PD Measurement On High Voltage Equipment by using the UHF Technology

Min-Yen Chiu[1], Chang-Hsing Lee[1], Yu-Chih Lin[2], Shih-Song Yen[3]
[1]Power Diagnostic Service Co.,Ltd
[2]National Synchrotron Radiation Research Center
[3]Industrial Technology Research Institute, Hsinchu, Taiwan
javis@pdservice.com

Abstract

Complying with the technology progressing, on-line partial discharge measurement becomes workable. Up to now, the sensor used in partial discharge measurement needs to be drawn near the high voltage terminal. This paper utilizes electromagnetic coupling to measure partial discharge signal without closing to high voltage terminal.

The difficulty of measurement with electromagnetic coupling is the selection of bandwidth and the identification of defects. This paper proposes the comparison between UHF and other sensor to setup the ability of partial discharge measurement with electromagnetic coupling. In the end of this paper, the field test is also made to confirm.

Keywords: Partial Discharge, Electromagnetic Wave, Corona, External Discharge, Internal Discharge.

1. Introduction

When high voltage equipment breakdown occur, most of the reasons are insulation Deterioration of its insulating materials. However the reason that causes the high voltage equipment deterioration particularly on contaminated insulators during the aging. The process of aging is cause by electric stress and thermal stress and mechanical stress. The whole process will speed up by the PD. It will cause shorter the life of the high voltage equipment. This process of aging can cause PD, there are some other main reasons can also cause PD, such as voids and cracks. The first one is during the making of high voltage insulators sometime it will blend with some foreign impurity. The second one is impact during the transporting process.

Since PD occurs in high voltage material is the main cause to speed up the deterioration. PD has become a necessary part of the testing for the high voltage equipment quality restriction. PD is the only testing which has a standard figure in all the tests which testing is according to IEC. From that you can tell PD is one of the most important tools for manufacturers to quality accreditation. But nowadays PD has not just become the important tool to the manufacturers, it can also insure if there is any exceptionally danger on the high voltage insulating materials during the maintenance.

Conventional diagnostics of insulation condition as DC high voltage withstand and power factor test can only estimate the insulation degree rather than detect defects. The majority of failure is the defects accelerating the insulation aging causing facilities insulation breakdown. Partial discharge measurement (PDM) is the most effective method detecting defects inside insulation system.

The standard PD measuring method accord to IEC60270 in general cannot be applied for on-line PD diagnosis measurements because the test object is energized and the coupling capacitor hence cannot be connected to the high voltage terminals, and the additional cost due to de-energize which is also needed to be considered. Hence, several non-conventional on-line PDM decoupling methods on high voltage system are developed.

When the PD occurs in the high voltage equipment, it will cause the fast pulse current in the nanosecond range and frequency spectra up to several hundreds of MHz. Hence PD events generate transient electromagnetic wave, which are radiated from the high voltage equipment. Therefore, they can decouple by choose correct sensor which does not need to get close to the high voltage equipment.

2. Bandwidth

This paper adopted the electromagnetic coupling method to do on-line PDM. In high voltage system, there are lots of noise sources surrounding, e.g. communication/radio emissions, power electronics, corona, and etc., interfering the on-line PD. Hence, selection of bandwidth for PDM is very important.

Figure 1 shows the spectrum of background noise measured at different substations. It shows that the frequency of background noise can up to 300 MHz, Also from the UHF band between 300MHz – 800MHz show the less noise. Finally the PDM frequency bandwidth between 300 MHz and 800 MHz was selected.

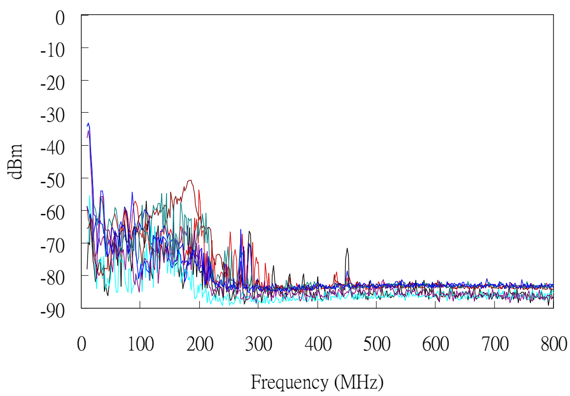
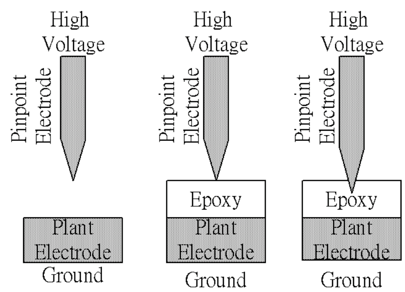


