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ON-LINE PD TESTING ON LOWER-VOLTAGE ROTATING MACHINES USING HIGH SENSITIVITY CAPACITORS

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Summary

On-line partial discharge (PD) measurement is a recognized tool to assess the condition of stator winding insulation of rotating machines under normal machine operation. 80 pF high voltage capacitors have been widely used as a sensor for PD measurement in rotating machines for more than ten years. However, its detection sensitivity with respect to various types of rotating machines has not been fully investigated.

As we know, PD activity in lower-voltage (e.g. 3.3 kV-6.9 kV) rotating machines is usually lower than that in higher-voltage rotating machines. Therefore, PD sensors with a higher sensitivity are required to detect relatively small PD pulses in lower-voltage rotating machines. This paper presents theoretical analysis, laboratory tests and field test experience to compare the sensitivity of 80 pF capacitors and 500 pF capacitors for on-line PD measurement in lower-voltage rotating machines. The PD detection sensitivity is studied by characterizing the frequency bandwidth of various capacitors and the frequency spectrum of a PD pulse. The relationship between the frequency characteristics of the various capacitors and the PD pulse indicates that the capacitor with a higher capacitance can detect more energy of the PD pulse, hence increasing PD detection sensitivity. The field test on a 6.9 kV operating motor verifies that the 500 pF capacitor can detect the PD activity which the 80 pF capacitor was not able to. A comparison of statistics analysis of a number of motors installed with 500 pF capacitors and 80 pF capacitors shows that 500 pF capacitors detect more PD activity than 80 pF capacitors.

This investigation concludes that 500 pF capacitors have higher sensitivity in PD measurement in rotating machines than 80 pF capacitors. 500 pF capacitors have been installed on more than forty rotating machines in utilities and petrochemical industries.

Keywords: *Partial Discharge – Stator Insulation – Rotating Machine – On-line Insulation Diagnosis.*

1. Introduction

On-line partial discharge (PD) monitoring of rotating machines is a recognized tool to assess the condition of stator winding insulation under normal machine operation. High voltage capacitors are one of the PD sensors most widely used for on-line PD measurement in rotating machines. High voltage capacitors with a capacitance of 80 pF have been used for measuring PD in rotating machines for many years. However, what capacitance values can provide better PD detection sensitivity is an interesting question.

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As we know, PD intensity decreases with the reduction of voltages applied to insulation systems. Hence, lower-voltage rotating machines usually have lower PD intensity than high-voltage rotating machines. The insulation breakdown voltage of lower-voltage rotating machines is also relatively low since the insulation is thinner. It has been found that the 80 pF capacitor is not able to detect partial discharges in some lower-voltage (e.g. 3.3 kV – 6.9 kV) rotating machines due to weak PD activity in these machines. Therefore, a more sensitive sensor than the 80-pF capacitor is required to reliably detect PD activity in lower-voltage rotating machines.

Field experience has shown that partial discharge activity may not be detected or may be detected with small PD signals using the 80 pF capacitor. PD measurements using 80 pF capacitors could lead to a false conclusion in some cases: there is no partial discharge activity in lower voltage motors and generators, despite the fact that partial discharge activity does exist. The problem is that the detection sensitivity of the 80 pF capacitor is not high enough to detect partial discharge activity in lower voltage rotating machines.

This paper presents theoretical analysis, laboratory tests and field test results to compare the detection sensitivity of the 80 pF capacitor and the 500 pF capacitor.

2. Relationship between PD detection sensitivity and frequency characteristics of the HV capacitors

The frequency bandwidth of the PD detection circuit has a significant impact on the detection sensitivity, since it determines how much of a PD signal can be acquired by the detection circuit. The frequency bandwidths of the 80 pF, 500 pF and 1000 pF capacitors terminated into 50 Ω are calculated and compared in Fig. 1. The frequency spectrum of the PD pulse is also displayed in Fig. 1 to show the relationship between PD detection sensitivity and frequency characteristics of the different capacitors.

Fig. 1 indicates that the lower the capacitance, the higher the cut-off frequency of the PD detection circuits. The -3 dB cut-off frequency of the different capacitors is listed in Table 2. The area underneath the PD frequency spectrum is equal to the signal energy of the PD pulse. The lower cut-off frequency of the frequency bandwidth of the capacitor covers more of the PD frequency spectrum, i.e. covers more energy of the PD signal. Hence, adequately increasing the capacitance of the capacitor can increase PD detection sensitivity by detecting more energy of the PD signal. That is why higher-capacitance capacitor can improve the PD detection sensitivity. In addition, attenuation of the PD pulse by the stator winding is smaller in the relatively lower frequency range [1] [2].

