# Partial Discharge Detection in High Voltage Equipment Using High Frequency Current Transducer

Cattareeya Suwanasri, Pongsakorn Thawonsukanan, Sayan Ruankon, and Thanapong Suwanasri

***Abstract***— *This paper presents a development of the high frequency current transducer (HFCT) for off-line partial discharge detection. The NiZn ferrite core and the 37 turns of 24 SWG copper winding were used for the designed HFCT. Different objects such as basic objects and insulator were tested for internal discharge, surface discharge, air corona at the high voltage side, and air corona at the earth side in order to investigate the performance of the developed HFCT. The commercial tool according to IEC60270 partial discharge detection was used to detect the partial discharge signals as reference and compare with the signals from the developed HFCT. The results show that this HFCT can effectively detect the partial discharges in the frequency range between 100 kHz to 14 MHz.*

***Keywords***— **About four key words or phrases in alphabetical order, separated by commas.**

## 1. INTRODUCTION

Reliability and stability of electric power system are of prime concern. The high voltage equipment such as power transformer, generator, and surge arrester should be correctly operated. The performance of high voltage equipment steadily decreases with the age, usage, maintainance and operating environment. Especially at the insulation either solid as cross link polyethylene (XLPE), liquid as oil, or gas as air or $SF_6$, the insulation condition needs to be assessed and maintained to aviod any failures. Thus, the inspection and maintenance for the high voltage equipment must be properly performed in order to early detect the problems. Partial discharge (PD) is a major problem occuring in such high voltage equipment. It is localized electrical discharge resulting from ionization in a poor insulation system when the system voltage exceeds the inception voltage of impurity or air void inside the insulation. Partial discharge consists of internal discharge, surface discharge, and air corona. The presence of partial discharge in equipment leads to gradual deterioration of the electrical insulation. Consequently, internal faults or the total destruction of the equipment can be occurred. This results in insulation breakdown and subsequently the failure of the equipment. Therefore, it is necessary to detect the partial discharge, analyze discahարge pattern and violence of the partial discharge. As a result, the equipment in electrical network can be protected in time. However, it is diffucult to detect the partial discharge of insulation in the equipment because it always happens inside the equipment. Thus, the tools for partial discharge detection is required. In this paper, the partial discharge detector so called High Frequency Current Transducer (HFCT) is proposed to detect the internal and surface partial discharge as well as air corona. The test objects are developed for each test condition.

## 2. BASIC THEORY

### 2.1 Type of partial discharge

Partial discharge consists of internal discharge, surface discharge, and air corona [1]. Internal discharges occur at dielectric with a number of cavities of various sizes inserted between two carbon or matal electrodes as presented in Fig. 1. The discharge occurs when the supply voltage is higher than the inception voltage of cavities. Surface discharge takes place externally along the insulation surface between two metal or carbon eletrodes as shown in Fig. 2. External corona discharge occurring at a sharp metal point or edge is shown in Fig. 3. If the discharges occur on the negative half cycle of the sinusoidal test waveform, the location of sharp edge is at high voltage side. On the other hand, if the discharges occur on the positive half cycle of the sinusoidal test waveform, the location of sharp edge is at the earth potential.

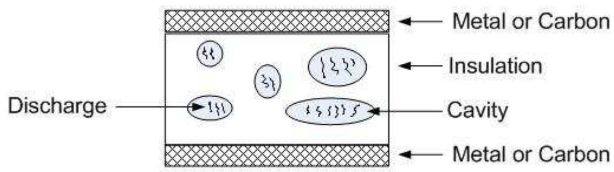


**Fig.1. Internal Partial Discharge**

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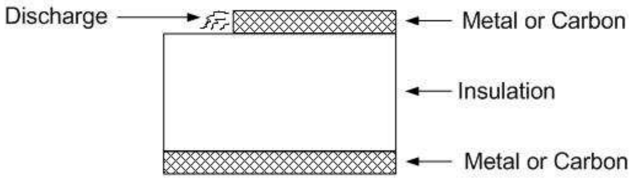



