Design and Fabrication of a PD Measurement System for Dielectric Test of Low-voltage Electrical and Electronic Devices

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Abstract: - Partial discharge (PD) analysis as a non-destructive dielectric test is getting spread. For the application of PD test to low-voltage electrical and electronic devices, PD test measurement system detects apparent charge below 1 pC is essential. In this paper, we described a PD measurement system which is composed of noise free power source and coupling network, a low-noise amplifier. A shielding enclosure was also adopted to get a better measurement environment against electromagnetic (EM) interferences. From the calibration, the low cut-off frequency of the coupling network estimated by a sinusoidal waveform was 125 kHz at -3 dB and 500 kHz at -0.1 dB, and the sensitivity of the PD measurement system was 28 mV/pC. In an application test on low-voltage isolation transformers, we could detect -0.53 pC at the applied voltage of AC 707 V.

Key-Words: - Partial discharge (PD), Dielectric test, Non-destructive dielectric test, Coupling network, Low-noise amplifier, Shielding enclosure, Low cut-off frequency

1 Introduction

Transient overvoltages in electrical and electronic devices have been issued by the use of high speed switching and digital control techniques. The overvoltages have been reported up to a few thousand volts even in low-voltage circuits [1-3]. The overvoltages could cause partial discharges at a void or insulation layers in a solid insulation system, and the degradation of insulation by partial discharges is without any doubt [4, 5].

In addition, the withstand voltage test (WVT) being carried out at the step of manufacturing or delivery for low-voltage electrical and electronic devices applies relatively high voltage over 1 kV, and this could stimulate degradation of insulation. It is therefore necessary to adopt the PD test for low-voltage electrical and electronic devices by detecting as low as charge below 1 pC [6-8].

In this paper, we represent a PD measurement system for low-voltage electrical and electronic devices. PD pulse was measured by a straight detection circuit considering a wide use in fields. Also, a shielding enclosure was designed to get a better measurement condition against radiated noise from outside. In the calibration, the fabricated PD measurement system has a low cut-off frequency of 125 kHz (-3dB), and a sensitivity of 28 mV/pC for the test sample. In a laboratory test on low-voltage isolation transformers, we could detect 0.53 pC level of PD pulse at the applied voltage of AC 707 V.

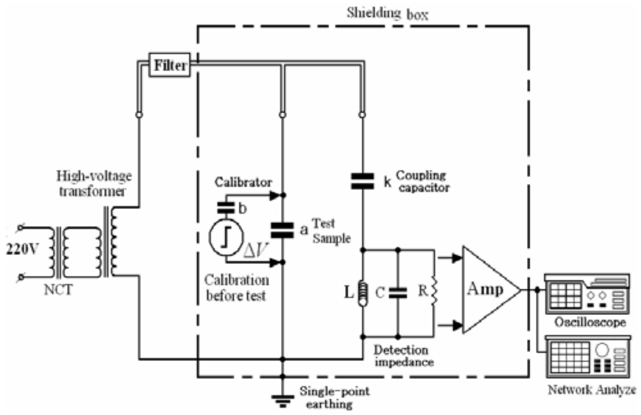
2 PD Measurement System

2.1 Design and Fabrication

PD measurement systems for testing low-voltage electrical and electronic devices have characteristics of wideband and high sensitivity not to stimulate insulation degradation by applying test voltage. A shielding enclosure is needed to suppress radiation noise and to detect PD pulse below 1 pC since the sensitivity of a PD measurement system changes by noise level.

The PD measurement system fabricated in this study was consisted of a noise cut transformer (NCT), a high voltage (HV) filter, a coupling network with a discharge free coupling capacitor, a detection inductor, and a low noise amplifier as shown in Fig.1. The HV filter was adopted to attenuate high frequency noises conducted through test voltage source.

Figure 2 shows the frequency response of the HV filter. The high cut-off frequency obtained by the sinusoidal input is 3.5 kHz (-3 dB). This is enough to pass AC test voltage and to suppress noises.



(a) Configuration

(b) Photograph

Fig. 1 Fabricated PD measurement system.

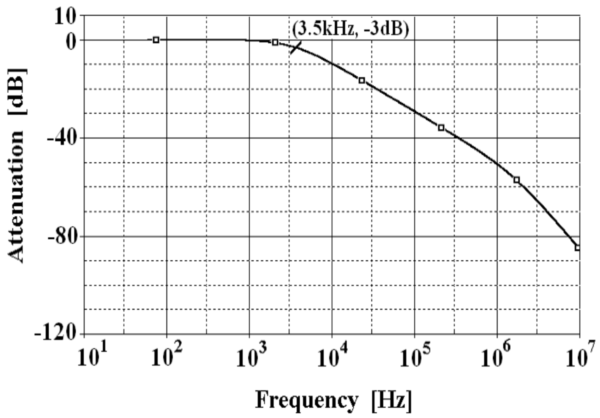


Fig. 2 Frequency response of the HV filter.

