COMPARISON AND ANALYSIS OF ON-LINE PARTIAL DISCHARGE MEASUREMENT METHODS FOR GAS INSULATION SUBSTATION

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Abstract

In this paper, we compare and analyze the signals of acoustic emission (AE) sensor, high-frequency current transformer (HF-CT) and capacitive coupled (CC) sensor inspection methods when they are used to detect the partial discharge (PD) in gas isolation substations (GIS). The PD location feasibility of the AE method is also studied. In general, the leakage currents are measured by using the HF-CT. And the electric fields are measured by using the CC sensors. However, the PD signals measured from the electric methods are usually hard to judge their accurate location while the AE method has good direction ability. Since the frequency of PD signals from AE measurements is usually less than 100 kHz, within the specific location, we can use AE sensors with frequency response range from 23 ~ 80 kHz to do the on-site, long-term observation. From the practically measured results, we definitely obtained the PD signals in a 161-kV GIS for all three different sensors.

1. Introduction

With the rapid development of the industry in Taiwan, people's requests for better power supply quality are also shifted since their standards of living are also promoted. In addition to developing more sources of electricity, Taiwan Power Company also has to build more power substations, which demand for larger space. However, it is not easy to obtain the required space to meet the demand. The gas isolation substation (Fig. 1) that filled with SF_6 gas demands for smaller area. All components such as circuit breaker, bus, switch, potential transformer, and current transformer are enclosed in the GIS. The advantages of GIS are mainly the larger maintenance period, safety, reliable operation, being suitable for any operating environment, and so on. Moreover, it is not exposed to electric conductor, since all the components are sealed up within the GIS tank which is filled with SF_6 gas [1]. The SF_6 has stable chemical property and is characteristic of very good isolation. It mainly functions as the isolation for the high-voltage power transmission.

To promote efficiency of electricity transmission, voltage during transmission is greatly increase, and thus the insulated material used for transformers and GIS in plants are necessarily capable of standing high potential. When the insulated material worsens, the transformers may be damaged or even explode, which will result in power failure and disrupt of plants. Therefore, it's more and more important to maintain and detect fault signals in power equipment.

During the operation of system equipment transport, some particles are possibly made. Hence the particles had been sealed in the chamber at the beginning. The equipment of GIS usually runs for a long time and then some materials will become deterioration in the interval. Also, if there are particles within the GIS, GIS will gradually evolve the PD into the problem in isolation. All of these are the reduction in the strength of isolation. We can find PD or particles signals before they cause power system fault so that we would be able to prevent the GIS breakdown and to make sure no accidents occurr.

The AE measurement method possesses a highly directional feature, which offers an advantage of precise fault-site positioning and, on the other hand, a disadvantage of short measurement distance. However, acoustic PD detection has several other advantages, such as low cost, small size, portability and accuracy [2, 3]. In this paper, we study the applications of AE and other electrical detection methods to the inspection of gas isolation substations.

Figure 1: *The gas isolation substation.*

2. Measurement Methods

The PD signals generated from the GIS, according to the sensor used, can be obtained by means of invasion or non-invasion measurement method. In this paper we use three kinds of non-invasion type sensors. So far, the non-invasion measurement technologies applied to detecting PD of power equipment can be mainly classified into two kinds, namely electric method and non-electric method.

Firstly, the electrical type sensor is applied to measure the electric field generated from the GIS. If a PD-like event generated in the GIS, a more detailed examination is made to determine whether the PD event occur or not. We used two kinds of electrical-type sensors for the measurements. One is the high-frequency current transformer (HF-CT). The HF-CT is encircled around the grounding conductor of the GIS. The measurement position is shown in Fig. 2. When a PD event occurs in the chamber of GIS, the electrical impulses will travel along the grounding conductor to the earth. This signal can be detected by using a HF-CT.

