2001 IEEE Electrical Insulation Conference, Cincinnati, October 16-18th

Partial discharge database: its benefits and limitations on assessment of stator insulation deterioration

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ABSTRACT

PD test data on various generators and motors has been collected over the last 15 years using on-line partial discharge analyzers. A large PD test database has been established. The database provides an overall view of PD activity on rotating machines. Statistical analysis of the database provides a study of PD distribution with variations of a number of the parameters.

This paper presents statistical analysis of a large PD database accumulated over the last 15 years. The statistical analysis shows distribution of PD levels with machine type, voltage rating, sensitivity of the PD sensor, etc. The benefits and limitations of the PD database on assessment of stator insulation condition are discussed in the paper.

1. INTRODUCTION

On-line partial discharge testing has been applied to hydro-generators, turbo-generators and HV motors for decades to evaluate the condition of stator winding insulation. However, what is an acceptable PD level? Does a machine with a higher PD level have a greater risk of failure than one with a lower PD level? Naturally, one expects that a criterion of an absolute PD magnitude exists for evaluating the condition of stator winding insulation. Unfortunately, such a criterion for an acceptable PD level does not exist for rotating machines [1], since there are a number of factors influencing PD readings from operating rotating machines. How is PD activity affected by those factors? What is general PD activity within different categories (e.g. different voltage ranges)? How does one compare PD readings from different rotating machines?

A database with a great number of PD test data (>10,000 sets of test data) from a variety of machines collected for the last fifteen years has been established. This paper presents statistical analysis of the PD database to oversee how PD activity varies with different types of machines, different voltage ratings, and different PD sensors. The paper discusses how the PD database can help the PD data interpretation and what is the limitation of the PD database in evaluating the condition of stator winding insulation.

2 STATISTICAL ANALYSIS OF THE PD DATABASE

2.1 Impact of Machine Type

A distribution of PD levels in different types of machines (i.e. hydro-generators, turbo-generators, and motors) is shown in Fig. 1. The figure indicates that how many machines in percentage have a certain PD level. Hydro-generators have the highest PD level among the three types of rotating machines. This may be due to

- most coupler installations on hydro-generators are in the differential mode. The capacitive couplers installed in the differential mode (i.e. connected to the stator circuit ring buses) within hydro-generators are closer to PD locations than those installed in the directional mode (i.e. connected to the terminals on isolated phase buses) outside rotating machines. Therefore, capacitive couplers installed in a differential mode detect comparatively more PD activity than those installed in a directional mode.

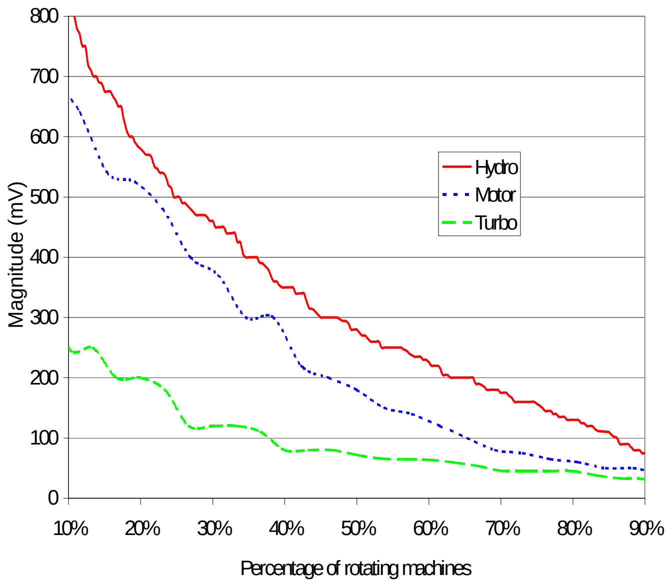

Fig. 1 Distribution of $-Q_{max}$ with different types of rotating machines

- more hydro-generators in the database have a higher voltage rating than other rotating machines in the database.
- hydro-generators are air-cooled, while many turbo-generators have gas (e.g. hydrogen) cooling, which suppresses PD activity.

Motors generally have lower PD levels than hydro-generators due to both lower voltage ratings and directional coupler installations. Turbo-generators have the lowest PD level due to hydrogen pressure. Hydrogen pressure in turbo-generators can suppress PD activity by masking voids and gaps.

