On-Site Partial Discharge Monitoring using the differential LEMKE PROBE LDP-5 and its accessories

Dirk Russwurm, HV Technologies, Inc.

Abstract

The differential LEMKE PROBE LDP-5 can be used for an quick scan of the partial discharge (PD) level of the different high voltage equipment, like cable accessories, power transformers, instrument transformers, switchgear and insulators.

To adapt the LEMKE PROBE to the different measuring tasks, a set of different sensors can be used. Ranging from galvanic connection on the simple side to ultra-high frequency and ultrasonic adapters on the most sophisticated side. These adapters are explained together with their working principle, advantages and limitations.

1. Introduction

Partial Discharges are known to be the major reason for the electrical aging of high voltage insulations. They can be used as an important indicator for aged or damaged insulation, before a breakdown occurs. Recent developments ease the difficulties partial discharge measurement faces under on-site conditions, like electrical noise, crosstalk and outdoor conditions.

The differential LEMKE PROBE LDP-5 can be used for an inexpensive PD scan of the different high voltage equipment on-site. The work of the equipment is not effected and no outages are required for the testing with the LEMKE PROBE. Hence a regular survey can be used for detecting dangerous PD spots, which allows condition-dependent maintenance, increases the reliability and avoids unnecessary preventive exchange of equipment.

Measurements on-site are often affected by electromagnetic noise. Therefore powerful noise suppression is necessary.

The modular approach of the LEMKE PROBE LDP-5 and its sensors and accessories gives the user the opportunity to customize the system.

For different measuring tasks, the use of different sensors for the LEMKE PROBE is necessary.

The sensors and other equipment to be used with the LEMKE PROBE LDP-5 are explained more in detail.

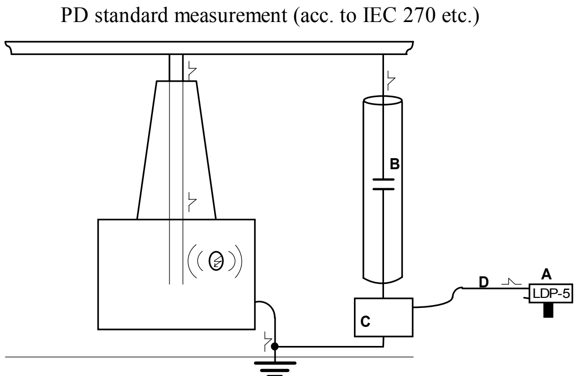
2. Common Sensors for PD Measurements

2.1. Standard PD Measurement Circuit

The LDP-5 can work as an inexpensive analogue PD detector if connected to a high voltage coupling capacitor and a measuring impedance. This is the setup recommended in IEC-270 and other standards.

Advantages:
- Standardized test setup
- Standardized calibration procedure
- High sensitivity

Limitations:
- Needs a direct connection with the high voltage
- Mostly restricted to the use in the laboratory
- Cannot be applied while DUT is in service



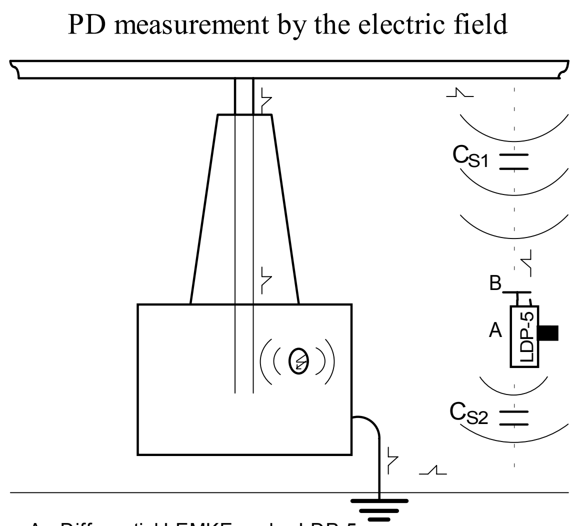
A - Differential LEMKE probe LDP-5
B - Coupling capacitor
C - Measuring impedance LDM-5
D - Connection cable

Figure 1: PD measurements according to IEC-270

2.2. Capacitive Sensor

The stray capacitance between the high voltage parts of the DUT and the electrode of the capacitive sensor are working as the coupling capacitor in this case.

