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Application of the integrated AE and HFCT sensors for online Dry-type Transformer Partial Discharge Monitoring. Case study

***Abstract**. This study proposes a measurement technique to identify and determine the occurrence of partial discharge in the insulation of Dry-type transformers, as well as their criteria level. Concerning IEC 62478, the four AE (acoustic emission) sensors were used to determine the PD sources and one HFCT (High-Frequency Current Transducer) technique was to identify the PD source and the criteria level. This process accurately identified the PD source location occurring at any position in a transformer. The gap time was 3.2 ms. The level of partial discharge for this case study is Major PD that means soon monitoring every 3 months. The results of this technique could prevent insulation failure of a transformer in time.*

***Streszczenie.** Zaprezentowano technikę wykrywania wyładowań niezupełnych w izolacji suchego transformatora. Zgodnie z IEC 62478 użyto czterech czujników emisji akustycznej AE oraz jednego czujnika prądów wysokiej częstotliwości HFCT. Umożliwia to lokalizację źródła wyładowania. (**Wykorzystanie scalonego czujnika AE I HFCT do online monitoringu wyładowań niezupełnych w suchym transformatorze**)*

Keywords: Partial discharge, High frequency current transducer, Dry-type transformer, Acoustic emission sensor.
Słowa kluczowe:wyładowania niezupełne, izolacja suchego transformatora, czujnik AE, czujnik HFCT.

Introduction

A transformer insulation inspection and partial discharge diagnosis (PD) is an important parameter and technology to reflect the state of theinsulation. Accurate PD signal measurement is the key to bringing online detection systems for transformer insulation [1]. Unusual devices produce nonstop PD pulses and allow physical phenomena such as electromagnetic radiation, noise and light. The main methods for detecting PD using these physical phenomena include ultra-high frequency pulse (UHF), as well as methods for measuring signals and light waves.

However, current pulse methods are at risk of various disturbances. Electromagnetic signals are mainly used for offline quantitative detection in environments with small disturbances. The methods of UHF may have the ability to prevent strong electromagnetic interference [2,3]. But the PD UHF quantitative problems have not been thoroughly resolved. Besides, the ultrasonic method is sensitive to all types of noise and is used primarily for evaluating the quality of operating equipment. Also, the complexity of the internal structure of the transformers requires that most existing PD detection methods rely on external access to capture signals, causing difficulty in locating internal faults (Such as winding insulation defects) precisely.

Therefore, the study of effective methods and equipment for PD detection is important and useful. The analysis of partial discharges using signal and electromagnetic wave detection methods is an effective technique that can detect that the transformer insulation is deteriorated without the need to stop the transformer operation. For decades, transformer users have tried to find ways to assess the insulation condition of transformers and identify possible problems. In the past, diagnostic tests have been greatly developed [4,5], causing some discharging analysis to identify the problem position of partial discharge more precisely.

Periodic offline diagnostic tests has continued to play an important role in the industry. However, "continuous" or "online" investigations are becoming increasingly popular. The offline work for the power system has been reduced for the last method. It can also increase the efficiency and reliability of transformers in power stations. It can reduce maintenance costs and help increase the efficiency of equipment and maintenance procedures, as well as helps manage the increased risk of aging transformers [6].

In this research, we present some methods for detecting and diagnosing discharges in order to identify sensors that detect, identify partial discharging problems, analyze the location of partial discharges, and assessing the risk of the partial discharges.

Therefore, Cast Resin Transformers are widely used in industrial systems such as heavy industries, airports, hospitals, public transportation systems, and high-rise buildings. Although Cast Resin transformers are safer than oil type transformers, the diagnosis of the insulation of Cast Resin transformers is more difficult. The life of Cast Resin transformers depends largely on the insulation conditions be it under the heat, electric field, mechanical force, and the environment that leads to the electric charge transfer in the transformer.

This research proposes a method for measuring partial discharge transfer on Cast Resin transformers, which is based on the IEC 62478 / Ed1 standard. These measurements will be put into actual use for Cast Resin transformers case study [7].

Experimental setup

The experimental setup is shown in Fig.1. Various methods have been explored for measuring PD-based electrical and non-electrical phenomena. The methods that can successfully identify and find PD are detecting signal emission based on the fact that PD appears to be the origin of acoustic waves [8,9]. These acoustic waves spread through the internal structure of high voltage devices until it reaches the external surface. Detection and coarse location of at least one source can be done by moving one or more external sensors to another location on the transformer housing. The accuracy of the position of the PD source may be determined by the relative time of the acoustic signal in each sensor. The electrical signal from PD is in the form of a unipolar pulse, with an increase in time that can be as short as nanoseconds. The increase in pulse at the point of origin depends on the type of discharge. The high frequencies are reduced when the signal propagates through the transformer and the pulse shape is modified due to multiple reflections and the exciting resonant frequency of the transformer components. The acoustic PD signal is compared to the electrical PD signal, which is based on the real PD signal from the transformer. The combined method is the electrical measurement that improves confidence in the results of the PD test. The data storage device used to view the results on a computer is called "PowerPD" (PD-TP500A).

