PARTIAL DISCHARGE LOCATION FOR CAST-RESIN TRANSFORMER BY UHF PD SENSOR AND PULSE WAVEFORM IDENTIFICATION

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Abstract: As the technique of on-line partial discharge measurement gets more precise, the goal of early warning is reached and the insulation breakdown is prevented. Besides the prevention of insulation breakdown, how to avoid the same defected equipment occurs again also attracts one's attention. As the defect is detected at low partial discharge level, the deterioration is at the early stage and the insulation material is possible not to be damaged yet. In such situation, it is hard to find the defect by dissecting defected equipment without partial discharge location.

For gas-insulated switchgear and oil-immersed transformer, there are several effective methods for partial discharge location. However, there is no effective method of partial discharge location for cast-resin transformer. However, the cast-resin transformer is broadly used in industries due to its small size and free maintenance, and it is importance to develop an effective method to locate partial discharge source.

The methods of partial discharge location for gas-insulated switchgear and oil-immersed transformer could be applied on cast-resin transformer, but, however, it would induce relatively large error because of the compact design of cast-resin transformer whose size is relatively smaller than GIS and power transformer. Although these methods are more suitable for cast-resin transformer than traditional method does, the suspected defect area is large due to the limitation of measuring instrument.

Authors modified the differential method, which compares the strength of measured signals to indicate the partial discharge location, and improved its performance by means of the adoption of UHF partial discharge sensor and the identification of the pulse polarity. The signal to noise ration is hence to be increased by UHF partial discharge sensor, and the location accuracy is also enhanced by the adoption of the identification of the pulse polarity of partial discharge signals.

One defected cast-resin transformer is taken as example to explain how this method works, and the defect is indistinguishable due to the early stage of deterioration. The mentioned method located the partial discharge source in a small area and the investigators can focus on the small suspected area to find out the partial discharge source easily. The analyses of scanning electron microscope and energy dispersive spectrometer confirm the defect discovered by this method.

Since the defect is discovered, the improvement of equipment could be made and the preventing recurrence of defected equipment could be also achieved. The field experience shows the mentioned method of partial discharge location is practicable and has good performance.

1 INTRODUCTION

As the progressing of measurement technique, on-line partial discharge measurement (PDM) is an effective insulation diagnosis, and is applied to prevention maintenance [1]. Once the equipment is confirmed to be with partial discharge (PD), most owner will replace it as soon as possible to prevent the breakdown event occurring. At the same time, the replaced equipment will be dissected to find how the defect be formatted, and then the production process can be modified to improve the reliability of equipment.

Comparing to other insulation diagnosis, periodic on-line PDM can assess insulation condition with high sensitivity. Hence, the insulation deterioration could be at the beginning stage, and the area of damaged insulation material could be too small to be found by visual inspection. In such condition, the mechanism initiating PDs could not be analysed. Therefore, only the risk of equipment breakdown be avoided, but the improvement of equipment reliability can be made.

One of conventional PD location method for cast resin transformer is differential method. The differential method calculates the amplitude difference between two measured PDs to locate the PD source [2] as shown in fig. 1. However, the accuracy of this method depends on the degree of property unity of PD sensors and the distance between sensors and transformer. The former results in the impedance matching problem, and the later leads to the safety distance issue. Therefore, this method is not suitable for onsite application due to property inconsistency of PD sensors and longer safety distance.

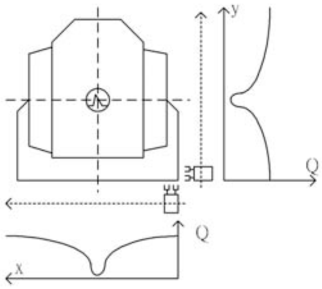


Fig. 1 PD location by differential method

Another conventional PD location method is time flying method. The time flying method calculates the time difference between arriving times of measured PDs to locate the PD source as shown in fig. 2. However, for the equipment with complex structure, such as transformer, the multi-path for PDs propagation will make the calculation of PD location difficult, and is not suitable for transformer.

