DETECTION OF PARTIAL DISCHARGE IN CAST-RESIN DRY-TYPE TRANSFORMER BY USING ACOUSTIC EMISSION TECHNIQUE

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Abstract: With a view to providing a stable electric quality, it is very important for industry to maintain their electronic equipment and to predict and diagnose their failures. Cast-resin dry-type transformers are humidity-proof, low-noise, inflammable and not harmful to the environment, so they are widely used in hospitals, high-tech companies, MRT system and aircraft industry. In order to increase the transmission efficiency of power line, Taiwan Power Company, therefore, raises the voltage to a higher level. The insulation in the transformer will then sustain more electrical stress. The cause of transformers failure is mostly due to partial discharge (PD) caused by the worsening of insulation. If there is no correct diagnosis in time, the cast-resin dry-type transformer will be stricken due to the breakdowns of insulating resin in the high-tension coil. Although the situation will not cause explosion, it will cease the production lines and result in the immerse loss of the industry. In this paper, the acoustic emission (AE) method was used to analyze the signals of PD in cast-resin dry-type transformer. First, to find the power-density spectrum of PD, we chose a 150 kHz resonant type AE sensor (VS150-M) which is the most popular one in the industry. The experiments show that besides the 148 kHz, there is another signal in lower frequency. Next step, we used a wide-band type sensor (Fuji 2045S, 200 kHz ~ 2.5 MHz), and found three main frequency at 60, 90 and 160 kHz. Finally, we used a low-frequency type sensor (VS30-V, 23~80 kHz), trying to find the actual power-density spectrum of PD signal. The research has the finding: after passing the 40-dB preamplifier, the signal amplitude is about 200 mV (peak-to-peak); power-density spectrum is between 40 kHz and 60 kHz. But 52 kHz is considered to be the lowest frequency of PD. The research is aimed to establish a simple and convenient on-line diagnostic method for cast-resin dry-type transformers by AE technique.

Introduction: Usually, there are two ways to detect partial discharge in cast-resin dry-type transformers.

1. Electrical Research Association (ERA). Partial discharge pulse current can be detected from the detection circuit through this way. This way is easy for quantitative measurement and it has high sensitivity. It is standardized by IEC (International Electrotechnical commission) to detect electric charge of partial discharge pulse current, using pico-coulomb (pC) as a unit. But there are three main disadvantages. First, because of its high sensitivity in measurement, its false alarm is also high. Secondly, this way puts focus on the ground connection of transformers which will produce electric current if the transformers have partial discharge. The maintenance of equipment can not be done because it is hard to distinguish which high-tension coil is partially discharged. Thirdly, this way is not suitable for long-term monitoring of transformers. It costs too much to connect measurement equipment to ground lines.

2. Non-electric approaches. They include acoustics, phonology and observing discharge effects of the objects tested. These approaches are not used in quantitative measurement but in recognizing the position of partial discharge. Acoustics approach contains two types, contact and non-contact types. Taiwan Electric Research and Testing Center has developed the latter for many years and gotten significant results [1], while AE technique used in our research belongs to the former. Our research used a contact-type AE sensor. In this method there are three advantages: 1. AE sensors can be attached to three different high-tension coils. By observing and analyzing signals collected by sensors, the researchers can find out the right high-tension coil that puts forth partial discharge. And then, further maintenance can be provided. 2. Acoustic signals will occur only when the partial discharge reaches certain intensity. Unlike ERA method, it does

not have high sensitivity and the problem of high mistaken rates. 3. This method is suitable to monitor transformers for long time and therefore the cost is reduced.

According to Tian's [2] discharge experiments with polymeric insulation model, AE sensors are attached to polymeric insulation to collect acoustic signals. And then impedance, coupling capacitor and the detecting equipment for partial discharge are used to collect electrical signals. There is a void in the middle of polymeric insulation sample which is shaped like a sandwich. A high voltage probe is attached above the void and another under the void. Finally, discharge occurs as a result of raising the electrical voltage on probes. The purpose of these experiments is to find out the relationship between acoustic signals and electrical signals from the void. The conclusion is that acoustic signals and electrical signals from the void are absolutely related and the strength of discharge influences the intensity of acoustic signals. In other words, only when the discharge reaches certain intensity do acoustic signals occur.