Figure 2: *The on-line PD measurement using a HF-CT.*

Figure 3: *The measurement using a CC sensor.*

The second electrical-type sensor is capacitive coupled (CC) sensor, as shown in Fig. 3. The couple capacitor with properties of divided potential and filtering is pasted on the GIS chamber. When a PD occurs in the chamber of GIS, the electric field intensity around the chamber is also influenced due to the effect of PD. The released energy of PD can be detected by the CC sensor over the surface of GIS; and the pulse current signals of PD are detected according to the principle of divided potential and filtering. As frequencies of the the PD signals are generally more than 5 MHz, cost for computer treatment at post-end of the couple capacitor is quite high. Therefore, this method is normally applied to quality assurance of equipment before releasing from plants other than on-line detection.

The third technique is a non-electrical measurement method which uses the AE sensor to detect the PD signals, as shown in Fig. (4). The signals detected are acoustic signals which have much lower frequency than the electrical methods [1]. The PD occurring inside equipment is similar to pulses and will generate mechanical pressure waves inside the media. This phenomenon can be analogized to AE, which is possibly caused by impact between molecules of interior material and adjacent structures. Such acoustic source will widely emit acoustic waves in the equipment.

Figure 4：*The AE sensor measurement position.*

In the AE method, an AE sensor firmly attached to the surface of equipment is utilized, and mechanical pressure waves are converted into electrically signals by a piezoelectric material inside the AE sensor, as shown in Fig. 4. The AE signals are further amplified through a preamplifier. In this method, frequencies of the acoustic wave signals generally range from 20 kHz to 80 kHz [3], which are much lower than those obtained in the above methods and thus costs much less. Since the main frequency components of the PD produced AE signal is less than 100 kHz [4], it can be transferred from analog to digital and then transmitted to a microcontroller or PC easily. The AE sensor used is VS30-V [5]. It has flat frequency response in the range from 23 kHz to 80 kHz. The pattern of frequency response is shown in Fig. 5.

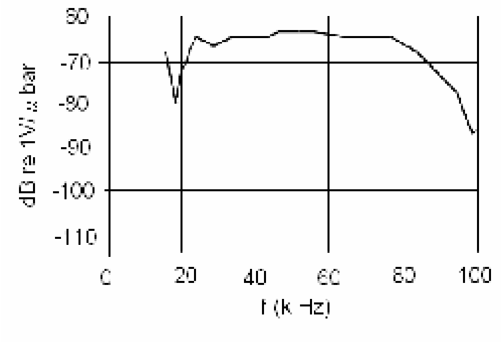

Figure 5: *The frequency response of VS30-V™.*

3. Experiments

3.1. Sample measurements in laboratory

To determine the correct characteristics of PD signals and verify the feasibility of the detection sensors, we start the experiments in the laboratory. The PD signals were measured from a sample transformer and the frequency of the measured signals was analyzed to figure out the proper skills for PD measurements. The field wiring diagram is shown in Fig. 6. In Fig. 6, ch1 represents the acoustic emission signal, ch2 denotes the output signal from the high-frequency sensors, and ch3 displays the output signal of the capacitive coupler. We note that when doing measurements in the laboratory there was disturbance or interference due to noises from the environment. However, the noises can be filter out by a band-pass or high-pass filter. After try and error, we found that the signal main frequency from HF-CT measurements is about 9.6 MHz. The spectrum mainlobe of CC measurements is about 9.8 MHz. The AE signals have main frequency at about 50 kHz.

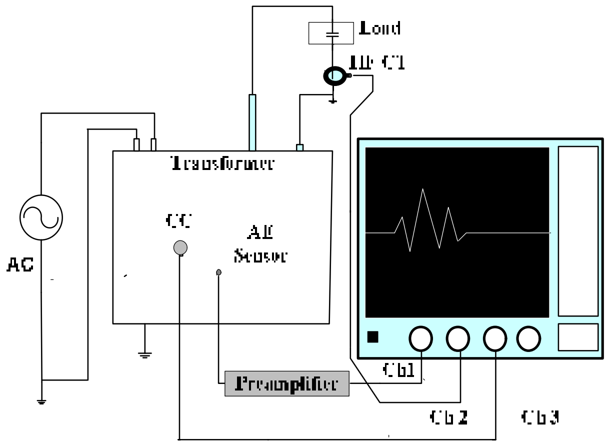

Figure 6: *The field wiring diagram.*

3.2. GIS on-line measurements

This paper mainly focuses on the 161-kV GIS on-line measurement. The results obtained by means of the measurements through these three kinds of the sensor, as the signals were measured from the AE sensor are shown in Fig. 7, the signals measured from the HF-CT are shown in Fig. 8, the signals measured form the CC are shown in Fig. 9. As shown, the signals from the AE sensor are much obvious than the CC and HF-CT sensors measured signals. Also, the PD signals in the HF-CT measurement is almost buried in noise.