Fig. 1 Common spectrum of background noise

3. Laboratory Test

Three types of specimen were made representing three defects: corona, external PD and internal PD. The electrodes of specimen with corona type were not touched to each other, and there was 1 mm distance between them, as shown in Fig. 2(a). There was an epoxy resin with 10 mm thickness between two electrodes to form the specimen of external PD, as shown in Fig. 2(b). The pinpoint electrode was embedded in the epoxy resin to simulate the protrusion inside insulation media, and the distance between electrodes was 0.5 mm, as shown in Fig. 2(c).

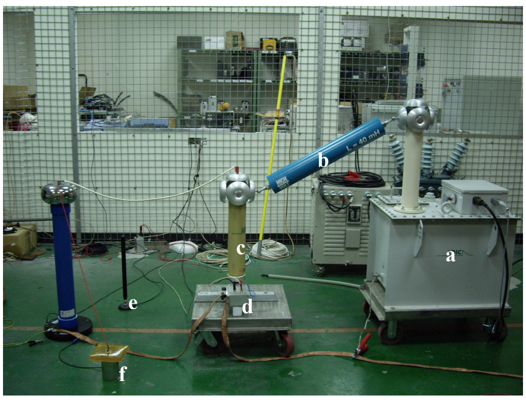
During the test, the specimen of external PD and internal PD were put in the oil to prevent unexpected partial discharge signals surrounding the surface of pinpoint electrode. The applied voltage is gradually increased till the partial discharge occurring, and the properties of PDs were recorded.



(a) corona (b) external PD (c) internal PD

Fig. 2 Specimen with artificial defects

In order to understand the difference between standard method (IEC 60270) and UHF method, an experiment was set up for the comparison between coupling capacitor and UHF method, as shown in figure 3. The test arrangement was according to IEC 60270, which consists of a partial discharge free voltage source, a conventional coupling capacitor, and a block impedance. The wide band sensor with 300MHz to 1.9GHz bandwidth is adopted as UHF sensor. The phase-resolved pattern was recorded by LDIC LDS-6 and Lecory oscilloscope, and the spectrum was measured by HP E4402B.



(a) High voltage supply (b) Block impedance (c) Coupling capacitor (d) coupling device (e) UHF sensor (f) test object

Fig. 3 Test arrangement

4. PD classification and spectrum

a) Corona Discharge

Corona is a form of PD that occurs in ambient air and ignites at electrodes of low curvature radius, sharp edges and protrusions. Corona not only appears in high voltage electrodes, will also appear on the grounded electrode.

•The properties of corona discharge were cloudy-like pattern, which located at the peak of reference voltage, as show in Fig. 4.

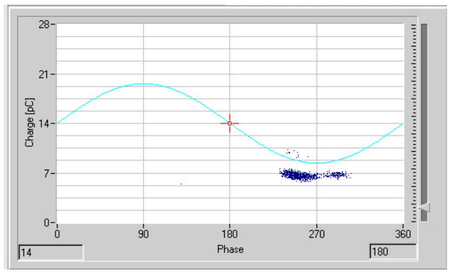
• When the voltage increases from 10kV to 15kV, the pulses magnitude remain, but the repetition rate increases. The area of partial discharge is from 200º -300º change to 230º-320º, as show in Fig. 4.

• When increase higher voltage, the pulses of higher magnitude will also be positive.