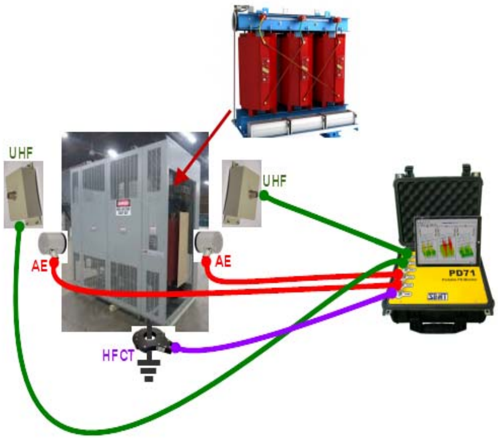


Fig.1. Experimental setup

The four AE sensors were mounted on the house of the transformer and the high frequency current transducer (HFCT) sensor was clamped to the ground wire of the transformer [10,11]. The signals from the four acoustic emission (AE) sensors and the HFCT sensor were measured simultaneously and the readings were stored on the computer. Then the dedicated software was used to analyze the PD pattern, frequency domain, and time domain. Acoustic emission sensor is a passive piezoelectric sensor. Its frequency response is characterized by a peak of 150kHz where it exhibits a resonance. The frequency range is 100 to 450 kHz. HFCT has a split core ferrite to allow retrospective fitting to earth straps without the need for disconnection. The HFCT is constructed with an aluminum body to provide RF shielding and improve performance in noisy environments. The frequency range is 100kHz to 10MHz with transfer function at 4.5-5.0 V/A. During the installation of AE and HFCT sensors, the AE sensor No.1 (Green color) is installed at the top of the HV side of the transformer. The AE sensor No.2 (Red color) is installed next at the bottom of the transformer, determined by the clockwise direction. The AE sensor No.3 (Yellow color) is installed at the LV side of the transformer at the top position approximately opposite to the AE sensor No.1. The AE sensor No.4 (Blue color) is installed approximately opposite to the AE sensor No.2 at the bottom position. The HFCT sensor on the other hand is installed at various positions of the ground connection from the transformer that is to be tested. The PD signal detects that the other AE sensors are moved to the corresponding AE sensor which detects the PD activity and installed in X-Axis and Y-Axis fashion before confirming the exact location of the PD source. If PD bursts were detected from both AE sensors and HFCT sensor, it could be concluded that the PD occurred within the transformer as seem in Fig. 2. The severity criterion of partial discharge is called "Gap time" and the unit is in milliseconds. The gap time is a space between the end of one burst and the beginning of the next burst, called burst interval as seen in Fig. 3. It gets dangerously close to 2 ms, clearly indicating that failure is imminent. Burst interval is a critical information in determining the severity of PD.

Results of Case Study

In this research, the transformer partial discharges were measured with real-life transformers while the transformers were still working. By adopting non-conventional measurement techniques, the technique of locating partial discharging on transformers was performed. In assessing the risks of partial discharges, the case study of the Cast Resin Transformer was 24 kV 800 kVA in/of 2004. This case is the measurement of an 800 kVA 24kV Cast Resin Transformer which is used in high-rise buildings. The transformer has not been maintained for at least 3 years. The techniques that will be used for measurement include the Acoustic Emission Sensor and the High-Frequency Current Transformer. The transformer measurements are as follows.

Signal frequency measurement results using Acoustic Emission Sensor.

In the measurement of transformers, 4 signal sensors (AE1-AE4) will be installed, with 1 installation on each side of the transformer, which is shown in Fig. 4, and Fig. 5, showing the waveforms of each sensor measured with the PowerPD program.

