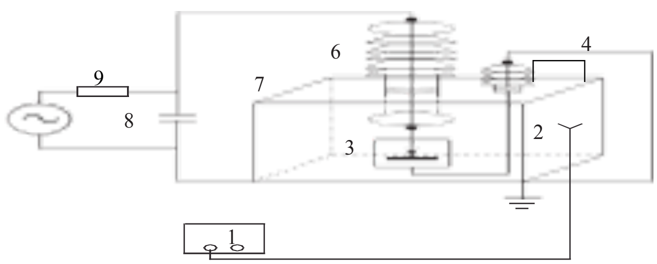
point discharge in transformer oil (P1)

Solid Insulation of Power Transformer (P2)

surface discharge in transformer oil (P3)

1 needle electrode 2 circular plate electrode 3 plate electrode 4 tank oil 5 ball electrode

Fig. (1). PD models of artificial defects.



1 PD detection instrument (IFD251) 2 High frequency Antenna 3 Electrode 4 Ground wire 5 0.4kV Insulating casing 6 10kV Insulating casing 7 Transformer oil tank 8 Coupling capacitance 9 Protection resistors.

Internal schematic diagram of 10KV/400V power transformer by AUTOCAD

Fig. (2). The ammonia storage capacity of catalyst.

Fig. (3). Experimental devices on o.4kV/10kV power transformer PD detection.

2.2. Experimental Procedure and Starting Discharge Voltage VS Extinction Voltage Mode

In order to have a good contrast effect, starting discharge voltage vs. extinction voltage mode are studied in this experiment. With the study of point discharge in transformer oil the source voltage is gradually increased from 3.0 to 5.8 kV by 0.2kV step and the PD distance is gradually increased from 0.5cm to 3.5cm. On the other hand, with the study of surface discharge in transformer oil, the source voltage is gradually increased from 6.3 to 7.3 kV by 0.2kV step and the PD distance is gradually increased from 1.5cm to 3.5cm. The experimental data (starting discharge voltage vs. extinction voltage) is shown in Tables **1** and **2.** Furthermore, with the study of solid insulation of power transformer, the source voltage is gradually increased from 4.4 to 7.8 kV by 0.2kV step and the PD distance is gradually increased from 1.5cm to 3.5cm. The experimental data (starting discharge voltage *VS*. extinction voltage) is shown in Table **3**.

Table 1. PD data on point discharge in transformer oil (P1).

Distance/cm	Starting Voltage/kV	Extinction Voltage/kV
3.5	5.8	5.0
2.4	5.0	4.6
1.0	4.5	4.1
0.5	3.0	2.4

Table 2. PD Data on surface discharge in transformer oil (P3).

Distance/cm	Starting Voltage/kV	Extinction Voltage/kV
3.5	7.3	6.7
2.5	6.8	6.2
1.5	6.3	5.7

Table 3. PD Data on solid insulation of power transformer (P2).

Distance /cm	Starting voltage /kV	Extinction voltage /kV
3.5	7.8	7.4
2.5	6.3	5.8
1.5	4.4	3.9

And the PD pulse maps are shown in Fig. (**4**) (point discharge) and Fig. (**5**) (surface discharge). As can be seen from the pulse map, the initial pulses are at the point of 90° and 270°. With the increase of source voltage, the number of PD pulses is increased and the PD pulse span are enlarged.

Fig. (4). Point discharge PD pulse map under the voltage (3.0kV *vs*. 5.8kV).

Fig. (5). Surface discharge PD pulse map under the voltage (6.3kV *vs*. 7.3kV).

Comparing with Fig. (**4**) with Fig. (**5**), there are some difference found between point discharge PD pulse map and

