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On-Line PD Measurement, Diagnostic Tools and Monitoring Strategy for Generators and Power Transformers

Th. Strehl; E. Lemke; H. Elze
LEMKE DIAGNOSTICS, GERMANY

Key words

live-cycle costs, condition assessment, PD measurement, on-line monitoring, generator, power transformer, signal decoupling, PD pattern, PD diagnosis, PD trending, warning system, remote control

Abstract

Presently computer-based monitoring systems are becoming increasingly important for the assessment of key components of electrical generation and transmission, such as generators and power transformers. Especially PD diagnostics facilities become more and more popular as part of complex monitoring and protection systems. They are installed to reduce the live-cycle costs and to enhance the availability and reliability of electrical energy by focussing on condition based maintenance strategies [1, 2].

The paper presents a new developed digital PD monitoring and warning device (LDWD-6). The design bases on practical experience of PD diagnostics on a large variety of test objects, both in the lab and on-site. The main features and advantages of this development are discussed including important general demands for trending and deeper diagnostics as well as practical questions, such as PD signal decoupling, noise rejection and digital signal processing. This contribution is also based on practical examples, concerning PD monitoring of generators and power transformers. Additionally, practical solutions are presented to fulfill the complex demands for trending, enhanced diagnosis and early warning under on-site conditions, i.e. matched decoupling and noise rejection technology. Finally, it is concluded, that an optimum condition assessment strategy can be achieved by treating these items combined to each other. This paper illustrates how this can be performed by the new developed PD monitoring and warning system LDWD-6.

1. INTRODUCTION

The increasing competitive international market of electrical energy requires an enhancement of the reliability and the availability of electrical energy as well as cost effectiveness. An essential contribution to this respect represents the special treatment of important key components of electrical power generation, such as generators and power transformers.

In each case, the main target is to anticipate a maintenance before the components are failing, because an unexpected breakdown would lead in most cases to secondary damages that cannot be estimated. Valuable information can be derived for planning a cost-effective maintenance schedule.

Hence, the strategy of power utilities worldwide is leading towards condition based maintenance. A fundamental condition to reach this target is a reliable assessment of the condition of all important HV equipment, as well as an early warning about an accelerated deterioration of the electrical insulation.

Periodical diagnostic measurements including comparison with a database is the first approach. However, an immediate reaction on sudden insulation changes, e.g. released by non-stationary loads, requires a continuous on-line monitoring system. Various diagnostic measuring methods have been established over several years that may give an indication about the condition of the HV power equipment when applied in a complex way and evaluated by experienced experts. Some of these methods are qualified for on-site on-line application, which is the root for a sophisticated condition assessment.

In order to facilitate the decisions of the operator, intelligent computer based systems are necessary not only to capture and store the data but also to give a convenient information ranging from several illustrative display modes, and calculated quantities up to sophisticated expert systems. Along with the measuring tools, there are currently several interesting approaches that may supplement each other for final condition assessment [3].

In order to give an indication about the insulation condition of the monitored device several quantities may be measured, such as gas-in-oil concentration, loss factor, acoustical emission AE and PD activity, which is the main subject of this paper. Due to practical experiences of diagnostic PD measurements, it should be noted that simply the magnitude of the PD level is not sufficient for any conclusion about the state of the electrical insulation. The better approach is the evaluation of the PD pattern as a fingerprint and its comparison between periodic measurements, i.e. trending.

Based on this requirements an advanced digital PD monitoring and warning system, called LDWD-6, is presented in the following. It can be matched to the specifics of a particular test object or to the computer linked protection system of a power plant or power utility. The LDWD-6 covers these aspects by PD decoupling via continuous data stream processing up to an automatic PD fault recognition and triggering a warning signal.

2. CONCEPT OF THE DIGITAL PD MONITORING AND WARNING SYSTEM LDWD-6

2.1 PD signal processing and evaluation

The PD signal conditioning of the new developed PD monitoring system LDWD-6 is characterized by several sophisticated features. One of this is the **auto-ranging** capability provided by the software controlled pre-attenuator over a range of 100 dB in 3 dB steps. This ensures always the optimum sensitivity range and represents an indispensable tool for the automatic running of the PD measuring procedure.

Another feature, especially matched to the high dynamic range of PD phenomena in rotating machines, is the pulse processing performed optionally by a **logarithmic processing** unit. It covers 3 decades dynamic range without changing the sensitivity range. Provided by the excellent single pulse resolution of up to 100 kHz and the high dynamic range covered by the applied unit, the subsequently performed post processing facilities, just like the phase resolved PD pattern, reaches an enhanced content of information due to the logarithmic scaling.

The third feature, especially matched to the below mentioned PD signal distortion of slot-discharges, is an **internal special filter**. It performs the PD signal integration of higher order to minimize the influence of a pre-filtering by the PD signal path on the reproducibility of the measuring results.

Simultaneously to the PD pulses, the instantaneous values of the **high voltage signal** derived from the measuring impedance is captured and stored. In this way, the necessary information is available to permit all display and diagnosis facilities from a rough overview about the PD magnitude up to the derivation of expert system analysis. The applied PD signal evaluation strategy is schematically shown in Fig. 1.