The 150 kHz sensors used in the above experiments are resonant type sensors, whose main property is that any tiny signal which occurs near 150 kHz will be strongly amplified because of resonance effect. But the amplification in other different frequencies varies very much; that is, the result is not the real frequency spectrum. Take the reflection chart of Vallen™ VS150-M for example. As we can see in Fig. 1, the sensitivity in 150 kHz is at least 7 dB higher than that in 100 kHz. However, we can see the main frequency is not in 150 kHz but in 100 kHz. Therefore, the main disadvantage of using resonant type sensors is that the signals measured is not the real ones. Because of the reason, the purpose of our research is to find out the real frequency spectrum of signals.

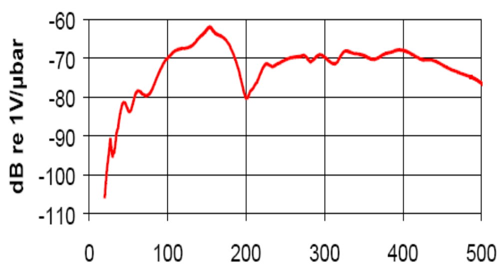


Fig. 1. Frequency spectrum of the VS150-M (kHz) AE probe [3].

Research Method: Partial discharge is similar to the phenomenon of pulse, which causes mechanical pressure waves in the material itself as the radiation of sound does. When the collision of molecules happens in the inner part of one material and its neighboring structure, a sound source is formed, which will radiate sound wave. The sound wave causes propagation everywhere in the inner part of equipment. And in AE method, AE sensors are closely attached to the surface of the equipment. The piezoelectric material in the AE sensors will transform the mechanic pressure wave into electrical acoustic signals, as shown in Fig. 2.

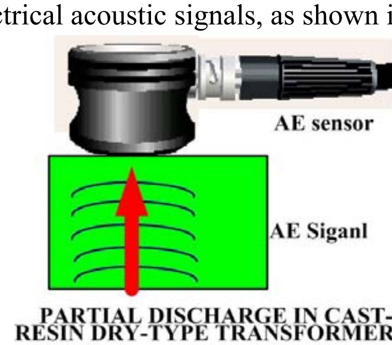


Fig. 2. The sensors – converting the mechanical wave into an electrical AE signal.

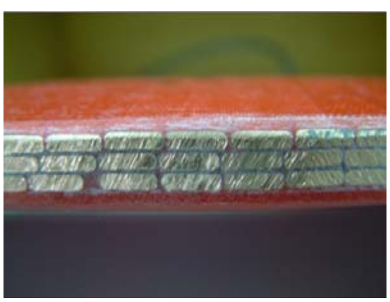
First, accompanied with the preamplifier (AEP4: 5 kHz ~ 3.8 MHz) is Vallen™ VS150-M, a 150 kHz resonant sensor commonly used in the industry. The result is the general wave the same as an ordinary experiment, which is to be compared with the following experiments. Second, accompanied with the preamplifier is Vallen™ Fuji 2045S, a wide-band type sensor. The sensor is used to analyze higher frequency spectrum. Because resonant sensors often make the confusion that signals appear in the frequency of 150 kHz, wide-band type sensors can detect more real signals. This experiment can ensure if higher-frequency signals appear. Finally, a Vallen™ VS30-V AE sensor is used for two reasons. (1) VS30-V, a low-frequency type sensor, has a flat frequency response between 23 kHz and 80 kHz. Hopefully the real frequency spectrum of PD signals can be found. (2) VS30-V has high sensitivity, and thus can be applied to find the most detail signals in low frequency.

The following will discuss the energy transmission and reflection of sound waves in the inner part of high tension coil. Figure 3(a) shows the cross section of partial high tension coil. Figure 3(b) shows the cross section of glass fiber in the resin of high tension coil. High tension coil consists of copper wires which are arranged one layer by one layer. In order to simplify the analysis, the hypothesis is made that the coil is a complete brass block and next to the brass block is a pure piece of resin. According to the relation among acoustic impedance (Z), material density (ρ) and sound velocity (V) [5]:

$$Z = \rho V \quad (1)$$

The acoustic impedance of brass is Z_1 = 41.61x10^6 Kg/m^{2}s, and the acoustic impedance of resin, glass fiber not contained, equals to Z_2 = 3.2x10^6 Kg/m^{2}s.

