News From Japan

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Development of Antenna-Type Partial-Discharge Testers for Coils

Power electronics have been playing a big role in many fields of our daily lives. However, as has been well known, at least among high voltage electrical insulation engineers for these two decades, this situation brings about a drastic increase in the risk of partial discharges (PDs). That is, compared with ac voltages with sinusoidal wave shapes at frequencies of 50 or 60 Hz, voltages fed from or induced by power electronic circuits or devices such as converters and inverters contain much shorter fronts and tails in their waveforms. In addition, such devices generate surge voltages with higher amplitudes. Therefore, as power electronic devices are used more and more widely, PDs could be induced much more frequently. This, in turn, increases the importance of monitoring the occurrence of PDs in electric power apparatus such as transformers and rotating machines like motors and generators. However, it is in general difficult for conventional PD testers to monitor PDs generated by such converter-fed voltages. With this background, ECG Kokusai Co., Ltd., Tokyo, has developed a variety of PD testers. In this short article, two of them are briefly introduced.

First, the development of a PD tester for impulse voltages is outlined. The tester is assumed to be used in combination with a patch antenna for monitoring PDs occurring at remote positions. Patch antennae are one of the permitted PD detection techniques in IEC 60034–27–5 [1], just published in a project headed by Ken Kimura. A patch antenna is a kind of printed microstrip antenna and is suitable for the detection of electromagnetic waves induced by PDs, since this type of antenna has a relatively narrow bandwidth and a wide directional window. Mr. K. Umezu of ECG Electronic (now ECG Kokusai) raised a question concerning the behavior of a patch antenna in electromagnetic waves. For responding to this question, Professors Y. Shibuya and S. Matsumoto of Shibaura Institute of Technology, their students, and researchers in Mitsubishi Electric conducted numerical calculations and demonstrated that a patch antenna can be used for detecting PDs occurring inside a coil [2]. The two professors and Umezu further demonstrated that a PD sensor equipped with a patch antenna can really detect PDs occurring in windings of an actual motor, numerically and experimentally, if it is not shielded by a metal frame [3]. As reported in this column, "News from Japan," Mitsubishi Electric developed a patch antenna for detecting PD in 2009 [4] and began the installation of a PD monitoring system using the antenna in rotating machines in 2010 [5].

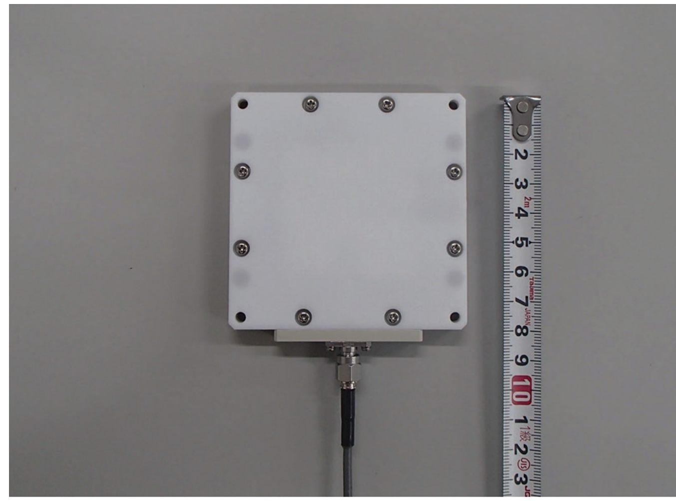

Figure 1. Patch antenna to be used in combination with a tester "DWX-05PD."

A patch antenna for the detection of PDs is designed so that it exhibits a narrow bandwidth with the highest sensitivity at a specific frequency, typically, in the L-band that ranges from 1.0 to 2.0 GHz. Figure 1 shows a photograph of a patch antenna, which is used in combination with a tester "DWX-05PD." Figure 2 shows a standard configuration of a PD monitoring system, consisting of a PD tester, a patch antenna, cables, and a coil to be tested. In Figure 2, as a PD tester, DWX-05PD is shown. Here, DWX-05PD can generate variable impulse voltages with peaks from 500 to 5000 V with a step of 100 V. Similar to instruments made by Baker Instruments and Schleich Test Technologies, shorted turns in the coil are identified by comparing the voltage waveform measured with a "master" waveform.

