The application of pulse waveform identification on partial discharge location for cast-resin transformer

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Abstract

On-line partial discharge measurement is verified as an effective insulation diagnosis, and is currently applied worldwide for the preventive maintenance. Because the defect is detected in the early stage of electrical tree degradation, the insulation material might not be destroyed or only very tiny area is damaged. Hence, nothing could be found as the transformer is dissected and the improvement of production process also could not be carried out due to the mechanism for initiating partial discharge activities is not clear. Therefore, this paper propose a novel method, which adopts the identification of pulse waveform polarities, to locate the partial discharge source in the transformer, and then investigators can focus on the suspected area for the further researching. One cast-resin transformer is confirmed to be with partial discharge activities, and the suspected partial discharge sources are also located by this approach. After dissection, there are abnormal oxide/ electrolytic corrosion on surface of the copper wire. The abnormal surface was checked by scanning electron microscope and these abnormal oxides might be the cause initiating partial discharge activities. The reason resulting in the abnormal oxides is oil stain deposite on the conductor, and it could be removed by degreasing process.

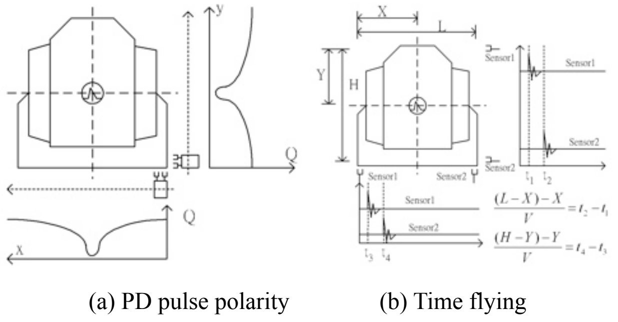
Keywords: partial discharge measurement, partial dischar location.

I. Introduction

Accompanied by the improvement of measuring technique, on-line partial discharge measurement (PDM) is broadly applied in the preventive maintenance due to its good performance of insulation condition assessment[1]. As partial discharge (PD) is detected inside an equipment, most customers would replace the suspected equipment as soon as possible to lower the risk of equipment breakdown. Then the replaced suspected equipment will be investigated to find out the mechanism resulting in PDs, and then the reliability of the equipment will be enhanced.

In the view of preventive maintenance, periodic on-line PDM is a kind of early warning insulation diagnosis. Therefore, it is possible that the detected defect is still at the beginning stage of insulation deterioration, and unusual spot damaged by PD could be tine to be easily ignored. Hence, the mechanism for initiating PDs could not be analyzed. In such situation, on-line PDM only can prevent the risk of the equipment breakdown, but can't improve the reliability of the equipement because no further investigation could be made.

The pulse waveform identification method, combination of PD pulse polarity and time flying, is proposed as the method of PD location in this paper. The conventional method of PD location based on PD pulse polarity is the to calculate the difference between PD signals measured by two similar PD sensors to locate PD, as shown 1 Fig. 1(a). However, the differential method of PD location is mainly affected by the identity of PD sensors and the holding position (ex. distance to the surface of test object). Hence, it is impractical for the application on the PD location. The conventional time flying method adopts two PD sensors at two ends of the object under test (OUT), and measures the time difference between the arriving time of two PD sensors as shown in Fig. 1(b). However, for equipments with coils, such as transformer, the multi-path of PD propagation would affect the measuring results, and enlarge the calculation errors. Therefore, the proposed pulse waveform identification only compares the pulse polarity and the arriving time rather than calculating the magnitudes and the time difference.



(a) PD pulse polarity (b) Time flying

Fig. 1 Conventional PD location

The transient magnetic (TM) type of ultra-high-frequency (UHF) PD sensor, which couples the change of TM field in the range of UHF band, is adopted to execute the on-line PDM and PD location, and TM type of UHF PD sensor also has better sensitivity than others[2]. One CRT is classified as PD inside by a periodic on-line PDM of two month interval, and the PD location was also taken place. According to PD location, the CRT was dissected, and the PD source was located. By the analysis of scanning electron microscope (SEM) and energy dispersive spectrometer (EDS), the defect leading PD was the contamination caused by poor production process of copper wire. The reliability of the CRT is then arose via the PD location.

