Optical Fiber Blind Sources Separation Sensor for Partial Discharge Detection in 12kV Power Transformer based on PSD-PSO Algorithm

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Abstract
In order to insure the stability of power grid ,a novel optical fiber sensor is designed on the basis of Blind Sources Separation in this paper, The sensor can arranged inside the 12kV power Transformers. There are several advantages of the optical fiber blind sources separation sensor, such asquick fault detection and location, immunity to the electromagnetic interference, and on-line monitoring. With the help of optical filber sensor , 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. At last the experimental results show that the proposed sensor can enhance the on-line PD monitoring in the 12kV power transformers and the real time performance of fault diagnosis in power transformer.
Keywords: OPTICAL FIBER, POWER SPECTRUM DENSITY(PSD), BLIND SouOURCES SEPARATION(BSS), FAULT DIAGNOSI

1. Introduction

There is no doubt that PD monitoring and fault diagnosis of power transformer is an important way to predit and prevent the failure of power transformer [1]. Moreover, the overall deterioration of insulation level on power transformers is an important reference index for stable running and economic operation of power system .Nowadays. increasing PD monitoring techniques and devices have been widely used in power devices. Moreover Partial discharge (PD) inside insulation is considered as one major cause of insulation degradation in transformer and attached importance to the safety and reliability of running transformer[2]. Many researchers pay much more attention to the study of fault diagnosis of power transformers [3-4]. Most of the on-line BSS techniques are based on Digital Signal Processing. With consideration of advantages of Blind Sources Separation(BSS) [5-7], an improved PSO method (PSD-PSO) is proposed in this paper.

In order to deal with weight distribution of PSO and the statistical analysis problem[8-10] , the comprehensive fault decision based on PSD-PSO algorithm is studied in this paper. According to the problems existed in field 12kV power transformer PD online monitoring system, this paper researches the PD propagation characteristics based on optical fiber sensors. In the first part of this paper, the theoretical basis is introduced. In the second part of this paper, the optical phenomena can be observed by fluorescence optical fiber that is sensitive to the well-known optical emission by internal PD. Based on these electrical equipments, the last part deals with the interpretation of the observations between PSD-PSO algorithm and BSS methods. This experimental results show that optical fiber blind sources separation sensor may do good to on-line PD monitoring in 12kV Power Transformer.

2. Theoretical Basis

2.1. Blind Sources Separation

If there are N unknown signals $S_i\ (t), i=1,2,...,N$, there exist column vectors $S(t)=[S_1(t),...,S_N(t)]^Y$, where t is the discrete time, and t=0,1,2...If Mixing Matrix A is a $M \times N$ matrix, then column vectors $X(t)=[X_1(t),...,X_M(t)]^T$ and X(t) is made up by $X_i(t)$, where i=1,...,M. Then the column vectors satisfy

$$X(t)=AS(t), where\ \ M>N \tag{1}$$

Then X(t) is known and A is unknown ,the solving nonlinear equations (1) is called BSS.

2.2. Independent Component Analysis

There are several assumptions should be considered:

(1)Independent component signals are statistically independent but linearly mixed;

(2)Independent component signals are followed non- Gaussian distribution;

(3)The Mixing Matrix A is a N*N matrix.

then the BSS can be changed to ICA.

If there is a N*N Inverse Mixing Matrix $W=(wij)$, X(t) can be obtained by W-transform, that is

$$Y(t)=WX(t)=WAS(t) \tag{2}$$

where WA=I(N*N unit matrix),then Y(t)=S(t);

The derivation process can be shown in Fig.1.

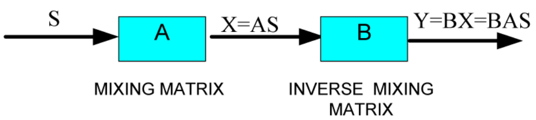


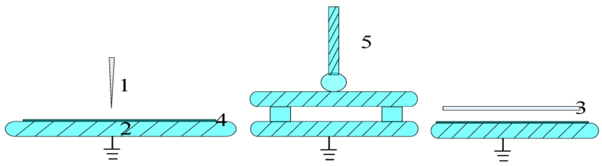
Figure 1. Derivation process of ICA

3. PD Test and Propagation Characters 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 then prevents equipment from the coming faults. In general, electromagnetic radiation, high frequency pulse, dielectric loss voice ,lighting and heating emitting can be monitored with the profile of PD in power equipments. And there are several PD propagation characteristics method discussed in the references[11-17].Electric methods and non-electric methods are to diagnose and correct 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 on PD propagation characteristics.

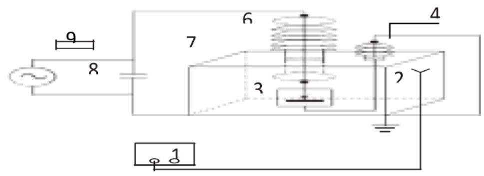
3.1. PD models and experimental devices

According to the internal insulation PD in the transformer and the PD propagation characteristics, there are three PD models are designed in this paper, which are shown in Fig.2. That is 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 software interface are shown in Fig.3 and Fig.4.