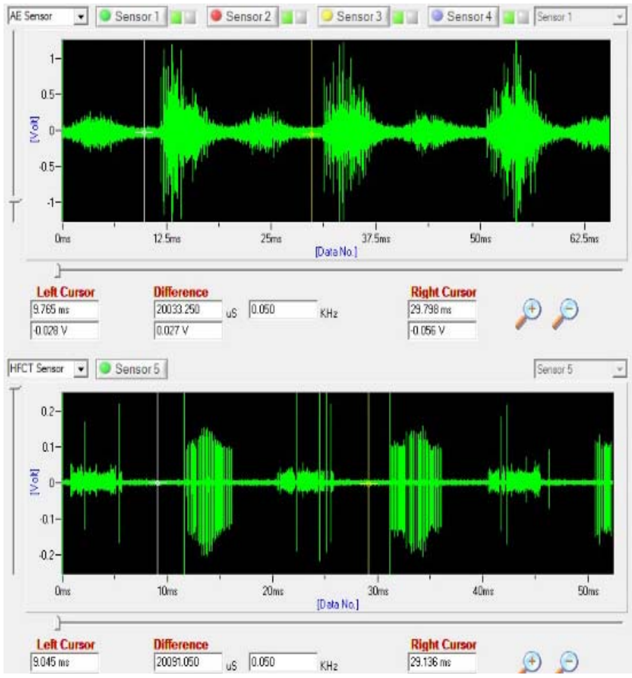
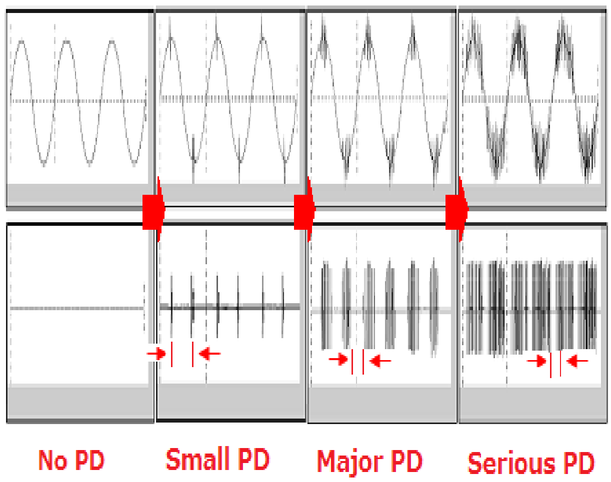


Fig. 2. Partial discharge signal

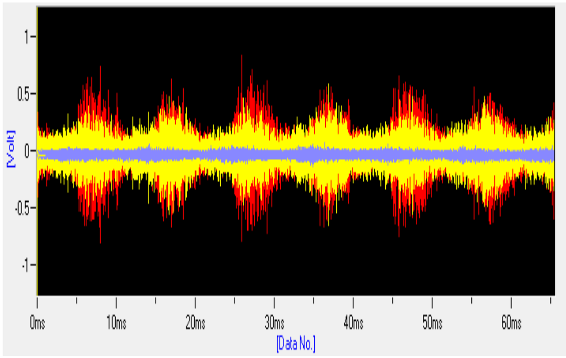


. 3 The severity criteria of partial discharge; Gap time

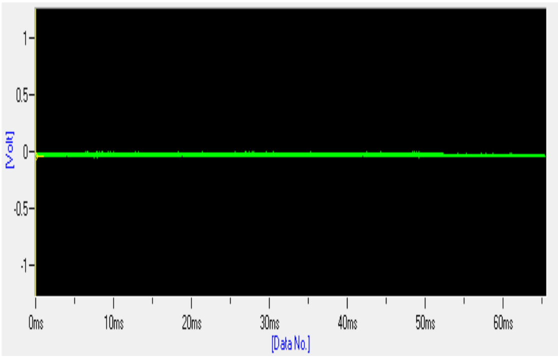
Results of electromagnetic wave frequency measurement results using the HF current sensor

To measure the transformer, 1 HFCT sensor will be installed by installing it on the ground wire of the transformer [12,13]. This will be shown in Fig. 6 and Fig. 7 showing the electromagnetic signal waveform that can be measured with the PowerPD program.

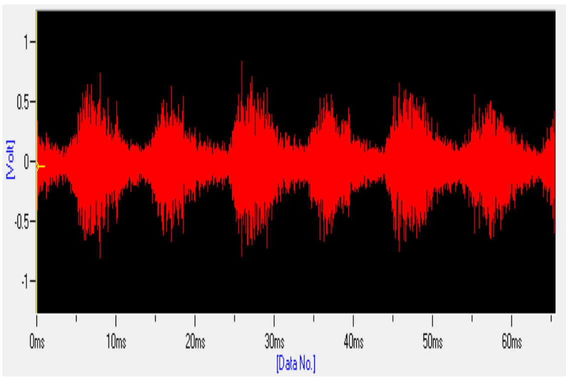
Fig. 4. The location of the signal sensor installation