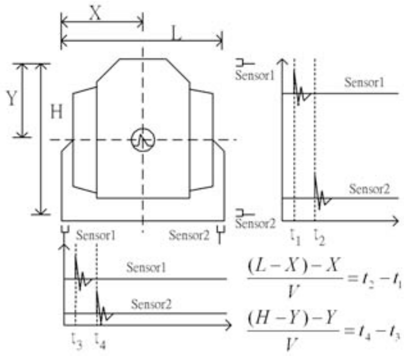


Fig. 2 PD location by time flying method

Figure 3 shows the cross section of windings. If the PD locates at the internal of the winding, PD pulses have two different path to travel to the ends of the winding: one is capacitive path through stray capacitance as the blue path shown in Fig. 3, and one is inductive path through conductor as the yellow dots shown in Fig. 3. The electric length of inductive path is longer than that of capacitive path, and the PD pulse measured by PD sensors would be the PD pulse via capacitive path. Because the electric length of capacitive path is determined by stray capacitance, the traveling time of PD pulse can't be estimated correctly, and the application of time flying method on PD location would be impractical. The multi-tap of coil also make lots of reflection and refraction of PD pulse propagation, and the time domain reflection method is also impractical.

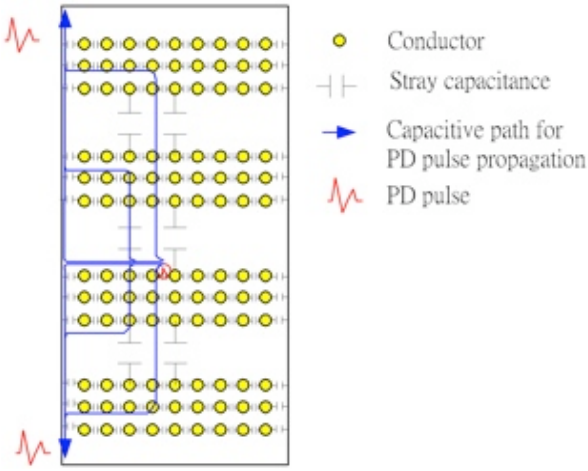


Fig. 3 Multi-path of PD pulse propagation

In order to overcome the difficulty encountered in field application, this paper proposes a novel method adopting pulse waveform identification for PD location of transformer. This method combines the ideas of the differential method and time flying method. Only the PD pulse polarity is compared rather than calculates the amplitude difference; only the arriving time is compared rather than calculate the time difference. Besides, the transient magnetic (TM) type of ultra-high-frequency (UHF) PD sensor, which has better sensitivity to PDs [3], is adopted, and the influence of background noise could be lowered.

One cast resin transformer, which is confirmed to be with PDs, is illustrated to show how PD location does. As the transformer was dissected, the defect was found at the position pointed by location result, and the defect was easily ignored without the PD location. Analysed by scanning electron microscope (SEM) and energy dispersive spectrometer (EDS), the defect is formatted at the process of copper manufacturing rather than the process of transformer manufacturing. This observation can help the manufactory to arise the reliability of transformer by the enhance the quality control of copper.