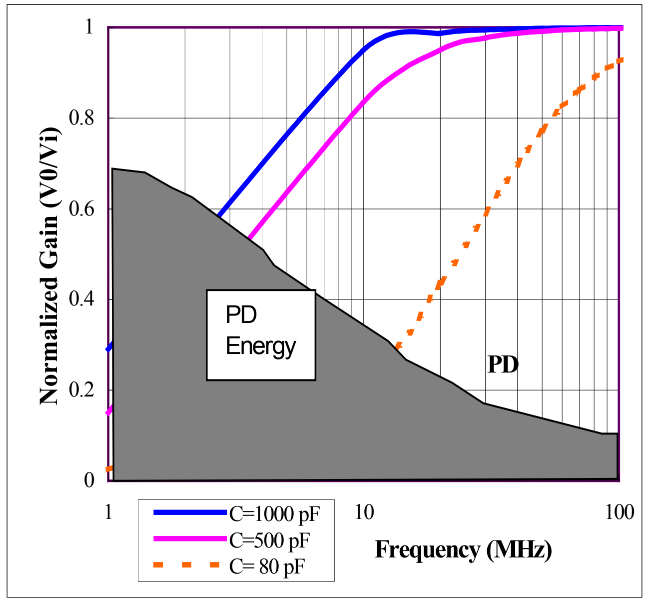

Fig. 1 Frequency bandwidth of the detection circuit with different capacitors.

Table 2 The lower cut-off frequency of the capacitors

HV capacitor	Cut-off frequency
80 pF	40 M Hz
500 pF	6.4 MHz
1000 pF	3.2 MHz

3. Laboratory tests of 80 pF and 500 pF capacitors

The detection sensitivity of the 80 pF and 500 pF capacitors was tested in a high voltage laboratory. A 500 pF capacitor and an 80 pF capacitor were connected to a 13.8 kV stator bar. A PDA instrument with a frequency bandwidth of 150 MHz was used to detect partial discharges simultaneously from the 500 pF capacitor and the 80 pF capacitor. The test results are shown in Fig. 2 and Fig. 3. By comparing Fig. 2 and Fig. 3, it is obvious that the 500 pF capacitor detects more PD activity in both the PD magnitude and the PD number.

This test result is consistent with that of PD bar screening tests [3]. The bar screening tests show that the 1000 pF capacitor detects more partial discharges than the 80 pF capacitor does. Although PD presents in various forms (e.g. internal PD, slot PD, surface PD), the frequency characteristics of all types of PD has, in general, the similar distribution as shown in Fig. 1. Therefore, capacitors with increased capacitance can detect more energy of the PD pulse regardless of PD types.

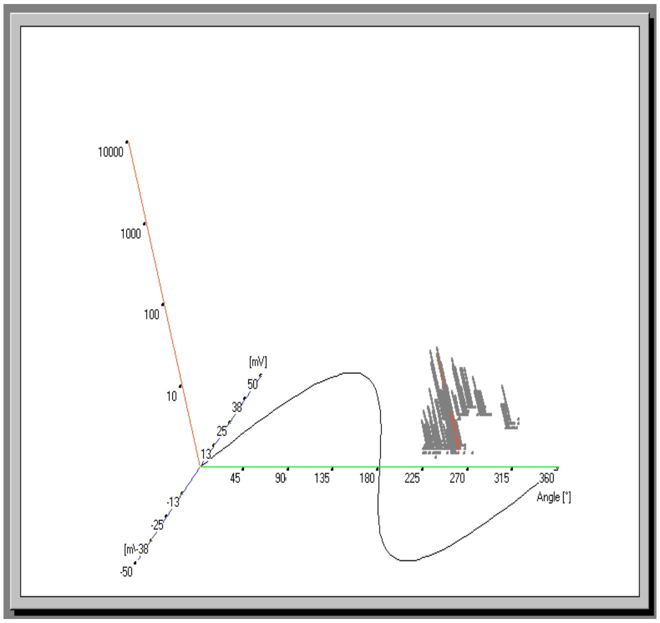

Fig. 2 PD detected with the 80 pF capacitor in the HV laboratory.