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

Figure 2. 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

Figure3. Test PD Detection Schematic Diagram

3.2. 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

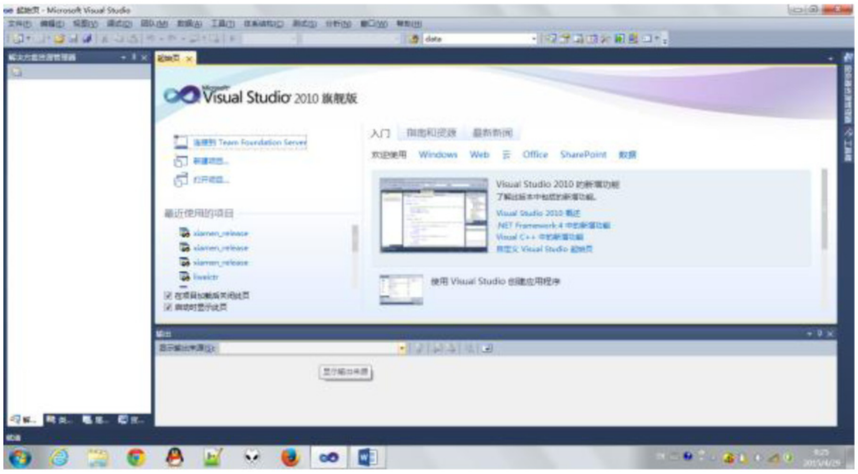


Figure 4. Software Interface on 12kV Power Transformer PD Detection

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 Table 1 and Table 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

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

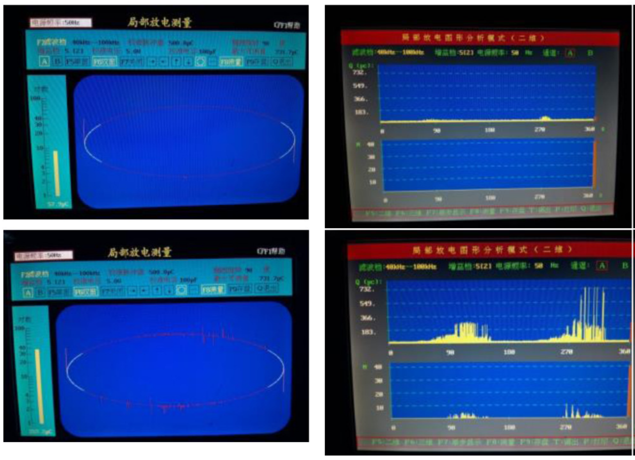


Figure 5. Point Discharge PD Pulse Map under the Voltage (3.5kV VS. 4.5kV)

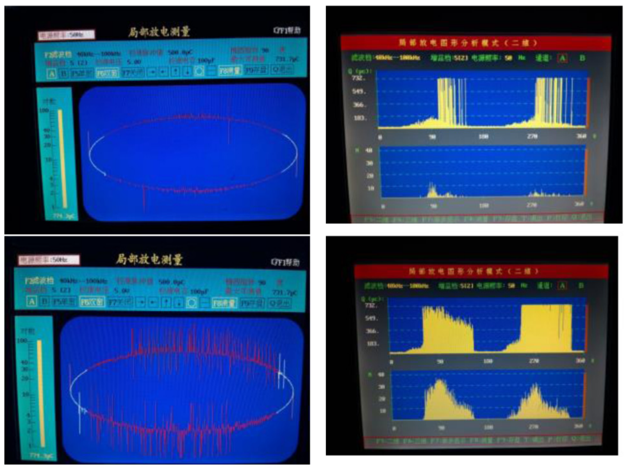


Figure 6 Surface Discharge PD Pulse Map under the Voltage (6kV VS. 7.5kV)

Compared with FIGURE.4 and FIGURE.5 , there are some difference between point discharge PD pulse map and 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) are introduced in this paper.

3.3. Power Spectrum Density Analysis

PSD analysis is the method which indicate 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 shown 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.).

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

4. Partical discharge pattern recognition

4.1. Data Preprocessing

With the help of PD monitor (JFD251) and 50 times PD experiments on 0.4kV/10kV power transformers, there are three types PD models ΔQ-U mode data can be obtained. As a PD data sample $x_i = [x_1, x_2, x_3, \cdots, x_k]^T$, where k is the sampling numbers in the unity 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.since the difference among the parameters k1,k2 and k3, normalization processing is very essential in PD data preprocessing. As is shown in equation 2, 120samples can be obtained in the experiments with the three modes (P1,P2 and P3).

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

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

4.2. Pattern Discovery Flow Chart

In order to have a good and fast pattern recognition result on the classification between 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.7.