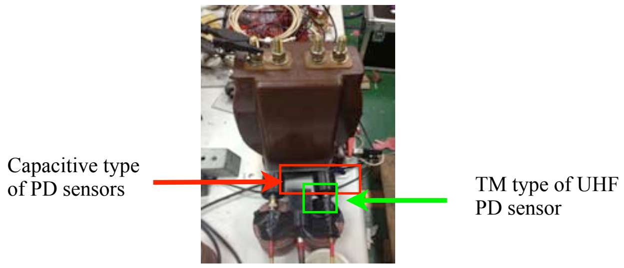
2 UHF PARTIAL DISCHARGE SENSOR

2.1 SENSITIVITY

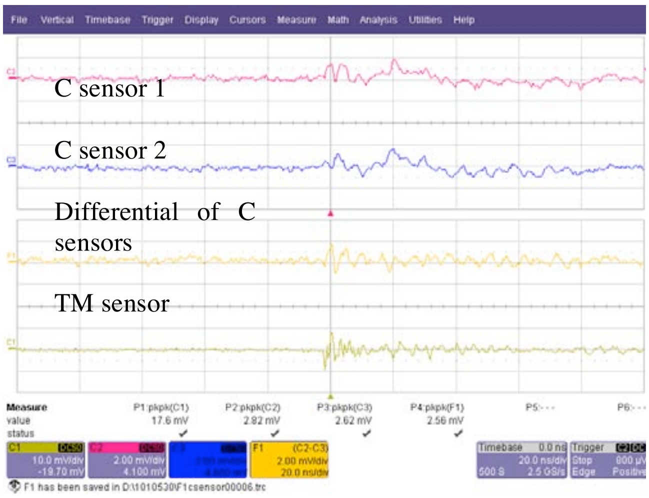
Conventional PD sensor applied on CRT for PD location is the capacitive type of sensor [2]. Hence, the distance between sensor and surface of OUT is one of the affection factor of sensitivity. The longer the distance is, the poorer the sensitivity is. In order to get sufficient sensitivity for the PD pulse polarity, the capacitive type of sensor might induce electric shock due to insufficient safety space.

Therefore, the transient magnetic (TM) type of ultra high frequency (UHF) PD sensor is adopted herein to replace the capacitive type of sensor. TM type of UHF PD sensor is measuring the change of transient magnetic field caused by PD pulse, and has better sensitivity than capacitive type of PD sensor.

Figure 4 shows the comparison of capacitive type of PD sensor and the TM type of UHF PD sensor. The maximum difference between two capacitive type of PD sensor is about 2.56 mVpp, and the maximum amplitude of TM type of UHF PD sensor is about 17.6 mVpp.



(a) Arrangement of Sensors



(b) Measured PD pulses (20 ns/div, C1: 10 mV/div, C2: 2 mV/div, C3: 2 mV/div, F1: 2 mV/div)

Fig. 4 Comparison of PD sensors

2.2 POLARITY

Once the PD occurs, the pulse current will flow toward two directions. Then current will induce magnetic flux, and the magnetic flux can be detected by UHF PD sensor as shown in Fig. 5.

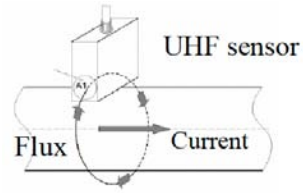


Fig. 5

Unlike capacitive type of PD sensors, the measured PD pulse will show different polarity as the direction of current flowing differs. Therefore, the TM type of UHF PD sensor has the advantage of identifying the direction of pulse current between two sensors, and PD location by the pulse polarity identification can be achieved.

3 METHODOLOGY

There are several paths for PD pulses to travel along, hence, the electric lengths of different traveling paths are different and can't be easily estimated. Therefore, the time flying method is not suitable to calculate the PD location, but it still can be used to identify which sensor is closer to the PD source.

The polarity of impulse current would be opposite as they travel along different direction. Therefore, the identification of pulse polarity could be helpful to locate the PD source.

3.1 PULSE POLARITY

Once the PD occurs, the PD pulse propagates to two ends of winding as traveling wave does, and two PD sensors are used to detect these PDs. The method of PD pulse polarity adopted herein is that only compare the polarities of two PD sensors rather than measure the difference between measured PD pulses. As shown in Fig. 6, if the PD source locates between two PD sensors, the measured PD pulses have opposite polarity. Otherwise, if the PD pulses have similar polarity, the PD source is outside the interval between the two sensors.

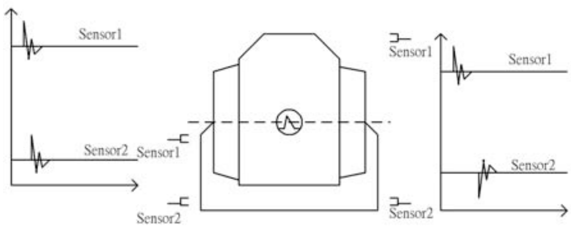


Fig. 6 PD pulse polarity

3.2 TIME FLYING

According to the location of PD source, the PD pulse polarity is sometime all the same along the transverse of the high voltage winding, which implies that the PD pulse polarity method can't be applied to locate the transverse coordinate of the PD source. In such condition, the time flying method is adopted.