When sound is transmitted between two materials, their acoustic impedances have a determined influence on the transmission coefficient and reflection coefficient of sound wave power in passing through the interfaces. Figure 4 shows the attenuation of sound wave in brass and resin. First, assuming that the initial power of sound wave in the brass block equals to 1, there is 26.7% of power passing through the resin and 73.3% of power reflecting back to the brass. Then, when sound wave continues to move from the resin to the below layer of brass, only 7.1% of power passed through the second layer of brass and 19.6% of power reflects back to the resin. Therefore, the transmission of sound in the inner part of high tension coil is very difficult.

(a) 

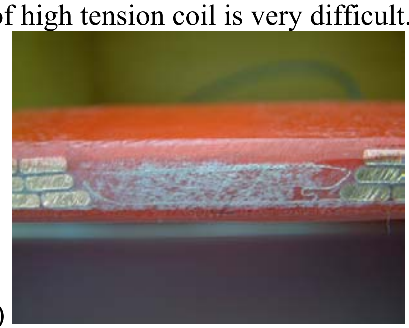
(b) 

Fig. 3. (a) The cross section of partial high tension coil. (b) The cross section of glass fiber in high tension coil.

$$Z_1 = 41.61 \text{ x } 10^6 \text{ Kg/m}^2 s$$

$$Z_2 = 3.2 \text{ x} 10^6 \text{ Kg/m}^2 s$$

$$R = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1} \right]^2 = 0.733$$

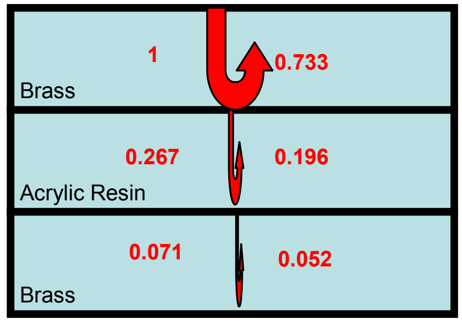


Fig. 4. The transmission and reflection of power wave in brass and acrylic resin.

The resin used in the above model is pure resin, which breaks down easily with the change of temperature. Most manufacturers add quartz sand or glass fiber to the resin in order to increase its mechanical strength. Hence, its acoustic impedance will differ from that of pure resin. But it is for sure that glass fiber increases the strength of resin, and meanwhile it attenuates the intensity of sound wave. So, it is more difficult for sound wave to transmit in genuine high tension coils. Therefore, the AE sensors which have higher sensitivity should be used to measure sound wave signals. Besides, the signals in lower frequency should be detected.

Experiment: The cast-resin dry-type transformer used in this experiment has the following standard. Capability: 10 kVA. Primary coil electrical voltage: 12 kV. Secondary coil voltage: 120 V. The procedure of this experiment is as follows. First, a three-phase auto transformer is connected to the secondary coil of the cast-resin dry-type transformer. Next, the output of the auto transformer is adjusted in order to let the primary coil induce the electrical voltage. And after an AE sensor is applied to the high tension coil of the cast-resin dry-type transformer, the filter is used to filter noise and electromagnetic interference. Then, through the preamplifier (AEP3), the signal will be amplified (gain: 40 dB). At last, the digital oscilloscope LeCroy™ LT354 is used to acquire the AE signals. Meanwhile, the spectrum analysis will be quickly completed with the FFT function of the scope. Figure 5 shows the basic block diagram of the measurement system. Figures 1, 6 and 7 show the frequency response of the sensors VS150-M, Fuji 2045S and VS30-V respectively.

