Application of Both On-line and Off-line Partial Discharge Testing on Hydrogenerators

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ABSTRACT

Partial discharge (PD) testing can effectively diagnose insulation problems in the stator winding of hydrogenerators, since partial discharges are a symptom of most insulation failure mechanisms. PD testing can be performed either when the machine is not operating (off-line) or during normal machine operation (on-line). Off-line PD testing is a well-known method to assess stator winding insulation. Over the last twenty years on-line PD testing has been proven to be a successful technique for monitoring stator insulation condition. It can forewarn plant personnel of possible machine failures and to help them implement a condition-based maintenance program.

This paper presents an on-line and off-line PD test on a hydrogenerator using the same test instrument and sensors. A comparison of the two tests indicates that the off-line test results are consistent with the on-line test results. Similarities and differences of the on-line and off-line PD tests are discussed.

1. INTRODUCTION

Partial discharge (PD) testing is a recognized tool to diagnose stator insulation deterioration in generators and motors. Voids in the stator insulation, created during manufacturing or by thermal and mechanical aging during service, can produce PD under high voltage stress. The progressive development of PD activity is a sign of insulation deterioration in generators and motors. Partial discharges also contribute to the aging of the dielectric system by gradually eroding away or deteriorating the insulation system. Hydrogenerator failures due to insulation breakdown may cause catastrophic damages to the equipment and expensive losses. Partial discharge testing can assess the condition of stator winding insulation and thereafter help to establish a condition-based maintenance program. Condition monitoring and predictive maintenance of stator insulation brings users the benefits of reliable operation, optimal number of maintenance outages and maximal lifetime of their generators.

Partial discharge testing can be performed in either on-line or off-line condition. A comparison of differences and similarities between on-line and off-line PD testing is listed in Table 1.

It is important that the same PD sensor and instrument be used to compare on-line and off-line PD test results. If PD instruments with different frequency bandwidths or different PD measurement units (e.g. pC, mV) are used, test results between on-line and off-line PD testing cannot be directly compared. The same PD sensors and instrument were used in the following comparison of on-line and off-line PD test results.

Table 1 A comparison of on-line and off-line PD testing

On-line PD testing	Off-line PD testing
On-line PD testing can detect and monitor winding problems during normal machine operation	Machine must be out of service and disconnected from the power system.
Normal electrical, mechanical, thermal and electromagnetic stresses on generators are present during test.	Electrical stress is present only, so off-line PD testing is not sensitive to slot discharge/loose winding due to absence of electromagnetic bar forces.
Many possible noise sources may be present such as attached equipment, radio stations, airborne noise, commutator noise, etc. On-line PD testing must eliminate noise to avoid false indication.	Most of noise sources are eliminated, since the generator is at the standstill and isolated from other electrical equipment.
No external HV power supply is required.	A large external HV power supply is required.
On-line PD testing is an fast and easy test.	Off-line PD testing is a cumbersome, time-consuming test.
Can identify PD sites down to a given phase or parallel circuit only.	PD sites can be accurately located by a corona probe.
Only line end bars are exposed to full rated voltage.	Rated voltage is applied to entire stator winding.

2. ON-LINE PARTIAL DISCHARGE TESTING

On-line PD tests can be performed by a non-specialist during normal machine operation. PD test results are displayed in the form of pulse polarity, magnitude, number, and phase position. Subsequent data analysis provides further information, such as, maximum PD values, normalized quantity number, historical trending of PD test results, variation of PD patterns with temperature and load, etc.

The generator under test is rated at 80 MW, 13.8 kV and has a class F epoxy-mica stator insulation. The stator winding was rewound in 1987. Six 80 pF capacitive couplers, two couplers per phase, were installed in this hydro generator. One coupler was installed at the circuit ring bus inside the generator and the other at the isolated phase bus outside the generator. The two capacitive couplers on each phase work as a pair to eliminate noise from outside the generator using the "time-of-flight" technique. The coaxial cables connected to the low-voltage end of the capacitive couplers transmit the PD signals to a termination box mounted outside the generator. A high frequency grounding device was connected to the shield of the coaxial cables near the coupler. The high frequency grounding dissipates the rapid charge that accumulates on the shield when a PD pulse enters the coaxial cable [2]. This significantly reduces cross-coupling interference among the coaxial cables and improves the signal-to-noise (SNR) ratio.