Because there are many groundings to the GIS so that the measured signals from HF-CT induced lot of noises from the earth. Moreover, the electromagnetic disturbance from the environment, such as the 60 Hz power line frequency, is also very large. The noises almost cover up the PD signals. The noise problem is a critical issue especially for on-site measurements. Before doing the comparison, the signals must be processed using band-pass or high-pass filter. Regarding whether the PD is produced or not, the noise disturbance on the signals from the CC and the HF-CT measurements are hard to tell without signal processing. Distinguishes is very difficult for the PD signal in these two cases.

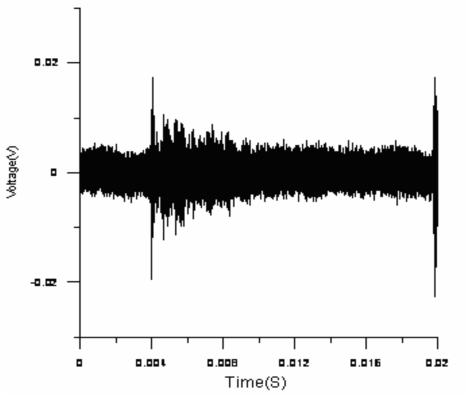

Figure 7: *Measured signal using AE sensor.*

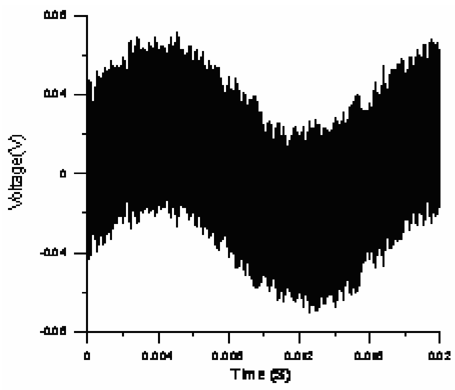

Figure 8: *Measured signal using HF-CT sensor.*

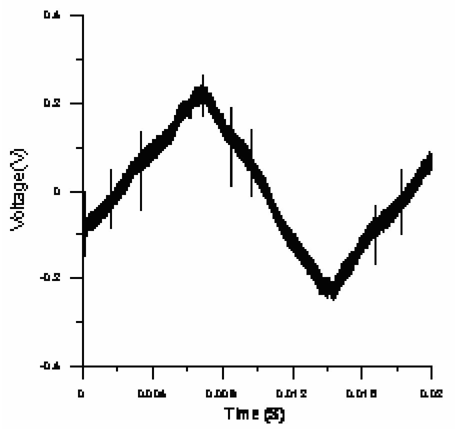

Figure 9: *Measured signal using CC sensor.*

3.3. GIL on-line measurements using AE sensor

To show the source location feasibility of AE technique, three AE sensors were firmly fixed on a GIL section, as shown in Fig. 10. The distances are 3 meters among the sensors. The distance of the first and the third sensors is 1.5 meters from the spacer that located on two terminals of the GIL section, respectively. As shown in Fig. 11, the measured signal amplitude from the channel 1 (the 3rd row) has greatest value. This one also receive the PD signal earier than the others. It is not difficult to locate the position of PD from the comparison of signal amplitudes and receiving time.