Also, the low cut-off frequency of the coupling network is 125 kHz (-3 dB) and 500 kHz (-0.1 dB) as shown in Fig. 3. This system has an almost flat response over 500 kHz. The reason why we set the low cut-off frequency of 0.1 dB at 500 kHz was to calculate the sensitivity of the PD measurement system by a standard calibrator which generates pulses a with narrow frequency bandwidth.

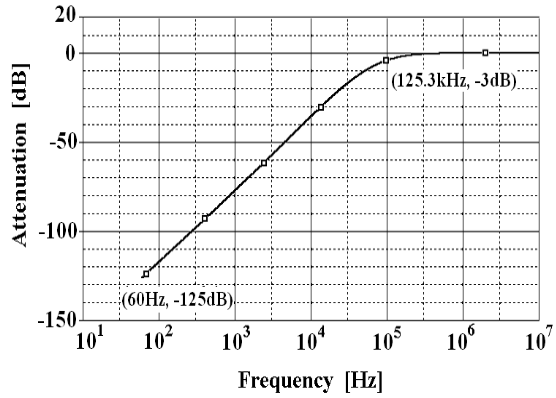
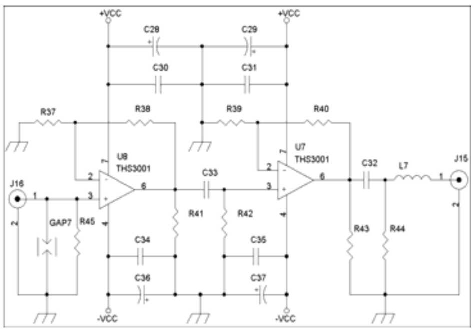
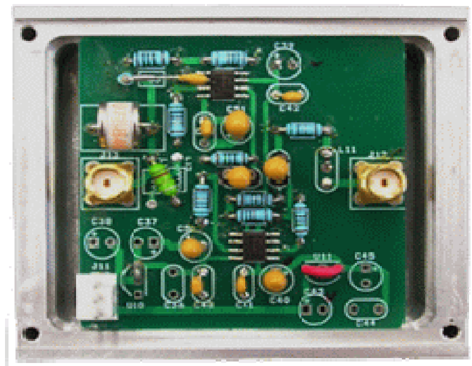


Fig. 3 Frequency response of the coupling network.

A low noise wideband amplifier is necessary for measurement of small PD pulses. We designed a two-stage amplifier using a high speed and low noise operation amplifier as shown in Fig. 4.



(a) Configuration



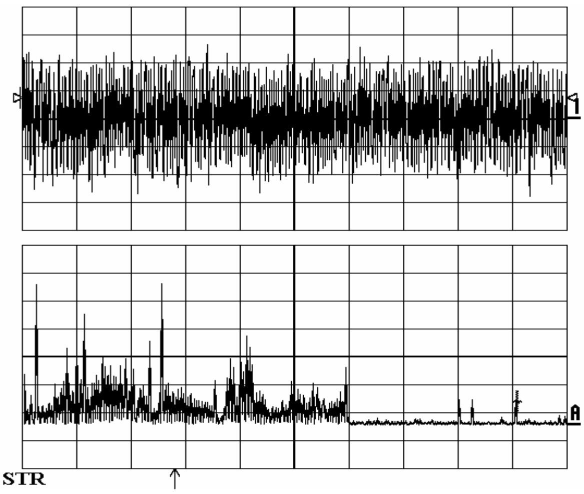
(b) Photograph

Fig. 4 Prototype amplifier.

The noise level of the amplifier is about $1.6nV/\sqrt{Hz}$, and the gain is 40 dB.

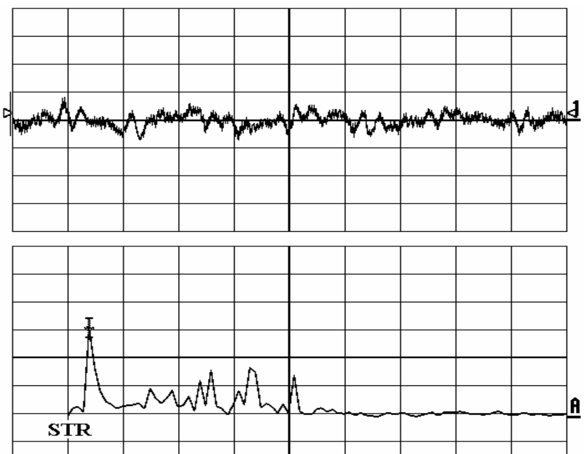
As we explained before, the PD measurement system was tested to noise interference because the sensitivity is influenced by noise level [9].

Figure 5 represents the noise level and spectrum measured at output of the amplifier when the maximum test voltage of 5 kV is applied.