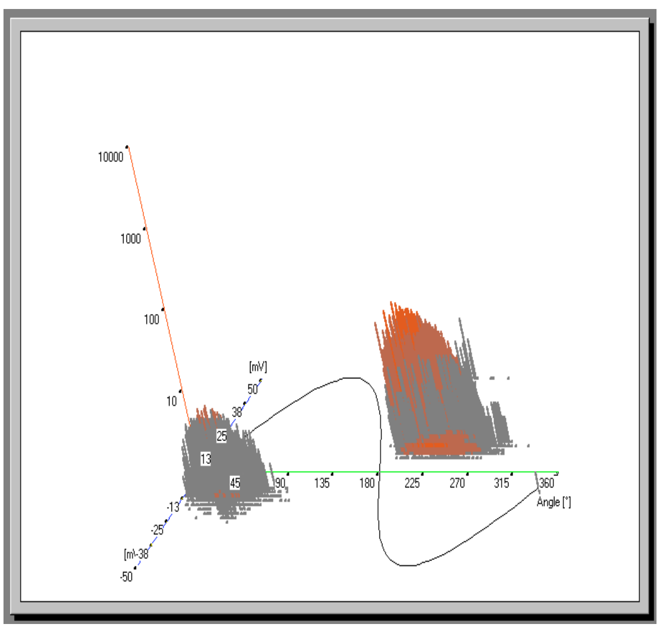

Fig. 3 PD detected with the 500 pF capacitor in the HV laboratory.

4. PD testing on operating machines

A 6.9 kV, 6000 HP motor operating at a turbo-generator power plant was tested to compare the detection sensitivity of the 80 pF capacitor and the 500 pF capacitor. The stator winding insulation of this boiler-feed-pump motor is epoxy mica. Initially, the 80 pF epoxy-mica capacitors were installed at the terminals of the motor. PD activity was not detected. As a trial test, the 80 pF capacitors were replaced by the 500 pF capacitors.

The PD test was performed with the same PDA instrument used in the HV laboratory test. The motor was operating under full load condition at a stator temperature of 55 °C. The PD phase distribution graph on phase A is shown in Fig. 4. Fig. 4 shows that a number of PD pulses were detected by the 500 pF capacitor without any signs of significant noise.

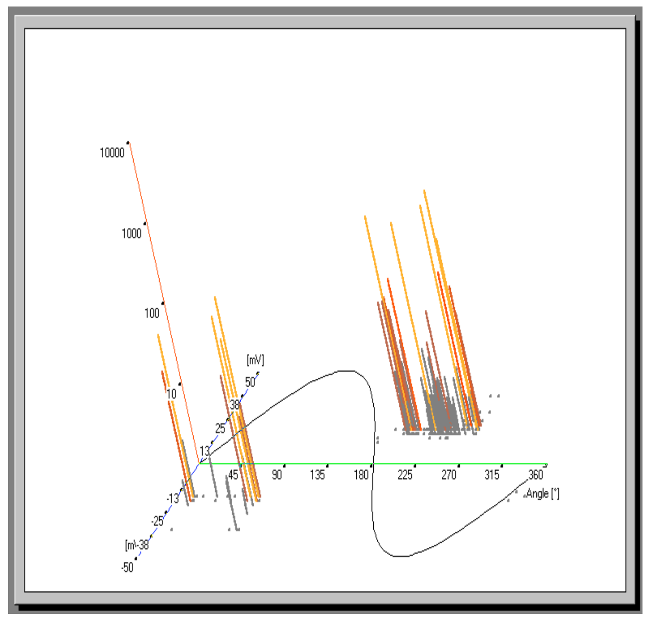

Fig. 4 PD phase distribution graph from the operating motor with the 500 pF capacitor.

Five months later, the 500 pF capacitors were replaced by the 80 pF capacitors to observe any difference in the PD readings. No events or repairs occurred on the motor between the change of the capacitors. PD testing was performed on the motor under the same operating conditions (e.g. the stator temperature of 56 °C) as before with the 500 pF capacitors. The same PD measurement instrument recorded almost no partial discharges with the 80 pF capacitors, as shown in Fig. 5.

Two months after the 80 pF capacitors had been installed, the 500 pF capacitors were again put back on the same motor to replace the 80 pF capacitors. Subsequent PD testing was performed using the 500 pF capacitor at the same voltage, load and temperature condition. Essentially the same PD activity as that obtained seven months earlier with the 500 pF capacitor was recorded, as shown in Fig. 6. This later test verifies that the 500 pF capacitor did detect more PD pulses than the 80 pF capacitor.