Table 1 shows the maximum, average, and minimum PD levels of different types of rotating machines from the statistical analysis. Q_{max} indicates the maximum PD magnitude with a repetition rate of at least 10 pulses per second in a PD test. Results from other databases may differ [2].

Table 1 - Q_{max} (mV) of various rotating machines

Machine type	Hydro	Motor	Turbo
Average (mV)	383.1	253.3	101.1
Maximum (mV)	1900.0	720.0	400.0
Minimum (mV)	18.0	40.0	18.0

2.2 Impact of Voltage

To remove the effect of hydrogen pressure, only air/water cooled machines are grouped from the database for statistical analysis with various voltage ratings. The machine voltage ratings are divided into five different ranges. The effect of voltage on PD activity is illustrated in Fig. 2. The voltage rating of the machines has a great impact on PD activity. In general, the lower the machine voltage, the lower the PD activity. Therefore a high sensitivity coupler (e.g. 500 pF capacitive couplers as described in [3]) is more appropriate for PD measurements on lower voltage machines.

Table 2 shows the maximum, average, and minimum PD levels of rotating machines with various voltage ratings from the statistical analysis.

Table 2 + Q_{max} (mV) of air/water-cooled machines with various voltage ratings

Voltage	5-7 kV	10-13 kV	13-15 kV	15-18 kV	>18 kV
Average	247.7	240.9	375.0	486.3	506.7
Maximum	1120.0	800.0	1900.0	2080.0	1600.0
Minimum	36.0	33.0	24.0	45.0	20.0

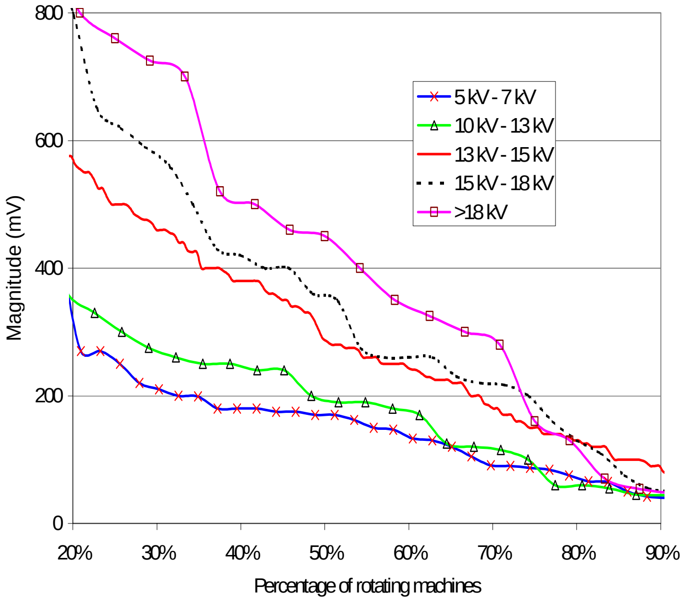

Fig. 2 Distribution of $+Q_{max}$ with different ranges of voltage ratings.

2.3 Impact of Coupler Type

A high voltage capacitor (coupler) is used as a sensor for PD measurements in rotating machines in the PD database. Capacitances of 80pF and 500pF couplers are used.

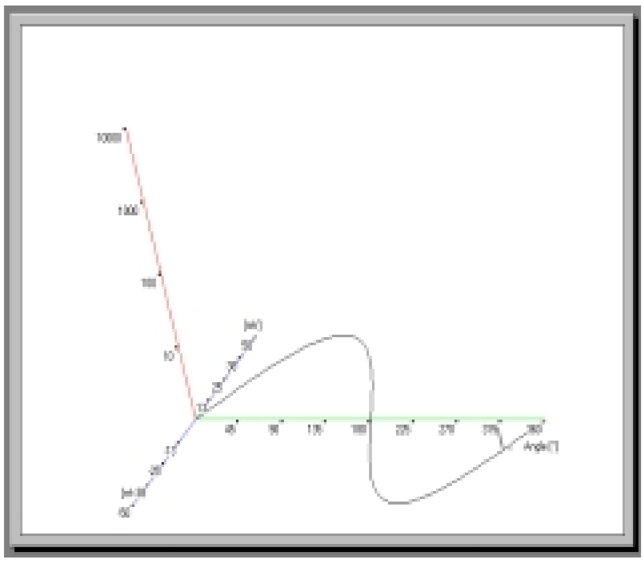

Fig.3 PD phase distribution graph from the operating motor with the 80pF capacitor.