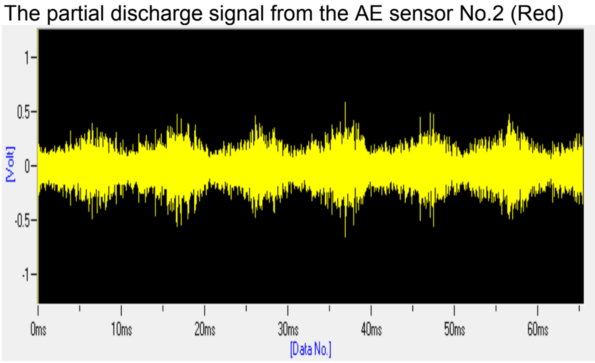
a) The comparison size of 4 signal waveforms,AE1-AE4



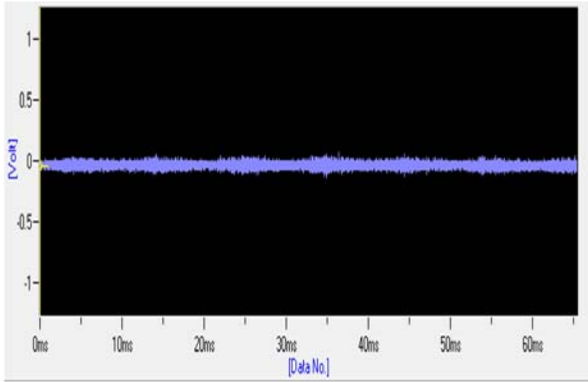
b) The partial discharge signal from the AE sensor No.1 (Green)



c) The partial discharge signal from the AE sensor No.2 (Red)



d) The partial discharge signal from the AE sensor No.4 (Yellow)r)



e) The partial discharge signal from the AE sensor No.4 (Blue)

Fig. 5. The graph of signal frequency waves, which a) compares the size of the signal waves of all 4 sensors, b-e) the signal waveforms obtained from each sensor.

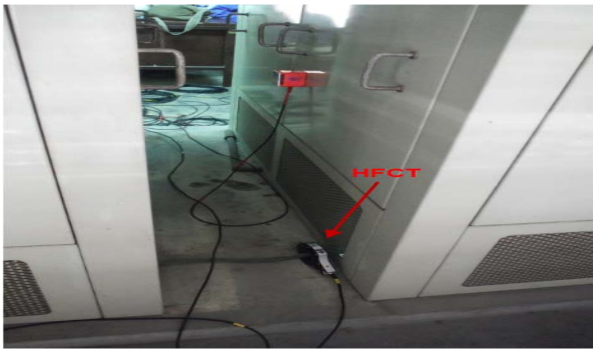


Fig. 6. The location of the installation of the HF current sensor

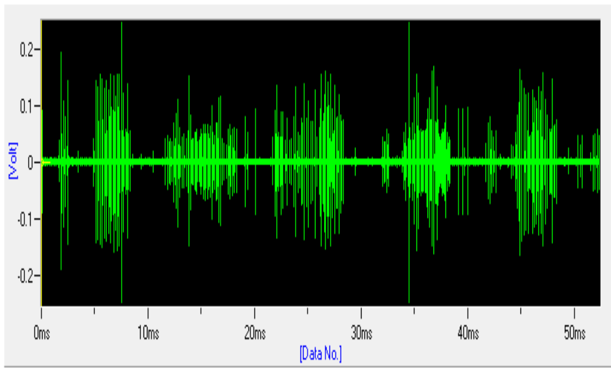
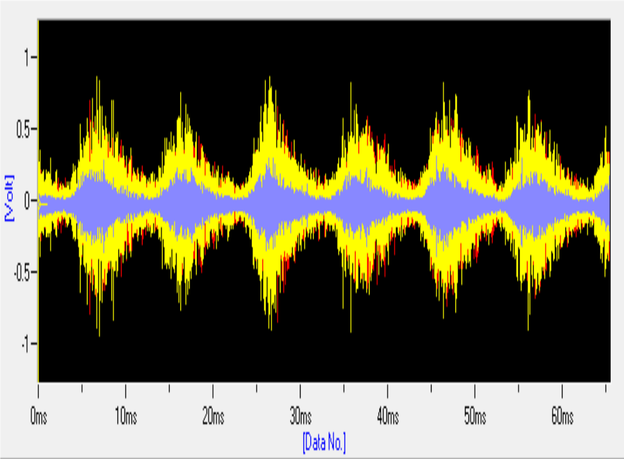


Fig. 7. The electromagnetic signal waveform

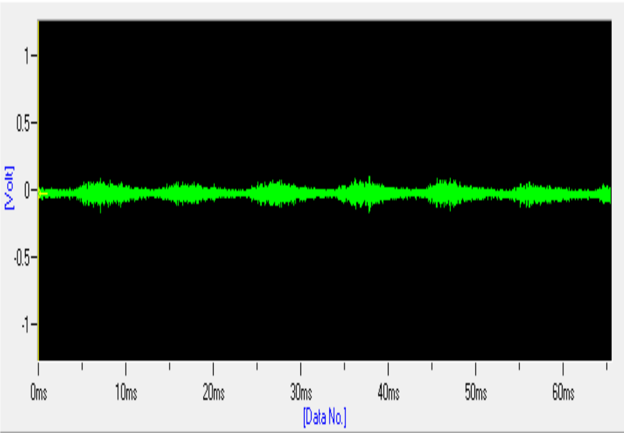
Fig. 8. The installation position of the horizontal axis signal sensor

Results of locating the partial displacement in the X-axis.