The on-line PD readings for this generator are listed in Table 2. The number of PD pulses against the PD magnitude in phase A is shown in Fig. 1 and their pulse phase distribution is shown in Fig. 2.

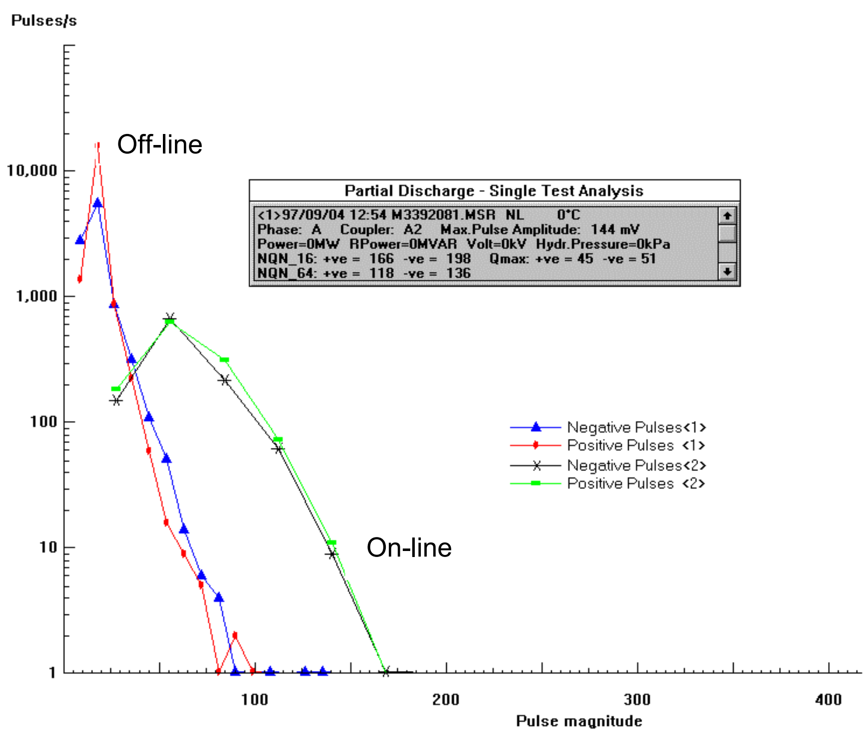

Fig. 1 PD pulse number against PD magnitude (on-line and off-line tests).