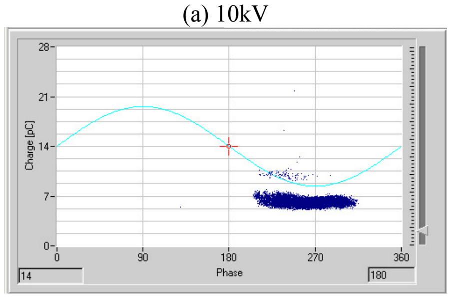
•The lower frequency components between 160MHz~240MHz in VHF bandwidth, as show in. 5.

•Figure 6 shows the comparison between coupling capacitor and UHF method. Although the testing in different coupling methods and different frequency, but the result will be still the same.

• When the electrodes close to the grounded, the range of pulses magnitude become higher, otherwise lower.



(a) 10kV



(b) 15kV

Fig. 4 Corona discharge Phase-resolved pattern

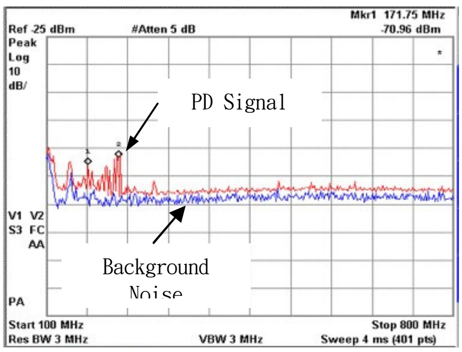


Fig. 5 Corona discharge spectrum

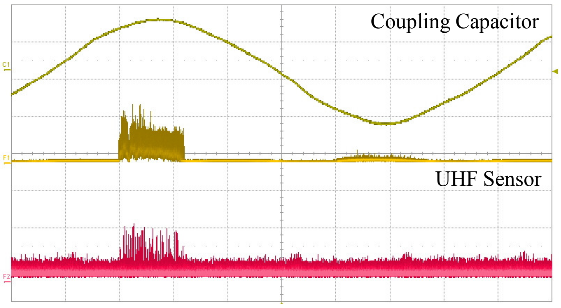


Fig. 6 Comparison between coupling capacitor and UHF sensor

b) External Discharge

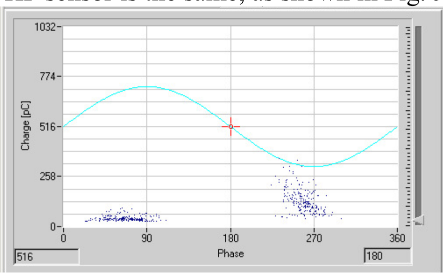
The external discharge activities usually result in un-uniform gradient of electric field relating to humidity and shape. The dangerous of these partial discharges is usually low degree.

•External discharges appear simultaneously in both half cycles, the area of partial discharge is between zero and voltage peak, and disappear immediately after voltage peak.

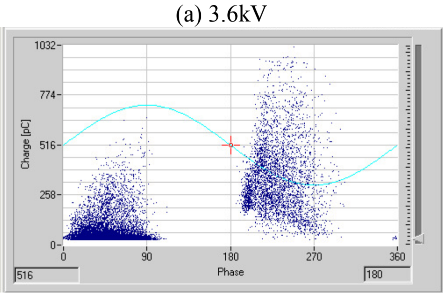
•Increase of pulse magnitude with voltage increase, as shown in Fig. 7 from 260pC of 3.6kV increasing to 1000pC of 6kV.

•The frequency components up to 480MHz , and higher frequency components between 640MHz-670MHz, as show in Fig. 8.

•The result of comparison between coupling capacitor and UHF sensor is the same, as shown in Fig. 9.