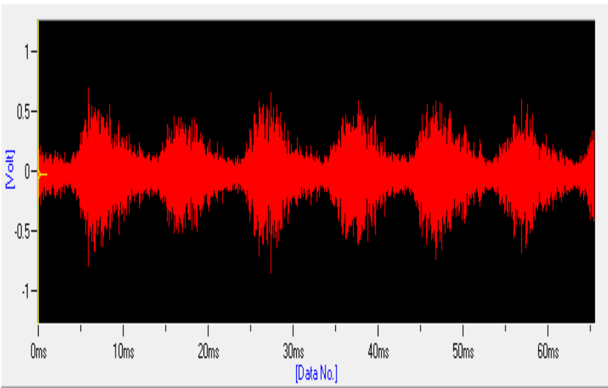
Due to the signal waveform measurement results shown in Fig.5, it is found that the maximum signal size is from sensor 2 (red), because the PD signal source is near the red sensor. After that, all 4 sensors will be moved to the 2nd sensor, arranged in the X-axis, and then compare the signal wave size again to find the closest PD position. Fig. 8 shows the position of the installation of the horizontal axis signal sensor and Fig. 9 shows the signal wave graph in which the 4 signal sensors are installed.



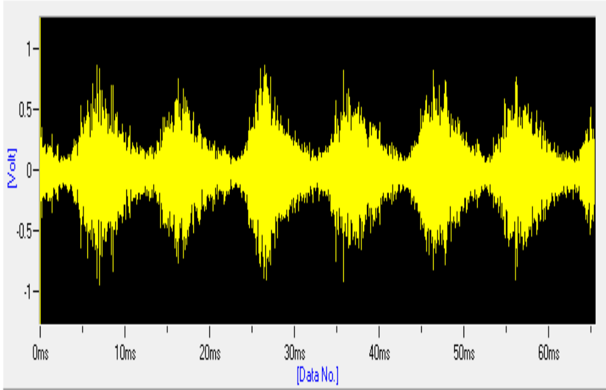
a) The comparison size of 4 signal waveforms,AE1-AE4



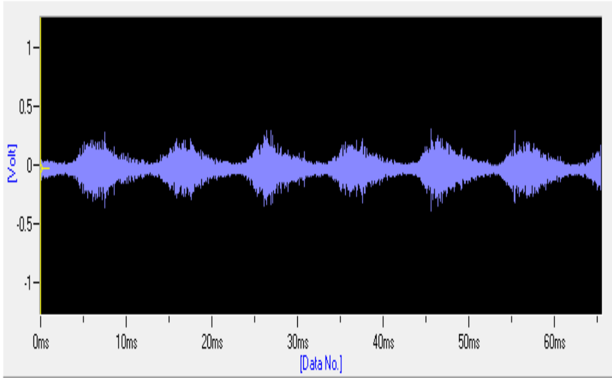
b) The partial discharge signal from the AE sensor No.1 (Green)



c) The partial discharge signal from the AE sensor No.2 (Red color)



d) The partial discharge signal from the AE sensor No.3 (Yellow)



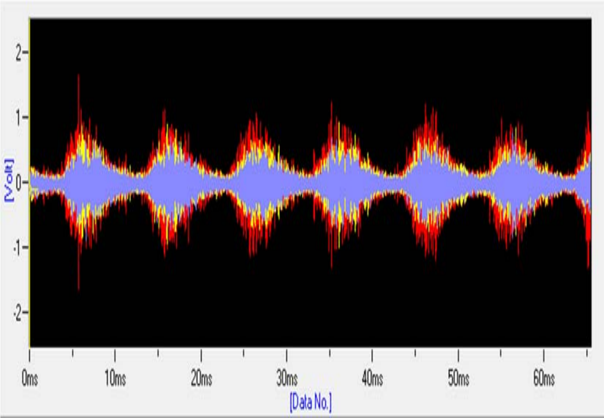
e) The partial discharge signal from the AE sensor No.4 (Blue)

Fig. 9. The horizontal axis of the signal frequency waveform, a) The comparison size of 4 signal waveforms,AE1-AE4, b-e) the signal waveform from each sensor, AE1-AE4.

