Application of on-line PD testing technology to extend lifetime of stator winding insulation

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Abstract

Rotating machine failures due to insulation breakdown can cause catastrophic damages to the equipment, loss or de-rating of power output, lengthy forced outages and heavy costs to the utility. Therefore it is desirable to detect the onset of significant insulation deterioration and identify potential failures as early as possible. As in the medical field, regular testing and early detection of problems mean better chances of survival for the 'patient'. Faced with increasing pressure to increase unit availability yet reduce maintenance costs, utilities and other electric power producers are moving away from time-based maintenance practices to condition-based maintenance efforts. Owners and operators of generators and large motors are using partial discharge analysis (PDA) systems to perform on-line condition monitoring of the stator insulation system.

On-line partial discharge (PD) measurements have been recognized as an effective, reliable method of assessing stator insulation condition to forewarn plant personnel of possible machine failures. The measurements are obtained with the machine in normal operation and thus form an integral part of a condition-based maintenance program. Regular condition monitoring of the stator winding insulation can give users the confidence to safely operate machines, even ones that have suffered some degree of insulation degradation. This paper presents two case studies of how utilities applied an on-line PD measurement system and other diagnostic testing techniques on a generator and a motor with insulation degradation to avoid substantial costs and forced outages. Long-term on-line PD monitoring has given the utilities confidence to continue running machines that have the potential for insulation failures. The paper describes the interpretation of the PD data and how it contributed to the life extension of the stator winding.

1. Introduction

Operating generators and motors are subjected to electrical, mechanical, thermal and environmental stresses that cause aging and degradation of the stator insulation system. Deterioration of the stator winding insulation is an important factor in the lifetime of high voltage generators and motors. Partial discharges (PD) are a sign of stator insulation deterioration. Deterioration of the stator insulation system on most generators and motors is a gradual process. The breakdown of the stator winding insulation usually occurs over a period of years or decades, not hours or days. Therefore periodic on-line PD measurements taken at, say, three-month intervals are ideally suited for detecting the onset and monitoring the progression of stator winding deterioration. Once PD activity is detected, assessment of the stator insulation condition can be made based upon the trend of the PD data. The machine owner can continue to operate the machine with on-line PD monitoring until a critical condition is reached and thus maximize the lifetime of the machine. Suitable maintenance actions can be taken before problems get worse to avoid insulation failures.

2. Lifetime extension of stator winding insulation of a generator

Thermal stress, especially overheating, is a major contributor to insulation aging and thus a principal root cause of many stator winding failures. The following example describes a case where the stator winding of a large steam turbine generator was briefly but severely overheated and how the utility decided to continue operating the machine. Our experience in using on-line PD measurement technology to monitor the condition of the damaged winding insulation and maximize the lifetime of the stator winding is presented.

The 730 MW, 20 kV steam turbine generator has been in service since 1972. The unit has been plagued by end winding 120 Hz resonant vibrations due to structural looseness. Between 1972 and 1988, the generator went through many maintenance outages to repair insulation damages such as phase to ground faults, loose blocks and weld cracks in the support rings. Fortunately, none of the damage was fatal. The generator end winding structure was improved in 1989 with the Westinghouse stator winding maintenance modules, which effectively stiffened the end winding structure and enhanced the integrity of the generator insulation.

During a start-up in 1993 the generator was extremely overheated due to a failure of the automatic hydrogen cooling system. The stator winding temperature reached 165 C° before the cooling failure was discovered and the generator was immediately shut down. The wedges, filler blocks and bracing ties of both the stator and rotor were melted or burned black beyond repair. The class B thermoplastic stator insulation, however, did not fail. The opinion of many experts at the time was that, if restarted, the stator winding would most likely fail, either during the restart or within a very short time of operation, and should instead be rewound immediately. The confidence to continue running the generator was lost.

The stator and rotor were immediately re-wedged with new slot wedges and fillers and painted with new resin. However, because of the lengthy outage needed and the high cost of an emergency rewind, the utility strove to determine just how severe the stator winding damage was before deciding upon an immediate stator rewind. Extensive tests such as power factor, DC hi-pot, core thermal scans and off-line corona/TVA probe tests were performed. The stator winding withstood the hi-pot but showed signs of winding looseness and accelerated winding deterioration in the structural FRF (Frequency response function) and power factor tests (see test data in Table 1).

