Synchronous Multi-Channel PD Measurements and the Benefits for PD Analyses

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ABSTRACT

Partial discharge (PD) measurements on transformers, cable systems and rotating machines are a worldwide accepted tool of quality control in factories and under on-site conditions. Common methods to improve the quality of noisy PD data are filtering and gating. Recently a new multi-channel synchronous method has been introduced, capable of separating PD from noise by comparing the amplitude relationship of simultaneous PD of any three channels (3PARD). PD pulses propagate from their origin to the decoupling site, and generate cross-coupling to other phases. PD from different locations inside the insulation will lead to unique pulse triples at any 3 decoupling positions. The amplitude relationship of the 3 synchronously decoupled pulses of one pulse source will be nearly constant. That allows a classification of single PD failures inside the device-under-test (DUT) by comparison of these amplitude relations. As an extension of this new approach of PD source separation, the 3PARD method was adapted to the 3 Center Frequency Relation Diagram (3CFRD). This technique allows PD and noise separation by the comparison of the frequency spectrum of different PD mechanisms and noise pulses. In real-time, a diagram can be constructed with single clusters representing different PD sources in accordance to their discharge physics. Additionally, 3CFRD is not exclusively applicable to 3-phase systems like power transformers, it can also be applied on single phase transformers, VTs and CTs. This paper presents promising results from the latest multi-channel PD measurements.

Index Terms: partial discharge, electromagnetic interference, separation, multi channel, diagnostics

1. INTRODUCTION

Partial Discharge (PD) measurement is a worldwide accepted tool for quality control of high voltage (HV) apparatus [1] [2] [3]. Outside screened laboratories, PD signals are very often superposed by noise pulses, a fact that makes a PD data analysis more difficult for both human experts and for software expert systems [4]. Therefore the handling of disturbances is one of the main tasks when measuring PD. Additionally, with the ongoing development of permanently installed PD monitoring systems the PD data analysis needs to become more effective to be done automatically. By using synchronous multi-channel PD acquisition it is possible to gain de-noised PD data from separated PD sources in order to make PD measurements more reliable.

PD measurements are often performed under noisy conditions. The PD signal is superposed by stochastic noise pulses or even multiple PD sources, which will lead to a complex phase-resolved PD pattern that is not easy to analyze [5]. Conventional frequency filters are not able to eliminate these pulse-shaped disturbances. PD experts and automated computer expert systems would have difficulties with the superposition of multiple PD soures and noise. Some well-known evaluation techniques as pulse-sequence-analyses [6] would even fail with non-correlated PD pulses to be compared. Separating PD from noise and separating multiple PD sources must be the first step to de-noise PD data. In the future this will become even more important with the rising numbers of automated PD monitoring systems installed at critical network points.

2. MULTI-CHANNEL PD ACQUISITION

Besides advanced mathematical PD analyzing algorithms concentrating on single-channel PD measuring results a considerable advantage can be gained by collecting synchronous PD data from multiple decoupling positions. This might be a HV cable system of some miles of length with PD decoupling at all joints [7] or a 3-phase power transformer with synchronous PD decoupling at the 3 high voltage windings (e.g. on bushing taps), neutral terminal, tank ground or also MV and LV windings.

3. PD MEASURING SYSTEM

The MPD 600 as a modern type of a fully digital PD measuring system is capable of performing synchronous multi-channel PD measurements. A brief overview of the system is given below (more detailed information in the product specification [8] and type test description [9]). The measurement system consists of one or more acquisition units (fig. 1), an optical interface (FO bus-controller) and a PC including the measuring software.

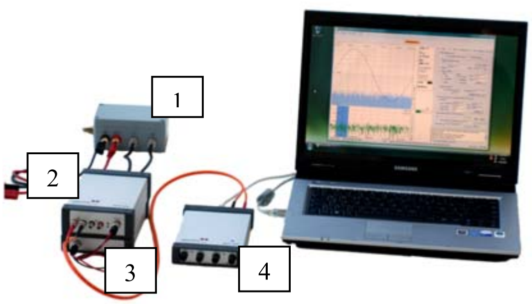

Figure 1 - Components of a MPD system: measuring impedance (1) , PD acquisition unit (2), battery pack (3), optic-USB converter (4), notebook.

