Advanced Measuring System for the Analysis of Dielectric Parameters including PD Events

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ABSTRACT: **For preventive diagnosis of HV equipment different measuring procedures are in use, such as the detection and analysis of PD phenomena as well as the measurement of the capacitance and loss factor. The submitted paper reports on the integration of such different measuring systems to a common, compact and computer based device. This offers for the first time the possibility of a simultaneous measurement of both, impedance-parameters of HV insulation and partial discharges. Simultaneously PD faults can be located. For analyzing characteristic PD types a database expert system is integrated. So the global insulation condition can be assessed in a complex manner.**

1. INTRODUCTION

Both the loss factor / impedance measurement and the partial discharge measurement are accepted techniques for investigations on the dielectric properties of high voltage insulation materials. For this purpose, the presented new developed system combines the technology of both proven methods.
Caused by the difference of these methods regarding to the appropriate usage most often are both [1] applied in order to get comprehensive test results. On the one hand the integral overall state of a system and on the other hand the differential local insulation system fault analysis is of interest to estimate the condition of HV systems [2]. Only, when applying both diagnostic methods, a meaningful criterion of the tested insulation system can be found [1]. For obvious reasons, the combination of both measurement techniques into one integrated system gains a high benefit.

2. SYSTEM ARCHITECTURE

The system is characterized by a general modular concept. It is designed to implement most of the functionality in digital components, exclusively. Analog parts are used only on a small indispensable scale.

The platform of the user interface for both systems is a conventional iX86-based computer system. The signal preprocessing is managed by separate independent DSP (Digital Signal Processing) units. These units feed the main system bus of the computer. Parallel running real-time NT kernel drivers transport the preprocessed compressed data to a Windows-based user front-end. Different input units with selectable digitizing characteristics are realized. The implementation of different acquisition units is cascadable.

2.1. Loss factor / Impedance Measuring Technology

Obliged by many inconveniences of the classical and traditional bridge technology based on the Schering-idea (1919) and it's improvement in the 1960-ies by Kuster-Peterson using the current comparator principle, a new system to measure loss factor and other impedance quantities was developed. The measuring principle [3] is schematically shown in FIGURE 1. The magnitude and phase relation of the two currents flowing in the measurement- and reference branch are continuously measured by two independent potential free, fibre-optical connected and battery supplied active current sensors.

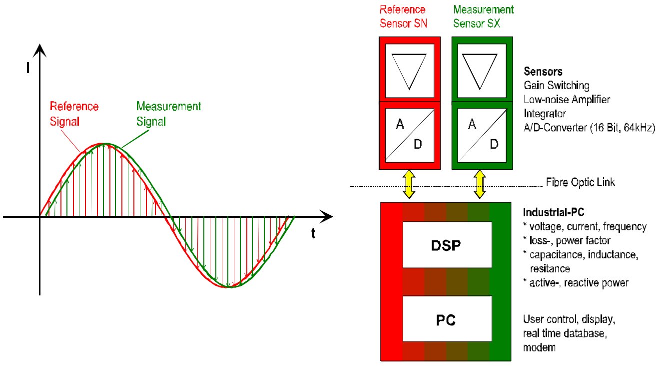


Figure 1: Concept of the loss / impedance measuring system

Signal Acquisition, Sampling, Digitizing

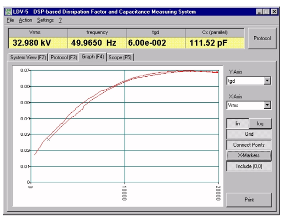
The voltage which drops across the equivalent input-capacitance of the two sensors is acquired and compensated by a fine graduate integrating amplifier (see FIGURE 1). The modulation range is automatically controlled by a fast under- overload-recognition system. Following the high-impedance, low-noise amplifier a 2-channel 16 bit A/D-converter and an electro-optical interface is running in each sensor. With a sampling rate of 64 kHz of both channels of the two sensors the digitized signals are transmitted via a fibre optic link to the receiving unit in the main-workstation. For potential-free signal acquisition the sensors are battery powered. Moreover, the battery charge state as well as the internal sensor temperature is monitored.

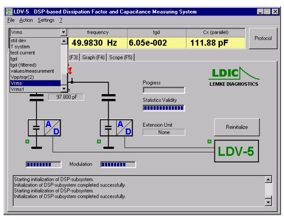
Signal Processing, Signal Compression

The continuously transmitted data stream of the two sensors is buffered and feeds one of the digital signal processing units. The processor performs continuously the spectral dispersion running the DFT (Discrete Fourier Transformation) of the signals of each sensor. The vectorial resolved and spectral dispersed quantities of the two very accurately measured current to voltage converted signals are transmitted to evaluate the requested impedance values.
A real time database on the computer is continuously refreshed with the frequency selective quantities of the complex current values.