After examining the data from the off-line stator insulation tests, the utility decided to install an on-line condition-monitoring system for the stator insulation and continue operating the generator with the same stator winding. A PDA system from ADWEL International (formerly FES International) was installed during the re-wedge outage in 1993

Table 1 Power Factor Test Data

	1985	1989	1993 *	1998
<u>ϕ A</u>				
% PF at 4 kV	0.81	1.17	2.34	2.54
“ “ “ 10 kV	1.16	1.82	2.40	3.02
“ “ Tip-Up	0.35	0.65	0.56	0.48
<u>ϕ B</u>				
% PF at 4 kV	0.72	1.27	2.24	2.27
“ “ “ 10 kV	1.12	1.84	2.89	2.79
“ “ Tip-Up	0.40	0.57	0.65	0.52
<u>ϕ C</u>				
% PF at 4 kV	0.86	1.17	2.30	2.36
“ “ “ 10 kV	1.10	1.74	2.92	2.89
“ “ Tip-Up	0.24	0.57	0.62	0.53
* Test data obtained after the generator was overheated.				

to enable future monitoring of the partial discharge activity in the stator winding.

The utility successfully restarted the generator and began closely monitoring the on-line PDA readings to detect any signs of severe insulation degradation. The first on-line PDA readings were taken in July 1993, as shown in Fig. 1 and Fig. 2. The PD levels were not alarmingly high. This suggests that the insulation system was still in good shape, even though the generator had been overheated. The confidence to continue running the generator was established. The positive and negative curves in Fig. 1 overlap with no predominance of one pulse polarity over the other. This is an indication of internal PD occurring within the groundwall insulation. Internal groundwall PD often occurs within slowly deteriorating thermoplastic insulation, especially if it has been overheated. Pressurized hydrogen gas reduces PD activity by masking voids in insulation materials.

The PDA trend was steady from 1993 to 1998 and consistent with the power-factor test data. A recent PDA reading taken in August 1998 is shown in Fig. 3. There is a slight negative pulse predominance in the curves. This is a sign of internal PD occurring closer to the interface between the copper conductor and the groundwall insulation. The low PD activity initially detected by the PDA system supported the utility’s decision to continue operating the generator with the overheated stator winding. Consistent PDA readings from 1993 to date have given the utility confidence to keep running the unit and to maximize its lifetime. The avoided cost of the emergency rewind was millions of dollars.

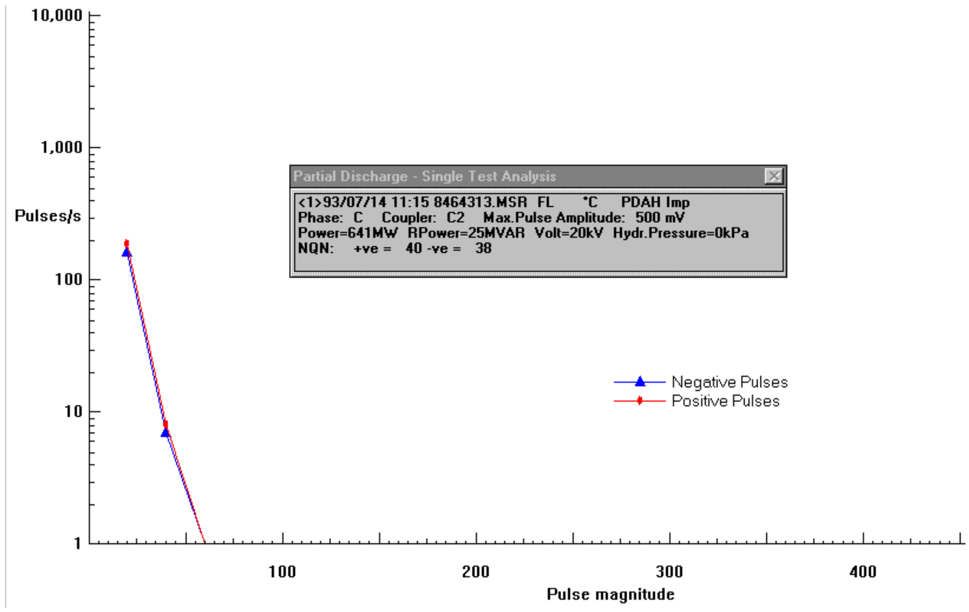

Figure 1. On-line PDA readings taken in 1993 immediately after overheating.

