Sensitive PD-Measurements on Power Transformers by Synchronous Multi-Channel Data Acquiring

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Abstract

Partial discharge measurements on HV systems are an accepted tool of quality control. Common instruments to improve the validity of PD data are filtering and gating. Recently a new method entered market, capable of clearly separating different PD sources inside the DUT as well as separating PD from noise. This multi-channel synchronous measuring method compares amplitude relations of contemporaneous PD of three phases (3PARD).

PD pulses propagate from its origin to the place of decoupling, even cross-coupling to other phases of a three-phased HV equipment as transformers. PD from different places inside the insulation will lead to unique pulse triples recordable at the places of decoupling at all phases. These pulse triples of a single PD source may differ in absolute amplitude but the amplitude relation of the three synchronous decoupled pulses will be nearly constant. That allows a classification of single PD failures by comparison of these amplitude relations.

This paper describes the requirements for the PD acquisition hardware, for the software evaluation and visualization. Some case studies show the results from PD measurements on transformers using synchronous multi-channel PD acquisition.

1. Introduction

For the last decades Partial Discharge (PD) measurements on high voltage insulation systems are a well accepted tool of quality control both in the laboratory and in the field [1]. In particular for on-site PD measurements, external interferences often impact the measuring results, sometimes drastically. Therefore the interpretation of the acquired PD data is a challenging task for the responsible engineer in order to avoid costly mistakes [2]. As a necessary demand, mathematic algorithms have to support the test engineer to gain highly reliable measuring results originating from the raw PD signals. Common instruments to improve the validity of PD data are filter and gating algorithms, as they are the subject of research within the last decades. In recent years a robust new method of measuring and on-line processing of PD signals entered the international market. This method is capable of separating different PD sources inside the DUT (device under test) and separating PD activity from noise or other signals not correlated to the DUT. By the use of simple mathematical transformations noise can be eliminated from PD phenomena. The remaining detected PD sources can be clearly separated from each other to evaluate the risk of every single PD source inside the insulation system.

These new evaluation techniques can be used when PD pulses of a single PD fault location are acquired synchronously on different phases (like in transformers, generators, cross-bonded cable systems), at different locations (like in extensive cable systems) or even at different measuring frequencies at the same measuring position or phase. Therefore a synchronous multi-channel PD measuring system is required, as described in this paper.

2. PD Measuring System

The MPD600 as a modern type of a fully digital PD measuring system is capable to perform synchronous multi-channel PD measurements. A brief overview on this system will be given here (more detailed information in [3]). This measurement system consists of one or more acquisition units (fig. 1), an optical interface (fibre optic bus-controller) and a PC including measuring software.

Fig. 1. MPD600 PD measuring system (measuring impedance, PD acquisition unit, optic-USB converter, notebook)

The PD signals are filtered, amplified and digitized. Having an amplitude quantization of 14 bit and a sampling rate of 64 MS/s, the time accuracy of detection of a PD signal is at about 2 ns. The quasi-integration is realized by a digital band-pass filter. The center frequency for the digital filter can be chosen continuously variable in a frequency range from DC up to 20 MHz, and the bandwidth in certain steps between 9 kHz and 3 MHz, respectively. Hence an optimal frequency band can be chosen to avoid disturbances and to reach a high SNR (signal to noise ration) even under noisy conditions on site. Furthermore, the test voltage signal is digitized in the acquisition unit to document the test voltage during the PD measurement (see fig. 2, 3).

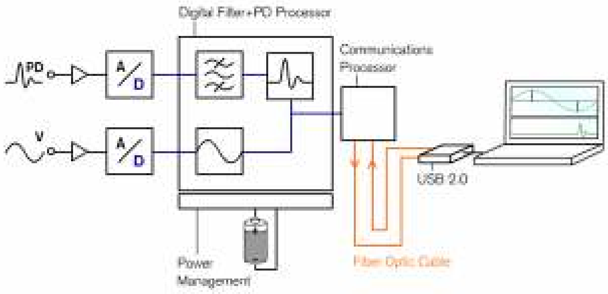


Fig. 2. Block scheme of MPD600 system

All data acquisition and data pre-processing is realized in the MPD acquisition unit to guarantee optimal performance in speed and signal quality.