II. PD pulse waveform identification

According to [4], partial discharge (PD) is the electrical discharge that only partially bridges the insulation between conductors. PD usually occurs at the area with high electrical stress, and it implies that there is a defect concertrating electrical field strength. Eventually, PD would induce the insulation breakdown, and should be avoided in advance.

Partial discharge measurement (PDM) is not only to detect PD to prevent insulation breakdown, but also to locate the defect for the further improvement of equipments. The conventional methods to locate PD source are time flying methods, PD pulse polarity method, and time domain reflection. However, for equipments with coils, it is difficult to locate PD source via above mentioned methods.

The conventional method of PD pulse polarity is measuring the difference between two sensors, and the degree of accuracy depends on the similarity of the PD sensors. However, the property of the PD sensors is hard to be exact the same, and the accuracy of location is limited. Moreover, the less sensitivity also leads to the insufficient safety space between sensor and the surface of OUT.

Figure 2 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. 2, and one is inductive path through conductor as the yellow dots shown in Fig. 2. 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. Therefore, the PD pulse waveform identification, which is a combination of PD pulse polarity and time flying method, is proposed for PD location, and the details are as following.

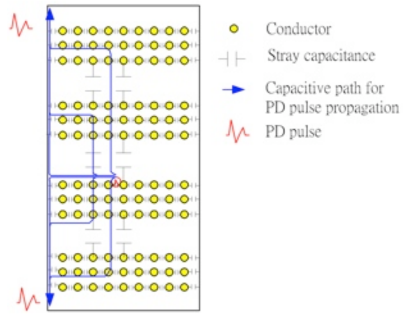


Fig. 2 Multi-path of PD pulse propagation

2.1 Pulse waveform identification

PD 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. 3, if the PD source locates between two PD sensors, the measured PD pulse have opposite polarity. Otherwise, if the PD pulse have similar polarity, the PD source is outside the interval between the two sensors.

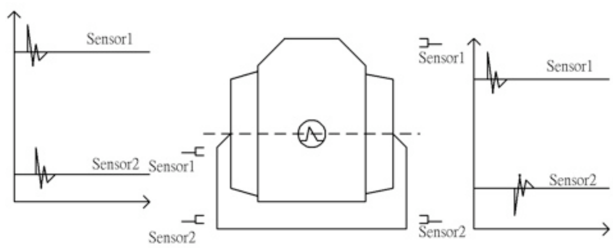


Fig. 3 PD pulse polarity

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.

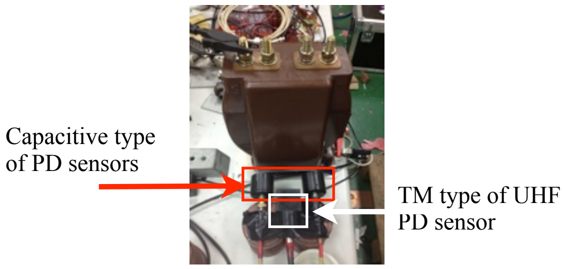
In the same manner, the time flying method adopted herein is to find out which PD sensors is closer to the PD source rather than calculate the distance between PD source and PD sensors.

2.2 TM type UHF sensor

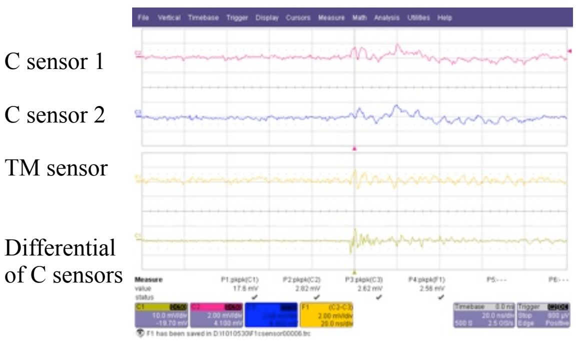
Conventional PD sensor applied on CRT for PD location is the capacitive type of sensor[2]. Hence, the distance between sensor and surface of OUT is one of the affection factor of sensitivity. The longer the distance is, the poorer the sensitivity is. In order to get sufficient sensitivity for the PD 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 5 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