Table 2 On-line PD readings

Phase	+PD (mV)	-PD (mV)
A	140	140
B	85	85
C	120	80

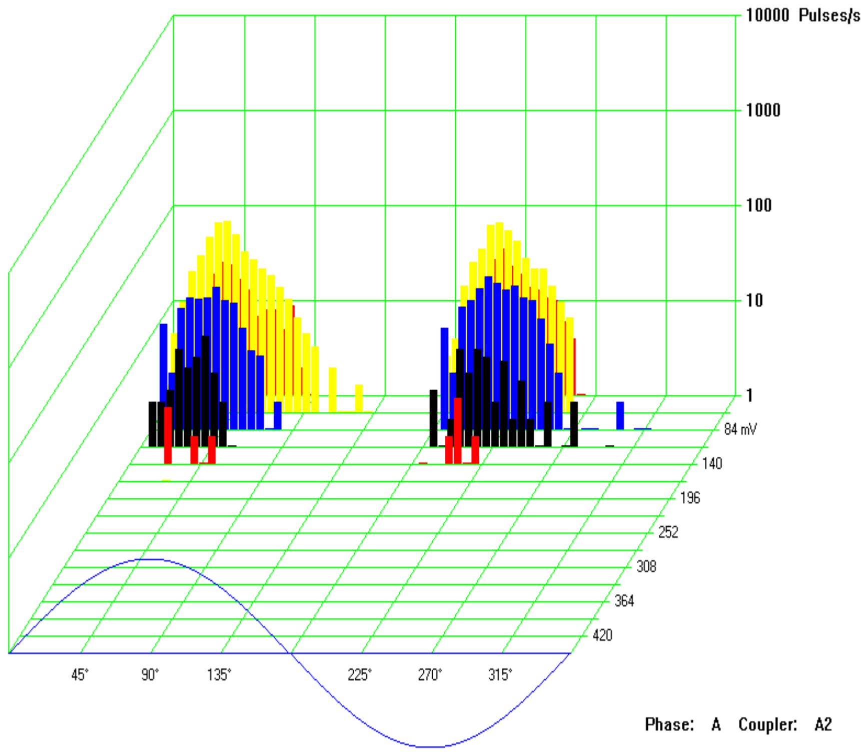

Fig. 2 Phase distribution of the PD pulses (on-line test)

Table 3 lists how to identify the type of stator winding problems using the graph of the positive and negative pulse distribution in Fig.1 obtained with on-line PD testing.

Table 3 Identification of type of stator winding problems using on-line PD testing

Characteristics of the PD distribution graph	**Type of stator winding problems**
Positive pulse predominance	Discharge on semi-conducting coating
Negative pulse predominance	Internal delamination/voids present at copper stack insulation interface
No pulse predominance	Discharge in voids in the main groundwall insulation
Deviation of full-load pulse and no-load pulse	Winding looseness

The graphs in Fig. 1 indicate that partial discharges in phase A were occurring within the groundwall insulation of the stator winding since neither the positive PD pulses or negative PD pulses predominate. Voids within the groundwall insulation can be created by poor impregnation of the bonding varnish or resin during manufacture or by delamination of the insulation layers during service. These voids cause partial discharges under high voltage stress. Insulation breakdown due to PD attack within the groundwall insulation is a slow process. Unfortunately, corrective action for this type of partial discharges can not be taken since the nature of groundwall discharges is internal. However, PD testing can monitor and track the progress of groundwall insulation deterioration. This can give maintenance personnel confidence to continue running the machine with degraded insulation until PD levels increase significantly, indicating a critical insulation deterioration. Then, further off-line tests and inspection should be taken.

3. OFF-LINE PARTIAL DISCHARGE TESTING

An off-line PD test on the same Hydrogenerator was performed to compare the on-line test results with the off-line test ones. The generator was disconnected from the other electrical equipment. The set-up of the off-line PD test is shown in Fig. 3. C1 and C2 represent the capacitive couplers. A Doble M-4000 tester was used to apply 4 kV and 8 kV high voltages to the stator winding. For a ground-specimen test, each phase was tested with the other two phases grounded. To make the test results comparable, the same capacitive couplers and Partial Discharge Analyzer (PDA) as used in the on-line PD test were applied to the off-line PD test.

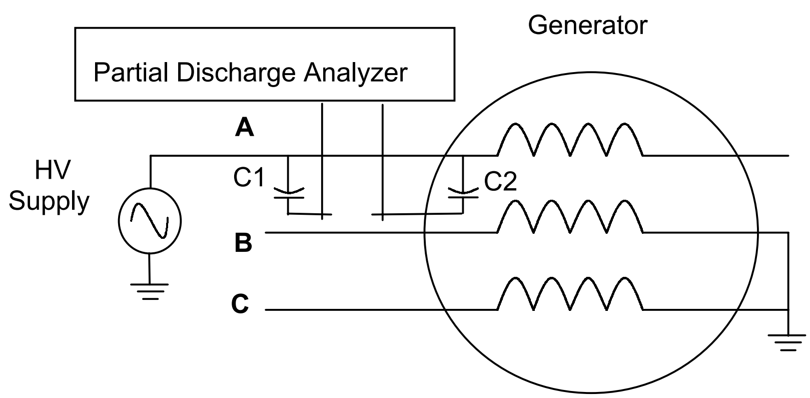

Fig. 3 Set-up of the off-line partial discharge test.

