News From Japan

Yoshimichi Ohki

Online Insulation Monitoring System for Rotating Machines

The necessity of diagnosis and monitoring of electrical insulation integrity has been steadily growing since many industries want to make the operational period of power apparatus as long as possible. Furthermore, natural renewable energy resources such as solar power and wind power are recently growing rapidly. However, the outputs from such renewable energy resources tend to fluctuate significantly. To balance such fluctuating outputs with the demands, thermal power generation is subjected to rapid load changes and frequent start-and -stop operations more often than before. This would cause severe degradation of electrical insulation in steam turbine generators. From these backgrounds, the importance of insulation monitoring has been increased significantly.

Partial discharges (PDs) are one of the major concerns to both manufacturers and users of high voltage power equipment. In the "News from Japan" column of the May/June 2009 issue [1], it was reported that Mitsubishi Electric Corporation, Tokyo, developed a patch or microstrip antenna suitable for an online PD monitoring system for high voltage rotating machines [2]. The present short article introduces the installation of the antenna to an online monitoring system. The PD detection system using the microstrip antenna is the same as that reported in [1, 2], although several system modifications and PD criteria to trigger an alarm have been added.

Figure 1 shows a schematic diagram of the system, which consists of two antennas, a PD detector, and a monitoring personal computer (PC). The antennas have a narrow bandwidth around 1.8 GHz, which is a typical characteristic frequency for detecting PDs occurring in the vicinity of stator coils, so that the antennas can catch only PD signals selectively among various noises. The antennas are set on the inside surface of the generator enclosure, away from the edges of a stator coil where a high voltage is applied. Therefore, no bad effects are exerted on the insulation of the stator coil. Furthermore, the removal of a rotor is not needed to install the antenna system into an existing generator. When PD signals are detected by one of the two antennas, they are transported to the PD detector and noise is removed. Then, the signals are converted to digitized data to send them to the monitoring PC. When the PD intensity reaches a certain preset value, an alarm will be issued. Because the PD signals can be transmitted through the Internet, the insulation condition can be monitored in a remote site.

Figure 2 shows a test bar, which simulates a real stator coil in a turbine generator. The arrangement of a PD detection system is also shown. Note that the length in Figure 2 is in mm. The specifications of the test bar, including the materials and dimensions of the coil conductor, mica tape, semi-conductive layer, and stress relief layer are the same as those of a real stator coil. Using this test bar, researchers in Mitsubishi did several tests to ensure that the antenna system worked as a PD monitoring tool. The tests include those to examine the effects of insulation damages on PD characteristics and those to know possible locations and the temperature dependence of PDs.

As an example, the test to examine the effect of abrasion of insulation surface was conducted as mentioned below. That is, stator coils in a turbine generator are always subjected to electromagnetic vibrational forces with a potential risk that their surfaces are abraded. Figure 3 shows a cross-section of the test bar used to examine the above point. Two metal plates were put on the test bar to simulate the stator core which is always at the ground potential during operation. Part of the main insulation

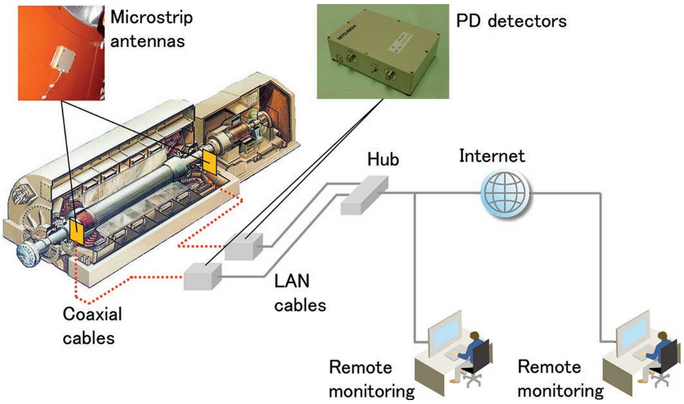

Figure 1. Schematic diagram of a monitoring system to confirm the status of electrical insulation in turbine generators.