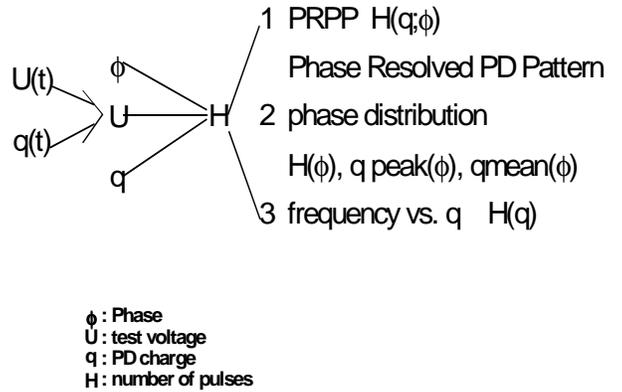


Fig. 1: PD Signal evaluation strategy

The sophisticated hardware structure, as introduced above, is controlled by an intelligent software conception to meet the requirements of a comprehensive monitoring and diagnosis performance. The applied software structures are evident from Fig. 2.

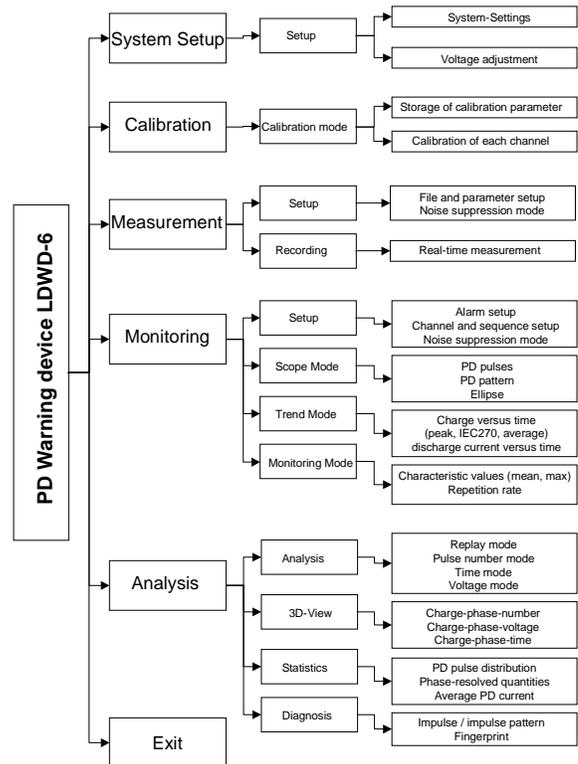


Fig. 2: Software concept of the PD monitoring system LDWD-6

According to the general practical demands for a monitoring system it is possible to specify three main tasks, that shall be discussed.

As already mentioned, the simple indication of PD magnitude is not sufficient to recognize possible problems of an insulation. Provided by the presence of all necessary PD and voltage information, it is possible to perform sophisticated diagnosis of the data in order to derive various quantities and display modes that support the operator to compare the pattern like fingerprint with a library for final judgement the condition of the object.

Several interesting approaches are already existing, exceeding the well known phase resolved PD pattern.

One example represents the so called **impulse/impulse correlation**, developed by Hoof [4]. That supplements the phase resolved PD pattern in an excellent manner, especially at PD phenomena produced by one failure or few. Significant differences of the pattern help to recognize different types of failures based on comparisons with an available data pool (Fig. 3).

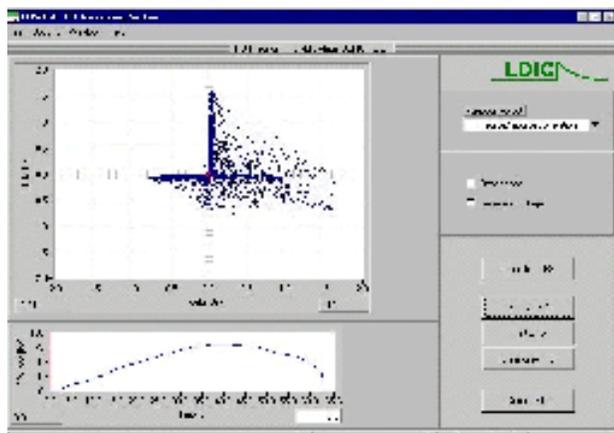


Fig. 3: LDWD-6 Window „Impulse/Impulse-Correlation“

In order to facilitate the comparison of the actual PD behaviour with a library for fault classification, an **expert system** is available that performs the comparison and finally gives out a scaled assignment to well-known PD faults, stored as pattern in the library via sophisticated mathematical tools (Fig. 4).



Fig. 4: LDWD-6 Window „Expert System“

In order to perform a deeper routine diagnosis, it is recommended to periodically download the measuring files as sample over a certain time to any linked computer e.g. via modem.

The other important requirement for **continuous storage** of the PD history is a data logger to record the full history file. For this purpose, the PD characteristics are downloaded to a host computer at the plant or network control system or to an engineering department via conventional **data network systems** (LAN, modem, Internet integration).

