HOW TO MINIMIZE THE RISK OF STATOR INSULATION FAILURE ON CRITICAL MOTORS

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ABSTRACT

A forced outage due to stator insulation failure on a critical motor in process industries like pulp and paper can be quite lengthy and extremely expensive. Even for a relatively inexpensive low-voltage motor (e.g. 4 kV) the cost of a failure is often thousands of dollars per hour, mainly due to lost production. This paper describes how in-service Partial Discharge Analysis (PDA) can be used to minimize the risk of stator insulation failure on critical motors.

1. INTRODUCTION

High voltage insulation in the stator winding of operating motors gradually deteriorates due to electrical, mechanical, thermal, and environmental stresses. Failure of critical motors due to insulation breakdown may cause catastrophic damages to the equipment and a heavy cost for repair and loss of service. Maintenance personnel are being pressured to reduce the amount and cost of maintenance and testing efforts at pulp & paper plants yet increase the availability of the critical motors. Many are moving away from overly conservative preventative maintenance schedules and instead doing more condition-based and predictive maintenance. This allows them to do the right maintenance on the right equipment at the right time.

Partial discharges (PD) are a symptom and a cause of stator insulation deterioration. In-service partial discharge measurements without interrupting normal motor operation have proven to be a successful technology for monitoring the stator insulation condition to forewarn plant personnel of possible motor failures.

A high-voltage capacitor is used as a sensor to detect PD in the Partial Discharge Analysis (PDA) system. Three capacitors are installed on a motor, one on each phase. Once the capacitors are permanently installed, plant personnel can perform in-service PD testing with a portable PDA instrument. The PDA instrument captures PD pulses and sends PD data to a PC. PD analysis software running on a PC can then enable a comprehensive data analysis and provide the following graphs:

- PD Magnitude-Number distribution;
- 3-D phase-resolved PD distribution;
- PD distribution varying with load and temperature;
- Historical trending of the PD distribution over time.

The Magnitude-Number graph displays the number of pulses per second and the magnitude of the pulses for both positive and negative polarity pulses. The phase-resolved PD graph displays the phase angle position of the PD pulses relative to the 60 Hz voltage sine wave. The 3D phase-resolved graphs can help identify endwinding discharges and phase-to-phase discharges.

Partial discharge activity in the stator winding is often temperature dependent. When the temperature is increased in the operating motor, the conductors and insulation materials expand and tend to squeeze voids and gaps in the insulation close. Therefore, internal partial discharge activity, characterized by a predominance of negative polarity PD pulses, will decrease in the stator insulation.

PD activity in the stator winding is also frequently load dependent. One can identify winding looseness by analyzing on-line PD data to see if the PD activity varies with load. For example, a sharp increase in positive polarity PD activity from no-load and full-load is a strong indicator of a loose stator winding.

Trending analysis monitors the variation of the PD activity over time. A dramatic increase in the PD distribution pattern on the trending plot of PDA test results indicates that considerable insulation deterioration has occurred in the stator winding. The trending analysis can thus identify those motors with that are more likely to have a costly stator insulation failure.

This paper describes how to use in-service PD measurement technology to monitor stator insulation condition and therefore minimise the risk of stator insulation failure.

2. INCREASED SENSITIVTY OF THE PD SENSOR

The detection sensitivity of the high-voltage capacitor has been improved by increasing the capacitance value from the traditional 80pF to 500 pF [1] [2]. The new 500 pF capacitors were tested on an operating motor in the field to verify their higher sensitivity.

A 6.9 kV, 6000 HP motor was rewound after 14 years of service as a boiler feed pump. After the rewind, three 500 pF epoxy-mica capacitive couplers were installed at the motor terminals. Normally, two or more capacitive couplers per phase are installed in a permanent coupling system on a rotating machine. In such configurations, each coupler pair rejects external noise using the "time-of-flight" method. On rotating machines connected to the power system by sufficient length of shielded power cable, external noise is greatly attenuated and only one coupler per phase is frequently used. One of the PD tests using the 500 pF is shown in Figure 1.