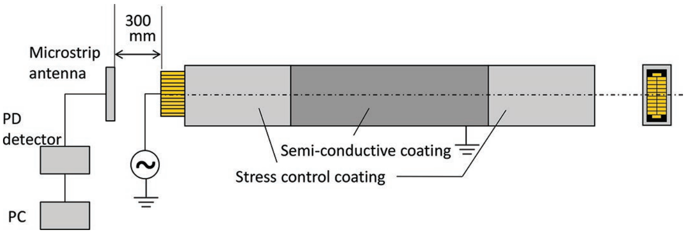

Figure 2. Test bar sample, which simulates a real stator coil in a turbine generator.

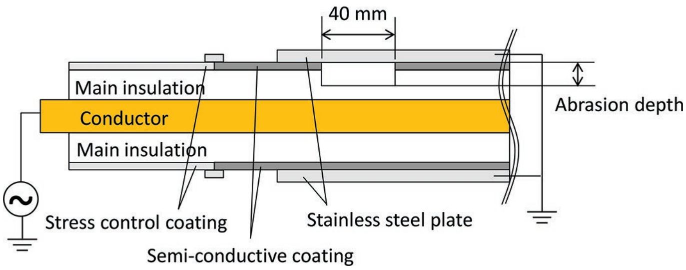

Figure 3. Cross-section of the test bar sample used for examining the effects of a planar abrasion of insulation.

under one of the two metal plates was abraded, as shown in Figure 3, to a depth of 6, 30, or 52% of the total thickness of the main insulation and the semi-conductive layer.

Figure 4 shows the result. In this case, the surface was abraded by 52% as a result of planar abrasion. An ac voltage of 10.5 kVrms was applied to the upper metal plate. The intensities and voltage phases of PDs were recorded for 5 s. Figure 4(a) shows the relation between the PD intensity and the PD phase. Here, the intensity is represented by a unit of dBm defined as 10log10P, where P is the quotient of the PD power received by the antenna, divided by 1 mW. On the other hand, the phase is defined as the angle θ of the sinusoidal ac voltage, at which the PD was detected. Figure 4(b) shows the relation between the number of occurrences of PDs and their intensities.

It is indicated from Figure 4(a) that PDs occur in relatively narrow phase ranges, near 45° and 135°, where the applied voltage is approaching a positive or negative maximum, showing nearly square intensity-phase patterns. Figure 4(b) indicates that about 1.5×104 PDs with intensities around -90 dBm occurred in the measurement period of 5 s. In the monitoring system, the occurrences of 300 PDs in 5 s or 60 pps (PD pulses per second) was used as a judgment criterion. This means that PDs with an intensity of -72.1 dBm is critical. Such a critical intensity of PD is calculated automatically by software for each measurement, and the temporal change in critical intensity can be used as a measure for periodical maintenance of generators. Here, the above values are for 60 Hz ac voltages and the critical number of PD occurrences is to be changed in proportion to the frequency; 50 pps for 50 Hz ac in the above-mentioned case.

Figure 5 shows the dependence of the PD intensity (at 60 pps) on the depth of the planar abrasion. It is clearly indicated that PDs can be detected when the abrasion reaches 30% of the insulation thickness and that the PD intensity increases abruptly when the abrasion becomes 52%. This means that the abrasion of the main insulator of a generator can be monitored by watching the intensity and the number of PDs.

The researchers in Mitsubishi conducted similar experiments using various potential PD sources like concave hollows and embedded metal plates in the main insulation. They also examined the positions where PDs occur. For this purpose, they replaced the upper electrode shown in Figure 3 by a transparent one, consisting of a glass plate with a vacuum-evaporated metal

