Continuous Partial Discharge Monitoring with Assessed Condition Trending System (ACTS)

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Abstract: ALSTOM has developed a powerful tool for unit diagnostic monitoring using analysis results from on-line partial discharge (PD) measurement. The function and advantages of a permanently installed continuous partial discharge monitoring system that includes real time assessed condition trending and alarm initiation capability will be presented. The objective is to improve condition-based and predictive maintenance strategies, which effectively reduce the overall total life-cycle cost of the unit.

The most effective way is to monitor the *assessed* condition of the unit. This implies that the unit has undergone a partial discharge measurement and, based upon the substantial knowledge of the PD analyst as well as the use of an extensive diagnostic database, the unit condition has been evaluated. Once the assessed condition has been determined, trending of this condition can be performed over time. A diagnostic system will be presented that provides continuous trending of the relevant parameters.

1. Basics of PD On-line measurement

Fig. 1 shows the basic configuration of an on-line PD measuring circuit [1]. As shown, one sensor is connected to each phase terminal of the machine. An additional sensor may be installed on the neutral connection for redundancy to gather information in case of a problem indication.

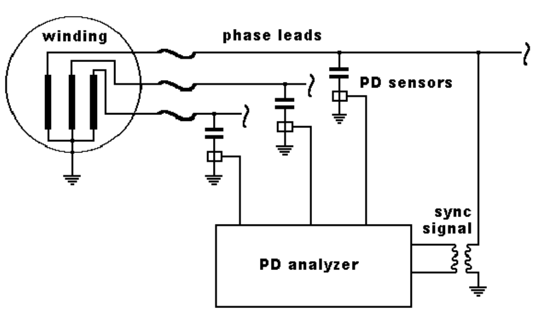

Fig. 1: Configuration of on-line PD measurements

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A synchronization signal obtained from one phase of the machine is required. Synchronizing all PD patterns to one phase allows determination of phase relationships between special PD events. Digital based automatic PD recognition systems employ the phase resolution as a fundamental base of data acquisition.

A PD event somewhere in the machine initiates an oscillation with a resonant frequency mainly determined by the capacitance C’ and the inductance L’ of the windings. As the resonant frequency is determined by the square root of L’ and C’, it is less influenced by the design parameters of the machine and is typically in the range of some hundred kHz. Taking advantage of the resonant frequency, the continuous PD monitoring system measures in the range of 100 kHz to 800 kHz. Only slightly influenced by the damping effect that higher frequency signals would experience, the measured range allows for longer PD sensing capability of the winding PD.

For standard on-line PD monitoring installations, sensors with a capacitance of 9 nF are preferred. Together with the impedance of the machine and the measuring device, the low-pass cut-off frequency is below 100 kHz and therefore also a good choice for the whole system. The sensitivity of the whole monitoring system is dependent on the capacitance of the sensors since they feed, together with the capacitance of the windings, the PD current. Therefore, the higher ratio of $C_{Sensor}/C_{Windings}$ provides better sensitivity during measurement.

It is well known that the higher the frequencies, the higher the signal cross-coupling between the windings and external components of one phase to another. As a result, when using high frequency high-pass filters, the PD readings of the various phases look very similar. The higher the frequencies the harder is it to determine the real location of the PD source with respect to phase and effected region (endwinding, slot, etc…).

A standardized calibration process during sensor installation is paramount for establishing a foundation for condition assessment using a manifold semi-intelligent database.

Lack of a calibration process of electrical machines, even if not accepted by all recognized PD experts [2], leads to a lack of very useful information. Without calibration, the assessment of the insulation condition can only be based on the trending of the PD activity from the current machine and on typical known PD patterns. There are only limited possibilities of comparing the measurements of one machine with other machines having similar design and periphery. Consequently, the available database for assessing the condition of a machine is limited.