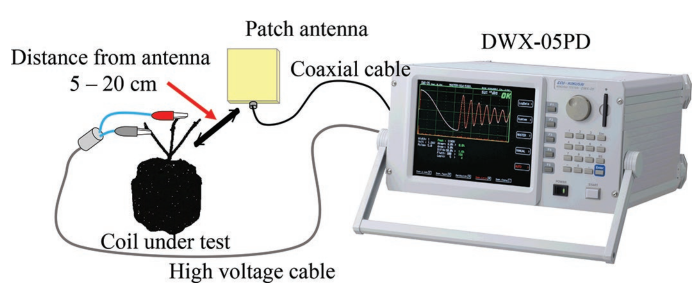

Figure 2. Standard configuration of the PD monitoring system, consisting of a PD tester, a patch antenna, cables, and coils to be tested.

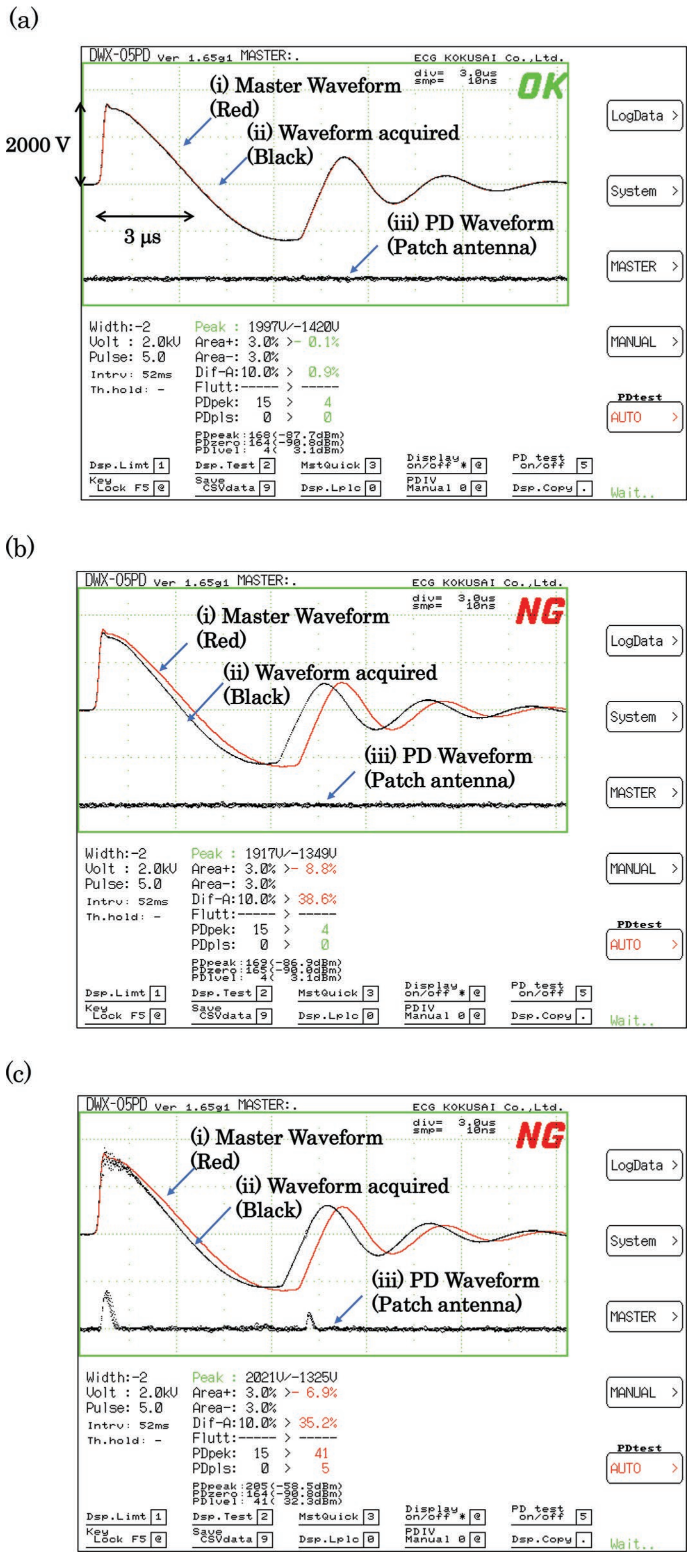

Figure 3. Signal waveforms that would be acquired for various coils. (a) Sound coil with no defects. Waveforms (i) and (ii) overlap with each other. (b) Coil with an electrically short circuit between two turns. (c) Coil with the occurrence of PDs.