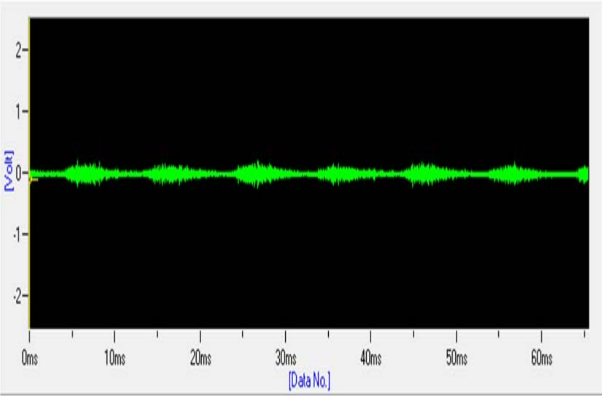
Results of finding the position of partial displacement along the Y-axis.

Due to the signal waveform measurements shown in Fig. 10, the maximum signal size is at sensor 3 (yellow), where the signal source PD is near the yellow sensor. After that, all 4 sensors will be moved to the 3rd sensor, arranged in a Y-axis, then the signal waveform size will be compared again. To find the closest PD position. Fig. 11 shows the location of the vertical signal sensor and Fig. 11 shows a graph of signal waves where all 4 signal sensors are installed.

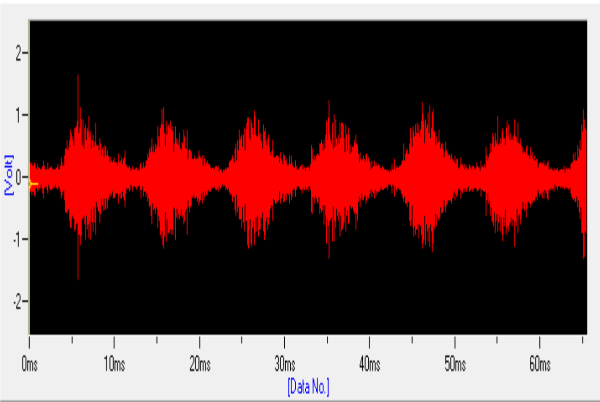
Fig. 10. The location of the vertical signal sensor installation.



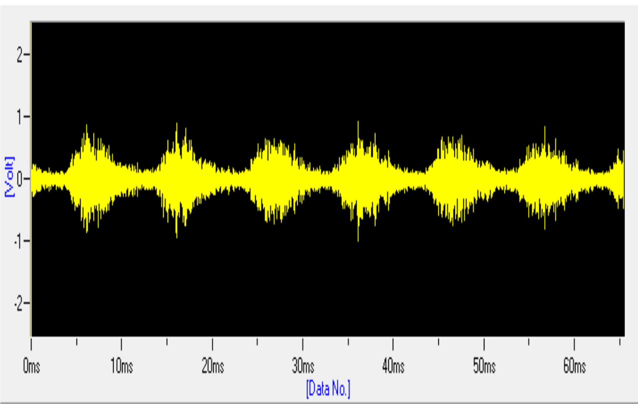
a) The comparison size of 4 signal waveforms,AE1-AE4



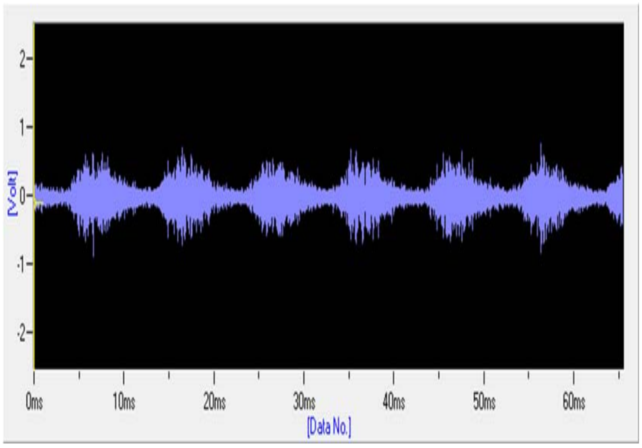
b) The partial discharge signal from the AE sensor No.1 (Green)



c) The partial discharge signal from the AE sensor No.2 (Red)



d) The partial discharge signal from the AE sensor No.3 (Yellow)



e) The partial discharge signal from the AE sensor No.4 (Blue)

Fig. 11. The vertical waveform of the signal , which a) compares the size of the sound waveforms in all 4 sensors, b) the sound waveforms obtained from each sensor.

Results of the locating of the partial discharges.