Fig. 4 Comparison of PD sensors

2.3 Discussion

As the conventional application of PD location has much non-convenience and impractical, the proposed pulse waveform identification method combines the benefit of PD pulse polarity and time flying. Moreover, the conventional capacitive type of PD sensor is replaced by TM type of UHF PD sensor, and the improved sensitivity lower the risk of electric shock because of sufficient safety space.

III. Field examination

As mentioned above, if on-line PDM could detect the PD at the early stage of insulation deterioration, the the tiny damage area should be figured out for further investigation. One CRT was classified as PD inside the winding, and PD location was carried out.

3.1 Routine on-line PDM

On march 17, 2012, one CRT was confirmed to have PD inside winding in a periodic on-line PDM, and the phase-resolved pattern are shown in Fig. 6. 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.

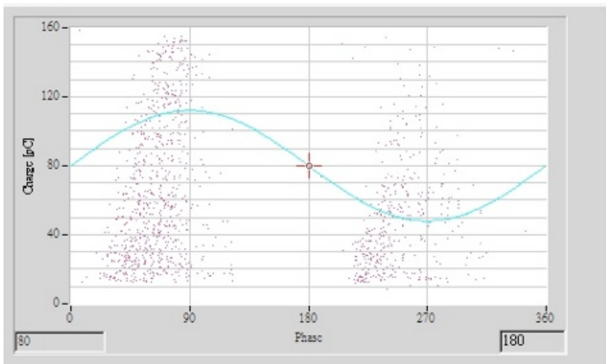


Fig. 5 Phase resolved pattern measured by UHF PD sensor

3.2 PD location

In order to inspect the reason making PD growth so quickly, a PD location was carried out at the laboratory in the manufactory. In the case of preventing saturation of the CRT, the frequency of applied voltage was 400 Hz. The test voltage was raised to 1.7 p.u. for 30 seconds and then lowered to 1.3 p.u. for PD location. The purpose of overvoltage is to result in stronger PDs. Two TM type of UHF PD sensors and one oscilloscope “WaveRunner 64Xi” were used to locate the PD source as shown in Fig. 6.

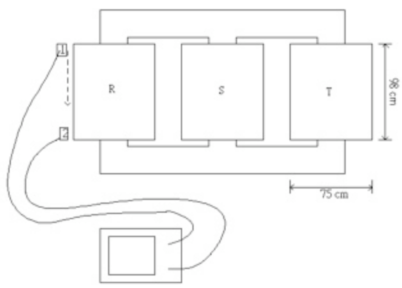
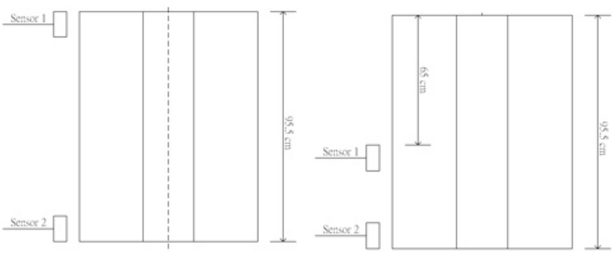
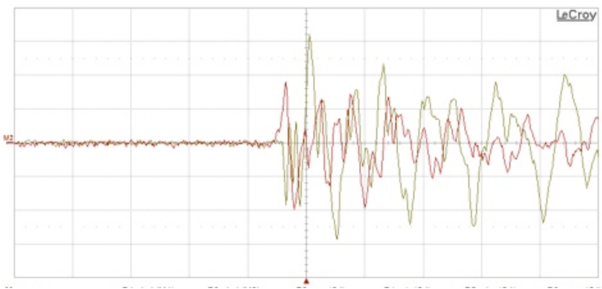