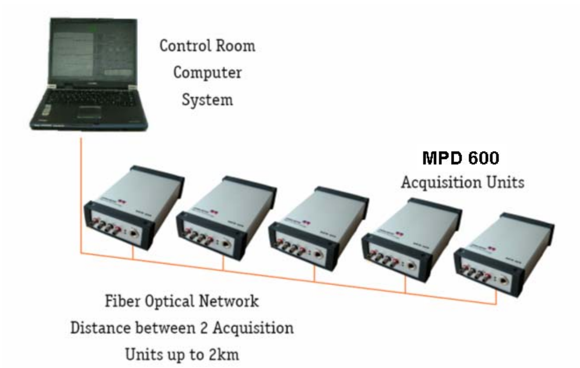

Figure 2 - Upgradeable to a multi -channel PD measuring system.

The PD signals are filtered, amplified and digitized. An optimum frequency band can be chosen to avoid continuous-wave disturbances and to reach a high SNR (signal-to-noise-ratio) even under noisy conditions on site. For multi-channel PD measurements several 100 acquisition units can be connected to one distributed PD system (see also fig. 2) while a maximum number of 64 units can be operated in a fully synchronized mode. Up to 25 phase-resolved patterns can be displayed by the software at one time.

With powerful adequate accessories, as the special inductive PD sensor MCT 100 [10], a set of bushing tab adaptors [11] or the measurement range extension UHF 608 [12], the MPD system can easily be adapted to various measuring conditions.

4. METHODS OF DATA EVALUATION

A new field of evaluation methods is opened by fully synchronous multi-channel PD acquisition in order to gain more reliable measuring results combined with effective noise suppression. Therefore the 3-Phase-Amplitude-Relation-Diagram (3PARD) was introduced [13] as a new powerful analysis tool to distinguish between different PD sources and noise pulses when measuring 3-phase high voltage equipment such as power transformers [14], rotating machines [15] and cross-bonded cable systems [16]. As an enhancement of 3PARD the 3-Center-Frequency-Relation-Diagram (3CFRD) is introduced as an additional tool for PD data analysis and PD fault separation in real-time on single-phase test objects. The synchronous consideration of three different frequency parts of the PD spectrum of a single PD pulse provides an information on its discharge nature and indicates its possible PD fault location due to PD signal propagation and attenuation.

Gating Interferences: With the possibilities of fully synchronous PD data acquisition, a second MPD measuring unit can be used for detecting external interference pulses, not generated by the DUT. Therefore, the second acquisition unit cannot be connected to the PD measuring circuit directly, but must be sufficiently decoupled from the test object.

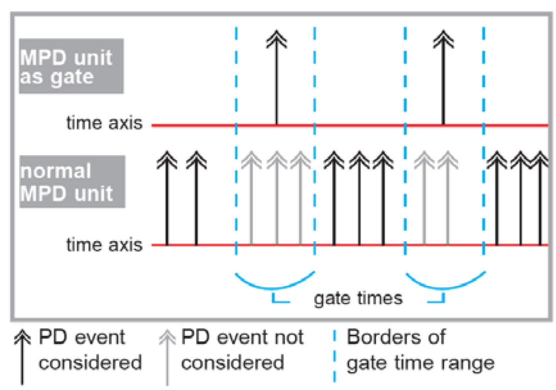

Figure 3 - Principle of unit gating

It has to be ensured, that the gating unit cannot acquire PD pulses from the DUT but only interference pulses. Typical ways to connect a gating unit are inductive decoupling from a ground connection or an antenna. Figure 3 describes the principle of unit gating. The PD acquisition unit detects both, the PD and disturbance pulses. If the gating unit detects a pulse, this will influence the PD data processing of the PD acquisition unit. For a certain gating time no pulse event is considered. These gated pulses do not influence the Q-IEC reading and they will not be plotted in the phase-resolved PD histogram.