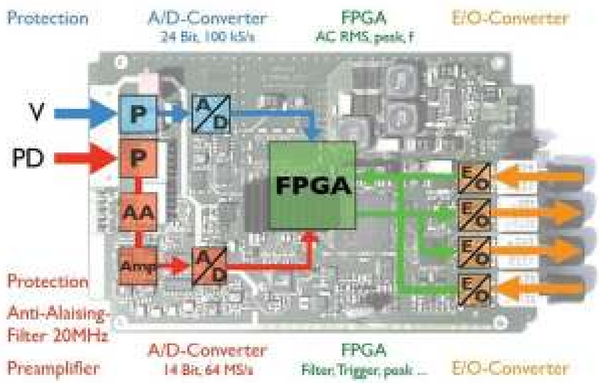


Fig. 3. Block scheme of MPD600 acquisition unit

For multi-channel PD measurements up to 960 acquisition units can be operated in one PD system (see fig. 4) with a maximum number of 64 units operating in a fully synchronized mode.

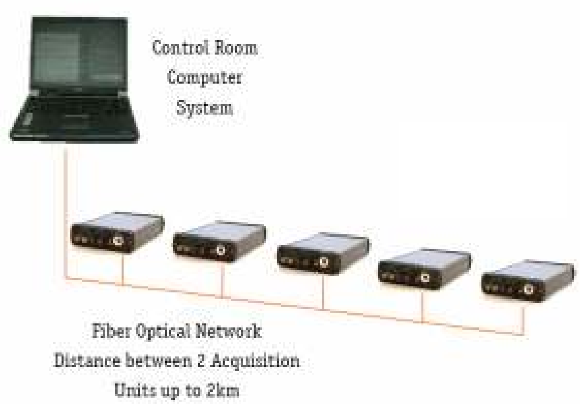


Fig. 4. Expanding to acquisition network

Due to the importance of real synchronism compared to non synchronous multiplexing of PD acquisition units the proof of timing accuracy is very important. Therefore (and in preparation for on-site PD testing of a 20 km 400 kV-XLPE cable system in London [4]) a multi-channel system check with 27 synchronous acquisition units was set up at the independent test center IPH in Berlin, Germany (see fig. 5).

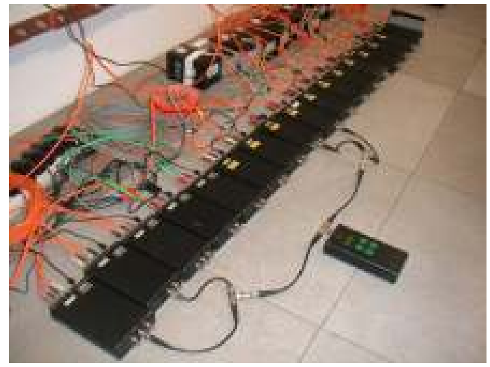


Fig. 5. Set up of multi-channel system check

The measured uncertainty of time was in a range of only 2 ns (As shown in fig. 6).

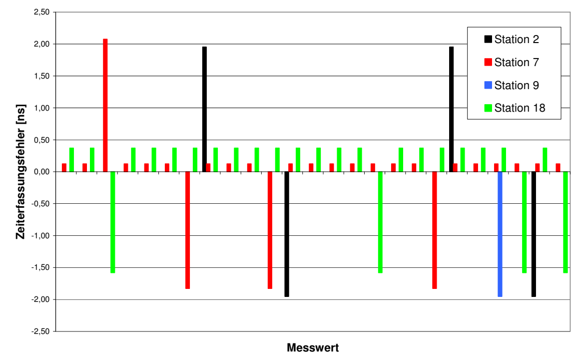


Fig. 6. Measured time difference [ns] of simultaneous injected test pulses in selected acquisition units 2, 7, 9 and 18

It could be stated that the digital multi-channel PD system fulfills all requirements [5].

3. Evaluation Methods

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 presented [6] as a new powerful visualization tool to distinguish between different PD faults and noise pulses when measuring 3-phase high voltage equipment like power transformers [7], rotating machines [8] and cross-bonded cable systems [9]. As sophistication to 3PARD the 3-frequency amplitude relation diagram (3FARD) is introduced as an additional tool for PD data analyses and PD fault separation. The synchronous consideration of three different frequency parts of the PD spectrum of a single PD pulse gives a conclusion of its possible PD fault location due to PD signal propagation and attenuation.