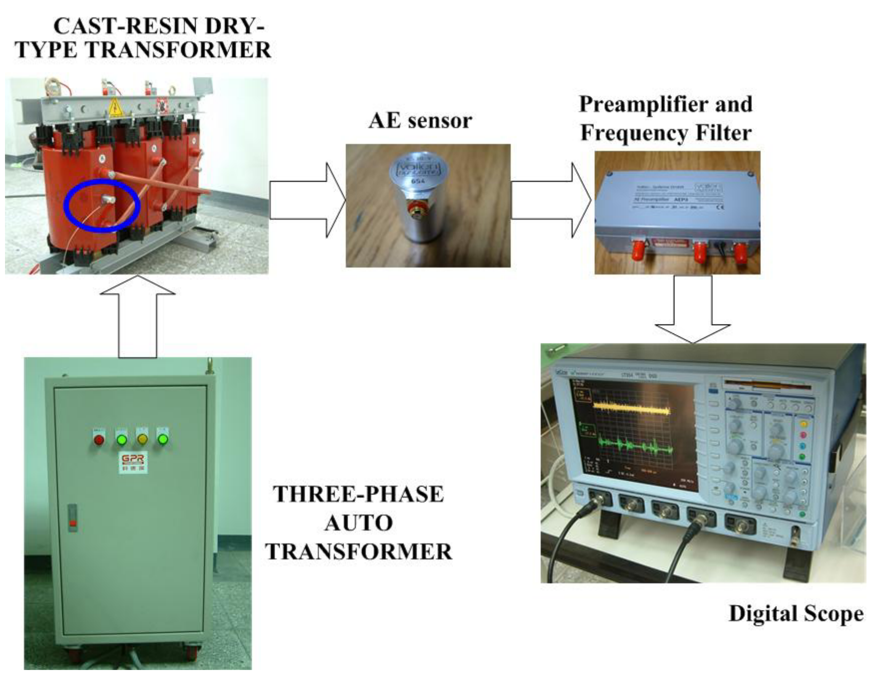


Fig. 5. Schematic diagram of the PD measurement system.

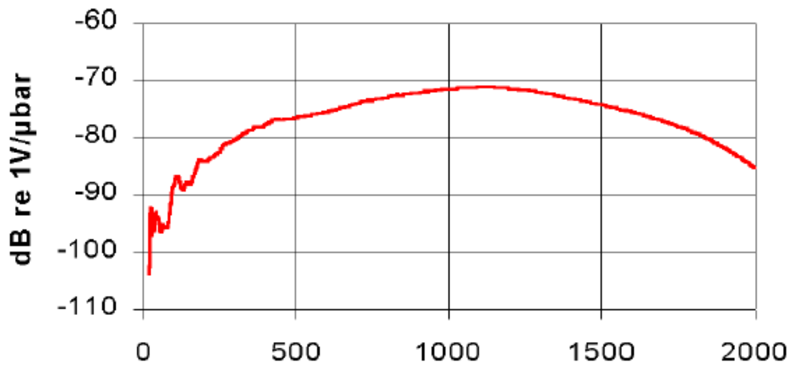


Fig. 6. Fuji 2045S, f(kHz) [3]

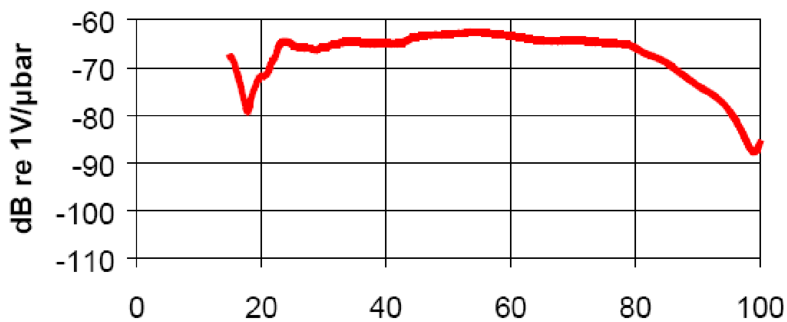


Fig. 7. VS30-V, f(kHz) [3].

Results and Discussion: As shown in Fig. 8, the AE signals detected by VS150-M along with the preamplifier (AEP4), the dominant frequency is 148 kHz. As can be seen, there is another frequency appears near 50 kHz. But the resonant type sensor performs badly around the 50 kHz frequency, as shown in Fig. 1. Besides, the sensitivity in 150 kHz is about -63 dB, while in 50 kHz it is about -83 dB. Their difference in sensitivity is 20 dB (ten times). So, the signal appearing in 50 kHz should be amplified ten times, which means lower frequency AE sensor should be used to look for lower frequency signals. It is for sure that signals in high frequency (> 300 kHz) are much weaker.