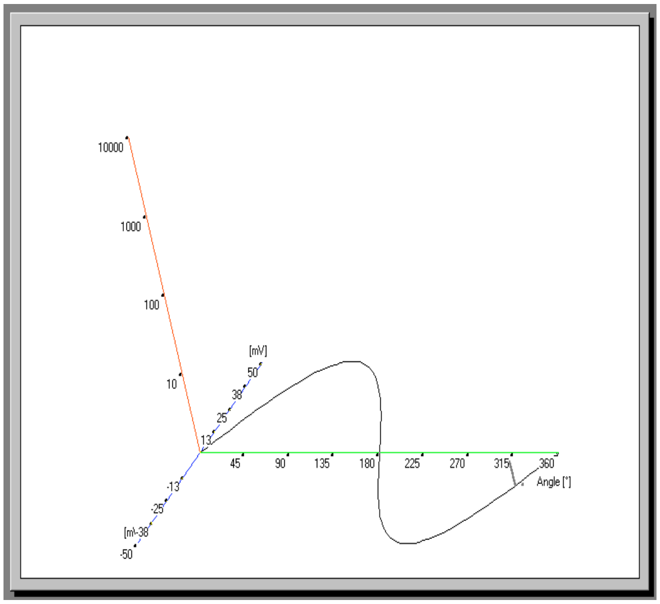

Fig. 5 PD phase distribution graph from the operating motor with the 80 pF capacitor.

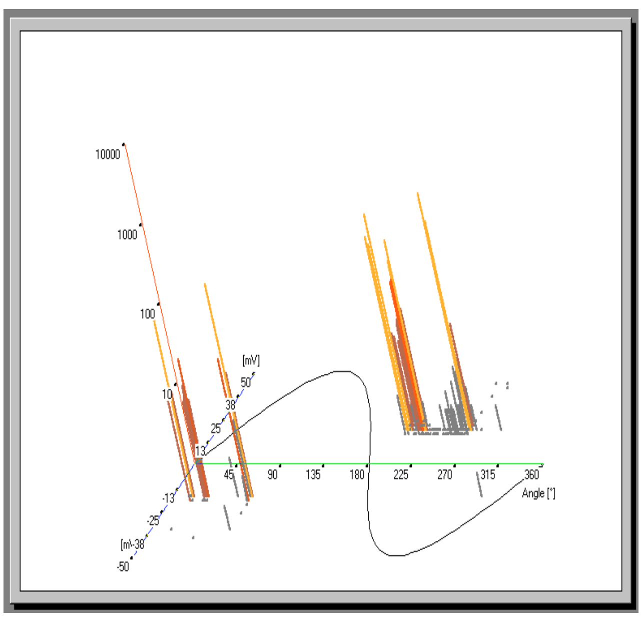

Fig. 6 PD phase graph obtained seven months after the previous test using the same 500 pF capacitor.

During the whole process of the replacement of the capacitors in the following order 80pF – 500 pF – 80 pF – 500 pF, no repairs were made on the motor. All of the above tests were performed under the same voltage, load and temperature condition. The repeated test results on the motor confirm that the significantly different PD readings between Fig. 4 and Fig. 5 resulted from the different capacitance of the capacitor.

Neither the positive pulses nor the negative pulses are predominant in Fig. 4 and Fig. 6. This indicates that there are partial discharges within the groundwall insulation of the stator winding. No corrective action can be taken for partial discharges within the groundwall insulation due to their internal nature. However, the progress of groundwall discharges can be monitored by on-line PD measurements to identify severe insulation deterioration. Once a significant increase of the PD activity is detected, an alarming may be given.

A comparison of statistics analysis of the PD readings from a number of motors (< 7 kV) installed with the 500 pF capacitors and with the 80 pF capacitors is shown in Fig. 7 and Fig. 8. The PD data were drawn from a large database of PD test results. NQN (Normalized Quantity Number) is a measure of the total energy released from partial discharges in a rotating machine and Q_{max} indicates the maximum PD magnitude.

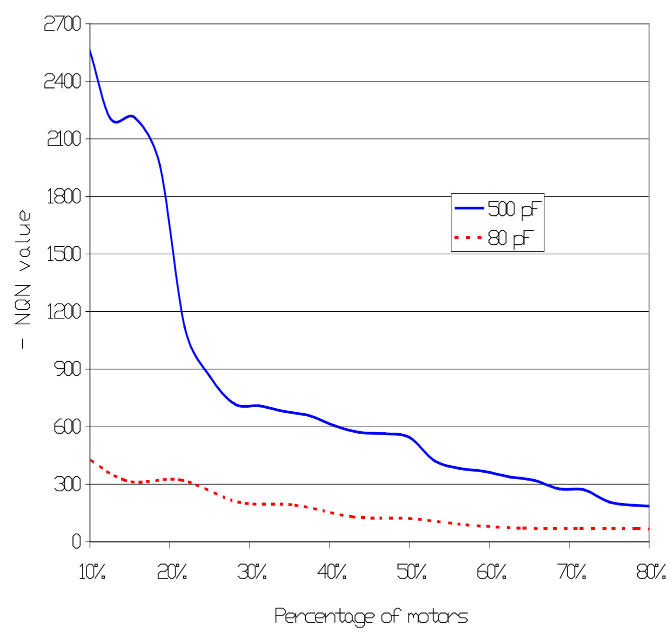

Fig. 7 A comparison of the statistics distribution of -NQN value acquired by the 500 pF and 80 pF capacitors.