A. 3-Phase Amplitude Relation Diagram (3PARD)

Because of the coupling of the 3 phases inside a transformer a single PD pulse of a certain phase can be measured as voltage signal in all phases and acquisition units, respectively. Figure 7 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) the voltage signal is also measurable in phases L2 und L3, with reduced amplitudes due to the attenuation of the additional windings. 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). As PD pulses are mainly located within clusters next to the axes of the diagram. Pulses due to noise (nearly same amplitudes) are placed next to the origin. Therefore a clear separation of PD and noise is possible.

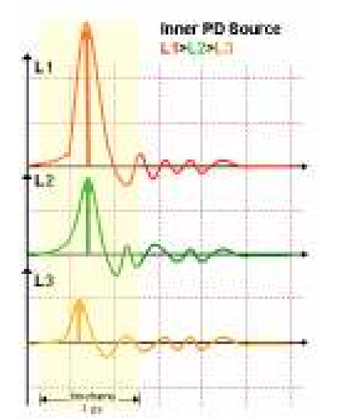
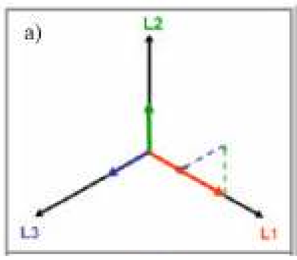
	
Voltage signals of a single PD pulse measured in all 3 phases	3PARD

Fig. 7. Creating 3PARD from voltage signals

Figure 8 shows a 3PARD created from real PD data acquired at a PD measurement on a 10kV 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.

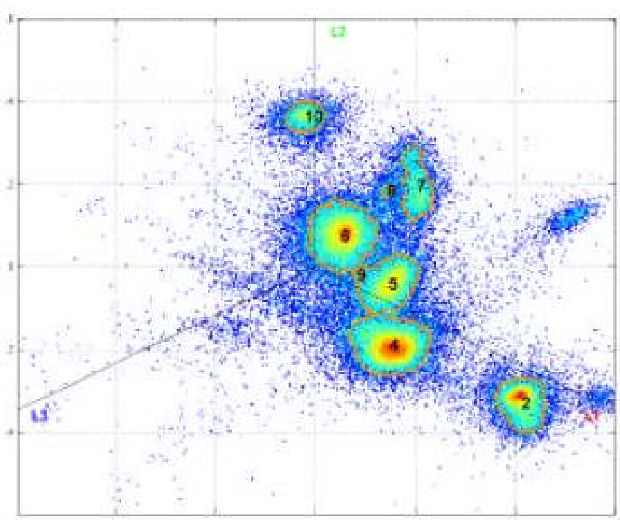


Fig. 8. 3PARD of several PD faults

As every cluster in figure 8 represents a different PD source inside 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 (in state of only one PRPD pattern with the confusing superposition of all PD faults and noise). The interpretation of this cleaned up PRPD pattern is considerably easier for the PD expert performing the measurement.

a. Case study: 136kV/20kV transformer

As an example, test results of a synchronous 3 phase multi-channel PD measurement on a 136kV/20kV power transformer at a manufacturer is presented.
PD decoupling was performed by using the 3 measuring taps of the transformers high voltage bushings as shown in Fig. 9.

Fig. 9. PD decoupling at bushing taps

The acquired 3PARD of phase L1, L2 and L3 (185kV, 153Hz test voltage) is shown in Fig. 10.