To compare detection sensitivity between the 80pF and 500pF capacitor, a field test was conducted on a 6.9 kV, 6000 HP motor. The PD test result from the 80pF capacitor is shown in Fig. 3, indicating virtually no PD activity. However, the PD test result from the 500pF capacitor under the same test condition clearly shows PD activity, as illustrated in Fig. 4. This demonstrates that the 500pF capacitor has higher detection sensitivity than the 80pF capacitor.

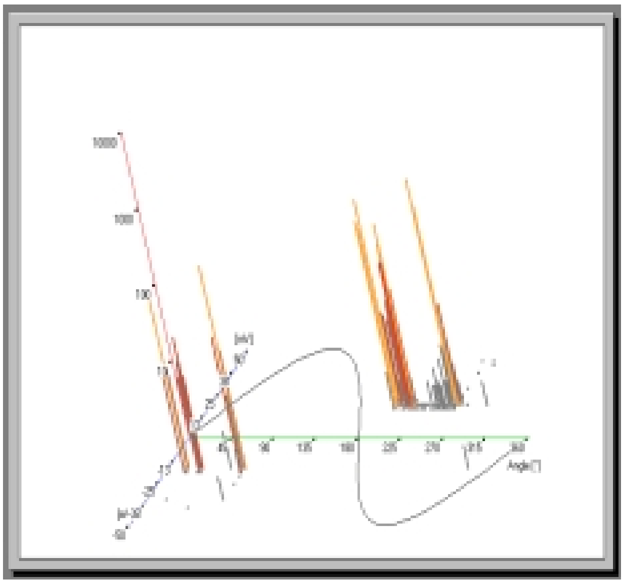

Fig. 4 PD phase graph obtained seven months after the previous test using the same 500pF capacitor.

PD readings from statistical analysis of a number of motors (<7 kV) installed with the 500pF capacitors and with the 80pF capacitors are compared in Fig. 5. The NQN (Normalized Quantity Number) value is a measure of total energy released from partial discharges in one phase of a motor [4].

Table 3 shows the maximum, average, and minimum PD value resulting from the 500pF capacitors and the 80pF capacitors from the statistical analysis. This table indicates that the 500pF capacitor, in general, detects higher PD readings than the 80pF capacitor.

Fig. 5 shows that 80% of the motors installed with the 500pF capacitors have a NQN value which is more than twice the value acquired by the 80pF capacitors. The overall PD readings from the 500pF capacitor are higher than those from the 80pF capacitor. This indicates that the 500pF capacitor detects more of the energy of collective PD pulses than the 80pF capacitor does, since the NQN value is proportional to the energy of all PD pulses in that phase.

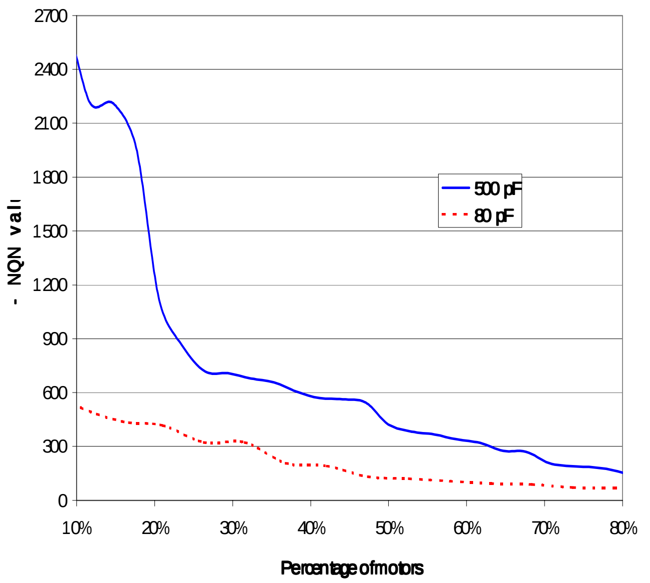

Fig. 5 A comparison of the statistics distribution of -NQN value acquired by the 500pF and 80pF capacitors.