Ch.1: Noise level [10 mV/div, 10 us/div]
Ch.A: FFT result [300 uV/div, 5 MHz/div]

(a) Door_open



Ch.1: Discharge signal [2 mV/div, 10 us/div]
Ch.A: FFT result [100 uV/div, 100 kHz/div]

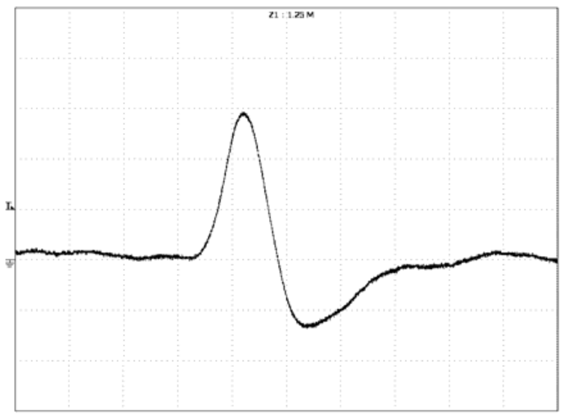
(b) Door_close

Fig. 5 Noise level of the PD measurement system.

In the test set-up, the peak noise level was 1.5 mV_{peak} and a shielding effect was about 26 dB by closing the door. Frequency spectrum of the noise appeared widely up to 30 MHz in opened-door, but did not appear over 420 kHz in closed-door. It was estimated that the high frequency noises were blocked by the shielding enclosure, and the low frequency noises below 420 kHz were conducted from outside through an earth line.

2.2 Sensitivity

A calibration to estimate the sensitivity of PD measurement system should be carried out because the sensitivity changes by capacitance of test sample. In this study, the sensitivity was calculated by injection of calibration pulses (CAL1A, ± 1 pC ~ 50 pC) between windings and iron core of low-voltage isolation transformers. Figure 6 shows typical response waveform of the system for the calibration pulse injection. The magnitude of response voltage to the calibration pulse injection was 28 mV for 1 pC. Sensitivity to both positive and negative injection pulses was same in ranges from 1 pC to 50 pC.



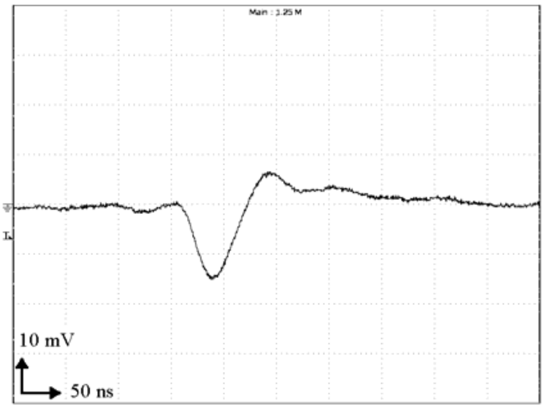
[10 mV/div, 50 ns/div]

Fig. 6 Response waveform to 1 pC-calibration pulse.

In the calibration, the PD measurement system can detect PD pulse as small as 0.1 pC (2.8 mV) considering noises and resolution of the A/D converter use.

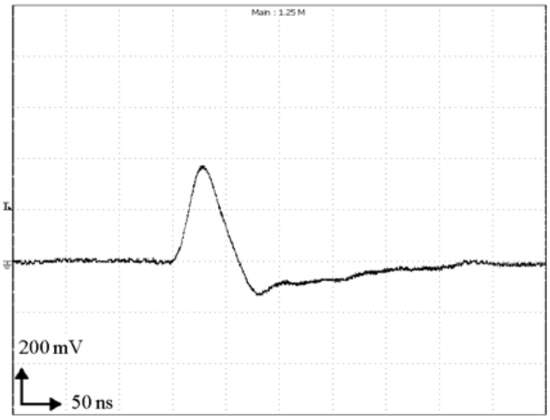
3 Measurements and Analysis

After calibration, we applied AC test voltage between winding and iron core of low-voltage isolation transformers. The initial PD pulse was detected at the AC test voltage of 707 V as shown in Fig. 7. Magnitude of the pulse was -15 mV and it is almost equivalent to -0.53 pC. Apparent charge increase with increasing test voltage, and was about 13.2 pC at 990 V.



[10 mV/div, 50 ns/div]

(a) AC 707 V



[200 mV/div, 50 ns/div]

(b) AC 990 V

Fig. 7 Detected PD waveforms.

Noise conducted and radiated from outside was attenuated largely enough to detect electric charge below 1 pC by using a NCT, a HV filter, and a shielded enclosure. Also, a precise calculation of sensitivity was possible without any attenuation by the coupling network with a low cut-off frequency of 500 kHz at -0.1 dB.

4 Conclusion

In this study, a high sensitive PD measurement system which can detect apparent charge below 1 pC was fabricated to apply PD test to low-voltage electrical and electronic devices. The PD measurement system consists of a NCT, a HV filter, a coupling network with discharge free capacitor, and a low noise wideband amplifier. Test on a low-voltage isolation transformers with a range of AC voltage, we could detect a PD pulse of about 0.53 pC at 707 V with the sensitivity of 28 mV/pC.

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