Synchronous conventional and non-conventional PD measurements: With a synchronous PD acquisition system it is possible to combine the benefits of conventional PD measurements according to IEC 60270 with the advantages of PD measurements in the UHF range. With the UHF sensor able to detect the relevant PD events, the information of the IEC method can be restricted to the relevant PD signals in order to assess the pC charge value. To evaluate the performance of the combined UHF/IEC method on-site field-measurements were taken on a 333MVA, 380kV/220kV/30kV single-phase auto-transformer (figure 4) during normal operation.

Figure 4 - PD testing of a 333MVA single-phase auto-transformer.

The transformer was taken out of service to install the PD equipment and for charge calibration. For PD decoupling the measuring tabs of all available bushings were used, an example is to be seen in figure 5.

For this outdoor application the PD measuring system was protected by a water-proof case. One of the main benefits of the PD systems used is that the PD acquisition units can be placed very close to the HV bushings of the transformer. This minimizes the required length of electrical connecting cables and allowes PD signal acquisition with high bandwidth, while minimizing electromagnetic interference.

A UHF PD detector was added to the synchronous PD system and a UHF probe was inserted inside the transformer tank via the oil drain valve. After using the built-in frequency sweep function a measuring frequency of 310MHz (1.5MHz bandwidth) was selected. The results of the synchronous PD measurements on the 245kV bushing are shown in the following figures 6-8.

Figure 5 - Connection of the PD system (inside yellow outdoor case) to the measuring tab (420kV bushing).

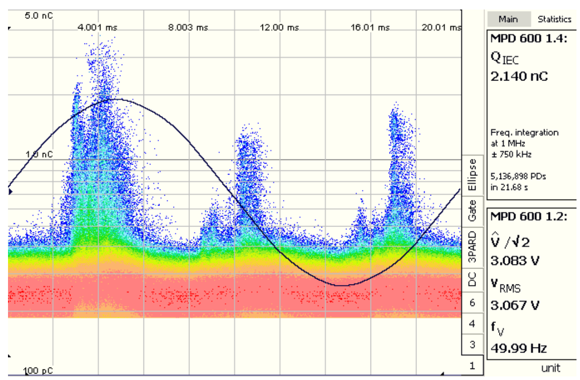

Figure 6 - PRPD pattern obtained on a 245-kV-bushing, electrical PD measurement according to IEC 60270, centre frequency: 1MHz, bandwidth: 1.5MHz, all PD data.

As usual for conventional on-line PD measurements the PRPD diagram shows a significant 3-phase corona cross-talk from the substation and the near overhead transmission lines. No PD activity from the transformer could be determined as the interference was in excess of 2nC.

Figure 7 shows the PD activity measured by the UHF method.

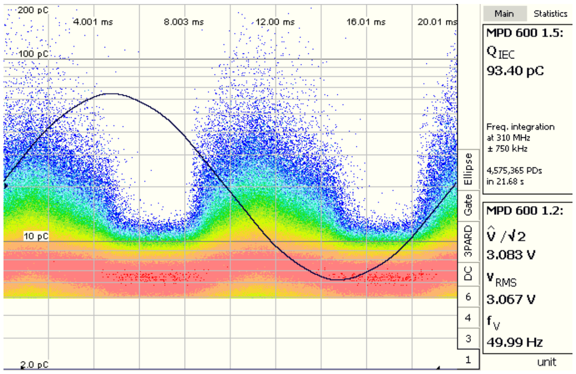

Figure 7 - UHF PD measurement, internal UHF probe, centre frequency: 310MHz, bandwidth: 1.5MHz

The recorded PD pattern showed no external interference, as the internal UHF-sensor was perfectly shielded against external influences. A typical PD pattern of discharges in oil can be seen. As the UHF-method cannot be calibrated, the displayed charge readings are not accurate.