Table 3 - Q_{max} (mV) from motors (<7 kV) using 500pF capacitors and 80pF capacitors

Capacitor	500pF	80pF
Average	262.9	140.3
Maximum	1050.0	700.0
Minimum	27.0	18.0

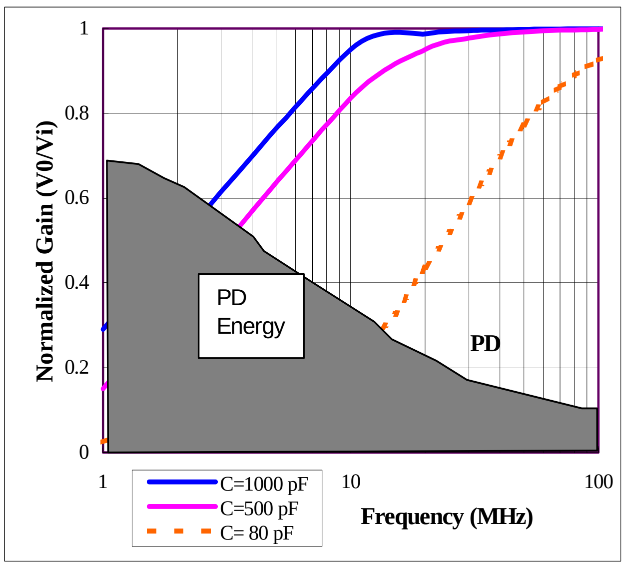

Fig. 6 Frequency spectrum of the different capacitors.

The PD test result from the statistical analysis of the 500pF capacitor and the 80pF capacitor is consistent with that from the frequency-spectrum analysis of a single PD pulse. Fig. 6 shows the frequency-spectrum analysis of the 500pF capacitor and the 80pF capacitor. The area underneath the PD frequency spectrum is the signal energy of the PD pulse. The 500 pF capacitor covers a larger area (i.e. more PD signal energy) than the 80 pF capacitor does, therefore detecting more signal energy of the PD pulse.

In summary, the 500 pF capacitor detects more signal energy of both a single PD pulse and a group of PD pulses than the 80 pF capacitor does.

4. TRENDING PD ACTIVITY TO IDENTIFY SEVERE INSULATION PROBLEMS

For a given machine, the operating conditions, e.g. load, temperature, humidity, can also affect PD readings. Trending PD activity on the same machine under similar operating conditions is usually regarded as the most reliable way to diagnose severe insulation deterioration [5]. Insulation deterioration is a long-term process. If the insulation system has a stable PD activity (even with a high PD level), insulation failure may not, in general, occur soon. If a significant increase in PD activity within a certain period of time under same test conditions is detected, it warrants investigation and is a warning sign of possible insulation failure. The following case demonstrates that an increase of PD activity rather than an absolute PD magnitude can indicate severe possible insulation failure.

This case compares PD readings of two "sister" motors (motor A and motor B) in a power plant. Motor A is a 6.9 kV, 7000 HP induction motor used for induced draft fan in a power plant. Motor A had Duraguard, class F insulation in its stator winding and was rewound in 1994. An on-line PD monitoring system was installed on the motor after rewinding. The trending graph of the maximum PD magnitude is shown in Fig. 7.

In Fig. 7, the maximum PD magnitude Q_{max} value in phase C increased more than two times from October 1998 to March 1999. This motor failed in service during a start-up in April 1999 due to insulation breakdown. There was a puncture in the groundwall insulation leading to the insulation failure, as shown in Fig. 8. The motor has been rewound since the insulation failure.

Motor B is an identical "sister" motor operating at the same site. The trending graph of the maximum PD magnitude Q_{max} is shown in Fig. 9. Comparing Fig. 7 and Fig. 9, motor B had twice the PD magnitude of motor A. However, motor B with the higher PD activity has been operating well while motor A with the lower PD activity subsequently failed in service in 1999. This is because the PD activity in motor B was stable, even though it was much higher than motor A. Stable PD activity over time indicates that insulation deterioration has not progressed much. A significant increase in PD activity within a relatively short period of time (e.g. six months) indicates that the rate of insulation deterioration and the likelihood of machine failure is increased.