Due to the signal waveform measurements shown in Fig. 11, it is found that the maximum signal size is from sensor 2 (red) because the PD signal source is near the yellow sensor. After that, all 4 sensors will be moved to the 2nd and 3rd sensors, then, the signal wave size will be compared again. To specify the position of the PD. Fig. 12 shows the location of the partial discharges on the transformer and Fig. 13 shows a signal waveform in which the 4 signal sensors are installed.

Fig. 12. The position of partial discharging on transformers.

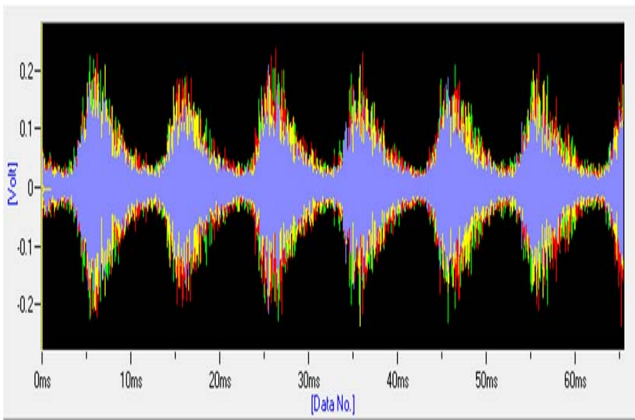
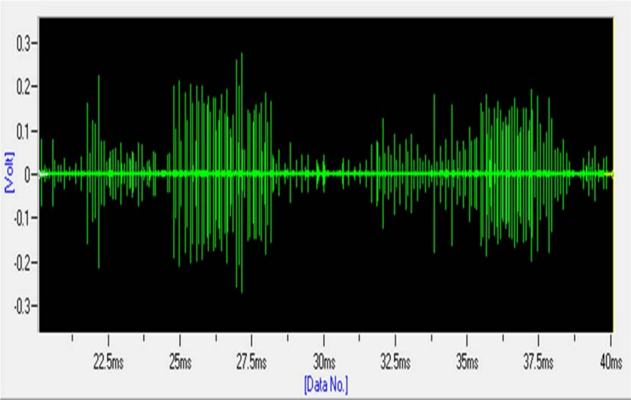


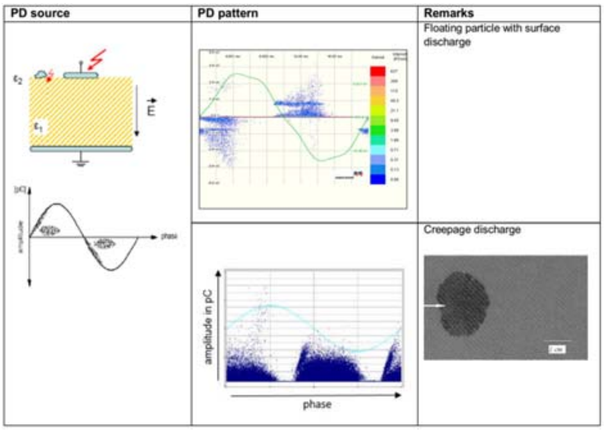
Fig. 13. The frequency waveform of sound waves in the position of partial discharging.

Assessment results of partial discharge type and risk

Due to the results of the electromagnetic wave measurement shown in Fig. 7, it was found that the form of the electromagnetic wave signal is characteristic of a partial discharge on the insulation surface (Surface Discharge), which is probably caused by dust and conductive (or semi-conductive) particles on the insulation surface. However, the risk level of PD according to PowerPD's reference data is moderate risk level (Major PD) of 3.2 ms. Fig. 14 compares some of the discharging waveforms with the standard format and Fig. 15 shows the result risk analysis of PD.

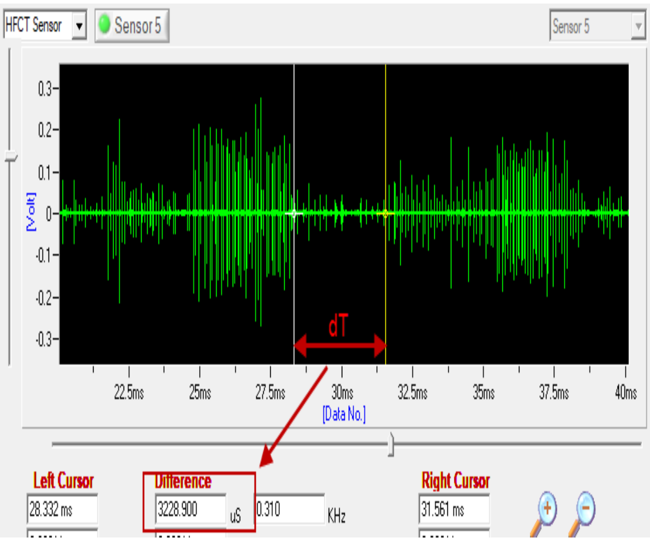


a) The electromagnetic waveform



b) The standard waveform graph of PD.