In order to obtain a valid PD charge information the PD results from the IEC-method had to be used. The external noise was successfully gated with the information from UHF PD acquisition unit. Figure 8 shows the corrected PD pattern recorded at the transformer bushing tab.

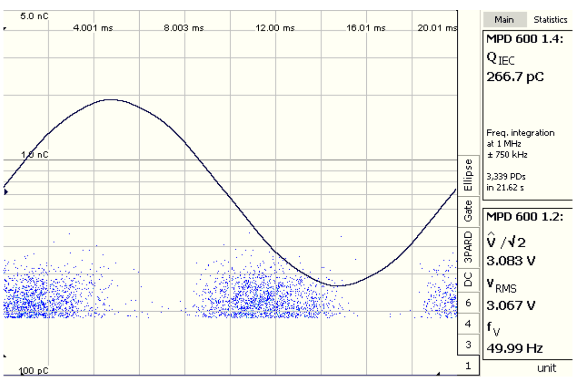

Figure 8 - Gated PRPD pattern, 245kV bushing, electrical PD measurement, centre frequency: 1MHz, bandwidth: 1.5MHz

As demonstrated the results of the UHF PD sensor can be used to eliminate all interference pulses from the classical electrical PD measurement in order to concentrate only on pulses coming from inside the transformer. As a result, the relevant charge level of the PD pulses can be determined.

3-Phase-Amplitude-Relation-Diagram: Due to the coupling of the 3 phases within a transformer (galvanic, capacitive and electro-magnetic) a single PD pulse occurring in a certain phase can usually be measured as voltage signal in all phases and acquisition units, respectively. Figure 9 shows a schematic view of three acquired PD voltage signals in the time-domain related to the same PD fault in phase L1. As L1 is the source of the PD fault the amplitude is highest there. Due to the galvanic coupling of the three phases (common neutral point of the transformer, for instance) the voltage signal can also be measured in phases L2 and L3, with reduced amplitudes due to attenuation in additional windings. In order to create a two dimensional color-coded 3PARD the amplitude vectors of the 3 phases are added with 120 degree phase shifting (in accordance to the phase shift of the test voltage, see fig. 10). PD pulses are mainly located within clusters next to the axes of the diagram. Pulses due to noise (of nearly the same amplitudes) are placed next to the axis' origin. Therefore a clear separation of the PD and noise is possible by selecting specific 3PARD clusters for real-time re-transformation to classical PRPD patterns.

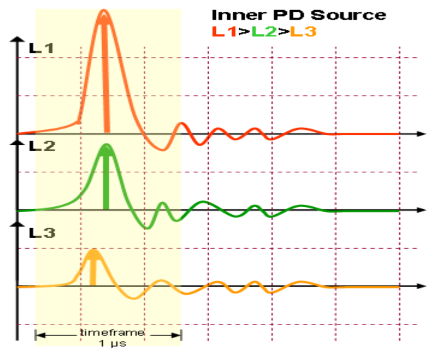

Figure 9 – Triplet of PD pulses in time domain.

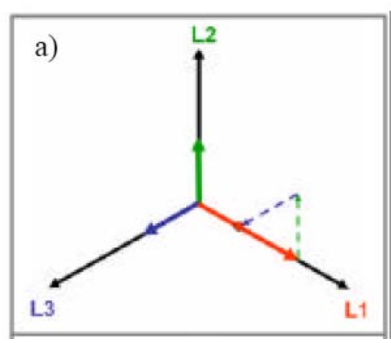

Figure 10 - Principle of adding vectors.

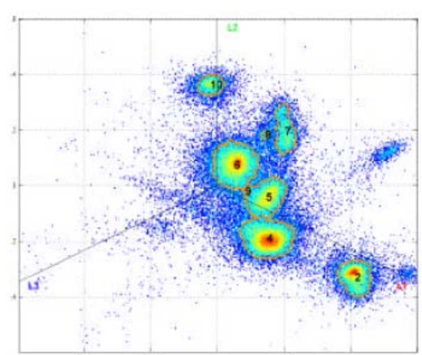

Figure 11 - 3PARD pattern created from PD data obtained on a 10 kV motor with major PD activity in phases L1 and L2.