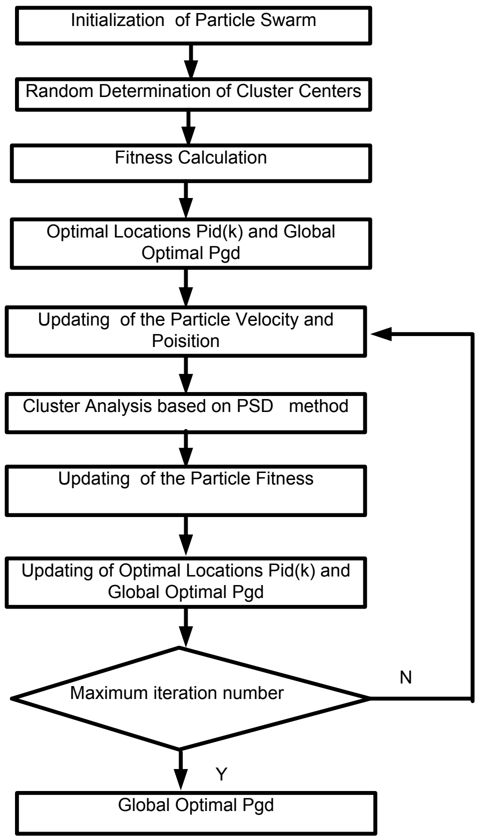


Fig. (6). Flow chart based on PSD-PSO algorithm.

surface discharge PD pulse map at the viewpoint of statistical analysis. In order to have a good weight distribution of PSO, the power spectrum density (PSD) is introduced in this paper.

2.3. Power Spectrum Density Analysis

PSD analysis is the method which indicates the relation between the power change and the frequency variation. The most part of the PSD is the calculation of spectral density function. With the help of PAD analysis, statistical operator, pulse waveform characteristics, and fractal characteristics in 2 dimensions or 3 dimensions can be considered. As can be seen in Equation **1**, the frequency of PD and the maximum PD value can be calculated by the different windows spectral density functions (such as Boxcar data sampling, Hamming data sampling and Blackman data sampling *etc*.).

$$\int_{-\infty}^{+\infty} |s(t)|^2 dt = \int_{-\infty}^{+\infty} |S(f)|^2 df \tag{1}$$

3. PARTICAL DISCHARGE PATTERN RECOGNITION

3.1. Data Pre-Processing

With the help of PD monitor (JFD251) and 50 times PD experiments on 0.4kV/10kV power transformers, three types of PD models ΔQ-U mode data can be obtained. As a PD data sample $x_i = \left[x_1, x_2, x_3, \cdots, x_k\right]^T$, where k is the sampling number in the unit time. In this paper, source voltage (in P1)is gradually increased from 3.0 to 5.8 kV by 0.2kV each step, so the k1=(5.8-2.0)/0.2=19.

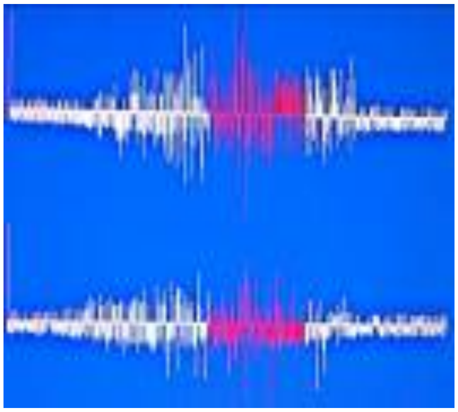
In the same way, k2(in P2)=(7.8-4.4)/0.2=17, and k3(in P3)=(7.3-6.3)/0.2=5. Because of the difference among the parameters k1, k2 and k3, so normalization process is very essential in PD data pre-processing. As is shown in equation 2, 120 samples can be obtained in the experiments with the three modes (P1, P2 and P3).

$$x(t)_{un} = \frac{\max\left\{x(i)\right\} - x(t)}{\max\left\{x(i)\right\} - \min\left\{x(i)\right\}} \tag{2}$$

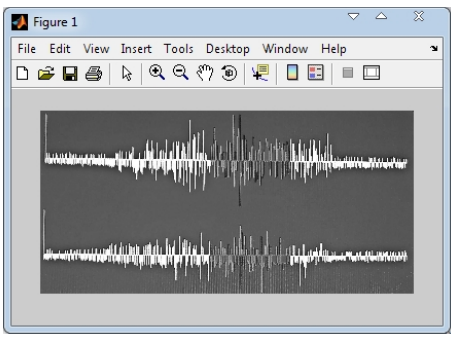
In order to have a good pattern recognition result, based on 10-fold, cross-validation is proposed. Moreover, there are 60 classification samples and 40 test samples. In this way, we can get a sample matrix X_{un}(120*60).