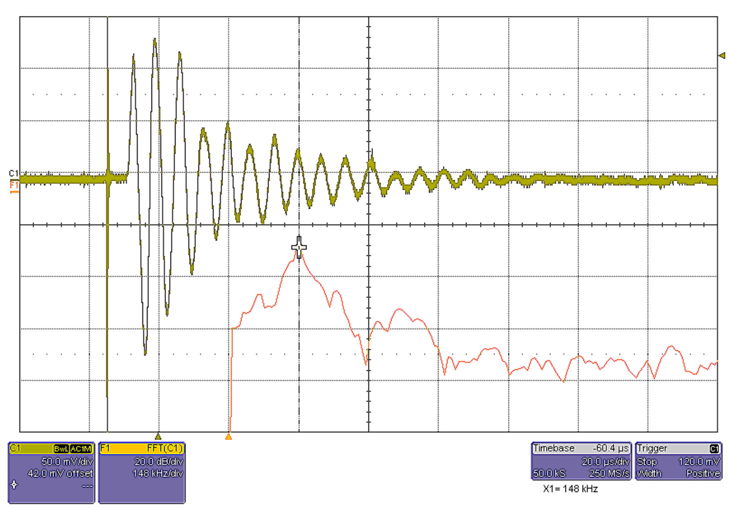


Fig. 8. AE signal and frequency spectrum that measured by using VS150-M.

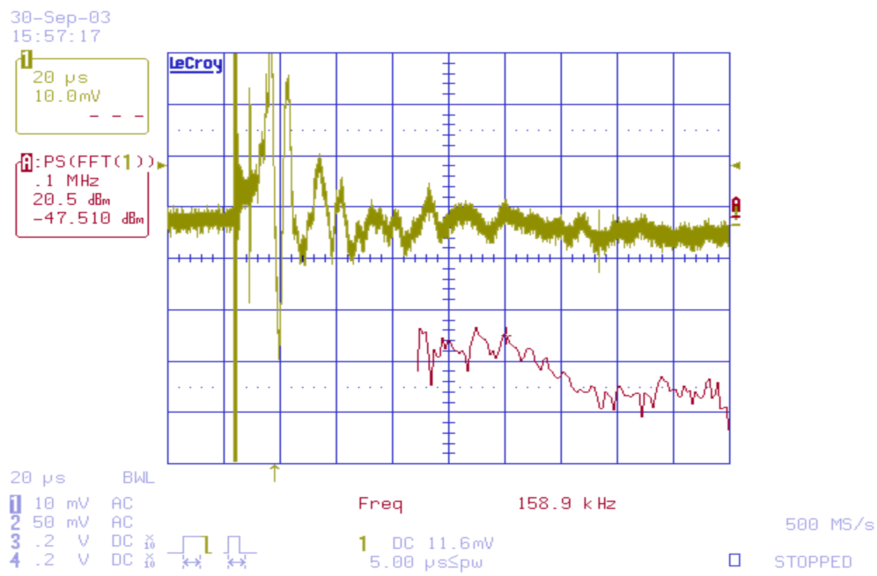


Fig. 9. AE signal and frequency spectrum that measured by using Fuji 2045S.