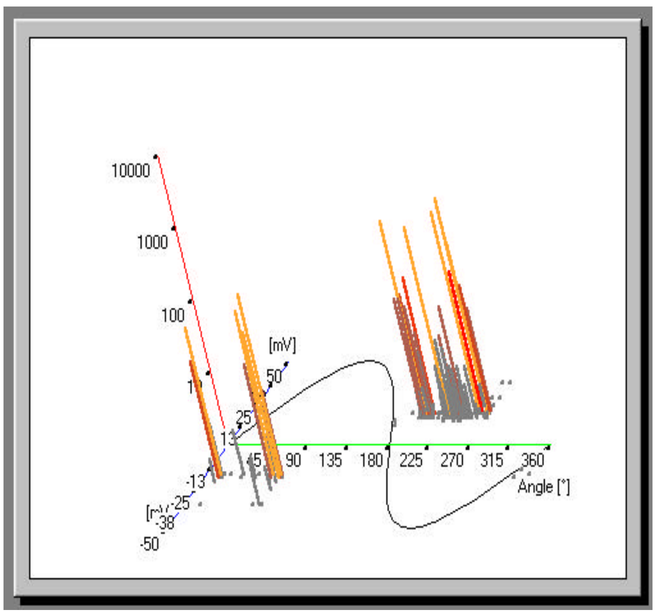

Fig. 1. Partial discharge detected using 500 pF couplers

On this graph, the relationships among the PD pulse magnitude (mV), the number of pulses per second and the phase angle position of the pulse are displayed. PD activity is a voltage related phenomena and PD pulses are normally distributed between 0° - 90° and 180°- 270° of the AC voltage sine wave. Figure 1 indicates a typical, noise free PD test result. Five months later, three 500 pF capacitors were temporarily replaced by three 80 pF capacitors to see what effect this had on the PD data recorded. No events or repairs occurred on the motor during this period. New PD tests were made in very similar operating conditions using the same PD instrument. No partial discharge activity was recorded (see Figure 2).

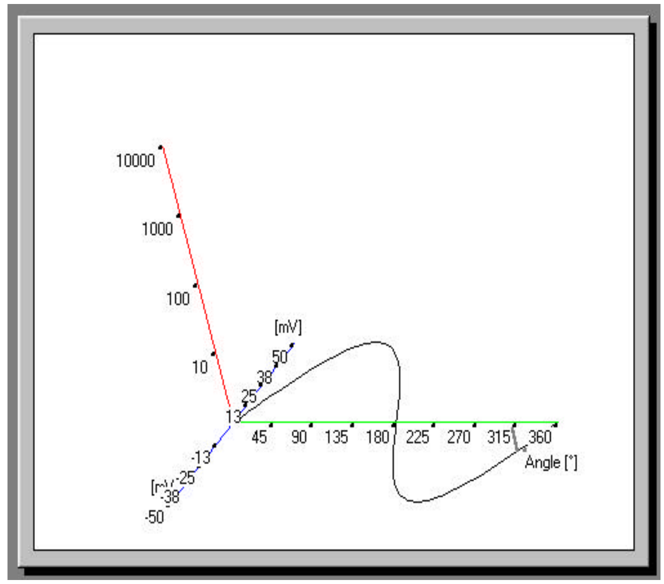

Fig. 2. PD activity detected using 80 pF couplers

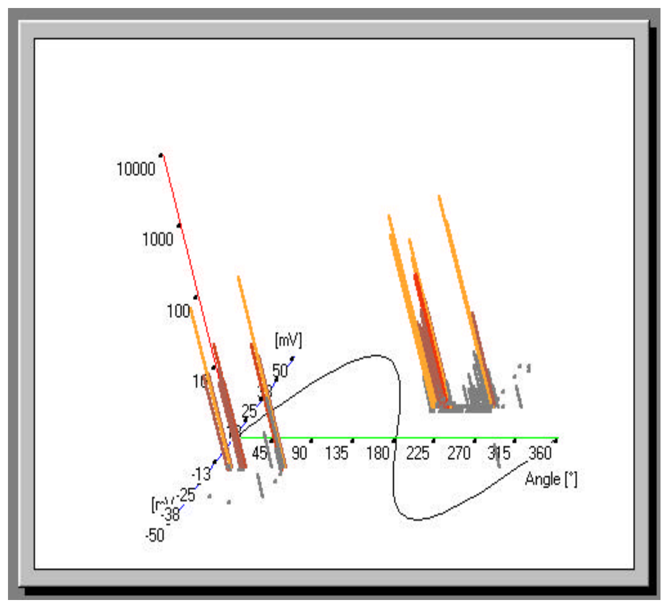

Fig. 3. Second PD test using 500 pF couplers

The 500 pF couplers were put back on the same motor two months later. Subsequent PD tests were taken and the results are shown in Figure 3. The results showed the same level of PD activity as was recorded seven months earlier using the same 500 pF epoxy-mica couplers. Obviously, the 80 pF capacitors were not sensitive enough to detect the PD activity.

During the whole process of changing capacitive couplers from 500 pF to 80 pF and back to 500 pF, no repairs were made on the machine. All of the PD tests were performed under the same voltage and load conditions. Only the stator temperature differed slightly, but that did not cause significant change in PD readings. These PD results clearly indicate that significantly different readings were due to different capacitances of the couplers, not due to the change of the operating or insulation conditions.