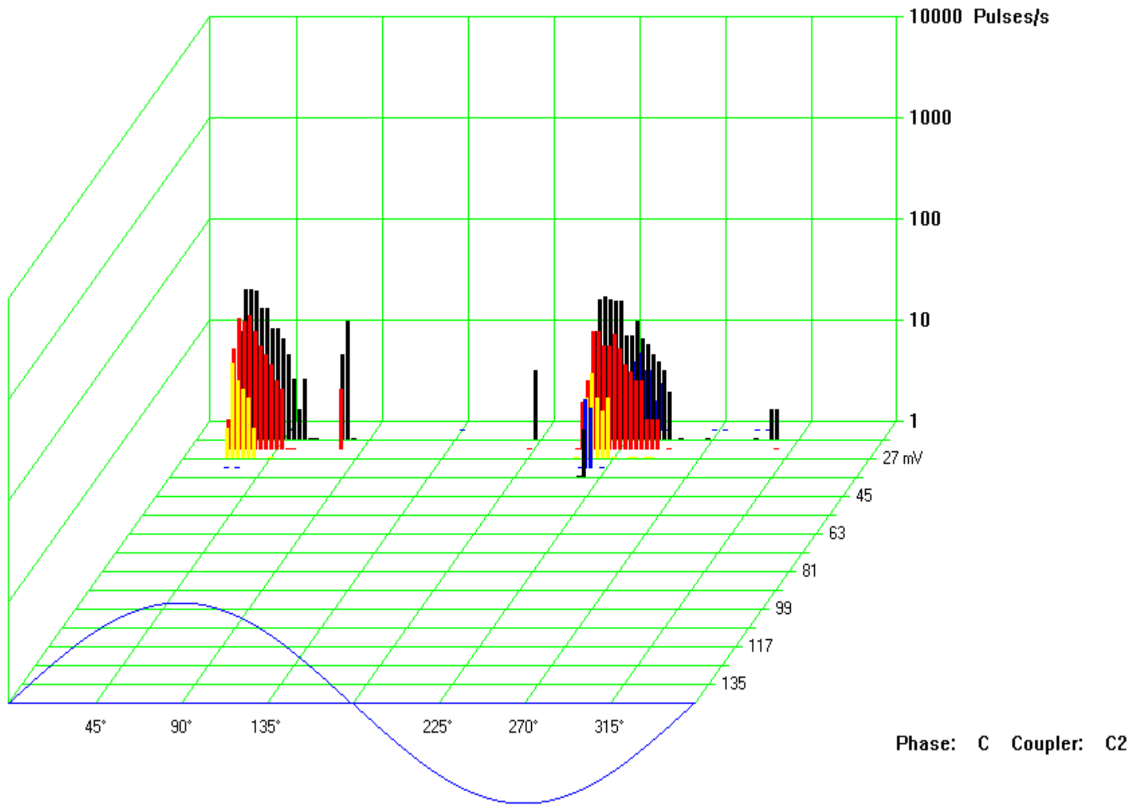

Figure 2. Phase–resolved PDA graph indicating internal PD activity.