Figure 11 shows a 3PARD created from PD data acquired at a PD measurement on a 10 kV high voltage motor with major PD activity on phases L1 and L2. As the position of the clusters indicate a certain relation to the phase the color represents the number of PD pulses acquired at the same position in the 3PARD (red = high pulse activity).
As each cluster in figure 11 represents a different PD source within the machine, (except cluster 6 and cluster 9 representing noise pulses) the on-line and real-time back transformation of a single cluster will lead to a PRPD pattern of only a single PD fault (instead of only a PRPD pattern containing superposition of all PD faults and noise). The interpretation of this screened PRPD pattern is considerably easier for the PD expert performing the measurement.

3-Center-Frequency-Relation-Diagram:
The 3PARD method requires PD pulse triplets. Three PD amplitudes are compared and plotted into a single diagram to form separable clusters. However, in principle this type of diagram can be created by any synchronously gained pulse triplets. Even for a single phase or a single PD decoupling position, pulse triplets can be acquired by using three different PD filter settings, for instance. So the signal output of three filters with different center frequencies or bandwidths would allow for a pulse-waveform-analysis. As a result, a 3CFRD graph can be generated. This refers to the fact that, due to the discharge physics, different PD types or noise pulses generate different but characteristic energy-frequency spectra, as can be seen in figure 12.

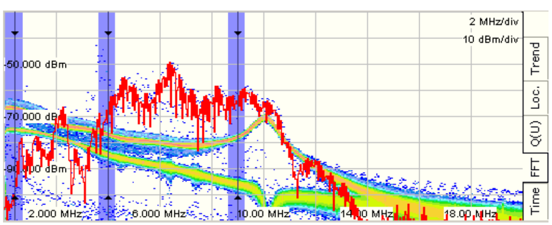

Figure 12: FFT of PD pulses, statistical view, 0MHz to 20MHz with 2MHz/Div, -30dBm to -110dBm with 10dBm/Div

By comparing the filter output of different PD-types these types can be distinguished, when proper frequency settings are selected. A separation of different PD sources and different noise sources is possible by focusing on single 3CFRD clusters. A real-time back-transformation will result in clear and de-noised phase-resolved patterns of single PD sources.
This PD evaluation method was demonstrated during a PD measurement on small insulating spacers in a HV lab. Figure 13 shows a sample in a test cell. The PD measurement was performed in accordance to IEC 60270.

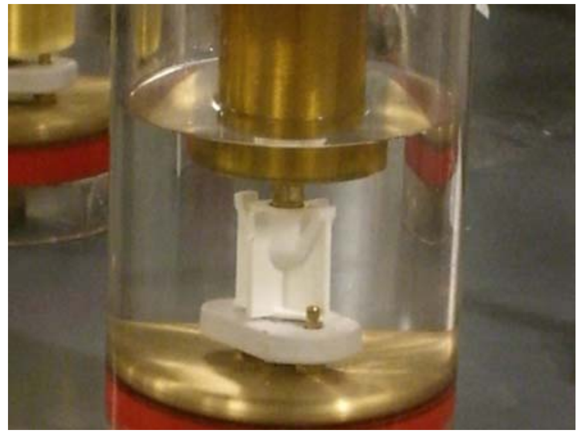

Figure 13 - Test cell for PD measurement.

3 synchronous PD acquisition units were tuned to different PD filter settings (filter 1: 200kHz center frequency, 160 kHz bandwidth, filter 2: 4.3MHz/160kHz, filter 3: 13.52MHz/160kHz). The relevant IEC result is shown in figure 14.