Figure 2: Lemke Probe LDP-5 with C-Sensor



A - Differential LEMKE probe LDP-5
B - Capacitive sensor (electrical field sensor, C-sensor)
C_{S1} - Stray capacitance between HV and LDP-5
C_{S2} - Stray capacitance between LDP-5 and ground

Figure 3: Using the C-Sensor

Advantages:
- No connection to the high voltage is required, can be used while the test object stays in service
- No coupling capacitor required
- Easy test allows a quick scan of all substation equipment
- When put on a hot-stick, the LDP-5 is potential-free and can be moved near the high voltage.

Limitations:
- Requires direct line-of-sight to the high voltage connection of the DUT
- Does not work thru electrical shields, metals screens etc.
- Not very sensitive (depending on sensor size)
- Not very directional, can be influenced by noise sources (corona on connectors, pd in nearby equipment, AM stations etc)

☛To improve the sensitivity, larger sensors and direct grounding of the probe can be used.

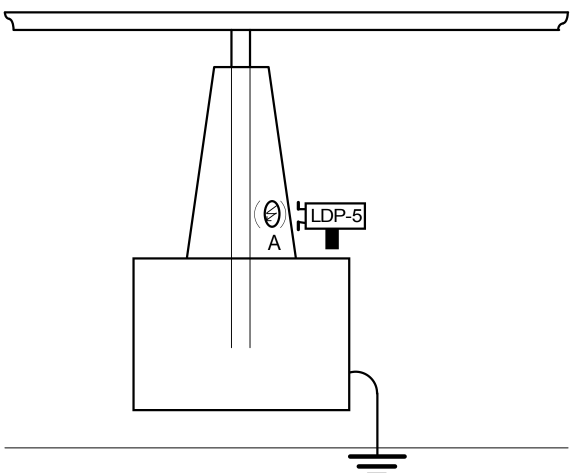
Differential mode

One special mode of operation is the differential mode. It requires two small C-sensors and is used to pinpoint PD locations.

The two C-sensors are connected to the positive and negative input of a differential amplifier. If both sensors see exactly the same signal, the output reads zero. So the goal is to "zero-out" the PD signal by moving the LDP-5 until the PD source is exactly in the middle between both C-sensors. An accuracy of a fraction of an inch can be reached. The differential mode is best used for pin-pointing a PD failure within an unshielded insulation, like dry-type transformers, instrument transformers, unshielded cable joints and terminals.

Figure 4: LDP-5 in Differential Mode

PD location by differential mode



A - PD site in the insulation (not shielded)
B - Differential LEMKE probe LDP-5 with two small C-sensors at the differential inputs

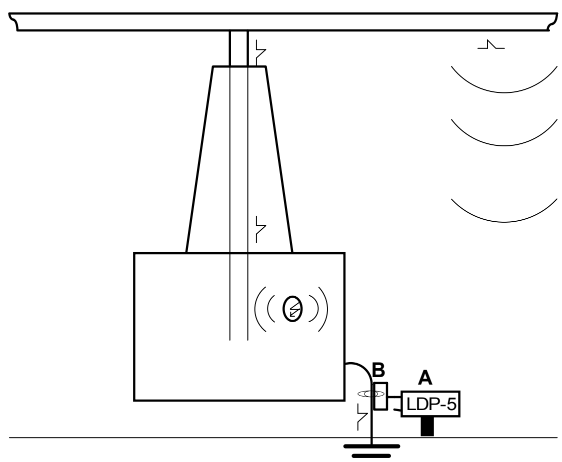
Figure 5: Differential mode for fault location

2.3. Inductive Sensor

The working principle of the inductive sensor (L-sensor) is known from current transformer and the Rogowski coil. The magnetic field around a wire (e.g. the ground connection) caused by the HF currents induces a voltage in the winding of the inductive sensor. This voltage is measured.