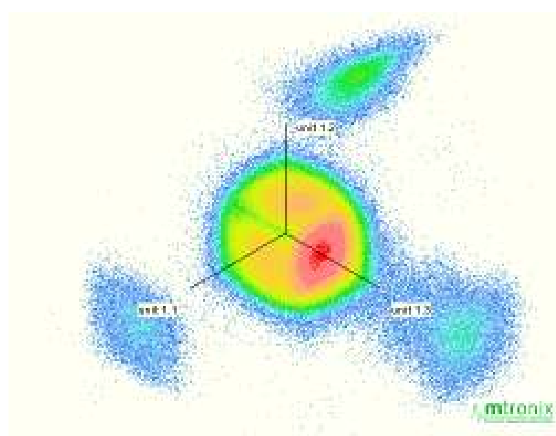
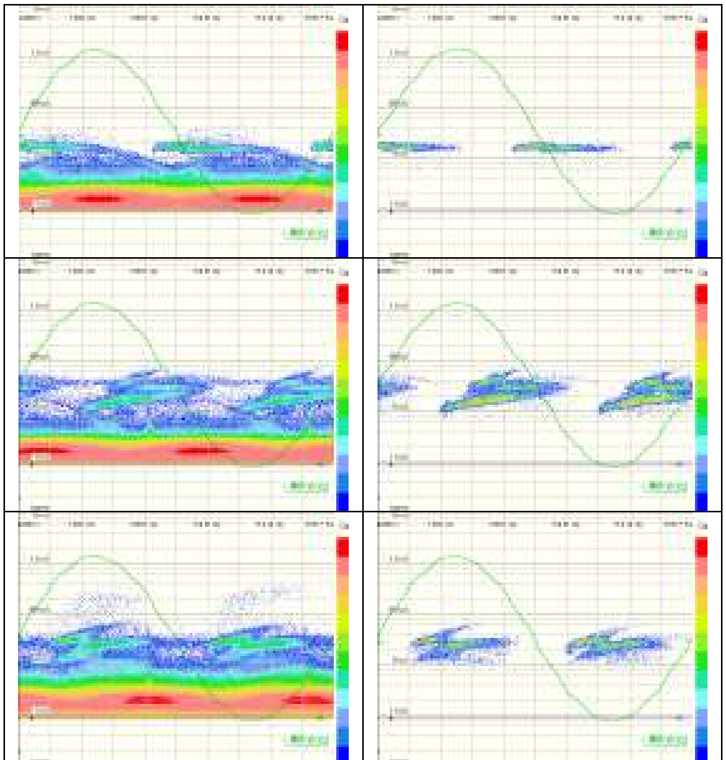


Fig. 10. 3PARD of PD measurement

This diagram shows 4 main clusters at characteristic positions. Beneath one bigger cluster in the origin of the diagram (representing noise) all three phases show PD activity. Figure 11 shows the comparison of the acquired PRPD pattern for all phases. Left column shows the PRPD patterns without the consideration of 3PARD clustering, right column shows the PRPD patterns using the benefits of 3PARD leading to cleaned up PD patterns.



no 3PARD clustering	3PARD clustering

Fig. 11. PRPD patterns L1, L2, L3

The remaining clusters in the PRPD patterns show the phase related PD activity with a high level of noise suppression. All PD-like pulses emitted by motors, crane drives and switching activity as present in the near environment of the PD measurement were successfully eliminated.

b. Case study: 400kV/400kV transformer

As the previous example showed PD activity in all phases of a power transformer the next example shows the possibility of 3PARD to separate even multiple PD sources within a single phase of a power transformer.

Figure 12 shows a 3PARD of a PD measurement performed on a 790MVA 400kV/400kV power transformer at the manufacturer.

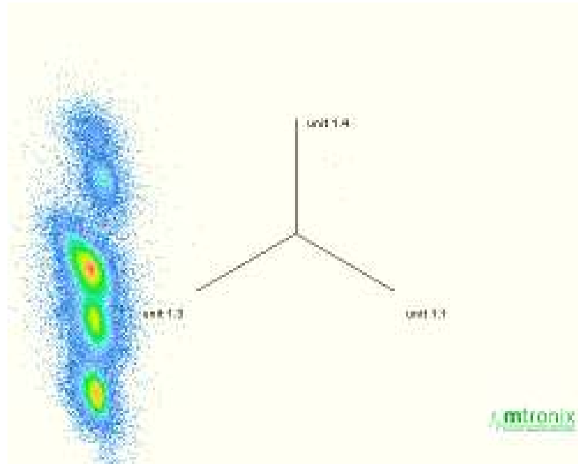


Fig. 12. 3PARD of 790MVA 400kV power transformer (unit numbers do not refer to phase names

In this diagram up to 5 clusters could be found representing different PD sources within the high voltage winding of one phase. The selective re-transformation to PRPD patterns showed clearly separated pattern with helpful information for the PD experts of the transformer manufacturer.

c. Case study: 115 kV/11.3 kV transformer

After replacement of a defective current transformer (draining of transformer oil was necessary) a 3 phased synchronous PD measurement on a 30 MVA transformer (see figure 13) was performed to ensure the quality of the undertaken maintenance work. The PDs were decoupled at the measuring taps of the transformers bushings.