Higher capacitance couplers provide many benefits in PD testing. They can make the difference between effectively monitoring the insulation versus waiting for failure to occur. For example, due to low sensitivity of 80 pF couplers it was not possible to establish a trending of the PD readings at an early stage of insulation degradation. To be detected by 80 pF couplers, much higher PD activity must occur. Therefore, the time between detection of higher PD activity and possible failure is dangerously shortened.

3. HOW TO ASSESS SEVERE STATOR INSULATION DETERIORATION

Two quantities are frequently used in evaluating PD test results to express the PD activity in terms of a single number. The first, Normalized Quantity Number (NQN), represents the approximate area under the PD Magnitude Number distribution curve. It is roughly equal to the triangle whose sides are made up of lines indicating activity (positive or negative), x-axis (pulse amplitude) and y-axis (number of pulses per second). The second quantity, Q_{max}, is the magnitude at which the PD pulse repetition rate is at least 10 pulses per second. While the NQN and Qmax numbers are widely used, the greatest benefit of PDA measurements lies in the trending of the data. Due to the wide variety of designs and other factors (e.g. installation, maintenance and operating practices), there is no general rule or standard defining acceptable levels of PD activity for a particular machine. Therefore, users are advised to trend the PD activity, comparing results taken in similar load and temperature conditions. It is important to make all tests using the same gain (sensitivity) setting on the PDA instrument, since accuracy of the NQN calculation and the scale of the graphs will depend upon this.

Simple comparison of absolute NQN/Qmax numbers to a database of PD test results from similar can be misleading in some cases. The most reliable way to assess a machine's stator insulation condition is to analyze the trend in PD measurements taken on that machine under similar operating conditions. This is the most effective method for scheduling maintenance and avoiding unexpected outages.

To effectively use the PDA testing, the user should establish base-line PD levels. This is done preferably at the start of a maintenance cycle or six months after commissioning of a new winding. The PD measurements are used thereafter to monitor the gradual deterioration of the stator winding insulation.

As an example of the importance of trending, two 6.9 kV motors of the same age and design were monitored. Motor A had relatively high PD levels compared to motor B, see Figure 4.

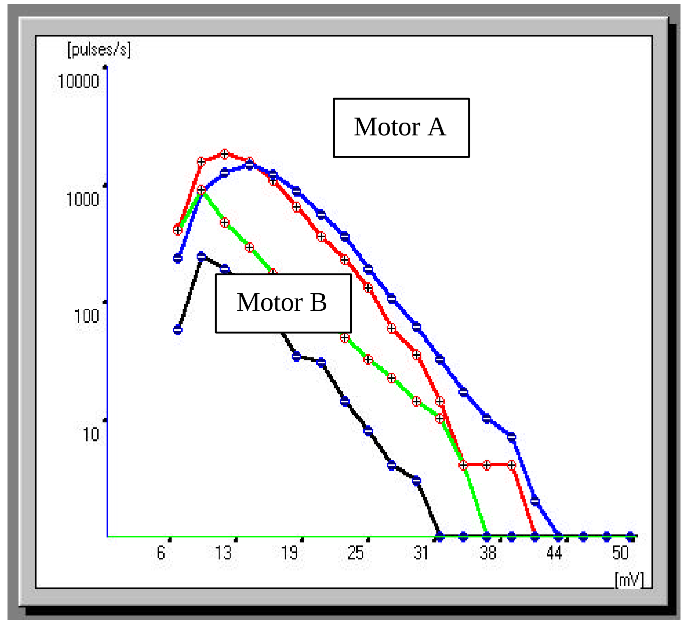

Fig. 4. Comparison of PD levels on motor A and motor B

However, Motor A had stable PD readings (Figure 5.), with essentially no change in a one year period while there was a noticeable increase of PD levels on motor B (Figure 6.) in the same time period. In Figures 5 and 6, the height of the stack represents NQN value. Three measurement results are shown in each Figure, with positive and negative NQN values for each coupler.

Comparison of Qmax (positive/negative) values for both motors are given in Table 1.

TABLE 1 PD test results from motor A and B

Test Date	Oct. 1998	Dec. 1998	March 1999
MOTOR A	62/45	56/38	65/48
MOTOR B	20/0	36/26	48/30

The rapid increase of PD activity on motor B was a strong indicator of rapid insulation deterioration. Subsequently this motor failed in April 1999, one month after the last PDA tests above, due to a groundwall insulation failure. Motor A, with stable PD trends, is still running.