For each period of the applied test voltage a data set is added to the measuring data base. From the windows based program platform the user controls on demand which of the impedance values are displayed, stored or embedded into other application software. The quantities under measurement comprise all sorts of interesting impedance parameters and derived mathematical and statistical parameters.

As shown in FIGURE 2 loss / power factor, capacitance, inductance, current, voltage, resistance, active / reactive power and charge can be displayed as a function of the frequency. But also drift and standard deviation are put out. All quantities can be displayed graphically as a function of each other (see FIGURE 2) or can be displayed and stored in an embedded EXCEL spreadsheet.





a.) b.)

Figure 2a: Main window, selection of the displayed quantities
2b: Graph, tan δ vs. voltage

To run a preconfigured measurement procedure [5], set points like timing and interruption commands can be adjusted. Furthermore, these set point variables can also be used to run, e.g., a impedance vs. frequency scan for certain nodes in order to perform a distortion factor measurement.

2.2. Partial Discharge Measuring Technology

The electrical PD detection is an indispensable tool for quality inspection tests in laboratory after manufacturing and for diagnostic field tests after installation and maintenance. Due to the wide range of applications of PD measuring systems the instrumentation arrangement can be varied according to the particular measuring situation. Hence, the PD-measuring system consists of different package modules.

Hardware Concept

The schematic diagram is shown in FIGURE 3. The following functional units can be distinguished.

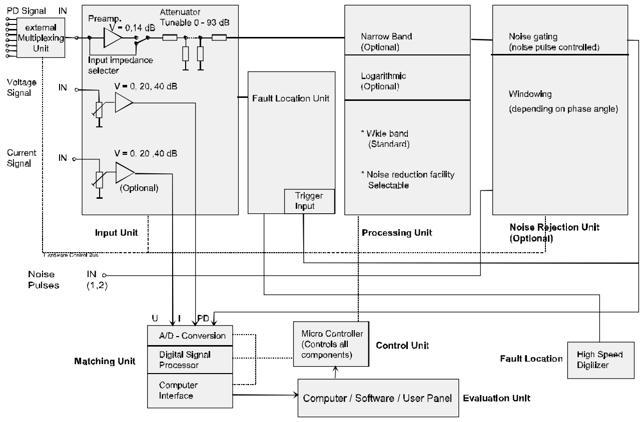


Figure 3:Schematic diagram of the PD-measuring unit

- **Input Unit:**
  - Receiving the signal from the coupling unit. (A wide range of different types of coupling units can be connected)
  - adjustable wide band pre-amplification
  - software controlled filter bank
  - tunable attenuator to get a very high dynamic range (93 dB)
  - Voltage input to acquire the instantaneous value of the test voltage, for phase resolved PD-assignment
  - High impedance input to acquire the instantaneous value of the test current, for PD-phenomena which appear as a function of the test current values
- **Processing Unit (PU)**
  different types of plug-in units can be assembled and combined
  - wide band PU for very sensitive PD-measuring, including special features to use the wide bandwidth for noise suppression

- logarithmic wide band PU of a very high dynamic magnitude resolution for processing each individual PD pulse
- frequency selective PU for narrow band PD-detection, tunable in a wide frequency range or for several selected fixed frequencies

- **Noise Rejection Unit**
  - phase angle resolved hardware windowing
  - noise impulse gating, triggered by external events or by corresponding gating input units, for masking of the noise signals, sensor / antenna inputs for noise impulse suppression

- **Matching Unit**
  - analog digital conversion
  - High-speed programmable gate array pre-processing, for PD impulse, voltage and current recognition, polarity detection, peak value detection, matching for further signal processing, digital noise reduction, timegating for reflection- and oscillation- suppression
  - Digital Signal Processing module for fast data evaluation & compressing, temporary buffering, time- & phase- assignment, control command translation & conversion
  - Software windowing
  - BUS-Interface and bridging to the workstation

- **Control Unit**
  - µ-Controller based control bus for all devices & components
  - auxiliary ports for additional operation functions

- **external Multiplexing Unit**
  - Software controlled switch over module for multichannel systems
  - remote controlling & routing of the switch-over-device