Here, the master waveform is the theoretically correct voltage waveform that should be observed by the system when the coil being tested has no defects. For the comparison, much attention is focused on the difference in the area surrounded by the waveform and the abscissa between the two waveforms and other parameters.

If the coil has no shorted turns, we would have signal waveforms shown in Figure 3(a). Here, the voltage waveform acquired by the system, which is labeled as '(ii) Waveform acquired' agrees perfectly with the master waveform (i). The voltage waveform (iii) in Figure 3(a) is a typical signal measured by the patch antenna, where no pulsive bursts that indicate the occurrence of PDs are seen. In this case, we can judge that the coil has no appreciable defects. If the coil has an electrical short circuit between turns, waveforms (i) and (ii) can be recognized as different as shown in Figure 3(b). Furthermore, when PDs occur in the coil, the waveform measured by the patch antenna becomes typically similar to waveform (iii) shown in Figure 3(c). Consequently, these three graphs clearly indicate that we can monitor whether the coil has shorts or not, and if PD is present. Here, the sampling rate of DWX-05PD

Table 1. Important specifications of DWX-05PD.

Impulse voltage	
Range of inductance	10 µH or higher (recommendation)
Sampling speed	8 bit / 10 ns (100 MHz)
Sampling memory	512 byte
Impulse voltage	300–5000 V (100 V step)
Output capacitance, Max energy	10 nF, 0.12 J
Input impedance	5 MΩ
PD detection	
Microwave sensor	Narrow-band plane patch antenna
Detection sensitivity	−90 dBm @ the input port
Antenna size	W = 80 mm, H = 80 mm, D = 10 mm;
Cable length between main parts	Cable length = 2 m
Displays and others	
Screen display	640 × 400 8.4 inch TFT color liquid crystal
Display size of waveforms	512 × 256
Size	W = 342 mm, H = 188 mm, D = 355 mm; Weight = 12 kg
Operating conditions	0–40°C, Power supply 100–240 V ± 5%

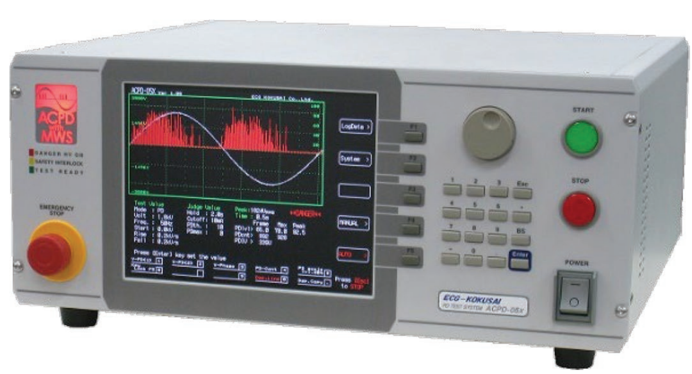

Figure 4. PD tester ACPD-05X.

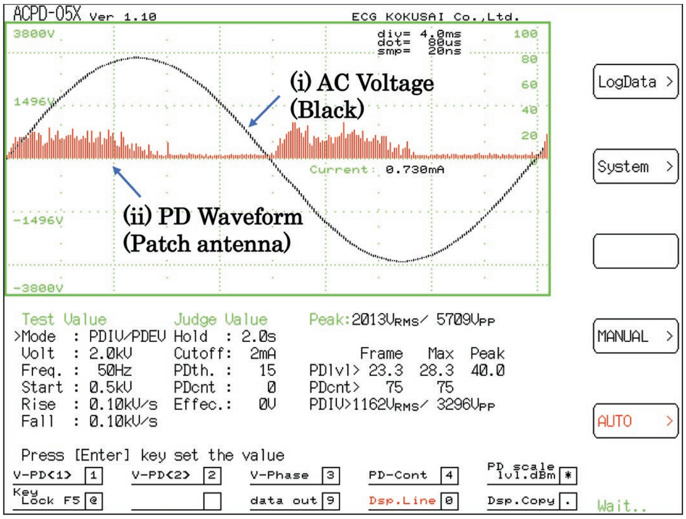

Figure 5. Typical result of the PD detection using ACPD-05X.