(a) 3.6kV



(b) 6kV

Fig 7. External discharge Phase-resolved pattern

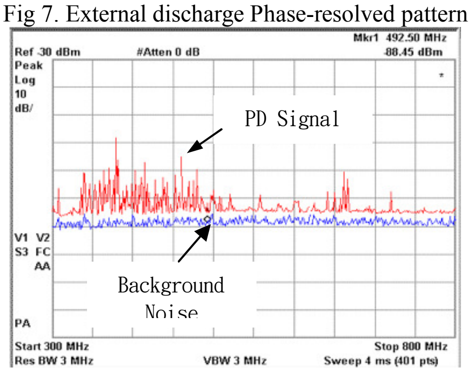


Fig. 8 External discharge spectrum

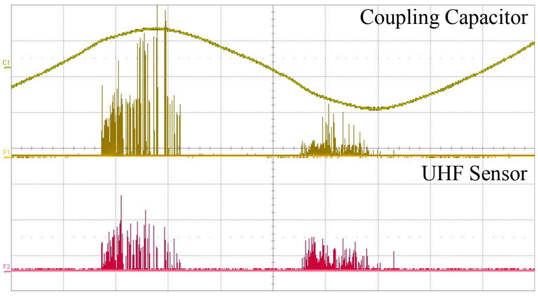


Fig. 9 Comparison between coupling capacitor and UHF sensor

c) Internal Discharge

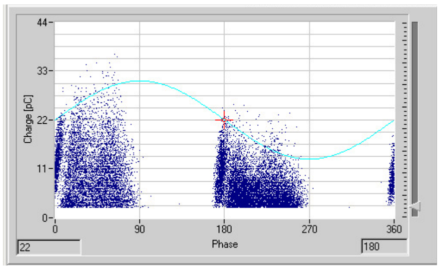
The internal discharge caused by foreign inclusions in solid and liquid dielectrics or combinations of them.

•Internal discharge appear simultaneously in both half cycles, the area of partial discharge is between zero and voltage peak, and around the zero crossing.

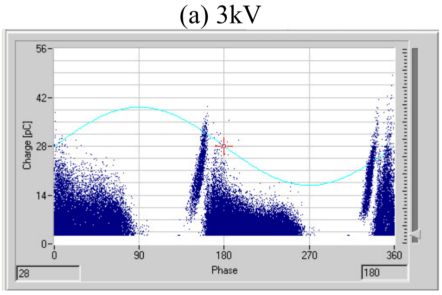
•No increase of pulse magnitude with voltage increase, because discharge channel cannot extend as it is limited by the geometric dimensions of the void, as shown in Fig. 10 from 35pC of 3kV to 38pC of 6kV, but the repetition rate increases. The area of partial discharge is from 353º-89º and 168º~267º of 3kV increase to 322º~95º and 134º~274º.

•Figure 11 shows the main frequency band between 300MHz-600MHz and 650MHz-750MHz.

•The result of comparison between coupling capacitor and UHF sensor is the same, as shown in Fig. 12.



(a) 3kV



(b) 6kV

Fig 10. Internal discharge Phase-resolved pattern

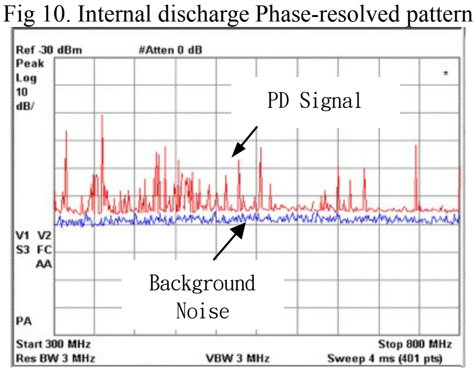


Fig 11. Internal discharge spectrum

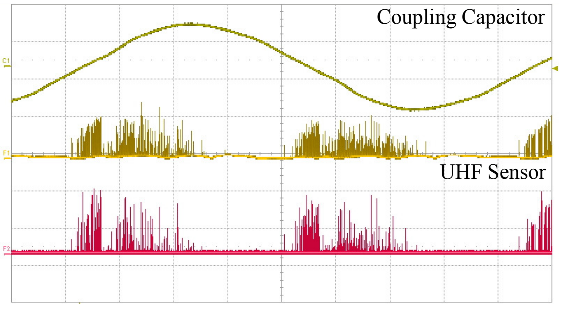


Fig 12. Comparison between coupling capacitor and UHF sensor

5. On-site Cases

The differences between on-site and in the laboratory PDM are background noise, and measurement uncertainty in test object. The measured partial discharge area is not similar to the typical areas, 0º-90º and 180º-270º, due to take the outlet voltage as reference voltage. Therefore, The difficulty of on-site identification of PD is increasing.