Table 4 Off-line PD readings

Phase	+PD (mV)	-PD (mV)
A	55	65
B	20	30
C	65	65

PD activity was observed when 8 kV line-to-ground voltage was applied. The off-line PD readings are listed in Table 4. The PD distribution was also shown in Fig. 1 and Fig. 4. The off-line PD test was taken at the same line-to-ground voltage (8 kV) as the on-line PD test for comparison of the test results. By comparing Table 2 and Table 4, the PD activity detected by on-line testing is greater than that detected by off-line testing. This is because, in addition to electrical stress, thermal and mechanical stresses contributes to the PD activity in the generator during the on-line PD test. On-line and off-line PD testing show a good correlation by indicating that phase A and phase C had the highest PD readings.

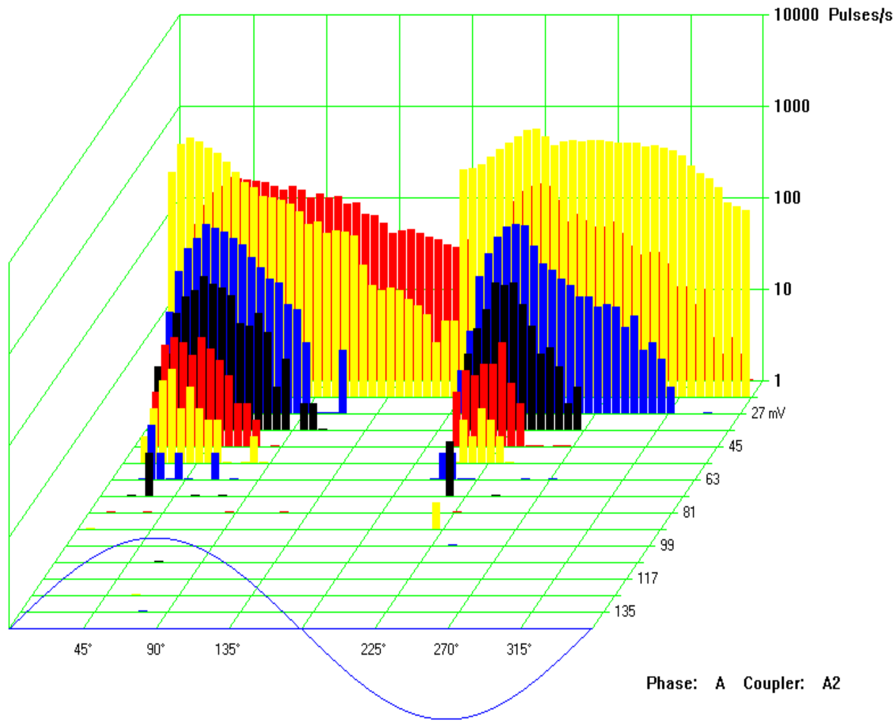

Fig. 4 Phase distribution of the PD pulses (off-line). The magnitude scale (y-axis) in Fig.4 is different from that in Fig. 2.

4. CONCLUSIONS

This comparison of on-line and off-line PD testing proves that on-line PD testing can reliably and effectively diagnose insulation problems which were verified by off-line PD testing. Since on-line PD testing is less costly and easier to perform, it can be used as a routine maintenance tool to monitor the progress of stator insulation deterioration between major maintenance outages. Based on the insulation condition determined by on-line PD testing, future machine outages and the need for off-line PD and other electrical testing may be decided.

If on-line PD testing shows that the stator winding insulation is in a good shape, intervals between off-line PD testing may be extended and fewer tests will be required. If a significant change in PD activity within a certain time interval occurs, (e.g. PD activity doubles within six months), this is an indication of severe stator insulation deterioration [3]. Thus, off-line PD testing is a good complement to on-line PD testing to verify insulation problems and assess insulation conditions. Consequently on-line PD testing can establish a condition-based maintenance program and the maintenance costs of generators can be reduced.

On-line PD testing is performed during machine normal operation with electrical, thermal, mechanical, and environmental stresses applied to the machine. Therefore, on-line PD testing indicates the realistic condition of the stator winding insulation as when the machine is in service.

5. REFERENCES

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2. Y. McNicoll, R. Ross, R. Tremblay, and C. Major, “Improvement in the measurements of partial discharges in hydrogenerators through high-frequency grounding of couplers”, IEEE International Symposium on Electrical Insulation, Toronto, Canada, June 3-6, 1990.

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