Figure 6: Lemke Probe LDP-5 with L-Sensor

PD current measurement by the magnetic field



A - Differential LEMKE probe LDP-5
B - Inductive sensor (magnetic field sensor, L-sensor)

Figure 7: Using the L-Sensor

Figure 8: PD Measurement in a Substation

Advantages:
- No connection to the high voltage is required
- Can be used while the test object stays in service
- No coupling capacitor required
- Easy test allows a quick scan of all substation equipment
- Very sensitive

Limitations:
- Has no directional selectivity
- Does not work thru shields
- Requires direct access to e.g a grounding wire

☛The L-sensor has to be held in parallel to the wire. Do not thread the wire thru the sensor opening.

2.4. Galvanic Coupling

The galvanic coupling uses the voltage drop over e.g. a piece of the shielding to measure the signal.

Advantages:
- No connection to the high voltage is required
- Can be used while the test object stays in service
- No coupling capacitor required
- Allows a measurement of currents flowing on the surface of a shield

Limitations:
- Needs a direct galvanic contact to the wire or shield used

☛ Always press both tips firmly on the surface. The galvanic coupling is seldom used.

Figure 9: Lemke Probe LDP-5 for direct measurement

3. Specialialized Sensors

These specialized sensors fulfill tasks that are impossible with the standard test setup.

3.1. UHF/VHF Sensor

Depending of the discharge conditions, the PD can have a frequency spectrum reaching up to several Giga-Hertz (GHz). The range above several hundred Mega-Hertz is called "Ultra High Frequency", abbreviated UHF. Many TV stations and cell phones e.g. are using this frequency band.
Using this frequency band for PD detection offers many advantages under certain circumstances. Many noise sources, like radio stations, semiconductor switches or even the "corona" PD in air have a lower frequency spectrum and therefore don't affect the measurement. These ultra-high frequencies will be rapidly attenuated within solid or liquid insulations, allowing a precise pinpointing of a PD location.
These characteristics also prevent the detection of a PD fault deep within a solid or liquid insulation.
On the other hand many shields designed for 60 Hz are not very effective at several hundred Mega-Hertz, thus allowing the detection of PD on otherwise shielded equipment.