Figure 13 shows the UHF sensor places in Epoxy resin transformer metal enclosure for on-site PDM, which is not necessary close to the high voltage equipment. Meanwhile, the capacitive and inductive sensor can be used for comparing the result of PD with UHF sensor.

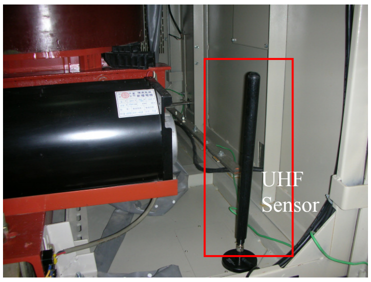


Fig 13. on-line/site PDM by UHF sensor

a) Case 1: 3000kVA epoxy resin transformer
Measurement phase-resolved pattern results of case 1 transformer were shown in Fig. 14 and 15, which is using by UHF sensor and capacitive sensor. The PDs spectrum is between 200-450MHz, and it is clear to see that there is more background noise under 150MHz from Fig. 16.
Comparing the results of phase-resolved pattern with UHF sensor and capacitive sensor, the sensitivity of UHF sensor is much better than the capacitive sensor, but the UHF sensor cannot locate the PD source. However the capacitive sensor can apply for PD location.
Then placing the transformer to a new one after on -line PDM and bring the original one back to the manufacturer for rechecking and dissecting this transformer, and there is carbonization inside it as shown Fig. 17.

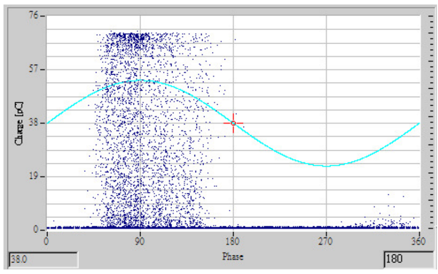


Fig. 14 PDs pattern by UHF Sensor of Case 1

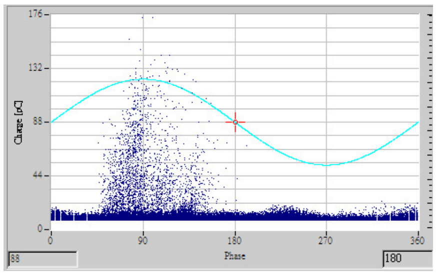


Fig. 15 PDs pattern by capacitive sensor of Case 1

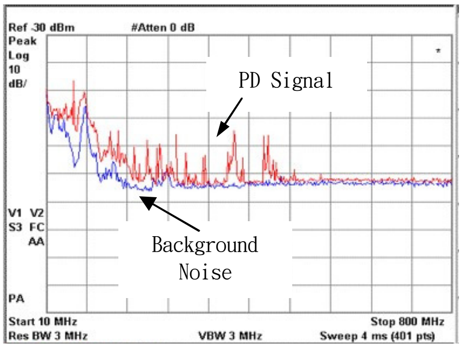


Fig 16. PDs spectrum of Case 1

Fig 17. The PD location of the dissection transformer in Case 1

b) Case 2: 1500kVA epoxy resin transformer
The sensitivity of UHF sensor is still much better than capacitive sensor, and its pattern is also much more obvious than the capacitive sensor.
Measurement results were shown in Figures 18, 19.
Normally the frequency band above 300MHz has less noise. However in this case the noise frequency is between 350-430MHz and 660-720MHz (Fig. 20). all these noise does not affect the results, it can still identify the difference between the PD and the noise.
The area of partial discharge is about over 120º, and repetition rate is a little bit higher. Thus suggest the customer replaces this transformer immediately. After retesting in the manufacturer, it is confirmed that there is a PD issue in this transformer.