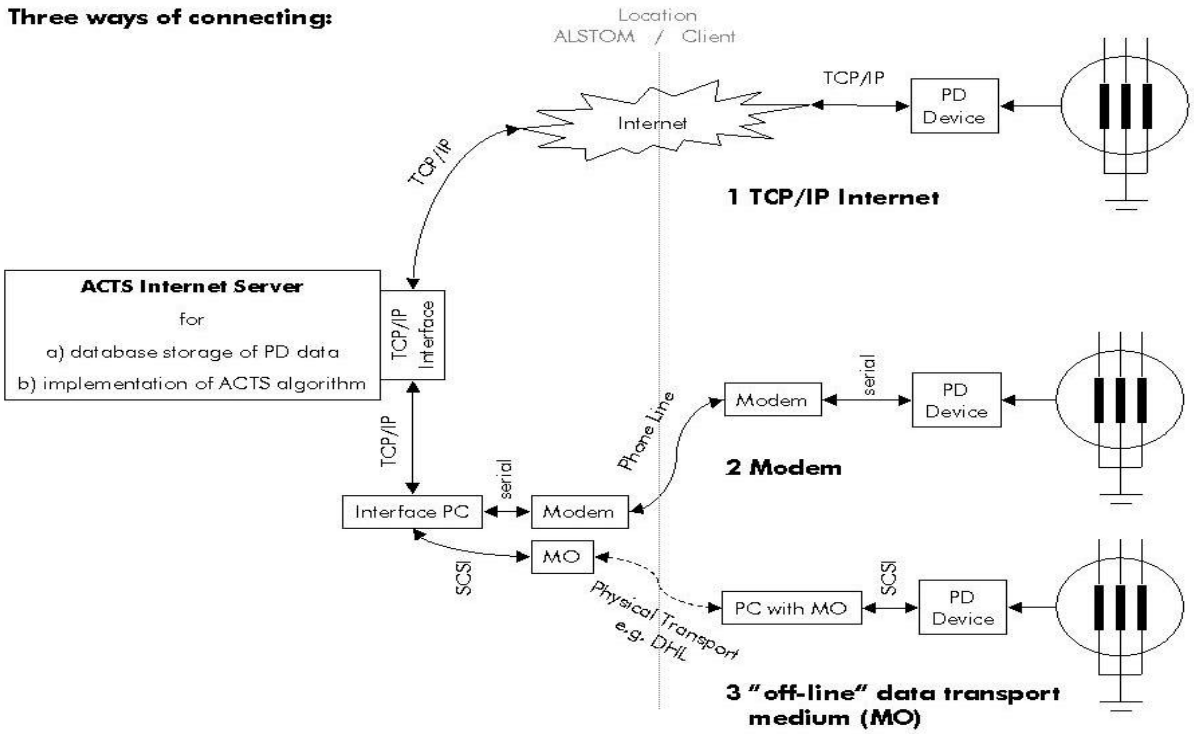


Fig. 2: Measurement and storage concept

2. Continuous PD Monitoring Concept

To improve the lifetime of the measuring device, no rotating parts are used, e.g. hard discs. As a consequence of this the capability of storing trending parameters is limited. A multi-level assessment and storing concept is implemented to achieve effective operation.

As shown in Fig. 2, one PD measuring device is used to monitor each machine. Each device is capable of monitoring four sensors (one per phase and one optional channel for the neutral connection). To enhance plant monitoring system reliability for several generators and large motors at a specific site location, all measuring devices are independent from each other. A failure in the periphery of one measuring device does not consequently lead to a loss of the PD data of other machines.

The assessment of the PD behavior as well as the storage is realized in the following way:

1st Level: The measuring device is capable of storing a defined amount of trending parameters and the last measured phi-q-n pattern for each sensor. This method enables site operators to recall trending parameters and information about the actual state of the machine and to get trending data over a certain period of time.

A first assessment of the actual PD behavior is performed by an intelligent routine implemented in the measuring device. This fundamental local evaluation of the measured PD patterns provides a simple three level indication for operation: normal operation, warning, and alarm.

2nd Level: The phi-q-n patterns are periodically transferred to a server. This server stores selected patterns. Therefore the whole PD history is stored and can be considered for performing a more extensive PD assessment. Depending on the result of this assessment the warning level in the measuring device can be set or an inspection of the data by human experts can be requested.

The method of using a large server for storage of PD patterns over smaller local computing devices was selected for several reasons. A central database is the most effective way for comparing a large amount of PD data and to take all PD measurements into consideration for further analyses. The physical separation between the measuring device and a server for the storage medium has the advantage in ease of improvement of the ACTS algorithm for a worldwide central database.

3rd Level: Periodically or in case of warning or alarm the PD data and the trending is analyzed by a human expert who is capable of adjusting the warning and alarm levels, changing the parameters of the ACTS algorithm or initiating the shut-down and further inspection to prevent imminent failure.

Depending on this extensive analysis further actions and repairs can be planned.

3. Requirements for automatic PD Assessment

Before discussing the special requirements that are necessary for a automatic ACTS algorithm some postulations must be made:

1. Some PD phenomena harm the insulation more than others do.
2. Typical PD patterns and their specific interdependencies (temperature, humidity, vibration, …) are known.

