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Design of a PD Measurement System for Low-voltage Electrical Devices

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ABSTRACT : *In this paper, we present the design and fabrication of a high sensitive partial discharge(PD) measurement system detect charge below 1 pC for dielectric testing of low-voltage electric appliances. The PD measurement system was composed of a noise cut transformer, a coupling network with discharge free capacitor, a low-noise wideband amplifier, and an associated electronics. A shielding enclosure was also designed 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. In a laboratory test on a low-voltage induction motor, we could detect 0.5 pC at the applied voltage of AC 660 V_{peak}.*

KEY WORDS : Partial discharge(PD), Dielectric testing, PD Measurement system, Discharge free capacitor, Coupling network, Shielding enclosure, low cut-off frequency

1. Introduction

Transient overvoltages in electrical and electronic appliances 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][2][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.

In addition, the withstand voltage test (WVT) being carried out at the step of manufacturing or delivery for low-voltage electrical and electronic appliances applies relatively high voltage over 1 kV, and this could stimulate degradation of insulation. It is therefore necessary to adopt the PD testing for low-voltage electrical and electronic appliances by detecting as low as charge below 1 pC [9][10][11][12][13].

In this paper, we represent a PD measurement system for low-voltage electric appliances. 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 (-3 dB), and a sensitivity of 10 mV/pC for a test sample. In a laboratory test on a low-voltage induction motor, we could detect 0.5 pC level of partial discharge at the applied voltage of AC 660 V_{peak}. I am sure that more study for the reduction of amplifier noise and conduction noise from the earth line will realize a detection of 0.1 pC charge.

2. PD Measurement system

2.1 Design and Fabrication

PD measurement systems for testing low-voltage electric appliances 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

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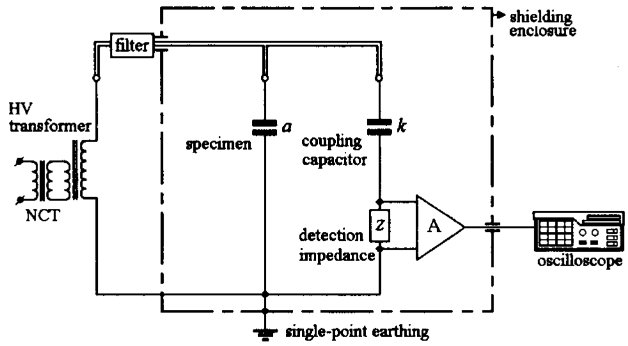
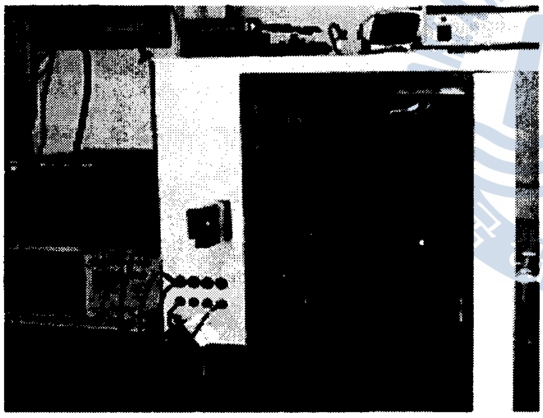
was consisted of a noise cut transformer (NCT), a high voltage (HV) filter, a coupling network with a discharge free coupling capacitor, a detection impedance, and a low noise amplifier as shown in Fig. 1. The HV filter was adopted to attenuate high frequency noises conducted through test voltage source.



(a) Configuration



(b) Photograph

Fig. 1 Fabricated PD measurement system.

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.
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.

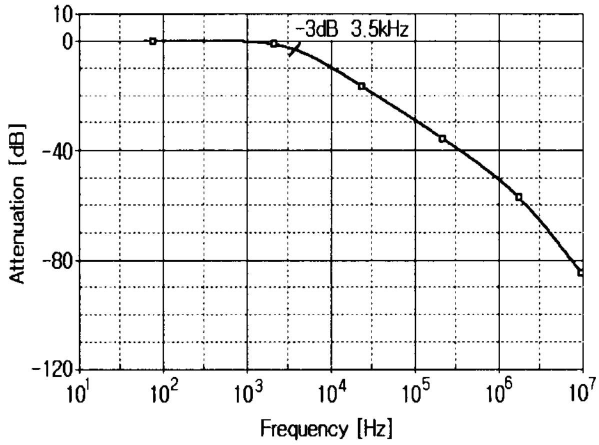


Fig. 2 Frequency response of the HV filter.