3.2. Pattern Discovery Flow Chart

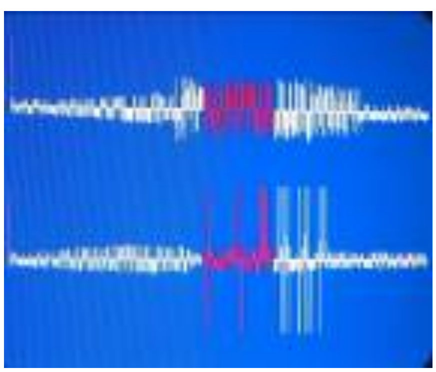
In order to have a good and fast pattern recognition result on the classification modes of P1, P2 and P3, there are two testing parts in the PD pattern recognition: data-training stage and data-testing stage. The flow chart based on PSD-PSO algorithm is shown in Fig. (**6**).



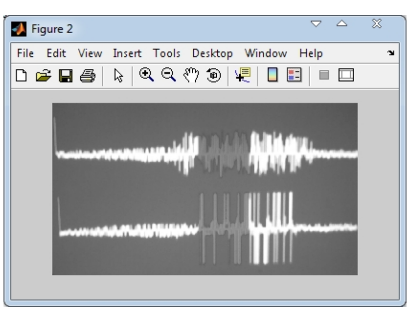
Point discharge PD pulse 3-D image



Point discharge PD pulse 2-D image



Surface discharge PD pulse 3-D image



Surface discharge PD pulse 2-D gray image

Fig. (7). Gray-conversion on PD Images.

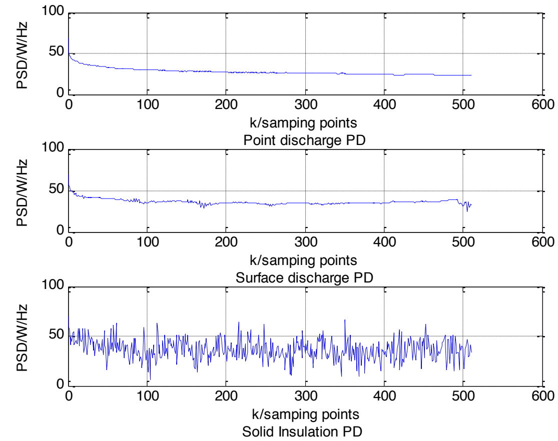


Fig. (8). Power spectrums of different PD propagation characteristics.

3.3. Pattern Analysis

In order to get fast and accurate pattern recognition results, the 3-D colourful PD images are converted to the 2-D gray PD images, as can be seen in Fig. (**7**). With the help of PSD method, the power spectrums of different PD propagation characteristics can be obtained in Fig. (**8**).

3.4. Identification Results

With help of Matlab 7.0, the PD propagation characteristics identification results and PD pattern samples (3 types P1, P2 and P3, 512 data in one type) are displayed in Table **4**. And pattern recognition results by BP algorithm with the same computer (with CPU of Celeron 400 MHz) are also shown in Table **5**.

Table 4. Results of pattern recognition by PSD-PSO algorithm.

PD Types	Results of Pattern Recognition			Tims/ms	Correct Rate
	P1	P2	P3		
P1	490	10	12	35	95.7%
P2	8	503	1	45	98.2%
P3	5	10	495	37	96.7%
Average				39	96.9%

Table 5. Results of pattern recognition by BP algorithm.

PD Types	Results of Pattern Recognition			Time/ms	Correct Rate
	P1	P2	P3		
P1	438	25	49	203	85.5%
P2	33	427	52	173	83.4%
P3	23	50	439	190	85.7%
Average				188.7	84.9%

As can be seen from Tables **4** and **5**, compared with the BP ANN network, PSD-PSO algorithm can improve the accuracy (from 84.9% to 96.9%) and the real-time performance (39ms *VS*. 188.7 ms) of fault diagnosis in power transformers.

CONCLUSION

In this paper, partial discharge comprehensive fault decision of 0.4KV/10KV power transformer based on PSD-PSO algorithm is discussed. The simulation results show that the improved PSD-PSO algorithm has the advantages of better classification effect (from 84.9% to 96.9%), being easy to realize and better real-time performance (39ms VS. 188.7 ms) of fault diagnosis in power transformers. And the simulation results also demonstrate the effectiveness of the improved method. On the other hand, the PSD-PSO method can meet the requirements of comprehensive fault decision on other power equipment such as power switchgears and porcelain insulators etc.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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