3. Noise suppression and elimination by filtering is possible, maybe with support by using external antennas or optional sensor for gating.
4. Rapid development of the PD magnitude is often an indicator for PD originating outside of the machine.
5. The PD development from PD sources within the machine is usually slower than the development of external sources.
6. High level PD sources are most likely outside of the machine.
7. Rapid increased or reduced PD activity is usually measured after repair or after mechanical problems with the machine.
8. The PD behavior of high voltage machines can be classified. Main classes are voltage levels and cooling system.

1. It is well known, that some PD phenomena in rotating high voltage machines, for example surface discharges, are not as critical as other phenomena, e.g. slot discharges. If an automatic system is able to separate between critical and less critical phenomena, the first step for a reliable automatic assessment is done.

2. For generating automatic routines the typical behavior of several PD sources must be known. By comparing measured PD patterns with typical patterns implemented in an intelligent algorithm most of the possible PD sources can be detected. One important condition is the knowledge of the operating data of the machine during the measurement.

3. In most cases, noise reduction is possible by using intelligent noise suppression. Additional gating with the use of external antennas, in critical cases, is helpful. When eliminating high disturbances, e.g. from the exciter, the remaining pure PD readings can be easily used for automatic assessment.

4., 5., 6. The development of PD sources from outside of the machine is significantly different to the PD behavior of PD sources from the insulation system. The automatic system must be able to recognize the differences. Usually the levels of very high PD in the range of ì C and higher result from external sources or disturbances. Mostly the development of the PD activity of external sources is much faster compared to the development of PD sources from the insulation system. Decrease of the PD activity may not necessarily indicate reduced deterioration, e.g. when over-voltage stress develops into high current failures (carbonization).

7. Significant changes in the PD activity are often a result of service and repair. In that case, they disappear most times after a certain period of time. They also appear after rapid instabilities of the operational mode of the machine, e.g. mechanical failures, or short circuits outside of the machine.

8. The PD behaviors of machines having similar design are very similar. For example the PD behavior of hydrogen cooled machines show very stable, constant PD behavior. The PD behaviors of machines with similar insulation levels are most times similar, more or less independent of specific variations of coil or bar design. Using the PD behavior of a large amount of data helps to create reliable algorithms.

When considering all items mentioned above a powerful intelligent device is possible, which is able to monitor the PD behavior and therefore most of the problems indicated by voltage overstress. In the present stage most of the items are well known by human experts and will be implemented in the intelligent ACTS algorithm. With further measurements and further maintenance works this algorithm will grow to a more and more powerful tool for supporting the service personnel at the plant.

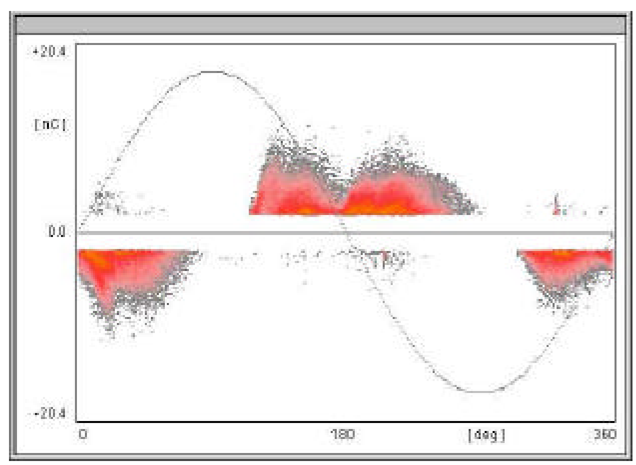
4. Case Studies

Two case studies will be given with examples of typical PD readings. Many other case studies can be found in [4] and some of really critical machines in [2].

Example 1	**Machine Data**
Type of Machine	Turbogenerator
Construction Year	1994
Rated Apparent Power:	119,2 MVA
Active Load during Measurement	50 MW
Stator Voltage:	13,8 kV / 60 Hz
Cooling Method	Air

This machine exhibited four independent PD sources resulting from the insulation. A good example for the demands on an automatic PD recognition system, **human experts found all PD sources** by using various information:

1. The phase separation PD can be determined by comparing the phase relations of the patterns visible in all three phases and by considering the absolute phase angles. For this PD source amplitude information must not considered.
2. The inner PD can be found by analyzing the typical pattern shape and the absolute phase angles.
3. Surface discharges in phase C are present. They can be distinguished by observing the typical pattern shape, the typical PD density and the absolute phase angles. In the example they are regarded to be absolutely harmless.
4. Slot exit discharges in phases A and B, caused by minor bar vibrations. They can be found when considering that these discharges result from a combination of several other PD phenomena.