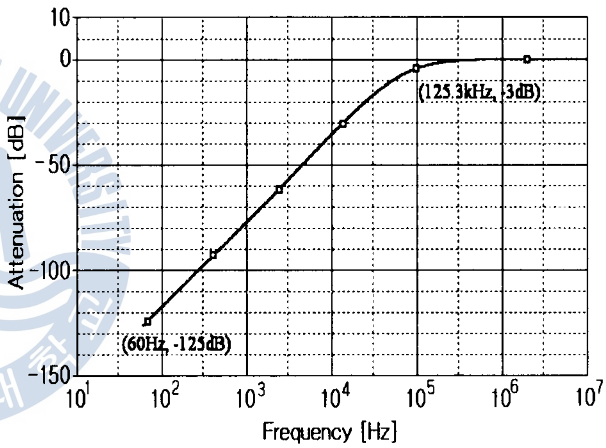
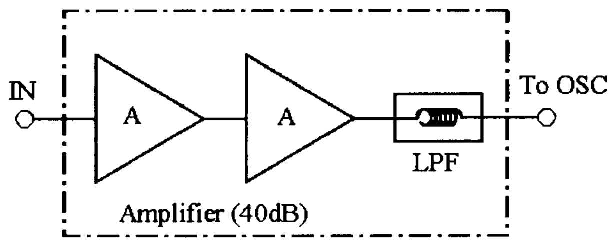


Fig. 3 Frequency response of the coupling network.

A low noise wideband amplifier is needed to measure a small PD pulse. We designed a two-stage amplifying circuit using a high speed and low noise operation amplifier as shown in Fig. 4. The noise level of the amplifier is about , and the gain is 40 dB.



(a) Circuit

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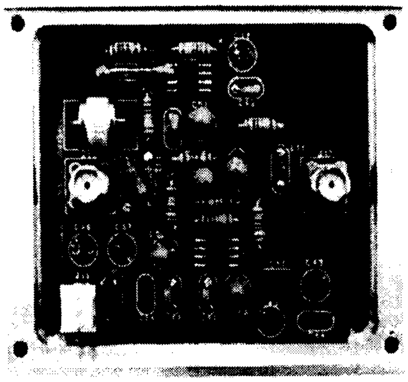
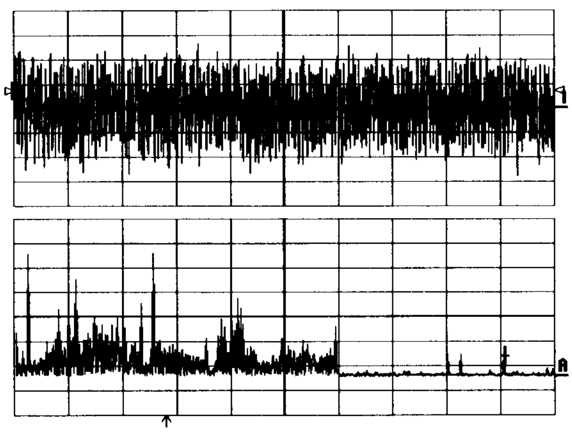


(b) Photograph

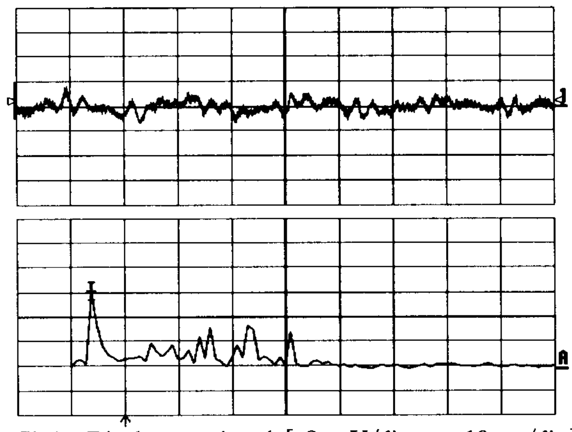
Fig. 4 Prototype amplifier.

As we explained before, the PD measurement system was tested to noise interference because the sensitivity is influenced by noise level. Figure 5 represents the noise level and spectrum measured at output of the amplifier when the maximum test voltage of 5 kV is applied. In the test set-up, the peak noise level was 1.25 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.



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

(a) Door opened



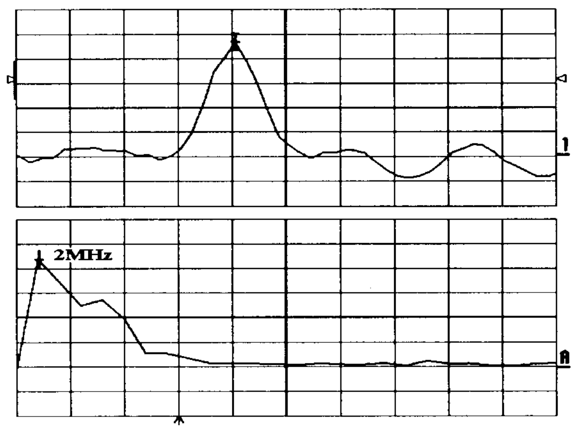
Ch.1 : Discharge signal [2 mV/div, 10 us/div]
Ch.A: FFT result [100 uV/div, 100 kHz/div]

(b) Door closed

Fig. 5 Noise level of the PD measurement system.