In the same manner, the time flying method adopted herein is to find out which PD sensors is closer to the PD source rather than calculate the distance between PD source and PD sensors, as shown in Fig 7.

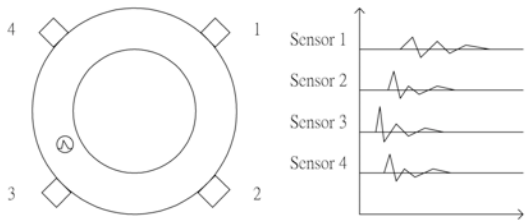


Fig. 7 Time flying

4 CASE STUDY

4.1 FIELD TEST

One CRT was confirmed to have PD inside winding in a periodic on-line PDM, and the phase-resolved partial discharge (PRPD) pattern is shown in Fig. 8. However, the CRT was classified as no PD in latest on-line PDM in two month ago. From PD free to the serious degree of PD activities in two months, it was supposed something quickly getting worse. Therefore, immediately replacement of the CRT is recommended.

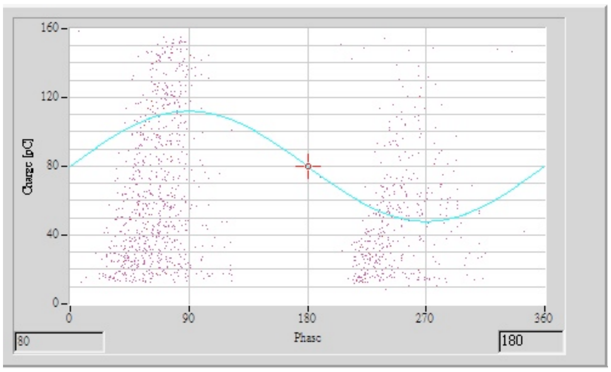
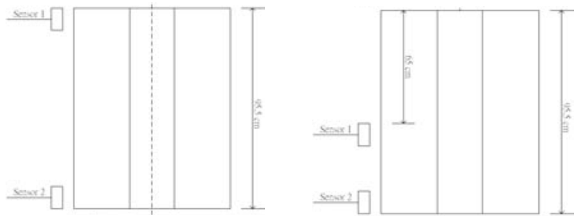


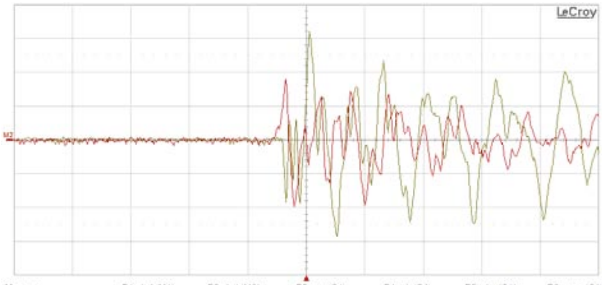
Fig. 8 Phase resolved pattern measured by UHF PD sensor

The defected CRT was moved to the manufactory, and PD location was carried out. Two TM type of UHF PD sensors and one oscilloscope (WaveRunner 64Xi) were used to locate the PD source.

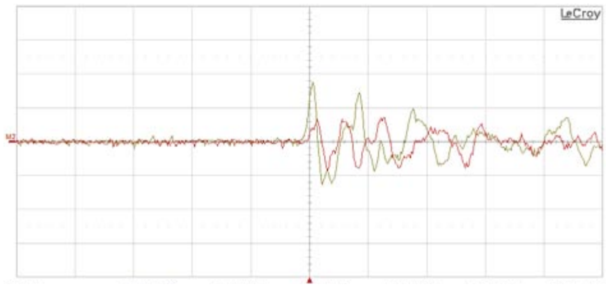
The waveforms measured by the PD sensors at different positions are shown in fig. 9. Figure 9(a)(c) show different PD pulse polarities, which implies that the PD source was between PD sensors. Figure 9(b)(d) show the waveforms measured by the PD sensors were the same PD pulse polarity, which implies that the PD source was outside the interval between PD sensors. Then the PD sensors were moved up and down to search the boundary of the change in PD pulse polarities, and vertical position of PD source was located.