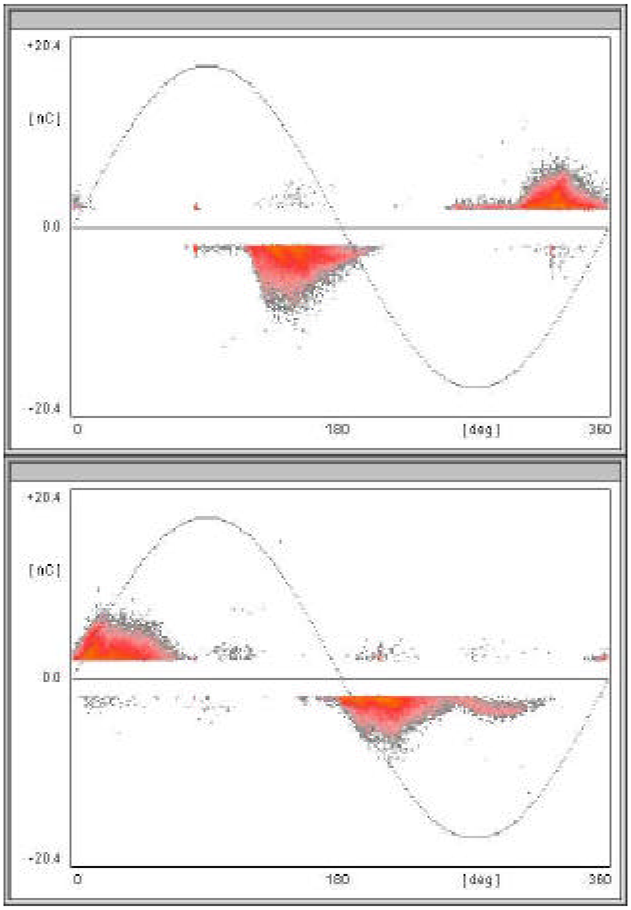


Fig. 3: Example for a turbo generator with multiple, independent PD sources, phases A, B and C

All results of the analysis of the PD measurements were verified by a visual inspection one-month after the PD analysis.

The next example describes the difficulties when too many data were taken into consideration for the analysis of the PD behavior. In this example two generators of the same type where connected in parallel via the same buss. Before a maintenance work on one generator it was impossible to locate the PD source, whether the PD came from generator one or two.

Example 2	Machine Data
Type of Machine	Turbogenerator
Construction Year	1992
Rated Apparent Power:	119,2 MVA
Active Load during Measurement	75 MW
Stator Voltage:	13,8 kV / 60 Hz
Cooling Method	Air

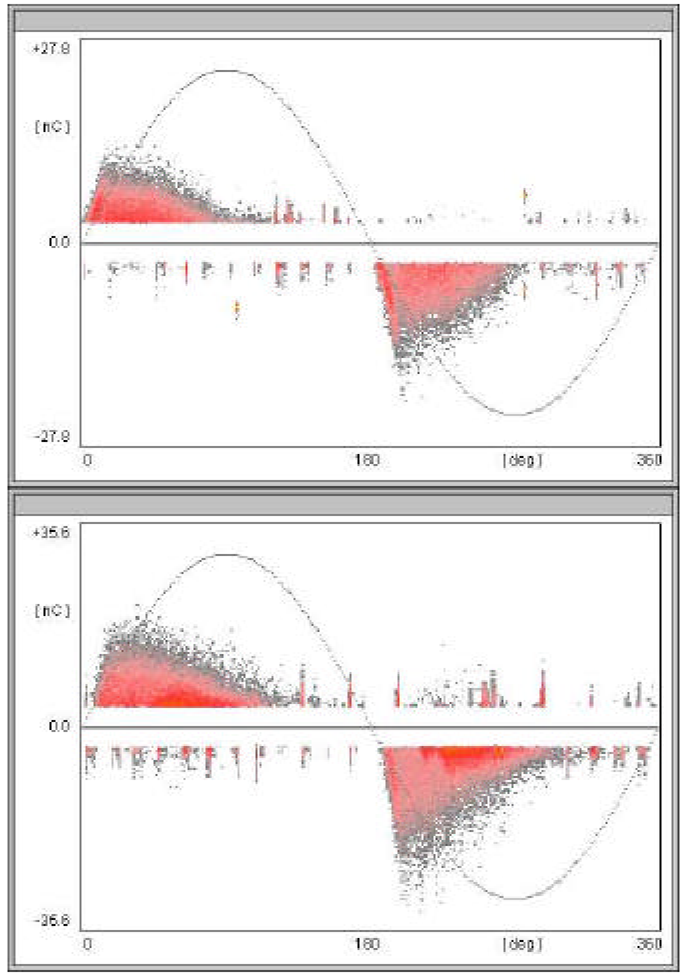
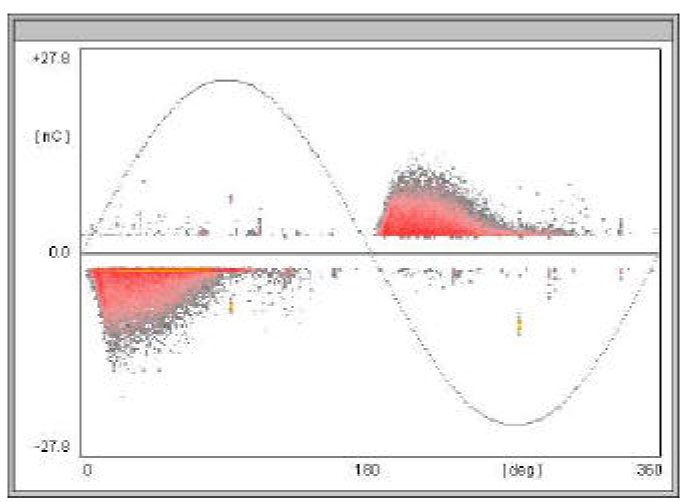