The overall PD readings from the 500 pF capacitor are higher than those from the 80 pF capacitor in Fig. 7 and Fig. 8, indicating that the 500 pF capacitor detects more of the PD activity than the 80 pF capacitor. Fig. 7 shows that 80% of the motors installed with the 500 pF capacitor have a NQN value which is more than twice the value acquired by the 80 pF capacitor. Fig. 8 shows that 80% of the motors installed with the 500 pF capacitor have a Q_{max} value which is almost twice the value acquired by the 80 pF capacitor. This outcome is consistent with the frequency-characteristic analysis of the 500 pF capacitor and the 80 pF capacitor in Fig. 2. Fig. 2 shows that the 500 pF capacitor detects more energy of a single PD pulse in the frequency domain, while the NQN value in Fig. 7 shows that the 500 pF capacitor detects more energy of collective PD pulses than the 80 pF capacitor.

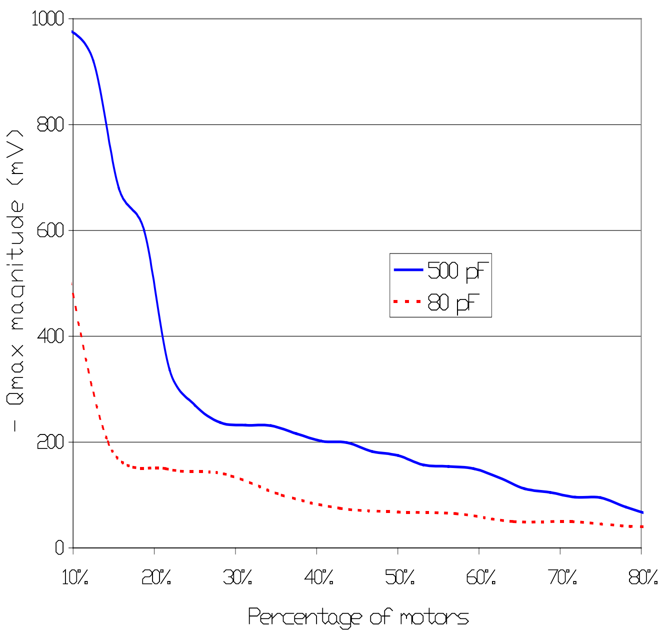

Fig. 8 A comparison of the statistics distribution of -Q_{max} value acquired by the 500 pF and 80 pF capacitors.

5. Conclusions

The frequency bandwidth of PD sensors is critical in determining the detection sensitivity of a PD measurement system. The HV capacitor with an adequate frequency bandwidth should be able to detect as many PD pulses as possible and yet prevent significant noise from entering the PD measurement system. The signal-to-noise ratio can be improved by increasing the PD signal portion (i.e. detecting more energy of the PD pulse), but still minimizing the noise portion.

Capacitors with higher capacitance than 80 pF have been developed and successfully applied to on-line PD measurement in lower voltage rotating machines. The theoretical calculation, laboratory tests, field tests and statistics analysis of the capacitors with various capacitances draw the same conclusion: the 500 pF capacitor has higher detection sensitivity than the 80 pF capacitor. The 500 pF capacitor is able to detect some PD pulses which the 80 pF capacitor is not sensitive enough to detect and still avoid noise.

The higher-sensitivity capacitors bring the following benefits:

- To detect small partial discharges. Both a small number of large PD and a great number of small partial discharges may indicate that damage has occurred to the stator winding insulation. A great number of partial discharges themselves can further exacerbate the damage. Therefore a great number of small partial discharges should not be ignored for insulation diagnosis.
- To identify and monitor the insulation problems at an earlier stage to give an early warning instead of detecting no PD signals.
- To detect more PD pulses and higher PD magnitudes to provide better PD information for analysis and assessment of insulation problems.

More than forty lower-voltage motors and generators installed with 500 pF capacitors in power plants and petrochemical plants have demonstrated the successful application of the high-sensitivity capacitors for on-line PD measurement.

6. References

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