**Fig.2. Surface Discharge**

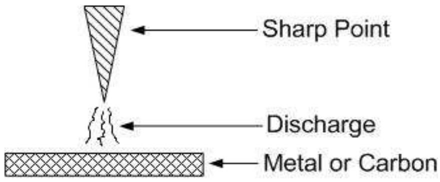



**Fig.3. External Corona Discharge**

## 2.2 Partial discharge detection

Partial discharge detection can be classified into two types that are on-line monitoring and off-line monitoring. The on-line testing techniques are such as ultrasonic PD detection, acoustic sensor and HFCT while the off-line testing techniques are as high potential testing, IEC60270 conventional PD detector, power factor/dissipation factor testing, very low frequency testing (VLF) [2]. Those PD detecting tools help to detect the abnormal condition at the beginnings of either small partial discharge, mechanic problems, arcing, surface contact of OLTC (On Load Tap Changer), or a loosen part inside transformer. Moreover, these tools can identify the problem's causes and severity. Then the maintenance can be properly acted. Partial discharge detection tecnique according to IEC 60270 standard [3], known as conventional method, is widely accepted with the highest accuracy. This technique can describe the phenomena of internal discharge, surface discharge, and air corona. The testing circuit is represented in Fig. 4. The circuit comprises coupling capacitor ($C_k$), filter (Z), input impedance of measuring system ($Z_{mi}$), connecting cable, coupling device, measuring instrument and test object ($C_a$).

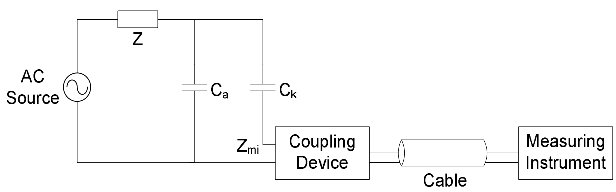
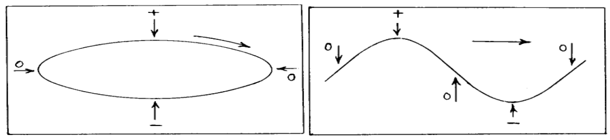



**Fig.4. Basic IEC 60270 Discharge Detection Circuit**

The discharge patterns are shown in the compendium as formalized diagram [1], in which the responses from individual discharges are supperposed on an elliptical time base that represents the sinusoidal test voltage. The positions of the voltage peaks and zeros and the rotation of the time base are indicated in Fig. 5 (a) and (b).



(a) Elliptical time base (b) Sinewave time base

**Fig.5. Display of Discharge Patterns**

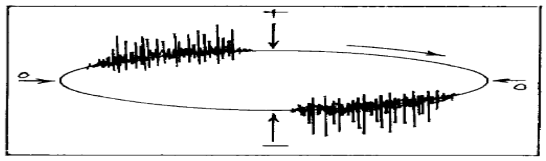


**Fig.6. Internal Discharge Patterns**

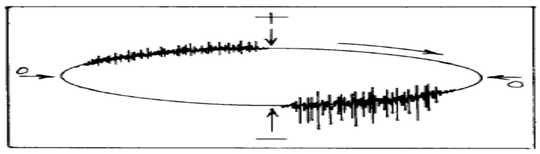


**Fig.7. Surface Discharge Patterns**

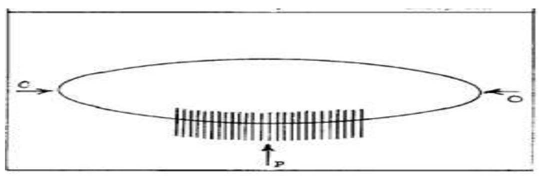


**Fig.8. Corona Discharge Patterns**

The discharge detection circuit in Fig. 4 can accurately detect incomplete discharge. The discharge results in form of elliptical time base of internal discharge, surface discharge, and air corona are given in Fig. 6-8.

For internal discharge in Fig. 6, the discharges occur approximately the same amplitudes on both half cycles. Number and location occur in advance of the voltage peaks. The number of discharges increases with the test voltage.

For surface discharge in Fig. 7, the discharges occur in advance of the test voltage peaks but the discharges on one half cycle of the test voltage waveform are greater in number but smaller in magnitude than on the other half cycle. There are degrees of random of variation in both amplitude and location. The number of discharges increases with the test voltage.