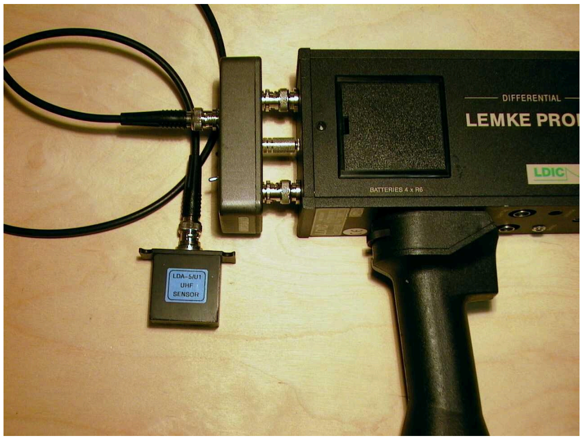


Figure 10: LDP-5 with UHF-Sensor LDA-5/U

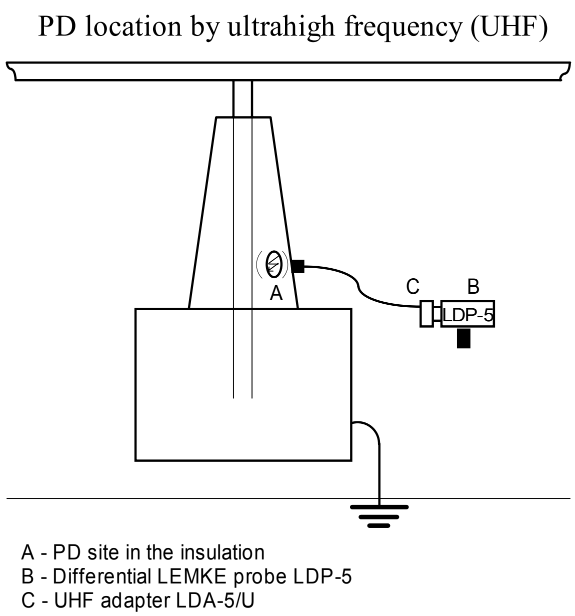


Figure 11: Using the UHF Sensor LDA-5/U

Figure 12: Cable Joint testing with the UHF-Sensor in a Manhole

Advantages:
- No connection to the high voltage is required
- Can be used while the test object stays in service
- No coupling capacitor required
- Perfectly suited for PD measurements on SF_6 gas insulated switchgear and lines (GIS and GIL)
- Best solution for pin-pointing a PD fault within shielded insulations, like power cables, cable joints and terminations

Limitations:
- Requires special built-in sensors for GIS and GIL
- Works only near the PD source in solid or liquid insulations (within inches)
- Needs proximity to the insulation surface. Safety distances to HV terminals can prevent the use
- In other than SF_6 insulated GIS a calibration for the PD level makes no sense. The common power equipment behaves very different in the UHF band. Many electrical resonances in the equipment, the strong attenuation of the signals on short distances, the short wavelength of the UHF signal and the strong influence of the calibrator connections result in a calibration not representing the real conditions in the PD fault. Instead an adapted calibration will be used which ensures the same input sensitivity of the detectors.

☛ The UHF sensor is direction sensitive. Turn it until the maximum reading is reached. The propagation of HF electromagnetic waves has to be taken into account.

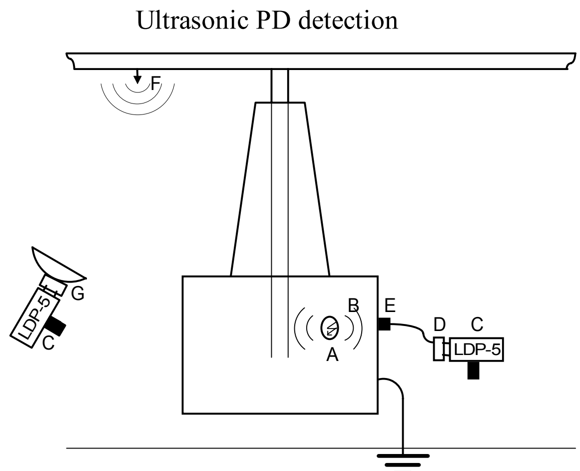
3.2. Ultrasonic Sensors

A partial discharge generates not only a fast transient electromagnetic field, which is picked up by the other sensors described in this paper, but also other phenomena like a light flash or an acoustic pressure wave are emanated.

Under certain circumstances it is advantageous to use the acoustic impulse for detection.

The **general limitations** for acoustic detection are:
- No calibration possible. There is no relationship between the electrical discharge and the generated sound wave, which could be used for calibration. The level of the sound

wave is strongly depended on the location of the fault and the wave distribution.
- Many PD faults cannot be recognized, because the attenuation of the signal path between fault and detector is too high. This is especially true if the signal has to pass thru several layers of different materials or extruded insulation.



A - PD in the insulation oil
B - Conducted ultrasonic sound
C - Differential LEMKE probe LDP-5
D - Ultrasonic adapter LDA-5/S
E - Ultrasonic transducer for conducted sound
F - PD on a pin in air ("corona")
G - Ultrasonic transducer for sound in air

Figure 13: Ultrasonic sensor LDA-5/S

3.2.1. Parabolic Reflector

One characteristic of ultrasonic waves compared to electromagnetic waves of the same frequency is that the wavelength is much shorter. This allows the design of highly directional sensors with reasonable mechanical dimensions.
One example is the parabolic reflector (dish-mirror). It concentrates the sound waves coming from one direction onto the transducer in its focal point. With its sights the user can determine the location of the discharge site from up to one hundred feet away.
The use of ultrasonic frequencies (above 20kHz) makes the equipment more sensitive and results in a better signal-to-noise ratio compared to the normal audio range.
Advantages:
- No connection to the high voltage is required, can be used while the test object stays in service
- Accurate location of the defects from a safe distance
- Best results for locating “corona” discharges in air or surface discharges (tracking) on insulators
- Best suited for scanning of insulator chains etc.