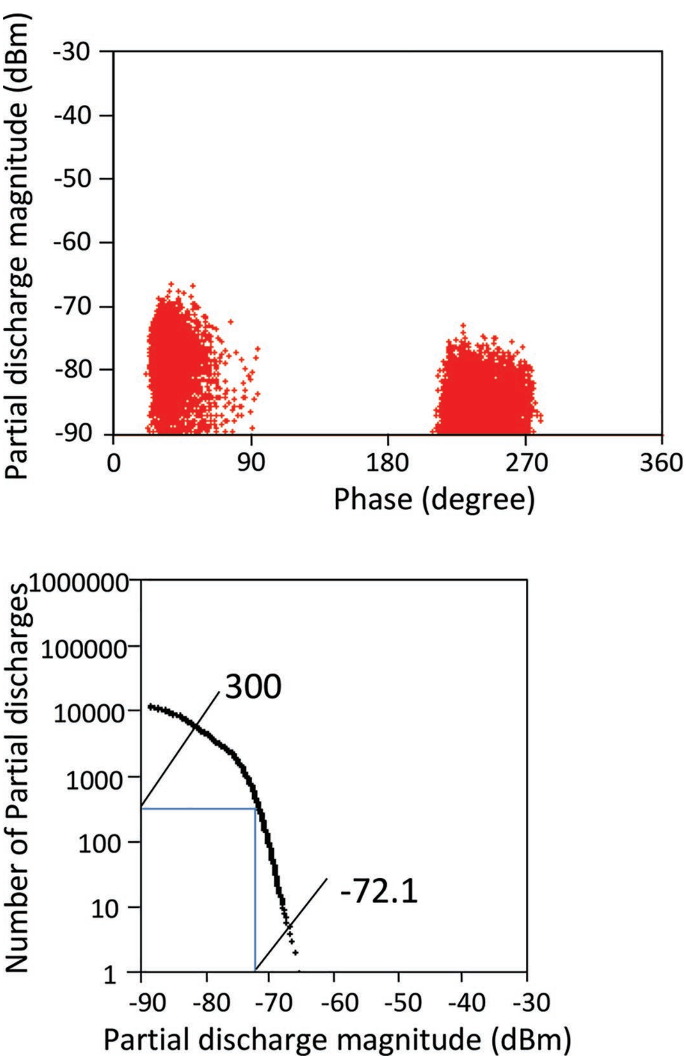

Figure 4. Examples of PD measurement results; (a) Phase-resolved intensity, (b) Intensity distribution of the PDs, recorded for 5 s.

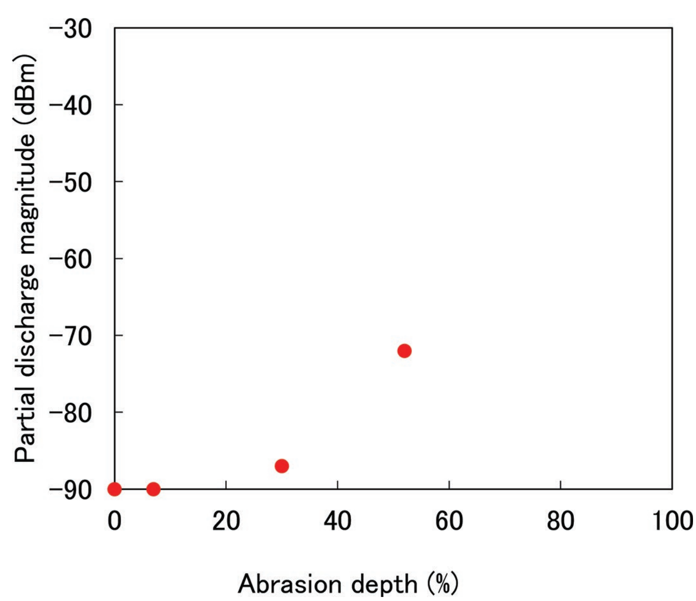

Figure 5. Relation between the PD intensity and the depth of the planar abrasion.