For corona discharge in Fig. 8, the discharges occur initially on one half cycle of the test waveform only. They are symmetrically disposed about the voltage peak. The equal magnitude and equally spaced in time can be observed from both cases. As the test voltage is raised the number of discharges increases rapidly and they spread out but are roughly symmetrical magnitudes about the peak.

However, the partial discharge detector in the market according the standard IEC 60270 is expensive. In this paper, then the High Frequency Current Transducer (HFCT) was developed. It is widely used in on-line partial discharge detection with discharge activity measurement in pC or nC.

## 3. DESIGN AND CONSTRUCTION OF HFCT

HFCT is one type of PD detector, which eliminates the low frequencies and passes the mid and high frequencies according to their frequency response characteristics [4-5]. The basic circuit of HFCT shown in Fig. 9 is used to detect partial discharge, as a fraction of its primary current ($i$) of HFCT, in form of output voltage across the resistor.

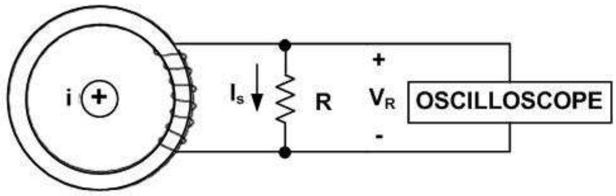



**Fig.9. Basic Discharge Detection by HFCT**

Where $I_s$ is secondary current of HFCT, $i$ is primary current of HFCT, $R$ is resistive burden, $V_R$ is output voltage of HFCT. The specification is given in Table 1.

**Table 1. Specifications of HFCT**

| Parameter | Specification |
|---|---|
| Testing source | AC, 50 Hz |
| Core type, Core material | Toriod, NiZn |
| Winding | 37 turns of 24 SWG Copper |
| Burden | Resistance 75Ω |

**Fig.10. Developed HFCT**

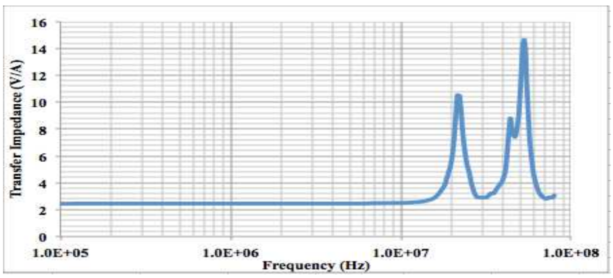



**Fig.11. Transfer Impedance Versus Frequency**

The designed HFCT is presented in Fig. 10. The response frequency is tested and presented in Fig. 11. This HFCT can effectively detect the PD in the frequency range between 100 kHz to 14 MHz.

## 4. EXPERIMENT SETUP AND RESULTS

### 4.1 PD testing circuit

The PD testing circuit is given in Fig. 12-13. It consists of AC power supply, conventional PD detector using the IEC 60270 standard (ICMsystem), PD detection using HFCT, voltage divider and test object. The results of PD detection by ICMsystem will be used as reference to verify the result from the HFCT. In Fig. 12, the test voltage is observed at CH1 by using voltage divider while the PD signal is observed at CH2 by using HFCT, which is connected at the system ground conductor.

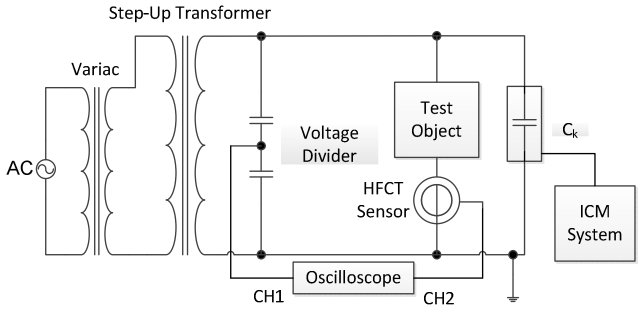



**Fig.12. Experimental Setup**


**Fig.13. Internal Discharges Detected by ICMsystem**

### 4.2 PD Testing Objects

Different objects shown in Fig. 14-17 are tested for internal discharge, surface discharge, air corona at the H.V. side, air corona at the earth side respectively in order to investigate the performance of the developed HFCT. The ICMsystem is used to detect the PD signals as reference and compare with the signals from the developed HFCT. The coupling capacitor ($C_k$) is connected to test object for signal proceeding to ICMsystem data acquisition and signal conditioning modules. Finally, a HV insulator is tested as a sample of HV equipment for internal discharge, surface discharge and air corona testing using HFCT.