- **Evaluation Unit**
  - Workstation to perform the complete diagnostic evaluation
  - Real-time displaying of all measured PD-parameters with a pulse repetition rate higher than 100 kHz
  - storing, reporting and user adjustable protocol generator
  - measurement process automation
  - database link, Object link and embedded interface
  - enhanced analysis & statistical toolbox (Phase resolved 3D Pattern evaluation, etc.)
  - implemented PD-Expert System

Software Concept

The software concept is characterized by strict partitioning of the numeric data processing into different programmable hardware units.
The first numerical data processing is realized in a field programmable gate array (FPGA). After that, the digital signal processing unit (DSP) is responsible to do the PD-pulse to voltage-phase assignment, the control command translation and the precompression for the main processor subsequent treatment. Based on all this progressive software grading the user interface program in the workstation runs exclusively for the front-end application.
Moreover, all control commands for the hardware management are operated by a separate internal µ-controller.

Analysis & Statistical Features

The front-end software is running under a Windows NT operation system. A comprehensive PD-evaluation toolbox [4] is implemented. It serves for all types of analyzing. Typical routines and evaluation-processes for quality tests in a production environment, on site tests or even for periodical or continuous monitoring are already realized. Also features for a wide range of scientific PD-investigations are available [4].
The analysis and statistical toolbox covers the following functionality:

- replay of all PD quantities in compliance with the specifications of the standards (IEC, VDE, AEIC, IPCEA, ASTM, ANSI) and derived quantities (q, q^2, qxU(t)) using an operation panel similar to an audio-video-player [4]
- display types:
  traditional presentation in time and elliptic mode
  time- and voltage dependent presentation of all defined quantities: apparent charge q; pulse repetition rate and frequency n, N; average discharge current I, discharge power P, quadratic charge rate D, etc.
  PD-frequency distribution, phase resolved 2D & 3D representation
- PD-pulse distribution, segmental or continuous display
- impulse / impulse correlation [5]
- water fall diagrams of the PD-distribution vs. charge
- average PD-current vs. phase and time
- all phase- and polarity resolved statistical PD-parameters (q, H(q)):
  maximum, minimum, mean value, standard deviation, skewness, kurtosis, and cross correlation

Software Automation & Control & Protocol Interface

The basic and enhanced extension capability of the analysis features is suitable to generate all types of requested protocols. The PD-data can be transferred on-line to spread sheet or data base software. Based on preinstalled custom designed document-templates all types of protocols and scoring sheets can be compiled and modified at any time. Additional evaluation procedures can be executed using other application software.

An OLE (object link and embedment) interface presumes the implementation and hosting of other software. Using this common exchange platform complete software based remote control is possible. Exemplary, the embedment of control units (PLC-Components) form High voltage test field automatization is a typical application to use object links in order to combine stored program controllers with measurement devices.
A bi-directional control signal and data transfer between different software packages is performed in the same way as using local or wide area network data transmission. When connecting the system with a digital or analog telecommunication network it is immediately possible to operate telecontrolled monitoring of Partial Discharge and Loss Measurement.

Partial Discharge Expert system

A common mathematical modeling of all occurring PD failures is not available up to now. Only for exceptional cases exists a mathematical model which is suitable to describe a subclass of PD problems. Therefore, a automatized diagnosis system for PD failures is limited to the recognition of specific symptoms in PD measurement data records.
In this connection it must be noted that the characteristic feature extraction of the data record is cut out for the key position [6] in the quality of the diagnosis result. In the scientific field of the PD-fault recognition exits a wide range of formulations about the suitability of different features to be extracted.
Realized for the presented PD expert system is a combination of two independent feature detectors. The Fourier correlation coefficient of the phase resolved charge signal is normalized to the number of the test voltage periods. To describe the phase resolved PD distribution is only a limited number of coefficients of the Fourier series necessary [6] and used for the feature extraction array. Additionally, the variation of the coefficients versus the test periods is inserted to the feature pool.
Furthermore, the classical statistical operators [7] of the derived histogram functions of the PD-frequency distribution are included in the feature extraction matrix.

After the extraction, the two resulting feature arrays are subjected by a classification schedule. The classification is effected by means of comparison of feature extraction arrays of the actual measured PD-data with feature objects of all existing PD failure records stored in a reference database. As the classification result, the qualified probability of the classmembership of the classified object array related to identified PD fault is evaluated and after a mutual coincidence check displayed on the computer screen of the PD-measuring system. A typical classification result is shown in FIGURE 4.