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, GmbH) between windings and iron core of a low-voltage induction motor. Figure 6 shows typical response waveforms of the system for the calibration pulse injection. The magnitudes of measured voltages to the pulses were 9.2 mV for 1 pC and 100 mV for 10 pC, respectively.



Ch.1 : Calibration pulse[2 mV/div, 50 ns/div]
Ch.A: FFT result [500 uV/div, 5 MHz/div]

(a) 1 pC

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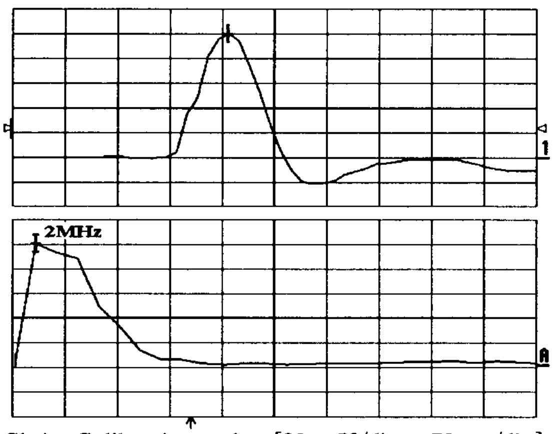


Ch.1 : Calibration pulse [20 mV/div, 50 ns/div]
Ch.A: FFT result [5 mV/div, 5 MHz/div]

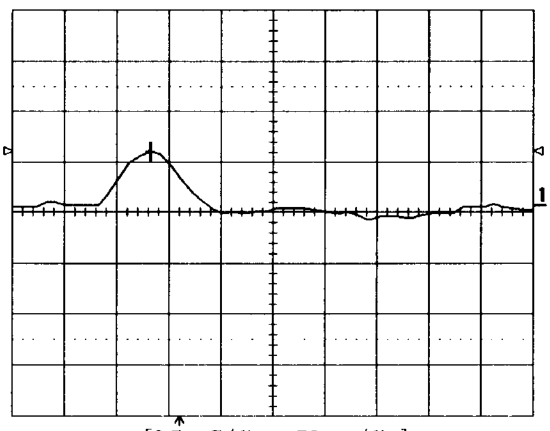
(b) 10 pC

Fig. 6 Calibration pulses and its FFT analysis.

The sensitivity to the positive and negative polarity of injection pulses were same in ranges from 1 pC to 50 pC. In the calibration, the PD measurement system can detect PD pulse as small as 0.5 pC (5 mV) with the error of 8 % considering noises and resolution of the A/D converter use.

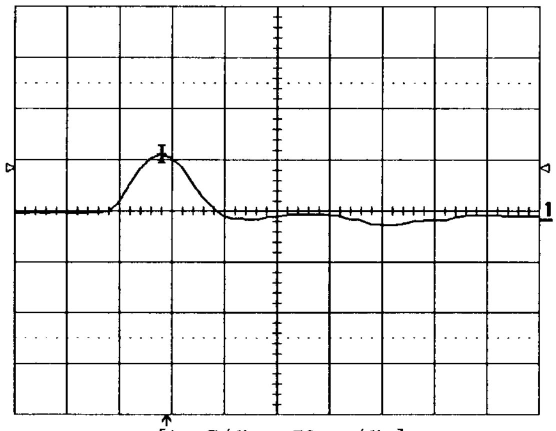
3. Measurements and Analysis

After calibration, we applied AC test voltage between winding and enclosure of the low-voltage induction motor. The first PD pulse was detected at the AC test voltage of 660 V_{peak} as shown in Fig. 7.



[0.5 pC/div, 50 ns/div]

(a) AC 660Vpeak



[1 pC/div, 50 ns/div]

(b) AC 1,000 Vpeak

Fig. 7 Detected PD waveforms.

The magnitude of the pulse was 5.33 mV and it is almost equivalent to 0.53 pC in apparent charge. Apparent charge increase with increasing test voltage, and was about 1.28 pC at 1,000 V_{peak}

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 shielding 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 paper, we carried out a study on the design and fabrication of a high sensitive PD measurement system. The system can detect charge below 1 pC to apply PD testing to low-voltage electric appliances. The PD measurement system was consisted of a NCT, a HV filter, a coupling network with discharge free capacitor, and a low noise wideband amplifier. Test on a low-voltage induction motor with a range of AC voltage, we could detect a PD pulse of about 0.5 pC at 660 V_{peak} by the PD measurement system.

Measurement of 1 pC charge was possible in a laboratory test, however I think that more studies on the earth system is needed for industrial use.

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