Limitations:
- Needs a line-of-sight between the PD failure and the detector
- Cannot locate internal PD
- Location can be misguided by the reflection of the ultrasonic wave on walls and other straight surfaces.
- No calibration possible

3.2.2. Transducer

Steel conducts ultrasound very well while it screens the electromagnetic field. Therefore it is possible to detect partial discharge inside an oil-filled power transformer steel tank by its emanated ultrasound. An ultrasonic transducer (a microphone for surface waves) is pressed against the outer side of the steel wall and receives the shock wave from the partial discharge in the transformer oil.
This also allows locating the PD sources by triangulation, if e.g. three transducers are used. The location is made difficult by reflections inside the transformer, refraction in different materials or caused by different oil temperatures, and the much higher speed of propagation in steel than in oil. Therefore it requires an experienced operator with a sound knowledge of the layout of the transformer and the propagation of the ultrasonic waves to reliably locate the PD source.
Advantages:
- No connection to the high voltage is required, can be used while the test object stays in service
- Allows PD detection thru the transformer steel tank
- Locating the PD source is possible
- Best used for oil-filled transformer with steel tank

Limitations:
- Best detection results for PD in oil with direct line-of-sight to the steel wall
- No detection of PD possible inside the winding, in the bushing and possible air cushion above the oil
- Calibration not possible

☛ For transformer testing, a combination of electrical and acoustic testing gives the best results. The electrical measurement detects PD in the winding and in the bushing. It gives the “pC” reading to estimate the severity of the PD fault. The electric signal can also trigger the acoustic measurement, thus simplifying the location.

4. Noise Suppression

The conditions for PD measurement in the field are far from optimal. AM radio stations, other transmitters, variable frequency drives and other electronic devices as well as other HV substation equipment generates a multitude of electrical noise which affects the PD measurement.
Noise sources can be divided into two different kinds.

- **Narrowband noise**: Examples are AM radio stations. They generate a strong electromagnetic signal on a very small frequency range. Normally this noise is continuous. Often the modulation (music, talk) can be heard from the built-in speaker of the Lemke Probe LDP-5.
- This noise can be suppressed with an additional filter or the built-in RIV suppression.
- **Wideband impulse noise**: Generated from all kind of electrical switching and other PD sources. Examples are thyristor switches (light dimmer), transistor switches (variable frequency drives), activated circuit breakers. An example for often undesired PD noise is the corona discharge from overhead power lines.
- This can be suppressed with the noise impulse comparator LDK-5.
- Sometimes these noise pulses are stable in respect to the power voltage phase angle (Thyristor and transistor switches). In this case these signals can be deleted from the recorded signal afterwards, using the software noise suppression of the LDS-5.

☛ Each kind of noise has to be treated differently to suppress this noise. The operator needs experience to correctly identify and suppress the noise.

4.1. Built-in RIV Suppression

To suppress noise from AM stations, the LDP-5 has a built-in RIV function (RIV = Radio Interference).
Its working principle is as follows: Because the PD detector has to integrate the signal over a given time, the continuous AM narrowband wave with a relatively small peak voltage (amplitude) gives the same reading as a short impulse with a higher peak voltage. By providing an adjustable threshold voltage, the smaller AM wave will be attenuated much more than the PD impulse and will be entirely suppressed.

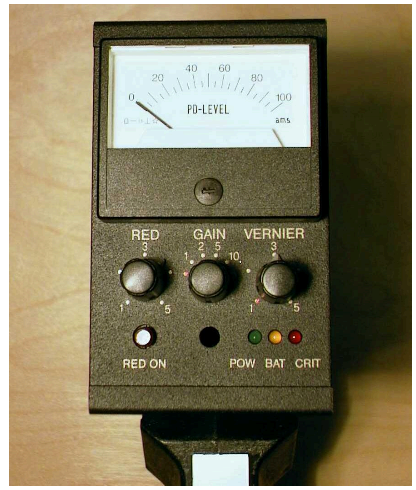


Figure 14:Operating the LDP-5 (RIV Reduction on the Lefthand Side)

Advantages:

- Improves the signal-to-noise ratio
- PD signals below the noise level can be detected

Limitations:

- Suppresses only AM noise effectively
- Creates a non-linearity in the reading

☛ If used, it has to be used for the calibration also. The RIV suppression makes the integration process nonlinear. The reading at the calibration setpoint still fits, but higher PD values might be less than indicated while smaller pulses will be displayed even less (e.g. when calibrated with 100 pC, a 50pC signal might be displayed as 40pC).