### 4.3 Experimental Results

#### *4.3.1 PD testing on basic objects*

The voltage from 100 kV test transformer is raised until the PD occurs. The acquisition period is 30 seconds for any test. The test voltage is displayed in sinusoidal waveform. The discharge detected by ICMsystem is displayed in form of dots while by HFCT is displayed in form of voltage spites.

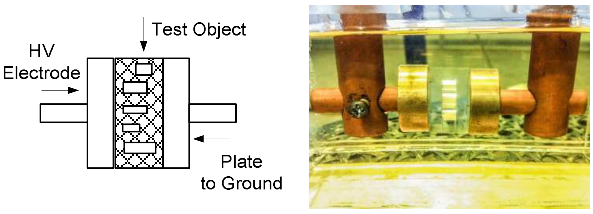



**Fig.14. Internal Discharge in Oil**

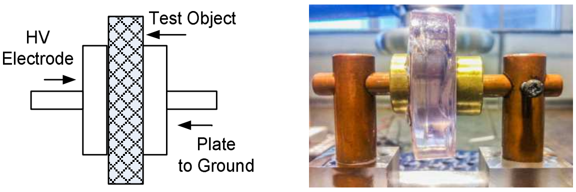



**Fig.15. Surface Discharge**

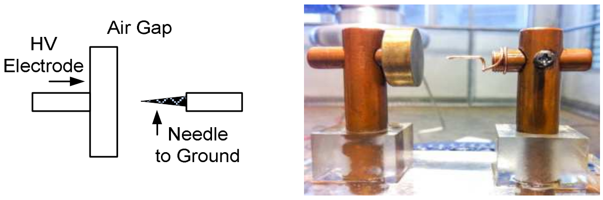



**Fig.16. Air Corona; Needle to Ground**

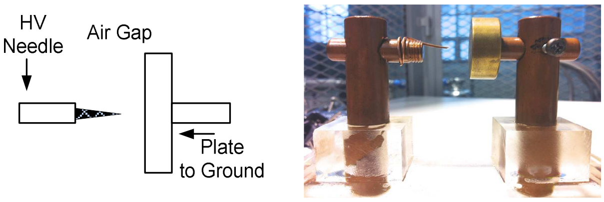
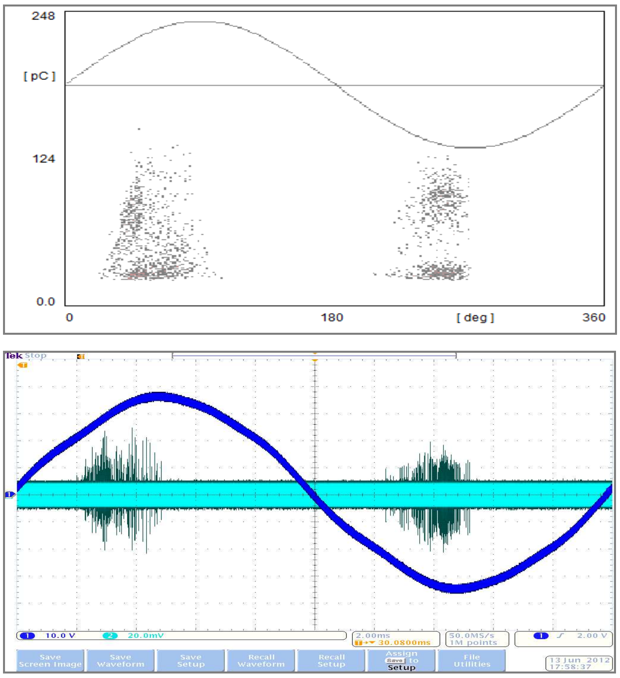



**Fig.17. Air Corona; High Voltage Needle**

For internal discharge in Fig. 18, the discharge occurred when the test voltage was up to 9.2 kV. The discharge amplitudes are nearly similar for both positive and negative cycles. The number and location of discharges from both ICMsystem and HFCT occurred in advance of the voltage peaks that are between 21-100 degree and 206-270 degree, respectively.