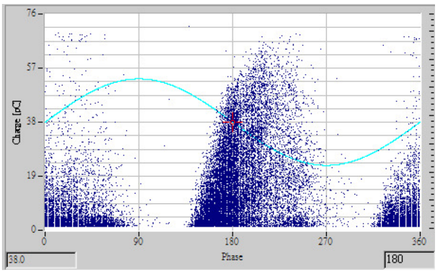


Fig. 18 PDs pattern by UHF Sensor of Case 2

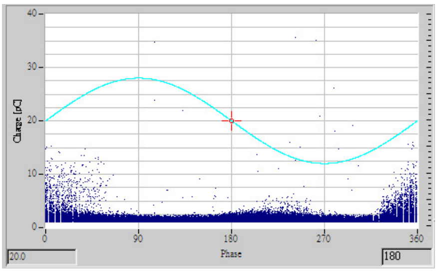


Fig. 19 PDs pattern by capacitive sensor of Case 2

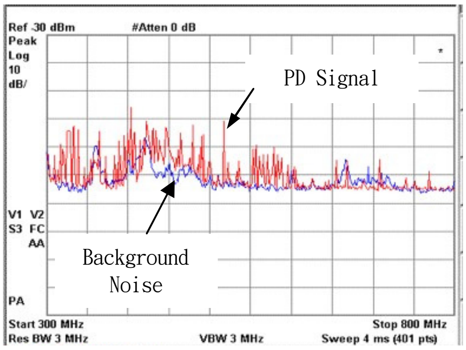


Fig 20. PDs spectrum of Case 2

c) Case 3: 1500kVA epoxy resin transformer
There are 2 phases PD activities in this case testing by UHF Sensor (Fig. 21). Also confirmed the PD location by capacitive sensor. The PD signals are founded on phase A and C, the result as shown in Fig. 22, 23.
In this case the noise frequency is at 500-600MHz, but the PD signal is more obviously at 300~500MHz, and all these noise does not affect the results.
This transformer has PD activities in 2 phases and it has been confirmed that there is PD issue on phase A and C by retesting in the manufacturer.

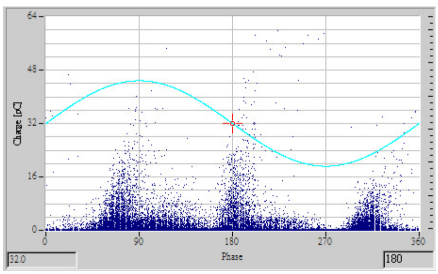


Fig. 21 PDs pattern by UHF Sensor of Case 3

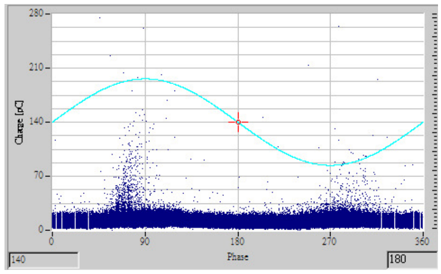


Fig. 22 PDs pattern by capacitive sensor in phase A of Case 3

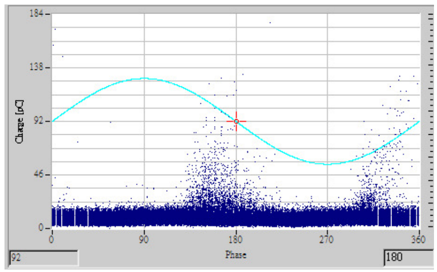


Fig. 23 PDs pattern by capacitive sensor in phase C of Case 3

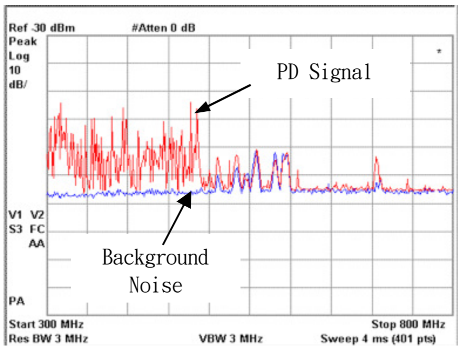


Fig 24. PDs spectrum of Case 3

6. Conclusion

According to the results above all, using the UHF technology for PDM between 300MHz and 800 MHz can avoid the noise form the system and low-risk corona.

Verified the Laboratory test, although the testing in different coupling methods and different frequency, but the result will be still the same, which means that PDM testing by UHF technology is effective.

The UHF sensor is not only easy to install but also the cost is low, which is suitable for on-line PD monitoring.

7. Reference

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