4.2. Noise Filter LDF-5

The wideband integration of the Lemke Probe LDP-5 makes the use of band-stop filters possible. A “Band-Stop Filter” suppresses only a small portion of the frequency spectrum but passes on the rest. The loss of a small frequency band does not affect the operation of a wideband detector; the calibration process will compensate for this.

When adjusted to the frequency of the narrowband noise, the Noise Filter LDF-5 will suppress this noise. An improvement of the signal-to-noise ratio by a factor of ten is possible under good conditions.

Figure 15: Noise Filter LDF-5

Advantages:
- Improves the measurement sensitivity if narrowband noise occurs
- Does not affect the linearity of the PD detector

Limitations:
- Multiple narrowband noise with widely different frequencies will not be suppressed effectively

☛ If the noise filter LDF-5 does not seem to work, check the battery first. It needs the battery also in the passive mode.

4.3. Noise Gating with the LDK-5

The electrical waveshape of impulse noise is very similar to a PD pulse. Therefore it cannot be filtered out as narrowband noise.
The approach to suppress impulse noise uses a second Lemke Probe LDP-5 to record the noise events only from a place where the noise is strong but the PD signals will not appear (e.g. the low-voltage power line). Then both signals, the PD signal with the noise disturbances and the noise signal alone will be fed into the Noise Comparator LDK-5.
The LDK-5 has two modes of operation: Noise gating and noise subtracting.
The **noise subtracting** basically subtracts the noise from the PD plus noise signal. While seeming straightforward, it is difficult to adjust and therefore the less recommended mode.

The **noise gating** uses an electronic gating circuit and closes the gate for the measurement when the noise level is above an adjustable threshold level, thus blocking the noise (and possible PD happening at the same time) from reaching the display.
Usually impulse noise happens only for a short time of some Microseconds. Therefore the likelihood of blocking PD signals together with the noise is small. It is very unlikely that it blocks two or three PD signals in a row, so the PD level and pattern will still be the same while using noise gating. Sometimes the measuring time can be increased to compensate for the loss in PD events.

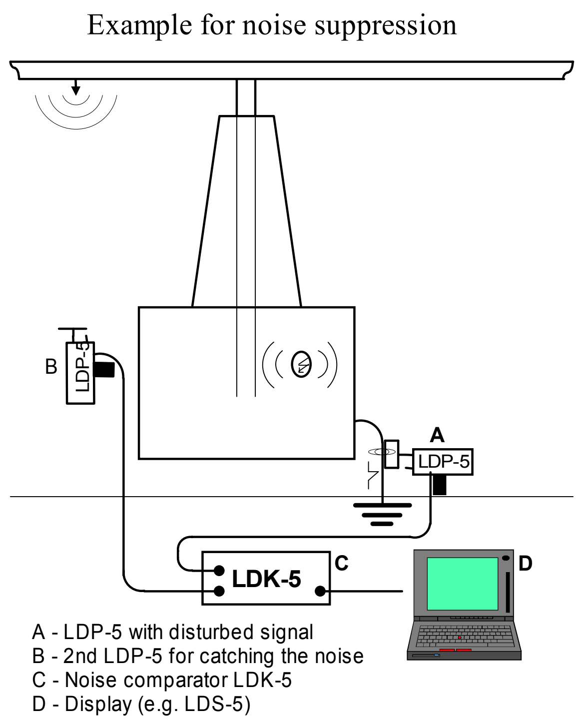


Figure 16: Use of the Noise Impulse Comparator

Advantages:
- Allows PD measurements in areas with strong impulse noise
- Very useful for measurements in substations and power plants

Limitations:
- Can suppress some PD signals together with the noise
- A second LDP-5 is needed together with the LDK-5

☛ Take care not to compensate too much or set the gating threshold level to low. A good test is to check if most of the calibration signals can still be seen on the calibration.