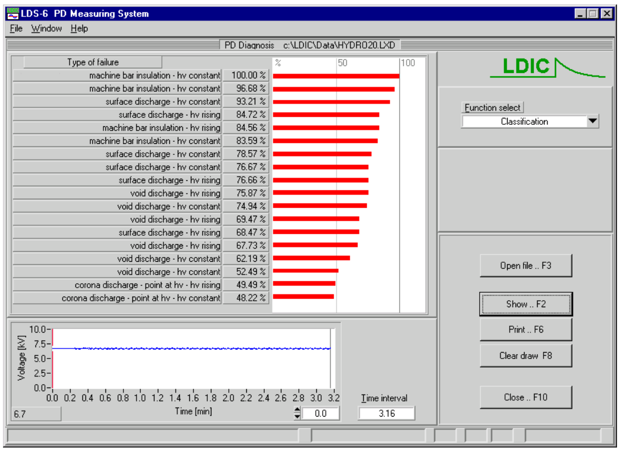


Figure 4: PD fault identification

2.3. PARTIAL DISCHARGE LOCATION TECHNOLOGY

It is obviously of high importance not only to know the values of the PD quantities like apparent charge level, repetition rate and phase correlation of a measured PD-signal, but also the source position of the detected pulses. Mainly, in spatial extended objects like power cables the PD-fault localization is of highest interest.
To locate PD-faults in cables the traveling wave principle is commonly used. A wide band digitizing unit for time-domain reflectometry is therefore installed in the system (see FIGURE 3).

Reflectometer Method

For the PD-pulses the cable appears to be a dielectric waveguide. Therefore the PD-pulse at the point of origin is divided into two equal parts in accordance to the differential characteristic impedance of the cable. A separate fault location amplifier supplies the highspeed digitizer with the received RF-PD-signal. The signals are converted with a digital dynamic of 10 or optional 12 Bit and a sampling rate of 100 Ms/s.
The time delay between the direct measured signal and the first subsequent reflected impulse echo is evaluated in the fault localization unit

The computer based system is able to run the impulse echo evaluation for the complete corresponding PD-impulse-reflectograms. Hence, not only the PD-fault with the highest magnitude is detectable but also localization of multiple faults [8] is possible. All localized PD-faults are extracted, evaluated and mapped automatically. Thus, the PD-mapping diagram represents the PD-pulse magnitude as a function of its particular position vs. the number of the localized PD-pulses. A typical PD-position map is shown in FIGURE 5.

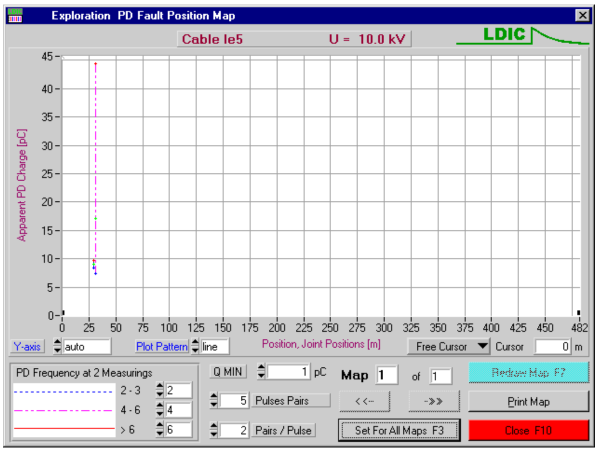


Figure 5: PD fault position map

This reflectometer functionality is easy accessible from the same common LDS-6 software platform.

Enhancement of the Location Sensitivity

To improve the location sensitivity and accuracy a number of high sophisticated features are realized additionally:

- A continuous pulse averaging and an adjustable threshold level can be applied to reduce continuous interference's, impulse oscillations and background noise.
- A FFT feature assists the user finding harmonic radio interference's. Supported by this harmonic analysis, a selection of digital filters can be adjusted optimally.
- The rise time of the pulses is used to discriminate between near and far-end PD-sources.
- For an exact position-independent determination of the real PD-impulse magnitude a transmission-loss-adjustment is automatically executed for all located PD-pulses.

3. SUMMARY

The presented system provides the possibility to combine together a great variety of measurement techniques to one system. A high accurate and frequency independent impedance- and loss factor analyzer can run parallel with a complete digital partial discharge analyzing system. With respect to the particular measurement task and the corresponding disturbance situation, several different processing units can be used. In addition, a reflectometer module for PD-fault location can be implemented.

The developed software for all available measurement devices complements the capability with regard to the noise suppression facility and therefore the improvement of the sensitivity. Comprehensive analysis and diagnosis software tools and a PD-expert system permit a user-friendly PD-fault recognition and identification.

The application range covers the complete spectrum: Scientific and industrial research purposes, routine tests in a production environment, on-site diagnostic tests and installations for condition monitoring.

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