Fig. 6 Arrangement of PD location

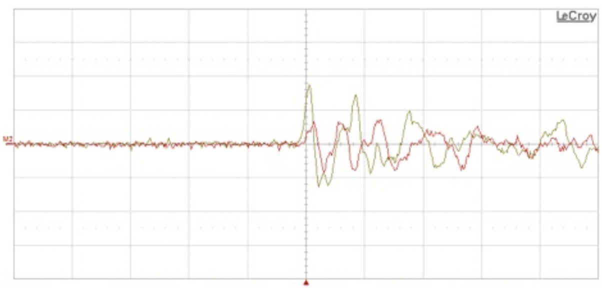
The height of PD sensor 2 was fixed at the botten of the high voltage winding, and the PD sensor 1 was moved from the top of the high voltage winding toward the PD sensor 2. At beginning, the waveforms measured by the PD sensors were different PD pulse polarities, which implies that the PD source was between PD sensores, as shown in Fig. 7(a)(c). When the height of PD sensor 1 was lower than the PD source, 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, as shown in Fig. 7(b)(d). Then the PD sensor 1 was moved up and down to search the boundary of the change in PD pulse polarities, and vertical position of PD source was located. The vertical position of PD source is 65 cm below the top of the high voltage winding.



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



(c) measured waveforms of (a)

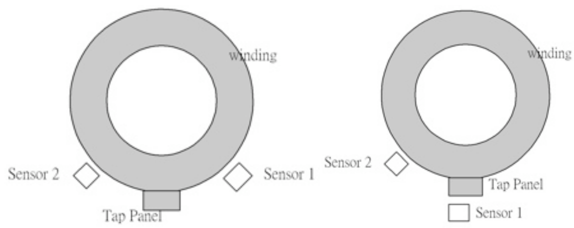


(d) measured waveforms of (b)

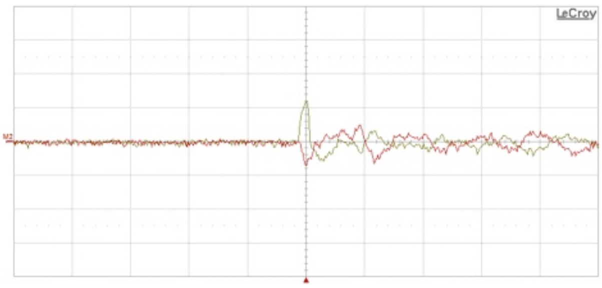
Fig. 7 Vertical position of PD location

Because the vertical position of PD source was located, the height of the PD sensors were put at 65 cm below the top of the high voltage winding. Then the transverse position of PD source could be taken.

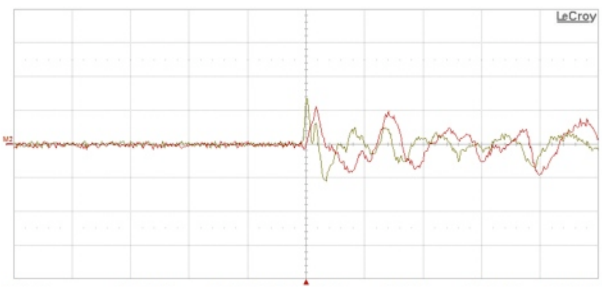
The PD sensor 2 was fixed at the left side of the high voltage winding, and the PD sensor 1 was moved from the right side of the high voltage winding toward the PD sensor 2, as shown in Fig. 8. At beginning, the waveforms measured by the PD sensors were different pd pulse polarities, which implies that the PD source was between PD sensores, as shown in Fig. 8(a)(c). When the position of PD sensor 1 was at left side of the PD source, 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, as shown in Fig. 8(b)(d). Then the PD sensor 1 was moved right and left to search the boundary of the change in PD pulse polarities, and transverse position of PD source was located. The transverse position of PD source is 3 cm right the center of the high voltage winding.