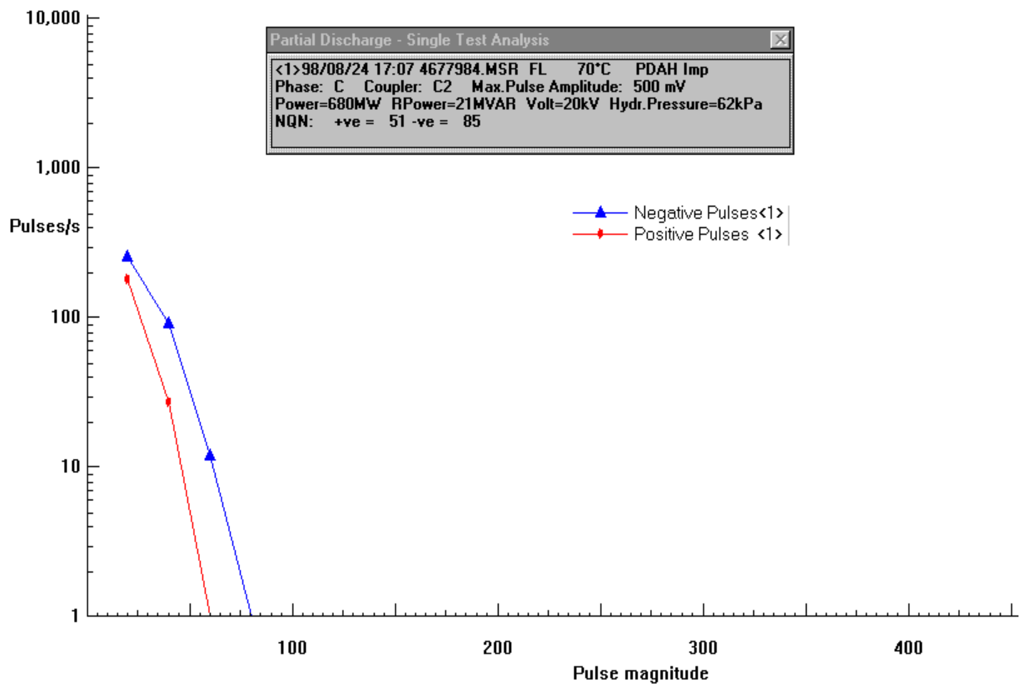

Figure 3. PDA readings taken in 1998, five years after overheating.

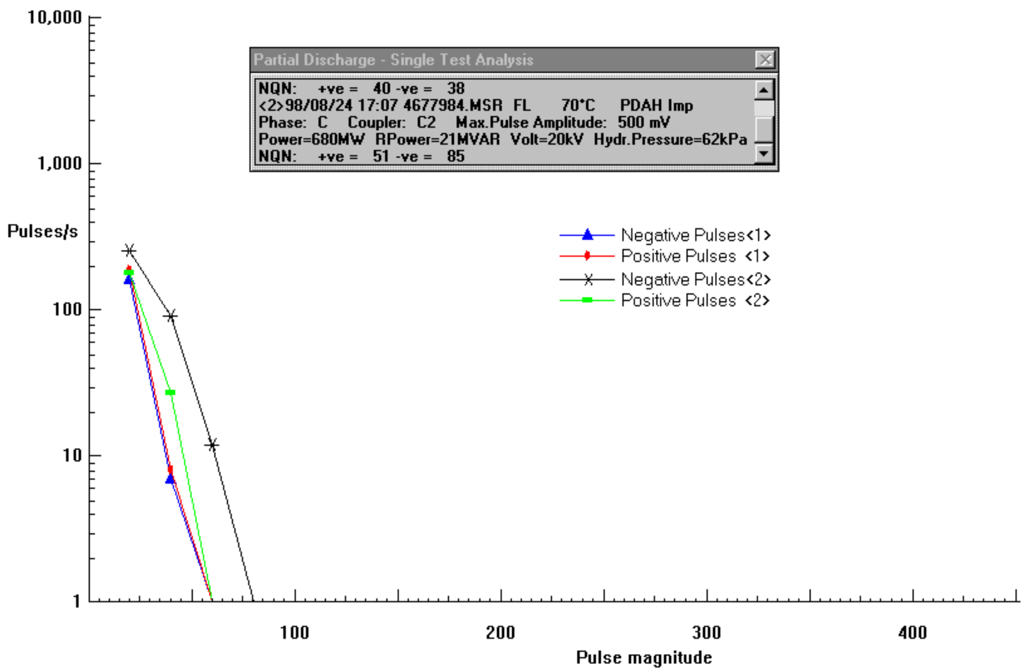

Figure 4. Comparison of PDA readings taken in 1993 <1> and 1998<2>.

3. Lifetime extension of stator winding insulation of a motor

In 1992 an on-line PDA system was installed on a 13.2 kV, 13,000 HP motor operating in a petrochemical plant. The insulation of the motor is epoxy mica. The first PDA test was carried out in 1993. There is high PD activity in phase C, as shown in Fig. 5. The predominance of negative pulses indicates that partial discharges and delamination were occurring at the interface of the copper conductor and the groundwall insulation. This type of partial discharge attacks both the groundwall insulation and turn-to-turn insulation, causing electrical treeing and turn-to-turn shorts. There is no practical means of repairing such defects. Regular PDA monitoring can detect any progress in PD activity and give an indication of further insulation deterioration.