The integrated **alarm function** will be initiated immediately if the PD activity exceeds a pre-selected threshold level regarding not only the peak values of the measured PD charge pulses but also the minimum pulse repetition rate and the duration of exceeding the predefined values. Comparable to a digital oscilloscope pre-trigger function, the PD data included in the pre- and post-history file are available for download and following deeper diagnosis.

As **combination of the continuous trending and PD pattern evaluation**, the device determines continuously on-line the distribution of PD repetition frequency versus charge magnitude. By free scaling of both axes (linear or logarithmic scaling), the display mode can be matched to the particular PD behaviour. The so created "living" profile may be updated, stored and transmitted immediately which unifies the PD pattern like information about the PD repetition frequency related to the charge magnitude and represents an enhanced kind of PD pattern trending. The recommended profile would quickly and sensitively react on changes of the typical PD behaviour and is also suited to form an additional alarm criteria when the profile exceeds a manually pre-selected template.

2.2.2 PD coupler for power transformers

For PD decoupling on power transformers, bushing taps are usually connected to an appropriate measuring impedance (Fig. 7). This method according to IEC 270 [5] is well proven in test labs. For on-site-application it requires just some more attention concerning external interferences.



Fig. 7: PD decoupling units of the monitoring system LDWD-6 installed in a power transformer

In most cases, power transformers are connected to an overhead line and, consequently, are subjected to broadcast interferences (single frequency sinusoidal shaped noises). For that reason optimally matched notch filters are integrated in the measuring impedances and connected directly in the PD signal path.

Additional antennas and sensors are also applied, to capture the background noise of pulse shaped interferences based on the so called noise pulse gating method. The block diagram of the developed concept for PD monitoring and early warning is shown in Fig. 8.

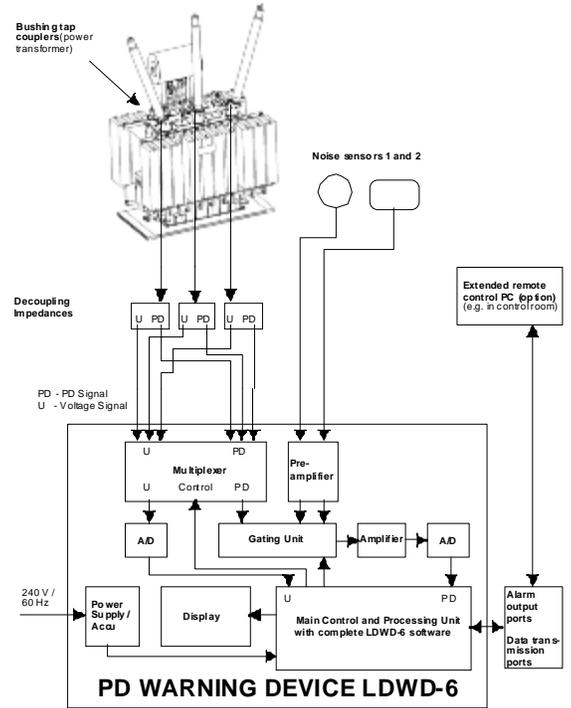


Fig. 8: Block diagram of the PD monitoring and warning system LDWD-6 for power transformers

A practical example of PD monitoring proven, for a 345 kV single phase transformer connected to an overhead line, showed excellent results.

By means of gating channels, which are used to suppress stochastically appearing disturbances, and two additionally inserted notch filters suppressing sinusoidal harmonic interferences in the AM frequency range, the noise level could be reduced to 60 pC on-line so that a detection level of 100 pC was achieved. Assuming typical factory accepted PD levels of up to 500 pC, the realized on-site monitoring assessment level is significantly lower compared to the accepted off-line test floor values. Therefore, this permits on-site detection of PD faults in early stages.

3. SUMMARY

Sophisticated software solutions and the increasing computer networking provide a new quality of operation strategy regarding condition assessment at convenient remote control and facilitated comparisons with data pools.

The paper presents an advanced diagnostic tool for the condition assessment of important key components, such as rotating machines and power transformers. The developed device LDWD-6 is designed not only for on-line PD monitoring but also for an early warning, if the PD activity exceeds a critical threshold. The alarm functions base on the combination of several PD parameters. According to the state of the art, the present monitoring technology provides several proven PD decoupling methods and noise suppression facilities. According to the importance of such projects, the reliability of the monitoring system itself plays an increasing role. Provided by the complete computerization and the available self check pulse generators, intelligent self diagnosis routines ensure the safe operation of the LDWD-6 by recognition of malfunction.

Based on advanced hard- and software strategies, continuously new approaches for enhancement of the performance of the presented system were developed and implemented in the new developed PD monitoring and warning device.

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Th. Strehl; E. Lemke; H. Elze
LEMKE DIAGNOSTICS GmbH
Radeburger Str. 47
01468 Volkersdorf / Dresden
Germany

Tel.: +49 35207 863 0
Fax: +49 35207 863 11
Mailto: info@ldic.de