5. Digital PD Measurement

Digital PD measuring systems offer many advantages over the older analog detectors. The clearer display at the measurement, the recording of each single PD event on the hard disk and especially the advanced analysis make the diagnosis easier and more accurate.
Most digital PD detectors are designed for the HV laboratory. To get a digital PD measuring systems for field tests, the Lemke Probe LDP-5 can be combined with the LDS-5, basically a selected laptop in a sturdy carry case.
The LDS-5 digitizes displays and records the whole PD measurement on the hard disk.

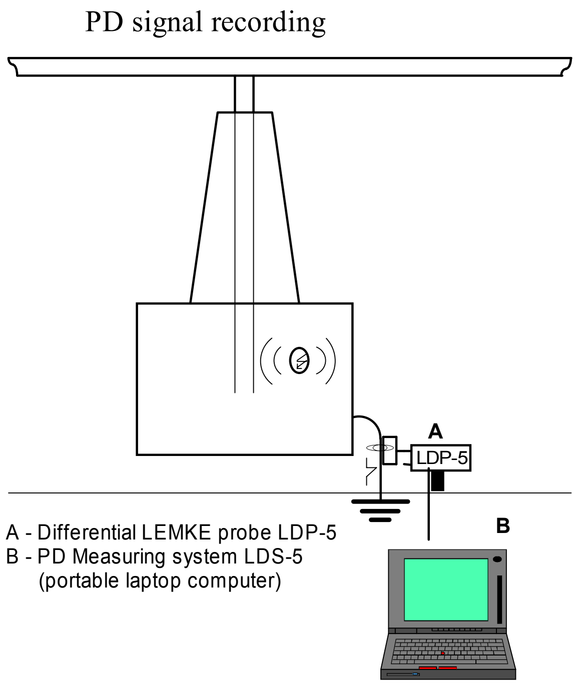


Figure 17: Digital PD Detector System by combining LDP-5 and LDS-5

Figure 18: Digital On-Site PD Measurement

Advantages:

- Converts the analog Lemke Probe LDP-5 or other analog PD detectors, e.g. the LDD-5, to a digital PD measuring system
- Records every PD event with respect to its magnitude, time and phase angle on the hard disk for later analysis
- Real-time display of the recorded PD gives an immediate overview and helps to recognize noise.
- Comprehensive analysis possible on-site or later in the office
- Comparing the data with datasets previously recorded shows trending.
- Analysis software creates e.g. a digital fingerprint of the PD characteristics and shows the maximum likelihood of the failure reason based on an internal database of previously recorded fingerprints. This can greatly simplify the analysis.
- The LDS-5 can be used advantageously for all kinds of PD tests.
- Connection of the computer to e.g. the Internet let you share data and experience.

Limitations:

- The laptop computer can handle max. 10,000 PD events per second. If two PD pulses are less than 100µs apart, only the larger one will be recorded.