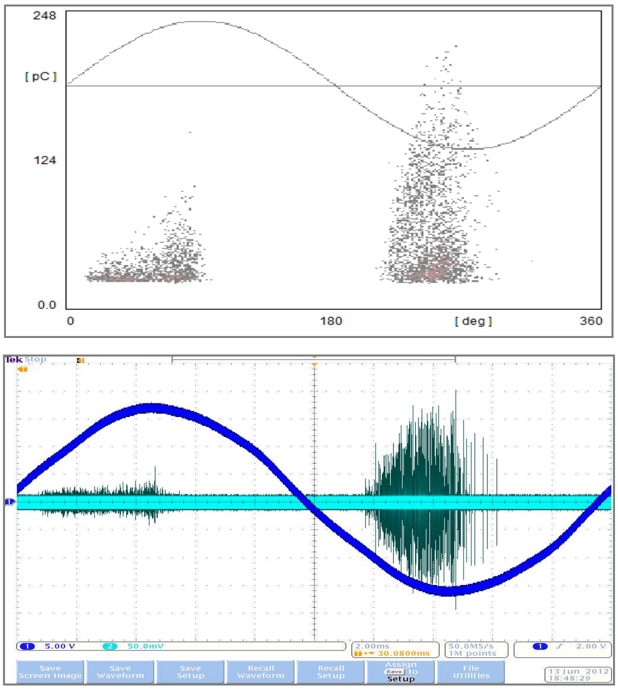
For surface discharge in Fig. 19, the discharge occurred when the test voltage reached 4.3 kV. The discharges occur in advance of the test voltage peaks that are mainly between 10-92 degree and 208-289 degree. But the discharge magnitudes on positive cycle are smaller than that on negative cycle. The negative discharge amplitude is about 2 and 4 times greater than the positive discharge amplitude for ICMsystem and HFCT respectively.

For corona discharges in Fig. 20, the discharges occurred only at half of cycle of the test waveform but they are symmetrical around the voltage peak. The corona discharge at the H.V. side happened when the test voltage was up to 2.3 kV, the discharges occurred between 250-274 degrees. For air corona discharge at the earth side in Fig. 21, the test voltage was up to 2.5 kV the discharges occurred between 60-110 degree.




(a) Detecting by ICMsystem (b) Detecting by HFCT

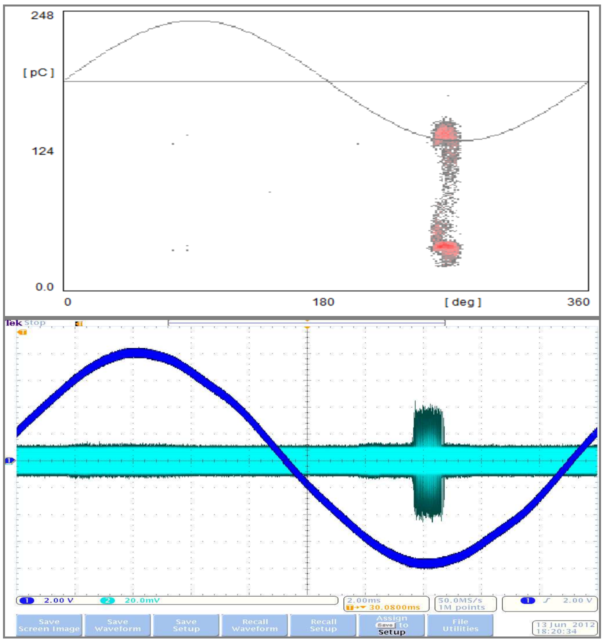
**Fig.18. Internal Discharge Detection**