Fig. 4: Example for the PD readings of two generators in parallel, measured at the same time before some repair was performed on the second generator

When comparing the PD readings of Fig. 4 it is nearly impossible to say whether the PD source causing these patterns is located in the first or the second generator. The automatic assessment of the insulation condition is nearly not possible without considering special demands for such machines.

After repair was performed on one generator, the differences between the readings of both generators were detectable (Fig. 5).



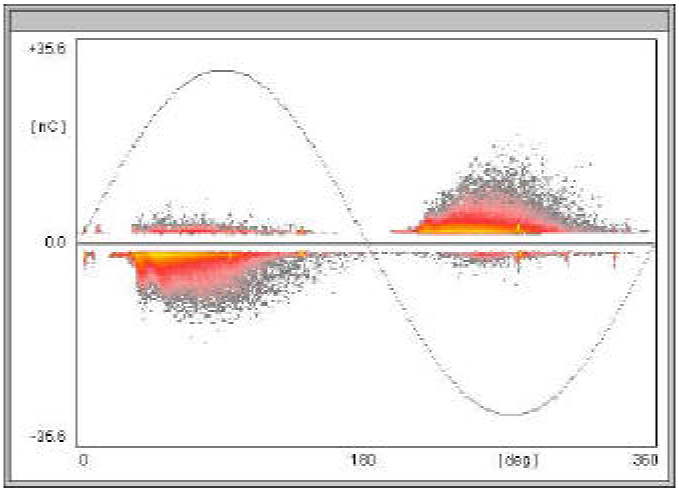


Fig. 5: Example for the PD readings of two parallel generators, measured at the same time after repair was performed on the second generator.

5. Conclusions

If performed correctly, on-line partial discharge measurement and analysis can be a very powerful tool for detecting local insulation defects in the generator insulation systems and therefore assessing the actual condition of the winding insulation. To obtain correct assessment of unit condition, proper coupling devices must be installed to ensure appropriate detection sensitivity and a standard calibration procedure must be followed.

Accurate condition assessment requires an extensive database containing not only specific PD behavior of various phenomena, but also detailed information on machine design features, various insulation systems, manufactures, material characteristics etc. The condition assessment can most efficiently be performed by evaluating suitable PD distribution maps (e.g. φ-q-n pattern) that are very sensitive to the type and location of the PD source within the stator winding insulation. When applying the approach of pattern evaluation / recognition instead of evaluating merely PD levels, it is possible to distinguish several PD phenomena that may arise in stator winding insulation systems. In contrast to using a purely level based PD database, this allows the actual risk to be evaluated as well as appropriate corrective measures to be planned, at minimal cost to the customer.

For key generators and motors, it is recommended to perform PD measurements with capable *continuous on-line* monitoring systems. Contrary to PD *level* monitoring, continuous on-line monitoring employing special technology such as ACTS (assessed condition trending system) may provide the users with the following benefits:

- early detection of deteriorating insulation components / auxiliaries
- reduction of in-service failure rates, i.e. reduction of unscheduled and costly downtimes
- planning of preventive maintenance
- optimized reinvestment planning
- optimized availability and reliability for operational effectiveness

However, due to the principles of PD measurement, not all machine problems can be detected unambiguously by PD measurements. Usually insulation defects that can be detected by PD measurements require locally increased high electric fields leading to repetitive transient current pulses. Therefore insulation failures where continuous leakage currents due to conductive paths between different insulation components are involved (e.g. shortcuts, burned out current path's etc.) may not be detectable.

6. References

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