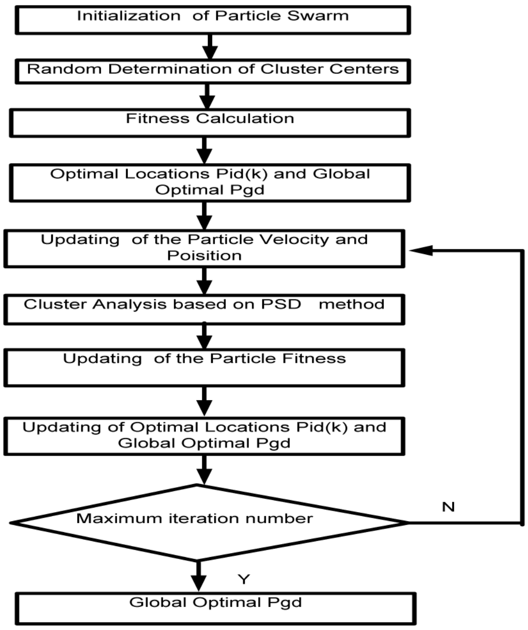


Figure 7. Flow Chart based on PSD-PSO Algorithm

4.3. Pattern Analysis

In order to get fast and accurate pattern recognition results, the PD ruesults under three different modes(TipVs. Tip mode, Tip VS. Board mode and High Voltage Point mode) are show in Fig.8. With help of PSD method ,the power spectrums of different PD propagation characteristics can be obtained in Fig. 9.

As can be seen from the Fig. 8, PD under Tip Vs. Tip mode is one type of internal discharge, PD under Tip VS. Board mode is one type of surface discharge and PD under High Voltage Point mode is one type of tip discharge. Three kinds of PD are happened in non-uniform field. The polar effect is very important to the study of quick fault detection and PD location.

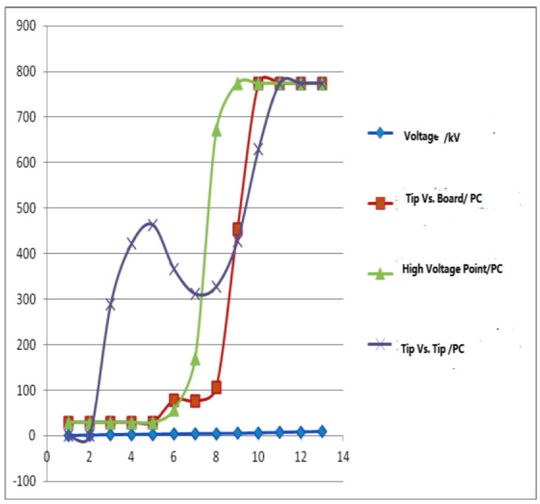


Figure 8. PD Results under 3 Different PD Modes

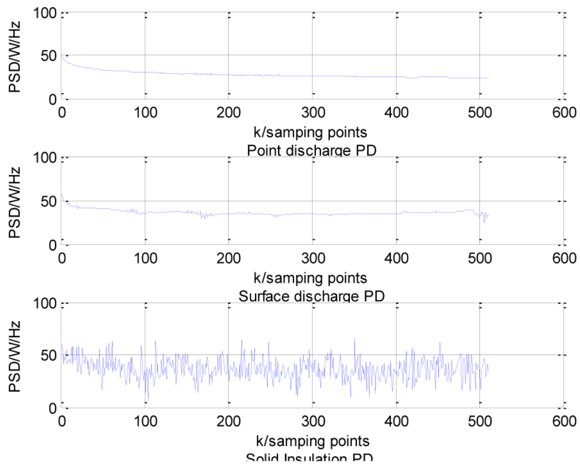


Figure 9. Power Spectrums of Different PD Propagation Characteristics

4.4. 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 Table4. 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			Tims/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 TABLE 4 and TABLE 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 transformer.

Conclusions

A novel optical PD sensor is designed on the basis of BSS digital signal processing technique. The proposed sensor can be placed inside the 12kV transformer, close to its uneven Tip or unevenness part of the transformer ,allowing for location of the detection of PD in fast and accurate way .

In this paper, partial discharge comprehensive fault decision of 12kV 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 transformer..

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.

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Partial Discharge Fault Decision and Location of 12kV Power Transformers based on Optical Fiber Sensor and Power Spectrum Density Algorithm

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Abstract
Partial discharge in polymeric insulation of medium voltage equipment causes cumulative damage that increasingly deteiorates the insulation, leading to eventual failure.With the consideration of electromagnetic interference from the envionment, the detection results may be unreliable.In such situations the detection of optical emission from partial discharge can greatly enhance its detectability, especially when the optical fiber sensor s are used. With the help of JFD251 partial discharge detection system and optical sensor, the partial discharge detection for different electrode model and the test methods are studied in the paper. Moreover, we present and discuss experimential results that show power spectrum density method is a good way for the fault decision and location of 12kV power transformer based on optical fiber sensor.
Keywords: OPTICAL FIBER SENSORS(OFS), PARTIAL DISCHARGE(PD), OPTICAL EMISSION SOURCE(OES) , FAULT DECISION AND LOCATION, 12KV POWER TRANSFORMERS