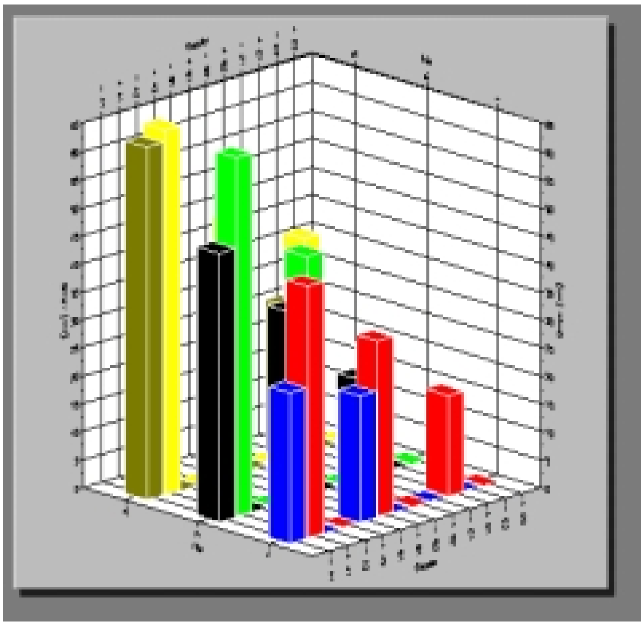

Fig. 7 Trending graph of Q_{max} values of motor A.

Fig. 8 Insulation failure of motor A.

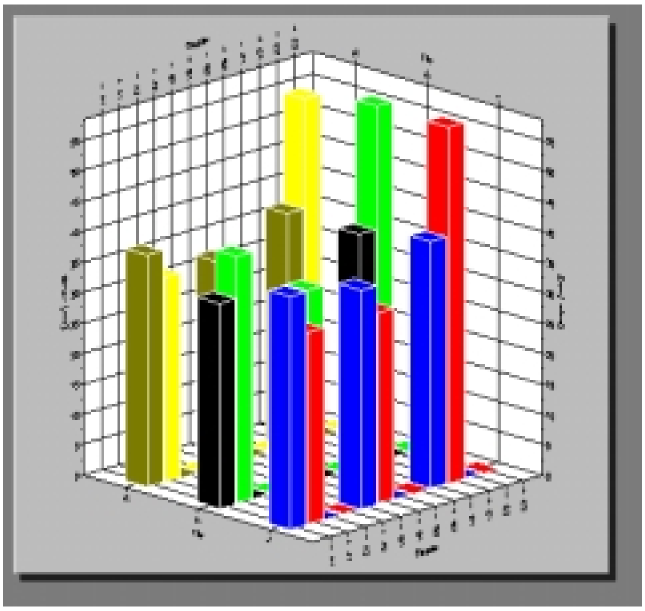

Fig. 9 Trending graph of Q_{max} values of motor B.

5. CONCLUSIONS

The PD database provides the following benefits:

- The PD database and the statistical analysis provide an overview of PD activity in operating rotating machines. For example, what is an average PD level for a particular type of rotating machines and how many machines reach a given PD level.
- A set of PD readings from a given machine can be compared with one from a group of similar machines to determine a relative PD level of the given machine.
- The effect that several factors (e.g. machine type, capacitance of the coupler, voltage rating, hydrogen pressure, type of insulation, etc) have on PD readings can be seen from the database and statistical analysis.

However, the PD database has some limitations in assessment of insulation condition of the stator winding. One should be cautious in using a PD level measured from a given machine to determine its risk of failure by comparing it with the statistical results from a PD database. Use of an absolute PD level to assess the risk of machine failure is not reliable, since a number of factors can influence PD measurement results. How the following factors unrelated to insulation condition can influence PD readings is discussed in [6].

- PD calibration difficulties.
- PD location and PD pulse propagation
- PD detector
- PD type
- Differences among machines and among PD measurements

Trending of PD activity on the same machine is the most reliable approach to provide a warning of severe stator insulation problems and increased likelihood of insulation failure.

6. REFERENCES

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