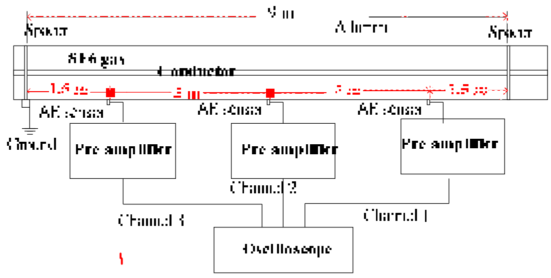

Figure 10: *The measurement position of AE sensors on GIL.*

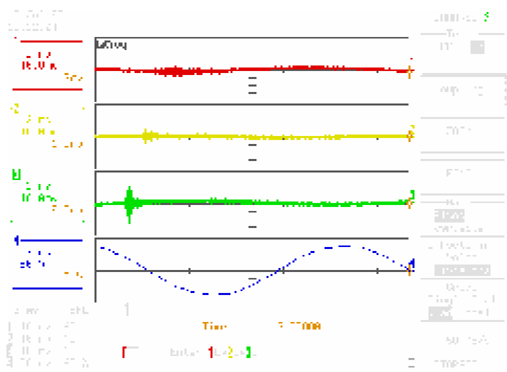

Figure 11: *The measured signals using AE sensors for GIL.*

4. Results and Discussion

4.1. Measurement results and signal comparative analysis for GIS

The processed data of HF-CT measurement are shown in Fig. 12. Here a band-pass filter that with pass band from 1 MHz to 15 MHz was used to extract the PD signal. As can be seen from the much improved results, the noises have been substantially removed. The 60-Hz interference is also suppressed. Same process can be applied to the CC sensor measured data. A band-pass filter that with pass band from 2 MHz to 15 MHz was used to extract the PD signal. The processed data are shown in Fig. 13. For the AE case, a band-pass filter that with pass band from 23 kHz to 80 kHz was used to filter out the noises in the measured data (Fig. 7).

When we compare the measured data from HF-CT and CC sensors, the relation between the two methods is very obvious. The patterns of the two waveforms are similar to each other. It can be noted that the CC sensor seems more sensitive than the HF-CT sensor.

Since the signal acquisition time is same for three sensors, we can further compare the AE signals (Fig. 7) with HF-CT and CC signals. One can find there is a delay time between the AE signal and the other two methods. It is reasonable since the speed of sound is much slower than the electricity signal. From the comparison of the three different measured data, we can easily recognize the PD signals.