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



(c) measured waveforms of (a)



(d) measured waveforms of (b)

Fig. 8 Transverse position of PD location

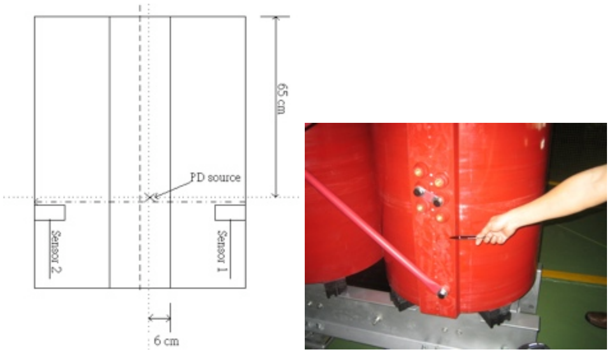


Fig. 9 PD location result

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. 9.

There is something interesting that the vertical position of PD source would be at 53 cm below the top of the high voltage winding as applying time flying method on Fig. 7(c). The difference between PD waveform identification and time flying method is caused by the multi-path of PD propagation.

3.3 Dissection

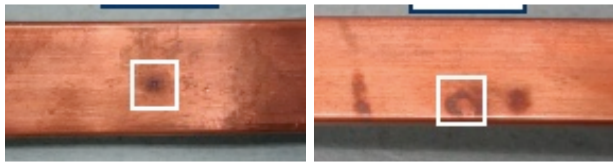
After the PD source was located, the high voltage winding was dissected as shown in Fig. 10. Figure 10(b) showed the defect located by the PD waveform identification, and it is easily to classified as incision made by dissected without PD location.

(a) Dissection (b) Defect on conductor

Fig. 10 Inspection of CRT

IV. Root cause analysis

The copper wire with defect shown in Fig. 10(b) was cut to be analyzed, and a new copper wire with similar black spots is also cut for contrast as shown in Fig. 11. The analysis of these copper wires are analyzed by SEM for surface of copper wire and by EDS for the contents of contaminations.

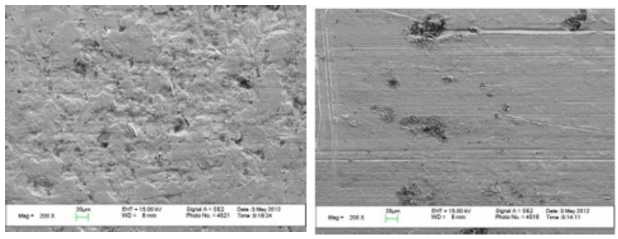


(a) Defect (b) new conductor

Fig. 11 Samples for analysis

4.1 SEM analysis

Figure 12(a) shows the 200 times of the area marked in fig. 11(a), and it shows that the surface is very rough. Figure 12(b) shows the 200 times of the black spot marked in Fig. 11(b), and the surface is smooth except some contamination on it.



(a) Zoom-in of Fig. 11(a) (b) Zoom-in of Fig. 11(b)

Fig. 12 200 times zoom-in of Fig. 11

There would be racrystallization of metal complying with the high temperature by PD, but there is no such phenomena in Fig. 12(a). Therefore, it is hard to say that the rough surface is exactly caused by PD. However, comparing with Fig. 17 and Fig. 18, Fig. 16 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.

4.2 EDS analysis

In order to understand what mechanism initiate the PD, the defect area shown in Fig. 12(a) and the contamination area shown in Fig. 12(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. 10(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. %)	50.00	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 byproduct of oxidization. As tracing the production process of the copper wire, the contaminations are the oil stain deposit, and the removing method is bured 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.

V. Conclusion

In order to improve the disadvantage of conventional PD pulse polarity method and conventional time flying method, the PD waveform identification is proposed. The PD waveform identification combine the PD pulse polarity and time flying method, and the PD location is also accurate.

As the example of the CRT mentioned herein, the on-line PDM could find the defect in the early stage of insulation deterioration. The located defect area was very tiny, and looks like incision produced by the poor workmanship during dissection. According to the PD location, the defect area could be located accurately and the following analysis of PD initiating mechanism could be carried out.

The oil stain deposit is general treated as insulation material, but it still has the chance to alternate the distribution of electric field. Then the PD could be initiated to age the insulation material. The proper degreasing process should be taken to remove the oil stain deposit clearly rather than burn it only.

VI. Reference

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