(a) Detecting by ICMsystem (b) Detecting by HFCT

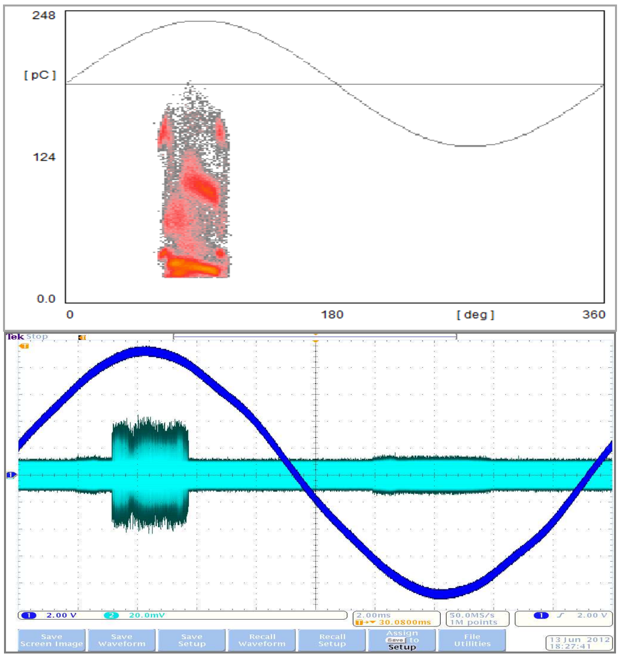
**Fig.19. Surface Discharge Detection**

The results show that the designed HFCT can successfully detect the internal discharge, surface discharge, air corona at H.V. side, and air corona at the earth side in the frequency range between 100 kHz to 14 MHz. The HFCT partial detecting results were confirmed by comparing with the results from a commercial tool according to IEC60270 standard for PD detection.




(a) Detecting by ICMsystem (b) Detecting by HFCT

**Fig.20. Air Corona Detection; Needle to Ground**




(a) Detecting by ICMsystem (b) Detecting by HFCT

**Fig.21. Air corona Detection; High Voltage Needle**

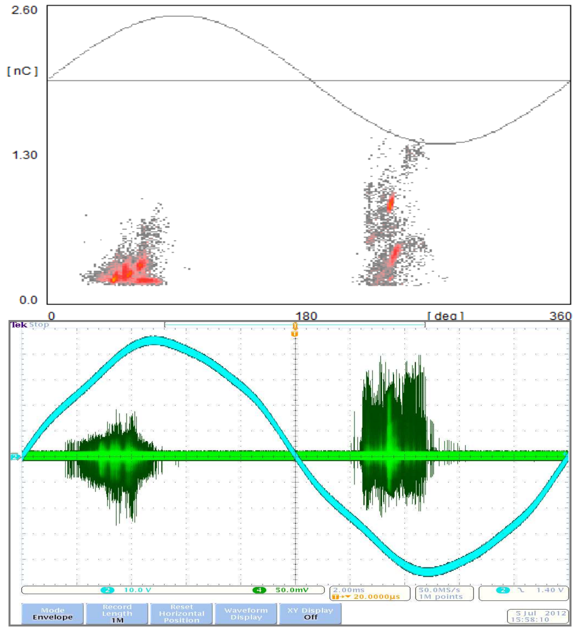
### *4.3.2 PD testing on HV insulator*

The PD testing results show in Fig. 22-24. The designed HFCT can detect the surface discharge on normal insulator, internal discharge in punctured insulator, and air corona at the H.V. side on a humid condition.

In Fig. 22, the discharge on the normal insulator occurred when the test voltage reached 30.11 kV. The discharges occur in advance of the test voltage peaks that are mainly between 23-82 degree and 212-274 degree. But the discharge magnitudes on positive cycle are smaller than that on negative cycle.