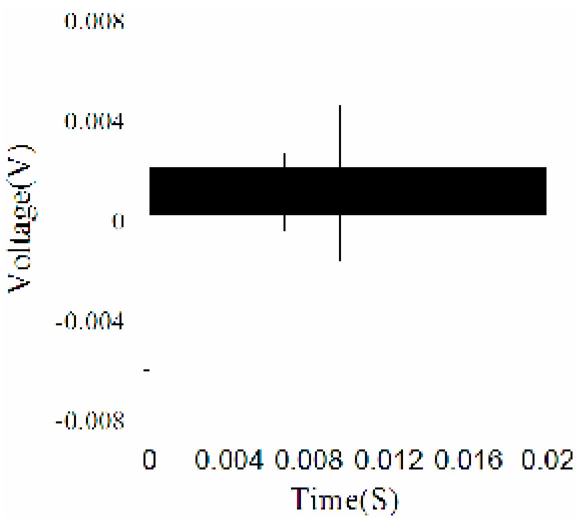

Figure 12: *HF-CT sensor measured data after processing.*

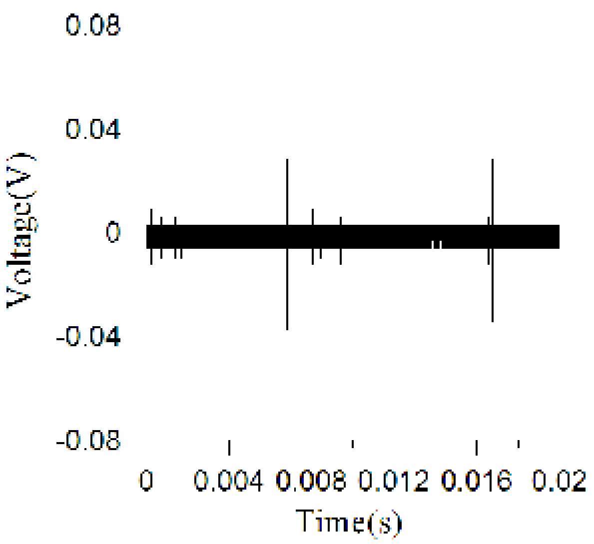

Figure 13: *CC sensor measured data after processing.*

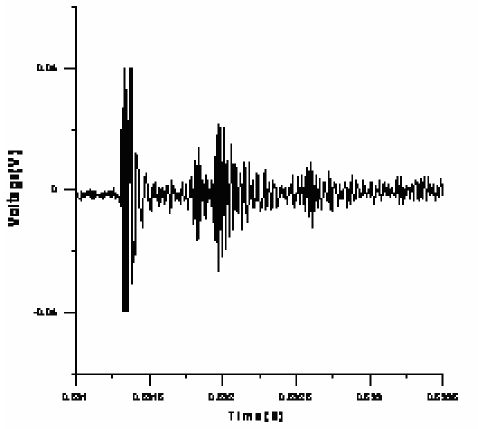

Figure 14: *AE sensor measured signal that may due to the impact of particle.*

Since all the three methods can detect signals from the GIS, it is very possible that the signal is from inside of GIS chamber. However, the signals for HF-CT and CC measurements may be due to PD, corona, or noise from environment. It is hard to distinguish the signals from PD if there is no other method to discriminate between ture PD and other electromagnetic interferences. Similar mystification may happen in the AE measurements. The acoustic emission and mechanical signals that are of an equivalent form may get confused [6]. By comparing the AE signals with the HF-CT and CC signals, we can have much more confidence with the measured data that it is from the PD phenomenon.

4.2. AE measurements on GIL and source location

The AE signals generated in GIS/GIL may be due to PD or moving particles [7]. In the experiments on GIL, we found that the AE data can be classified into two different patterns, one is as shown in Fig. 7, and the other one shown in Fig. 14. The most obvious difference between these two patterns is that the latter one has repeated bounces. Both patterns are gradually decayed with time. When the sound sources are close to AE the sensor, we found that the AE signals are very obvious. Since GIL is aluminums alloy pipe, the transmission of sounds in cylinder is very complex. Further study is necessary to figure out the problem. So AE signals may be due to PD or the particle impact.

The fundamental premise in locating sources of acoustic emission provides an advantage over other nondestructive testing methods [6]. As shown in Figs. 10 & 11, the AE signals were detected from three measurement positions. We can judge the position of PD or the particle impact generator from the signal characteristics, such as amplitude and subsequence of the AE signals. The acoustic waveform's magnitude is related to the distance between the AE measurement location and the PD site. To locate where the acoustic waveform's magnitude reaches its maximum will help us find the discharge site's location. Thus the method's fault-site positioning capability.

Table 1 summarizes the comparison of the three methods. The advantages and disadvantages is explained as following. In general, the measured data must be processed using band-pass filters that with appropriate bandwidth. The HF-CT and CC sensors are more sensitive than AE sensors. Since they can easily effected by the electromagnetic noises from the environment. The frequency of measured data from HF-CT and CC sensors are much higher than the AE sensor. The main frequencies of the HF-CT and CC sensors measured signals are about several MHz. While AE method shows its main frequencies in 40 ~ 60 kHz. The AE method also exhibits better source location ability than the other methods.

Table1 : The comparison of the three techniques.

Sensor	AE	HF-CT	CC
PD detectability	good	good	good
Noise	small	large	medium
Signal Frequency	low	high	high
Sensitivity	middle	high	high
Source Location	easy	difficult	difficult

5. Conclusions

Three partial discharge detection methods for GIS/GIL nondestructive testing are discussied in this paper. All the methods have detectability to the PD phenomenon. Generally, the measured data must be processed using band-pass filters that with appropriate pass band. The HF-CT and CC sensors are more sensitive than AE sensors, while AE method exhibits better source location ability than the other methods.

6. Acknowledgements

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