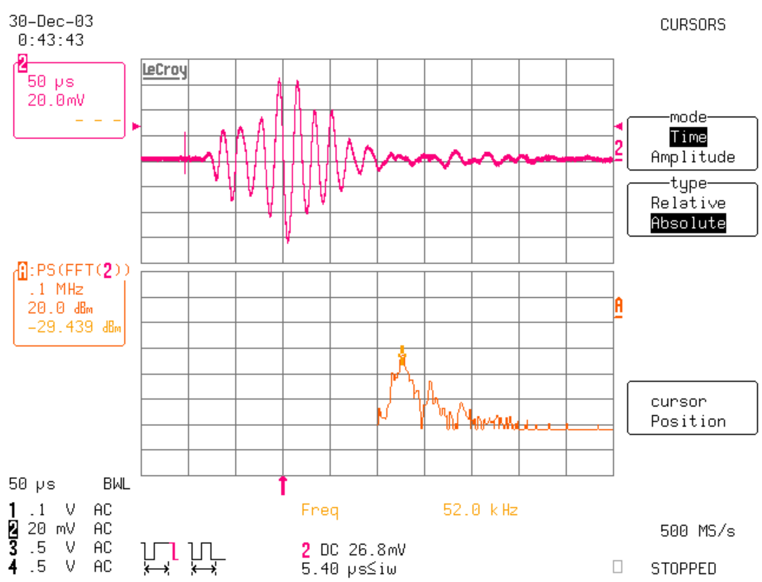


Fig. 10. AE signal and frequency spectrum that measured by using VS30-V.

Figure 9 shows the waveform measured by Fuji 2045S along with a preamplifier (AEP4). Three dominant frequencies, 60 kHz, 90 kHz and 160 kHz were found. Because there is still a signal in 60 kHz, the real signal should be bigger. In contrast, there is no signal in high frequency. From the above two results, the finding is as follows. There is definitely no signal in the frequencies higher than 300 kHz, while in the low frequency between 50 kHz and 60 kHz there is definitely some signal. Therefore, lower frequency sensor should be used to measure PD signals.

Figure 10 shows the AE signal measured by VS30-V. Its dominant frequency is 52 kHz, which means the real location of acoustic signal frequency in the cast-resin dry-type transformer is around 52 kHz. The spectrum of VS30-V between 23 kHz and 80 kHz is very flat, as shown in Fig. 7. Because VS30-V is a low frequency sensor, it will receive the audio frequency signal lower than 20 kHz. So, in measuring the real signals, a preamplifier (AEP 3) and a filter should be used in order to reject the audio signal lower than 20 kHz. The passband of filter is from 30 to

300 kHz. In the time-domain waveform, no noise of high frequency is observed. In frequency-domain waveform, the frequency not between 30 kHz and 300 kHz is filtered out. As shown in Figs. 9 and 10, a big inductive interference of high frequency appears which will affect the reception of acoustic signals. Filter can minimize the interference.

Conclusions: We have tried using three different AE sensors to detect PD signals in the cast-resin dry-type transformers. In the beginning, the most popular 150 kHz resonant type sensor is used. Then 200 kHz ~ 2.5 MHz wide-band sensor is used, there is no frequency higher than 300 kHz, but there is a low-frequency signal in 60 kHz. Finally, a 23 ~ 80 kHz low-frequency sensor is used; as a result, it is found that near 52 kHz exists the real PD signal. It is concluded that the acoustic signal of partial discharge mainly appears at 52 kHz.

The insulation materials of high-tension coil have great influence on the transmission of sound wave. Therefore, the inner structure and materials of high-tension coil will influence the production of partial discharge. Especially in the aspect of material, some of the resin in added quart sand, others added glass fiber, both have great influence on the transmission of sound wave.

The filter is necessary because high frequency induced signal appears in using the 150 kHz resonant type sensor and the 200 kHz ~ 2.5 MHz wide band type sensor. From a sequence of experiments, the filter is set between 30 kHz ~ 300 kHz in order to reject unnecessary noise and to keep acoustic signals that wanted.

Based on the conclusions, an on-line partial discharge detection system may be established.

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References:

1. “Study of high-voltage transformer partial discharge field testing”, Taiwan Electric Research and Testing Center, Ministry of Economic Affairs, Dec. 2002.
2. Y. Tian, P. L. Lewin, A. E. Davies, Z. Richardson, “Acoustic emission detection of partial discharges in polymeric insulation”, High Voltage Engineering Symposium, 22–27 Aug. 1999, Conference Publication No.467, IEE.
3. Vallen-Systeme GmbH, Acoustic Emission Sensors Frequency Responses.
4. Vallen-Systeme GmbH, AE Testing, Fundamentals, Equipment, Applications, 2002.
5. NDT Resource Center, http://www.ndt-ed.org/GeneralResources/MaterialProperties/UT/ut_matlprop_metals.htm.
6. PANAMETRICS, ultrasonic transducers catalog.