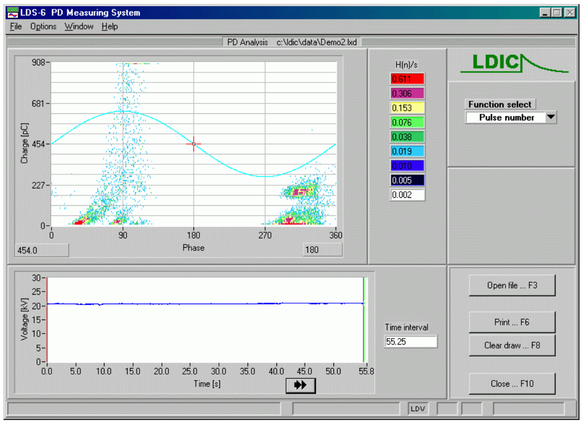


Figure 19: Recorded PD Pattern

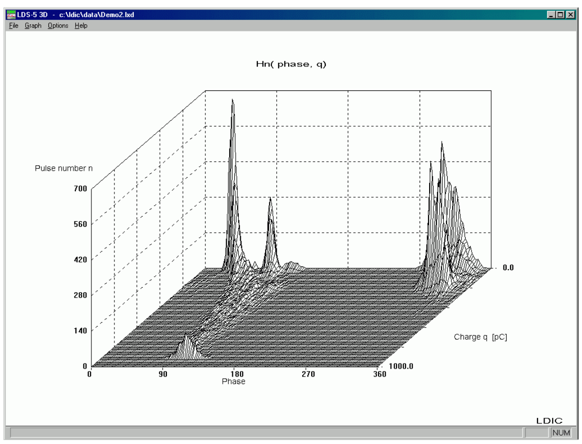


Figure 20: 3-D-Representation of the PD Recording

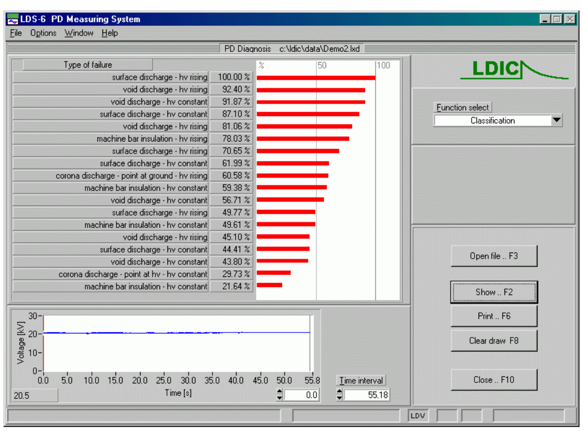


Figure 21: Automatic Failure Diagnosis

6. Summary

The Lemke Probe LDP-5 is a small hand-held partial discharge detector for on-site measurements and PD location.
This paper showed the application of the different sensors of the Lemke Probe LDP-5 for the different measurement tasks, together with noise suppression and digital recording.
The modular approach lets you start with e.g. the Lemke Probe LDP-5 and add the needed components, like special sensors, noise suppression and the computer system LDS-5 later.

7. References

/1/ „Partial discharge measurements“. IEC Publication 270, 1981.

/2/ Manual Differential Lemke Probe LDP-5, Lemke Diagnostics, Germany, 1994

/3/ Manual UHF/VHF Converter LDA-5/U, Lemke Diagnostics, Germany, 1997

/4/ Manual Ultrasonic PD Sensor LDA-5/S, Lemke Diagnostics, Germany, 1997

/5/ Manual PD Noise Filter LDF-5, Lemke Diagnostics, Germany, 1994

/6/ Manual PD Noise Impulse Comparator LDK-5, Lemke Diagnostics, Germany, 1995

/7/ Manual Partial Discharge Measuring System LDS-5, Lemke Diagnostics, Germany, 1998

/8/ Lemke, E., Schmiegel, P.: “Introduction to fundamentals of PD diagnostics”, Lemke Diagnostics, Germany, 1991

/9/ Lemke, E.: “A new partial measuring procedure based on the evaluation of the cumulative charge”, Conference on PD in Electrical Insulation, Bangalore / India, 1976, pp. 1 - 22.

/10/ Lemke, E.: “A new method for PD measurement on poly ethylene insulated power cables” 3rd ISH Milan / Italy, 1979, paper 43.13

/11/ Lemke, E.: “A new procedure for partial discharge measurements on the basis of an electromagnetical sensor" 5th ISH Brunswig, 1988, paper 41.02.

/12/ Lemke E.: "PD probe measuring technique for on-site diagnosis tests on HV equipment" 6th ISH New Orleans / U.S.A., 1989, paper 15.08

/13/ Lemke E., Schmiegel P.: "Progress in PD probe measuring technique", 7th ISH Dresden / Germany, 1991, paper 72.01

/14/ Lemke, E., Schmiegel, P.: "Fundamentals of the PD Probe measuring technique" , Lemke Diagnostics, Germany, 1992