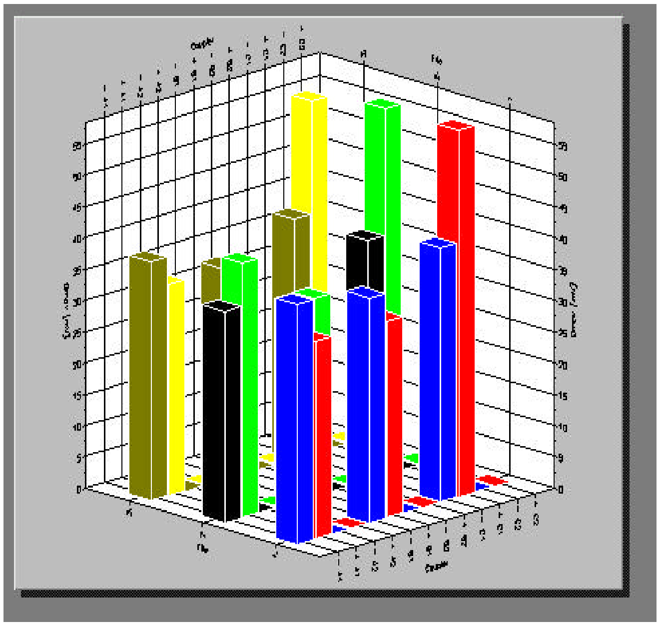

Fig. 5. Stable Qmax values on motor A

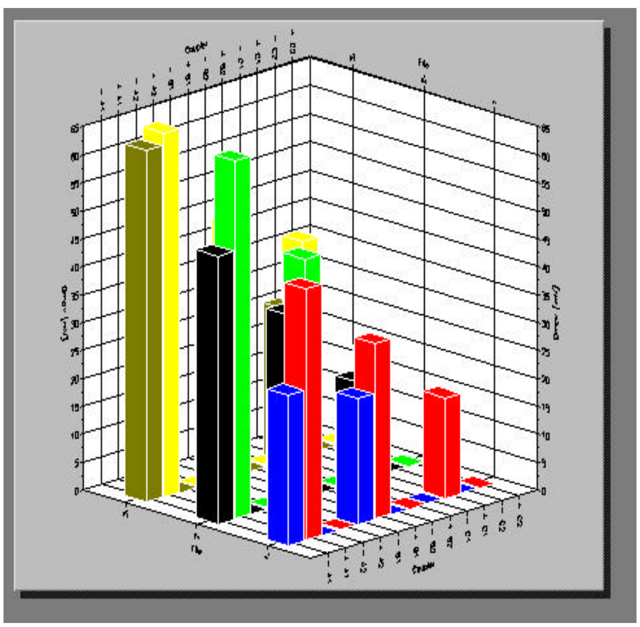

Fig. 6. Steady increase over six months in Qmax values on motor B

4. CONCLUSIONS

The 500 pF capacitors with higher sensitivity can detect more PD pulses and higher PD magnitudes sooner than 80 pF capacitors. This enables one to earlier identify insulation deterioration and to decrease likelihood of stator winding failure. The ability of a PD measurement system to detect small partial discharges enables plant engineers to monitor the insulation problems in the stator winding at an early stage.

Trending of PD activity is the best way to identify those machines that are most likely to fail. A significant increase in PD activity within a certain period of time indicates severe stator insulation deterioration. The rate of increase in PD activity is a key factor in determining the likelihood of failure.

In-service partial discharge monitoring using capacitive sensors with greater sensitivity can give an early warning of stator insulation deterioration of motors. This early warning allows maintenance engineers to monitor the progress of stator insulation deterioration and to take action based upon the actual stator insulation condition, hence minimizing the risk of motor insulation failure. Regular partial discharge monitoring of motors can also help to implement a predictive maintenance program based upon the stator insulation condition. Switching from regular time-based maintenance to condition-based maintenance/predictive maintenance can save motor users considerable maintenance costs while still minimizing the risk of failure.

5. REFERENCES

[1]. H. Zhu, V. Green, M. Sasic, and S. Halliburton, "Increased sensitivity of capacitive couplers for in-service PD measurement in rotating machines", IEEE Transactions on Energy Conversion, Vol. 14, No. 4, December 1999, p1184-1192.

[2]. H. Zhu, V. Green, M. Sasic, and S. Halliburton, “Recent improvement in detection sensitivity of PD monitoring of motors”, <u>EPRI Motor Predictive Maintenance Conference</u>. USA, February, 1999.

[3]. H. Zhu, V. Green, and D. Huynh, “How to identify stator insulation problems using on-line partial discharge analysis”, <u>IEEE International Electrical Insulation Symposium</u>, Anaheim, CA, USA, April, 2000.

[4]. IEEE P1434: IEEE Guide to the Measurement of Partial Discharges in Rotating Machinery.