(a) PD between sensors (b) PD outside sensors



(c) measured waveforms of (a) (10 mV/div, 10 ns/div)

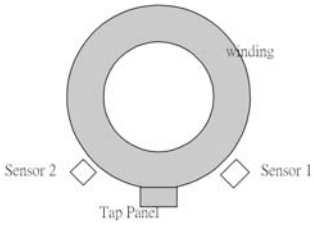


(d) measured waveforms of (b) (10 mV/div, 10 ns/div)

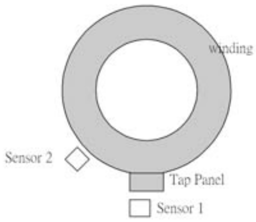
Fig. 9 Vertical position of PD location

Then the transverse position of PD source could be taken, and fig. 10 show the waveforms measured at different positions.

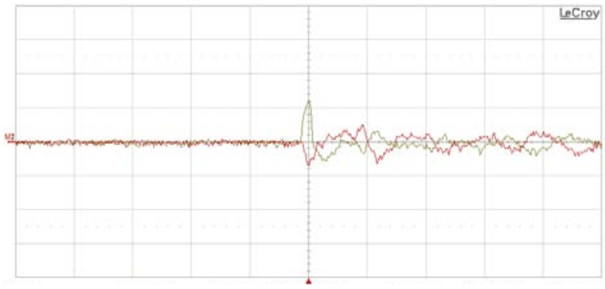
Figure 10(a)(c) show the waveforms measured by the PD sensors with different PD pulse polarities, which implies that the PD source was between PD sensors. Figure 10(b)(d) show the waveforms measured by the PD sensors with same PD pulse polarity, which implies that the PD source was outside the interval between PD sensors. As the PD sensors were moved right and left to search the boundary of the change in PD pulse polarities, and transverse position of PD source was located.



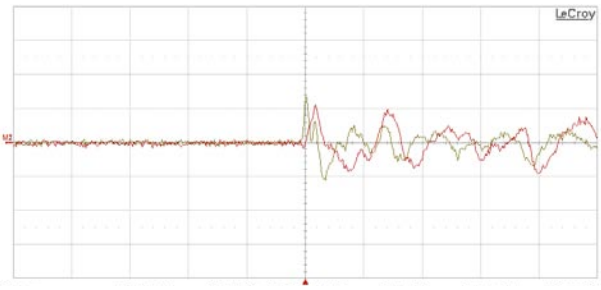
(a) PD between sensors



(b) PD outside sensors



(c) measured waveforms of (a) (10 mV/div, 10 ns/div)



(d) measured waveforms of (b) (10 mV/div, 10 ns/div)

Fig. 10 Transverse position of PD location

After the PD source location, the PD source was located at the 65 cm below the top of high voltage winding, and 3 cm right the center of the high voltage winding as shown in Fig. 11.

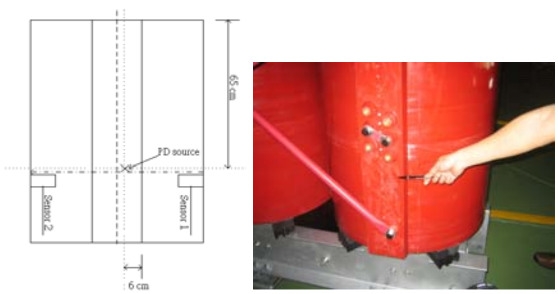


Fig. 11 PD location result

After the PD source was located, the high voltage winding was dissected as shown in Fig. 12. Figure 12(b) showed the defect located by the PD waveform identification, and it is easily classified as incision made by dissected without PD location.