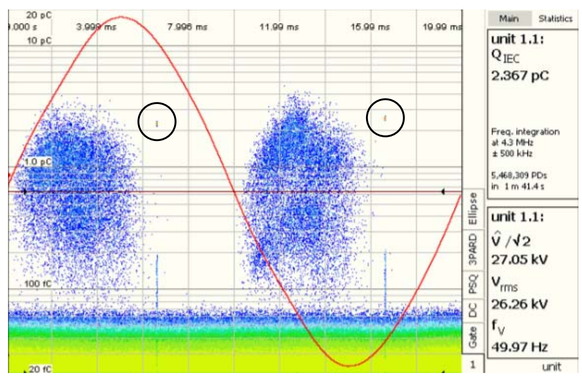

Figure 14 - PRPD pattern with IEC method.

The PRPD diagram shows different phenomena. The PD pulses from the test sample are forming a typical PD pattern. Additionally to a basic noise floor a phase- and amplitude-fixed disturbance can be seen at a phase angle of about 130° and 310°, respectively (see markers in fig. 14). By selecting single 3CFRD clusters the traditional PRPD diagrams can be generated by re-transformation for single PD or interference sources (figure 15).

By selecting only the relevant 3CFRD cluster, the PD activity can be isolated from the environmental noise. Figure 16 shows the relevant PRPD pattern, generated in real-time during the PD measurement. As a result, not only the PRPD pattern is de-noised, but also the displayed QIEC value shows the true value of PD activity in the test sample.

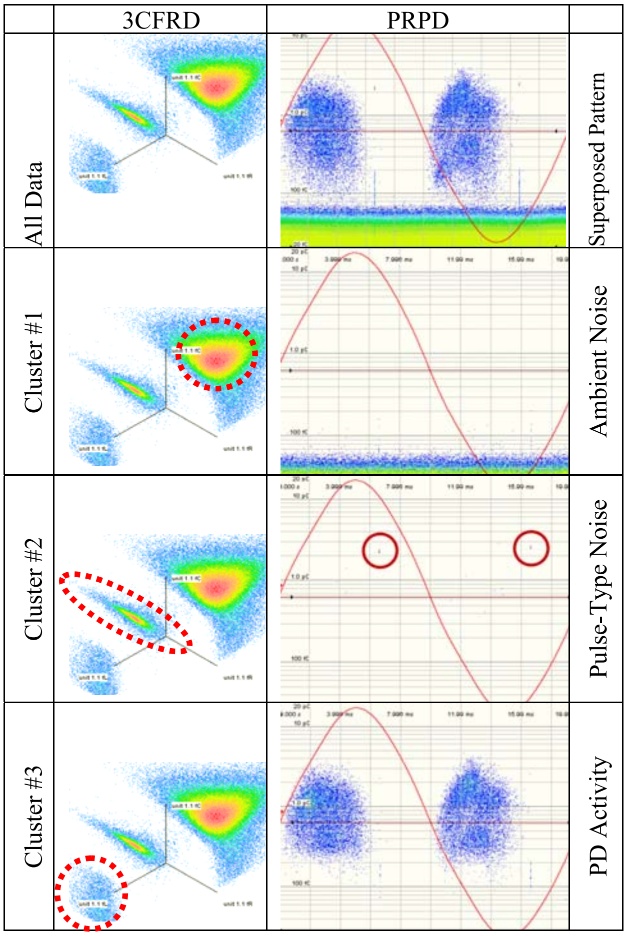

Figure 15 - Synchronous 3CFRD PD Data Evaluation.

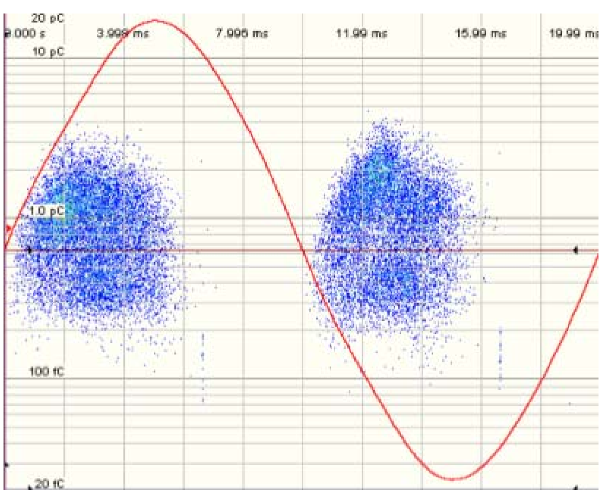

Figure 16 - De-noised PRPD pattern.