Fig. 14. The comparison of partial discharges waveforms with the standard model, which a) is the electromagnetic signal waveform from the PowerPD meter. b) is the standard signal waveform of PD.



a) the electromagnetic signal waveform from the PowerPD meter

Gap time / dT (ms, milliseconds)	Condition Level	Recommended action
No Partial Discharge Signal	Acceptable	Continue Normal Operation Monitoring every 12 months
Gap time > 7 ms	Small PD	Satisfactory (May be non-damaging PD) Monitoring every 6 months
3 ms < Gap time < 7 ms	Major PD	Engineering review and evaluation needed If the trend is increasing, consider removal from service in near future Monitoring every 3 months
Gap time < 3 ms	Serious PD	Unsatisfactory, Make plans to remove and repair now Monitoring every 1 week or Continuous Monitoring should be installed
Arcing Signal	Serious	Engineering review and evaluation needed If the Arc source is important point of equipment, consider removal from service in near future
Mechanical Signal	Abnormal	Engineering review and evaluation needed Other technologies should be performed to combining the data

b) The risk level of PD according to the PowerPD reference.

Fig. 15. The comparison of the risk level of PD, which a) is the electromagnetic waveform curve from the PowerPD meter, b) is the table of the risk level of PD according to the PowerPD reference.

For the case study, the transformer has been stopped, and insulation surface of the transformer checked. Particles were found as partial discharge marks on the high-voltage coils as shown in Fig. 16 where the trace positions match the measurement and analysis results.

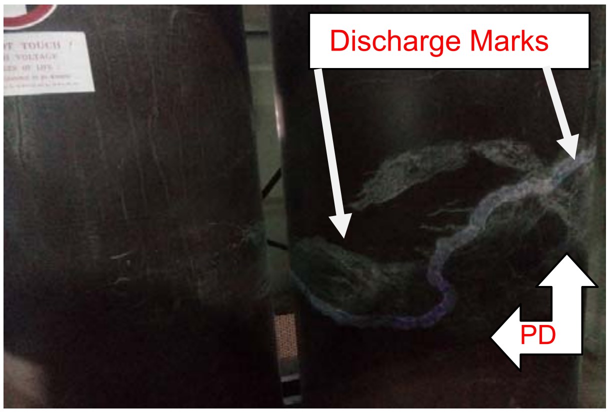


Fig. 16 The evident of partial discharge on the insulation surface of high voltage coils.

As the results show, this transformer was tested with the combined AE and HFCT detection technique and it was detected that there is partial discharge within the surface and inside the insulation of the coil of the transformer. This detection led to immediate shut down of the equipment and correction was carried out and the transformer was put to normal use. This transformer was tested at a hotel in Thailand with the combined AE and HFCT detection technique and it was detected that there is PD within the Surface of insulation between the terminator of phase B and HV tap bar [14-17]. The treeing can be clearly seen within the coil of the transformer which could have led to fatal consequences as seen in Fig. 15. The gap time of the Partial discharge source was 3.2 ms that is “major PD ” state. If the trend is rising, consider removal from service in near future in monitoring every 3 months.

Conclusions and discussions

From the online PD measurements on dry-type transformers using the PD-TP500A together with the emission sensor (refer to IEC62478) and the HFCT type mounting, the PD source can be detected and searched. By using the AE sensor to measure the PD, it is possible to find the PD position that occurs within the dry type transformer. The equipment used for measuring PD (PDTP500A, AE, and HFCT sensors) can be installed on the measuring device during operation and there is no need to turn the equipment off and separate it from the electrical system. This set of devices can detect and analyze problems occurring within the transformers at initial conditions for solutions. More importantly, it can be determined whether the problem is caused by PD, mechanical problems, arcs, or loose parts within the transformer [18,19]. This PD diagnosis method can accurately detect and locate the PD position occurring within the transformer which will enable timely and efficient maintenance. This will help prevent the complete erosion of the transformers and reduce the costs resulting fromserious repairs of damaged transformers. Online partial discharge measurement is a method to prevent transformer damage caused by t explosion and it provides guidelines for determining transformer maintenance for safer use [20,21].

To help solve the problem of electrical instability caused by power outages due to the weather in Thailand with heavy rain and lightning, leading to the defective electrical insulation of transformers caused by partial discharges in the transformer system, this therefore applied AE and HFCT device for the measurement and positioning of partial discharges in transformers. It has been found that it can be used to measure and locate partial discharges. The data can also be used to plan for transformer maintenance as per the plan.

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