Although the PD activity in this motor was relatively high, a decision was made to continue running the motor with regular PDA tests to monitor the condition of the stator winding insulation rather than to do an immediate rewind. The regular PDA test results for five years show that the PD activity in phase C is stable even though it has been high. This indicates that further severe insulation deterioration has not been occurring. The test result of phase C in 1998 is also shown in Fig. 5. Regular PDA monitoring has given the maintenance engineer the confidence to keep the motor with the insulation degradation running for five years. The lifetime of the stator winding insulation has been extended and a considerable saving for the petrochemical plant has been achieved. This motor is still in service today. It will continue to run until a significant change in the PD activity is detected or an appropriate time for rewind is reached, then a repair action may be taken.

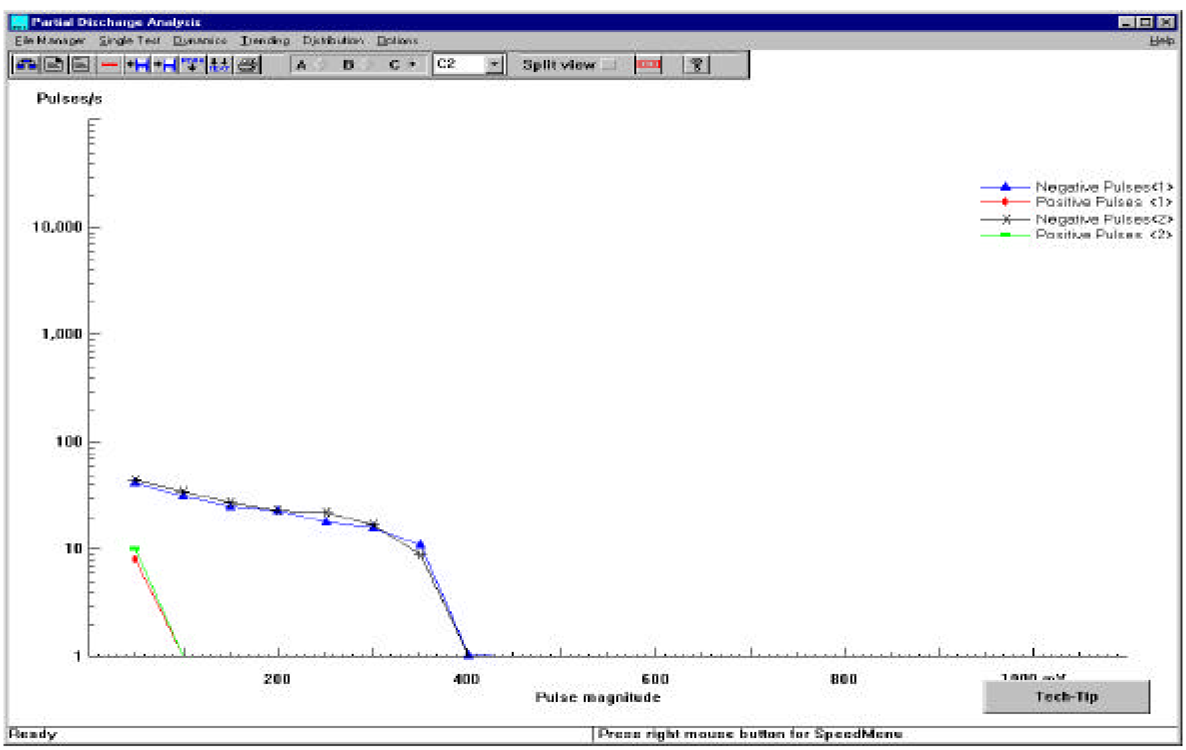

Fig. 5 PDA test results of the motor in 1993 <1> and in 1998 <2>.

4. Conclusions

The lifetime extension of the stator winding insulation of generators and motors can be extended using on-line PD testing. On-line PD testing provides a useful tool to assess condition of stator winding insulation under machine normal operation. This condition-monitoring tool gives users confidence to run generators and motors that have some degree of insulation problems. Without such a tool, failures of such machines at any time would be a great risk for maintenance engineers. Stable PD activity observed from on-line PDA readings indicates that further severe insulation deterioration has not been occurring. Any drastic change in the PDA test data indicates that severe insulation deterioration has occurred and a rewind may be considered. Until then, the useful life of the generator stator winding has been maximized.

Estimating the remaining life of machine stator insulation is technically difficult, however, its service lifetime can be extended with the condition monitoring technology. New higher sensitivity sensors can detect partial discharges in stator winding insulation at an earlier stage and present more PD information [4], hence giving better chances of lifetime extension of the stator winding insulation.

5. References

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