(a) Dissection

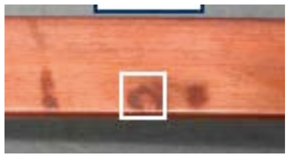
(b) Defect on conductor

Fig. 12 Inspection of CRT

4.2 EXAMINATION

The copper wire with defect shown in Fig. 12(b) was cut to be analysed, and a new copper wire with similar black spots is also cut for contrast as shown in Fig. 13. These copper wires are analysed by SEM for surface of copper wire and by EDS for the contents of contaminations.

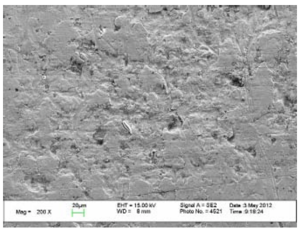
(a) Defect



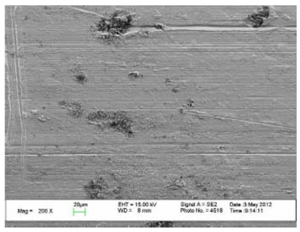
(b) new conductor

Fig. 13 Samples for analysis

Figure 14(a) shows the 200 times of the area marked in fig. 13(a), and it shows that the surface is very rough. Figure 14(b) shows the 200 times of the black spot marked in Fig. 13(b), and the surface is smooth except some contamination on it.



(a) Zoom-in of Fig. 13(a)



(b) Zoom-in of Fig. 13(b)

Fig. 14 200 times zoom-in of Fig. 13

There would be racrystallization of metal complying with the high temperature by PD, but there is no such phenomenon in Fig. 14(a). Therefore, it is hard to say that the rough surface is exactly caused by PD. However, comparing with Fig. 14(a) and Fig. 14(b), Fig. 14(a) shows much different condition. It could be that the ageing process is at the beginning stage implying that the temperature and energy produced by PD is still low, and the temperature resulting in recrystalization of metal is not reached yet.

In order to understand what mechanism initiate the PD, the defect area shown in Fig. 14(a) and the contamination area shown in Fig. 14(b) are analyzed by EDS, and the analysis result are shown in table I and table II in respect. Table III shows the contents of good area of conductor in Fig. 13(a).

Table I Contents of contamination in Fig. 11(a)

Element	O	C	Fe	Cu	Si
Norm. C(wt. %)	50	30.86	4.51	4.09	3.42
Element	Ca	Al	S	K	Mg
Norm. C (wt. %)	2.29	1.89	1.57	0.8	0.4

Table II Contents of contamination in Fig. 11(b)

Element	Ca	C	Cu	O	Si
Norm. C(wt. %)	50.0	23.88	17.2	6.3	1.35
Element	Cl	S	Al	Mg	
Norm. C (wt. %)	0.76	0.24	0.23	0.1	

Table III Contents of contamination in the clearing area of Fig. 10(a)

Element	Cu	O	C
Norm. C(wt. %)	98.35	0.84	0.81

Table I and Table II show the similar components, which not belong to copper wire itself. Table III shows that the normal area of copper wire only contains Cu, O, and C, and this could be the by-product of oxidization. As tracing the production process of the copper wire, the contaminations are the oil stain deposit, and the removing method is burned by high heat rather than degreasing process. Therefore, the surface of copper wire would have lots of black spots, and these contaminations could affect the distribution of electric field inducing PD.

5 CONCLUSION

In order to overcome the problems of conventional PD location for transformers, this paper applies the pulse waveform identification method on PD location for transformers and test result also shows good accuracy.

As illustrated in this paper, the defect at the beginning stage of insulation deterioration is easily ignored by visual inspection without PD location. The improvement of equipment reliability, the further effect of PDM, won't be achieved if the defect is not located.

According to the PD location, the defect is correctly located and be analyzed. The defect is formatted during the process of copper production. Hence, this kind of defects can be avoided by modifying the copper production process.

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