is 100 MHz. As a result, the PD display becomes an envelope of many PD signals like waveform (iii) in Figure 3(c). It is indeed true that we need much higher sampling rates to monitor individual PD signals for research purposes, but the sampling rate of 100 MHz is enough to monitor the occurrence of PDs. In addition, by adopting the low sampling rate, the device cost can be suppressed.

Table 2. Several important specifications of ACPD-05X.

Power supply	Test voltage and capacity	Maximum 5 kVrms 500 VA
	Minimum step	4 Vrms
	Frequency	50 to 200 Hz with a step of 1 Hz
Partial discharge detection	Sensitivity	−90 to −30 dBm in 100 levels
	Minimum detectable charge	50 pC
Current disruption		1–25 mA @ a step of 1 mA or 100 mA
General	Power supply	AC 100–250 V ± 5%, 50/60 Hz 10 A
	Temperature/humidity	23 ± 5°C 20–80%RH
	Size/Weight	W430 × H177 × D442 mm, 22 kg

This PD monitoring system can measure the PD inception voltage (PDIV), the PD extinction voltage (PDEV), and the repetitive PDIV (RPDIV) of an insulation system as required by IEC 60034–27–5 [1], since the DWX-05PD can repeat the application of impulse voltage according to a program installed beforehand. The sequential pattern of raising and lowering the voltage, the number of repetitions of voltage application, the detection level of PDs, and so on can be altered. Table 1 shows other important specifications of DWX-05PD. Furthermore, the tester can be used to check whether a coil system would pass or fail the PD tests prescribed in an international standard IEC60034–18–41:2014 as to the electrical insulation's ability to withstand so-called converter-fed voltages if we use a repetitive impulse voltage generator IPX-05BP [6]. The tester can provide enough energy to test stator windings with winding capacitance less than 4nF if we regard the windings as a capacitor.

Figure 4 shows a PD tester, ACPD-05X, which can generate 50/60 Hz ac high voltages. The tester is equipped with an ac power source with a capacity of 500 VA that can output an ac voltage of 5 kV_{rms}. The tester is also equipped with a high-speed A/D converter and a 16-Mbit wave memory. With this PD tester and the above-mentioned patch antenna, it can conduct real-time PD monitoring of coils under power-frequency ac voltages, typically as shown in Figure 5. Table 2 shows several important specifications of ACPD-05X.

This article was completed in cooperation with Mr. Kiyoshi Umezu of ECG Kokusai Co., Ltd., Tokyo.

References

[1] IEC 60034–27–5:2020 Rotating electrical machines—Part 27–5: Off-line partial discharge tests on winding insulation of rotating electrical machines during repetitive impulse voltage excitation.

[2] Y. Shibuya, S. Matsumoto, M. Tanaka, H. Muto, and Y, Kaneda, "Electromagnetic Waves from Partial Discharges and their Detection using Patch Antenna", IEEE Trans. Dielectr. Insul., Vol. 17, No. 3, pp. 862–871, 2010.

[3] Y. Shibuya, S. Matsumoto, T. Konno, and K. Umezu, "Electromagnetic Waves from Partial Discharges in Windings and Their Detection by Patch Antenna", IEEE Trans. Dielectr. Insul., Vol. 18, No. 6, pp. 2013–2023, 2011.

[4] Y. Ohki, "News from Japan", IEEE Electr. Insul. Mag., Vol. 25, No. 3, pp. 60–61, 2009.

[5] Y. Ohki, "News from Japan—Online Insulation Monitoring System for Rotating Machines", IEEE Electr. Insul. Mag., Vol. 35, No. 5, pp. 47–49, 2019.

[6] Y. Ohki, "News from Japan—Development of an Innovative Repetitive Impulse Voltage Generator", IEEE Electr. Insul. Mag., Vol. 34, No. 5, pp. 50–53, 2018.