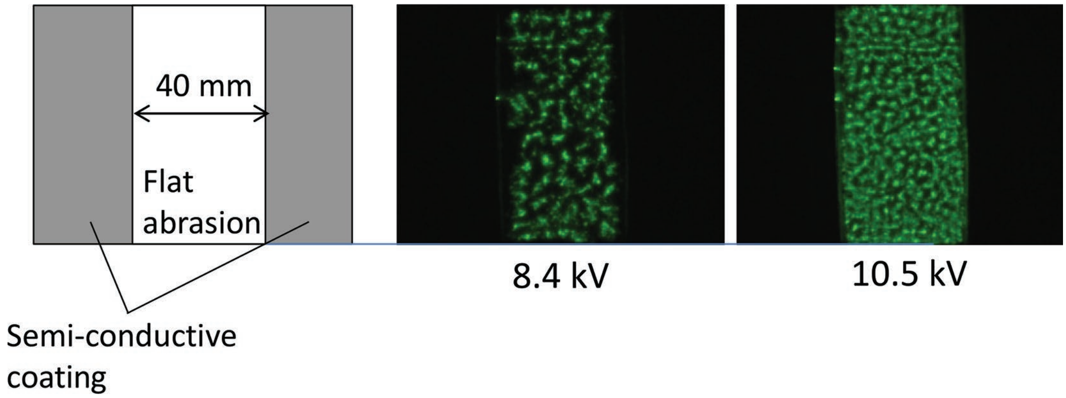

Figure 6. Photoluminescence images observed when ac 8.4 or 10.5 kV was applied to the planar abraded hollow shown in the leftmost column.

electrode. They observed weak luminescence induced by PDs using a digital camera with an image intensifier for 0.5 s.

Figure 6 shows the luminescence images observed when ac voltages of 8.4 and 10.5 kVrms were applied to the transparent electrode on a rectangular hollow. In this case, the depth of the hollow was 52% of the insulation thickness with the top semi-conductive layer inclusive. If the hollow is planar, the electric field in the hollow would be uniform. Therefore, PDs are induced almost uniformly, which is consistent with two figures in Figure 6.

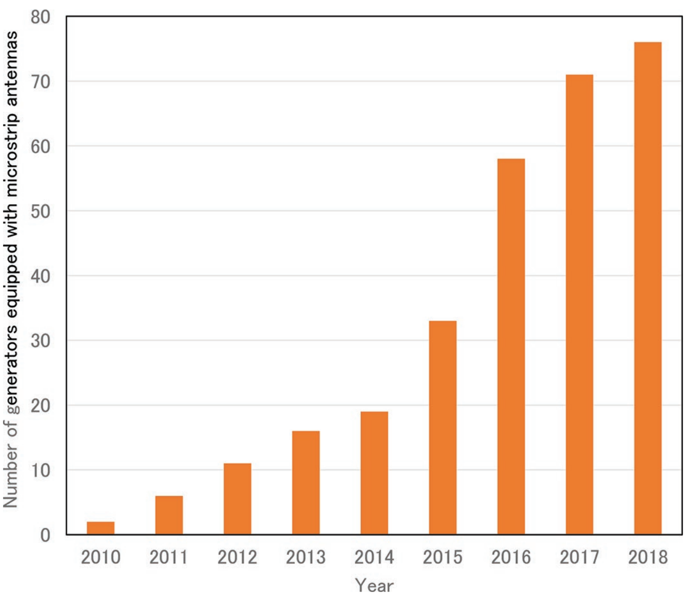

Figure 7. Cumulative number of installations of the PD monitoring system up to January 2019.

Mitsubishi has installed 76 sets of the insulation monitoring systems up to January 2019 (Figure 7) in air-cooled and hydrogen-cooled turbine generators. The world's first hydrogen-cooled 900 MVA turbine generator, which was introduced in this News from Japan column in the January/February 2018 issue is also equipped with this system [3].

This article was completed in cooperation of Mr. Shinichi Okada and Dr. Hirotaka Muto of Mitsubishi Electric Corporation.

References

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

[2] H. Muto, Y. Kaneda, H. Aoki and O. Hamamoto, "On-line PD monitoring system for rotating machines using narrow band detection of EM wave in GHz range", Int. Conf. Condition Monitor. Diagn., pp.1093-1096, Beijing, China, 2008.

[3] Y. Ohki, "News from Japan – Development of a High-Performance Indirectly Hydrogen-Cooled Turbine Generator", IEEE Electr. Insul. Mag., Vol.34, No.1, pp.61-63, 2018.