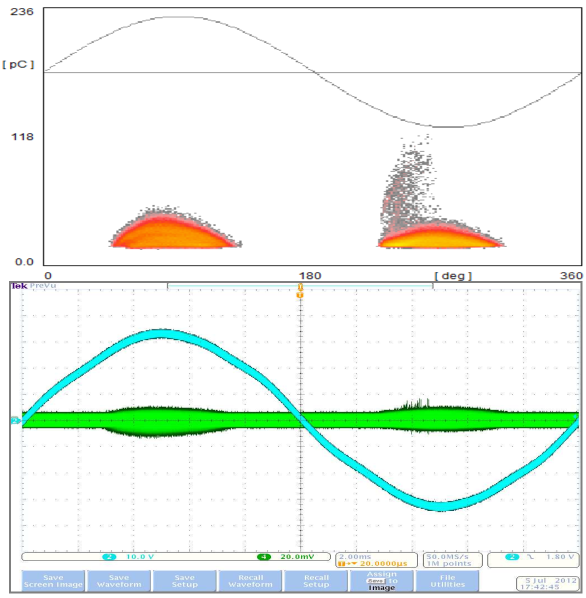
In Fig. 23, the discharge on the puncture insulator occurred when the test voltage was up to 22.11 kV. The most of discharge amplitudes are nearly similar for both positive and negative cycles. The number and location of discharges from both ICMsystem and HFCT occurred in advance of the voltage peaks that are between 21-100 degree and 223-308 degree, respectively.

In Fig. 24, the discharges on humid insulator occurred only at negative half of cycle of the test waveform. The corona discharge at the HV side happened when the test voltage was up to 30.25 kV, the discharges occurred between 251-272 degrees. These results from the HFCT detection were similarly compared and confirmed with the results from a commercial tool according to IEC60270 standard for PD detection.



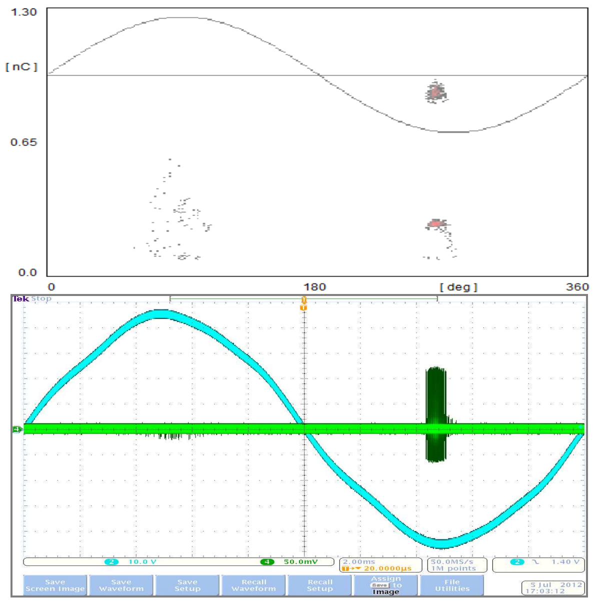

(a) Detecting by ICMsystem (b) Detecting by HFCT

**Fig.22. Surface Discharge on Normal Insulator**




(a) Detecting by ICMsystem (b) Detecting by HFCT

**Fig.23. Internal Discharge in Punctured Insulator**




(a) Detecting by ICMsystem (b) Detecting by HFCT

**Fig.24. Air Corona at the H.V. Side on Humid Insulator**

For all tests, the background noises from the environment were 8 pC and 11 mV, which were measured with IEC60270 and HFCT, respectively.

### *4.3.3 Practical implementation*

HFCT is an effective tool for on-line partial discharge measurement due to it can be performed at site while the equipment is energized in service. Since the HFCT is used as clamp-on device around the ground wire connecting between equipment grounding terminal and system grounding, it can measure almost all types of high voltage equipment such as power transformer, power circuit breaker, instrument transformer etc. Moreover, due to its advantages of easy for installation, less time consuming and no service interruption, this method is now preferred for field measurement to quickly investigate the partial discharge at site. However, the measurement comparison with conventional PD measurement system, background noise reduction and filtering system should be further investigated to obtain the reliable result.

## 5. CONCLUSIONS

In this paper, the HFCT were developed for off-line partial discharge (PD) detection such as internal discharge, surface discharge, air corona at the H.V. side, and air corona at the earth side. The NiZn ferrite core and the 37 turns of 24 SWG copper winding were used in the design and construction. Four different object-types as well as the HV insulator were tested. The results show that the designed HFCT can successfully detect the internal discharge, surface discharge, air corona at the H.V. side, and air corona at the earth side in the frequency range between 100 kHz to 14 MHz. The HFCT partial detecting results were confirmed by comparing with the results from a commercial tool according to IEC60270 standard for PD detection. This HFCT can be further developed for on-line PD detection of the high voltage equipment such as power transformer.

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