5. CONCLUSIONS

The separation of multiple PD sources and noise is absolutely mandatory for a clear PD data analysis. By handling single PD faults, PRPD patterns and pulse-sequence analysis will work best in order to deliver reliable results. Synchronous multi-channel PD measurements provide new and advanced options of PD evaluation such as 3PARD, 3PTRD and 3CFRD. Therefore a powerful hardware is needed to allow synchronous PD acquisition in a time frame of a few nanoseconds and real-time data-handling. The presented digital PD measuring system is capable of performing this kind of measurement, as proven in many PD tests in the laboratory and especially under noisy on-site conditions.

References:

[1] J. Smit: "Trends in PD-diagnostics for Asset Management of Aging HV Infrastructures" -14th International Symposium on High Voltage Engineering, Bejing/P.R.China, 25-29th August 2005

[2] D. König and Y. N. Rao: "Partial Discharges in Electrical Power Apparatus", VDE 1993

[3] J. C. Montanari: “Insulation diagnosis of high voltage apparatus by partial discharge investigation”, Liu-Yeda Memorial Lecture, in Proc. IEEE ICPADM, Bali, Indonesia, 2006

[4] E. Gulski and F. H. Kreuger, “Computer-aided recognition of discharge sources,” IEEE Trans. Elect. Insul, vol. 27, no. I, pp. 469—479, Apr. 1992

[5] CIGRE WG 21.03: “Recognition of discharges”, Electra, no. 11, pp. 61–98, 1969.

[6] M. Hoof and R. Patsch: “Pulse-sequence analysis: a new method for investigation the physics of PD-induced ageing,” IEEE Proc. Sci., Meas. Technol., vol. 142, no. I, pp. 95—101, Jan. 1995.

[7] S. Sutton, R. Plath and G. Schroeder: "The St. Johns Wood – Elstree Experience – Testing a 20km long 400kV XLPE-insulated Cable System after installation", 7th International Conference on Insulated Power Cable Jicable07, France, Versailles, 2007

[8] Omicron electronics: "MPD600 - Product brief and specification", Austria, 2007

[9] R. Holle, R. Plath, K. Schon and W. Lucas: "Type testing a digital PD measuring system according to IEC 60270", ETG conference on Diagnostic, Kassel, Germany, 2006

[10] Omicron electronics: "MCT100 – Product brief and specification", Austria, 2008

[11] Omicron electronics: "Meausurement adapter for bushing – Product brief and specification", Austria, 2008

[12] Omicron electronics: "UHF608 – Product brief and specification", Austria 2009

[13] K.-D. Plath, R.Plath, H. Emanuel and W. Kalkner: "Synchrone dreiphasige Teilentladungsmessung an Leistungstransformatoren vor Ort und im Labor", ETG conference on Diagnosic, Berlin, Germany, 2002

[14] S. Schaper, W. Kalkner, R. Plath. "Synchronous multi-terminal on-site PD measurements on power transformers", 14th International Symposium on High Voltage Engineering, Bejing/P.R.China, 2005

[15] A. Obralic, W. Kalkner et al. “Verbesserte Zustandsbewertung durch neue Auswerteverfahren bei der Synchronen Mehrstellen-TE-Messung an Hochspannungsmaschinen,” ETG conference on Diagnosic, Kassel, Germany, 2006

[16] W. Weissenberg, F. Farid, R. Plath, K. Rethmeier, W. Kalkner: "On-Site PD Detection at Cross-Bonding Links of HV Cables", CIGRE Session 2004 - Paris, France, 2004

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