Figure 14 shows the recorded PRPD pattern of phase L1. The patterns show three different discharge structures. Statistically distributed noise pulses not related to the test voltage frequency generated a band at the bottom of the diagram (base noise level of 5 pC). Two phase stable clusters due to the power generator (voltage source for the induced voltage test) are noticeable at a discharge level of 20 pC. As a third structure the partial discharge pattern can bee seen with a discharge magnitude of about 100 pC.

Fig. 13. PD test on transformer, 30 MVA 115 kV

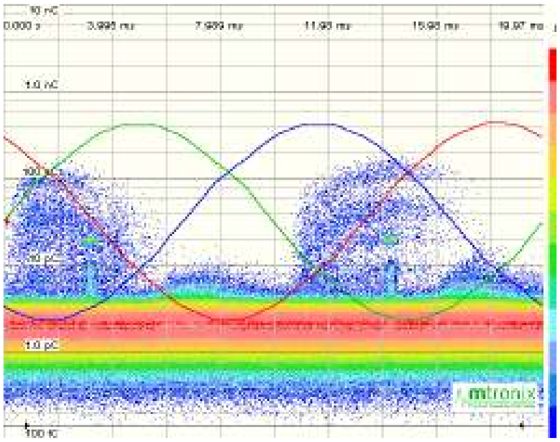
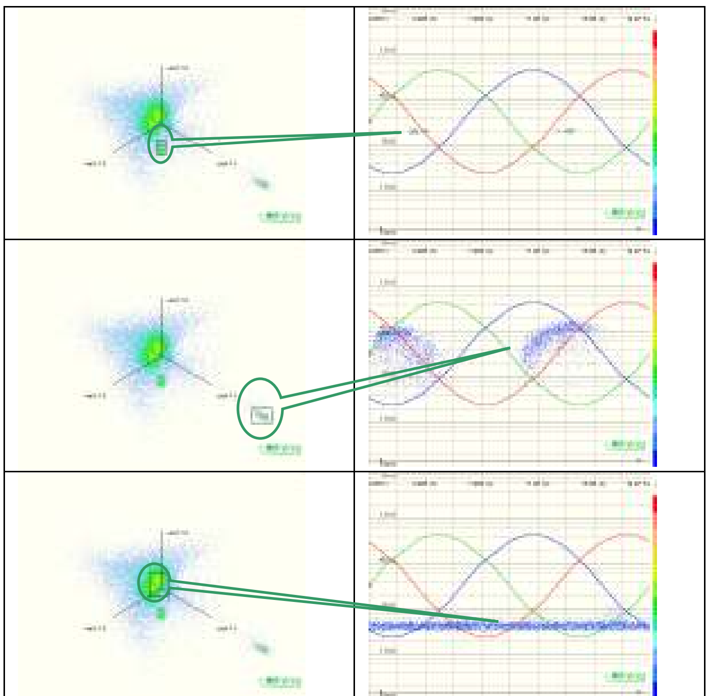


Fig. 14. PRPD pattern of phase L1

By the use of 3PARD all this structures can be separated and can be in real-time re-calculated to cleaned-up PRPD pattern, as shown in figure 15.



3PARD clustering	PRPD pattern

Fig. 15. 3PARD and PRPD pattern separated by discharge type

B. 3-Frequency Amplitude Relation Diagram (3FARD)

Instead of measuring PDs at three phases (with comparable or identical measuring frequencies and filter settings at all acquisition units) the PD measurement also can be performed by decoupling PD pulses at a single phase in different ways. Therefore multiple PD acquisition units with differing filter settings can be connected to a single PD sensor to take advantage of the frequency characteristics of the test object. Different PD sources inside the transformer will lead to different voltage amplitudes at the measuring ports after filtering with different band passes. Similar to the 3PARD method 3FARD creates different zoned clusters representing different PD fault locations within the transformer.

As a case study a PD measurement was performed on a 500 kVA medium voltage dry type transformer (according to IEC 60076-11: 30 s @ 1.8 V_N, 3 min @ 1.3V_N). Figure 16 shows the phase resolved PD pattern (middle phase) with a superposition of some PD faults and noise pulses, as it would be seen with standard single channel PD measuring systems.

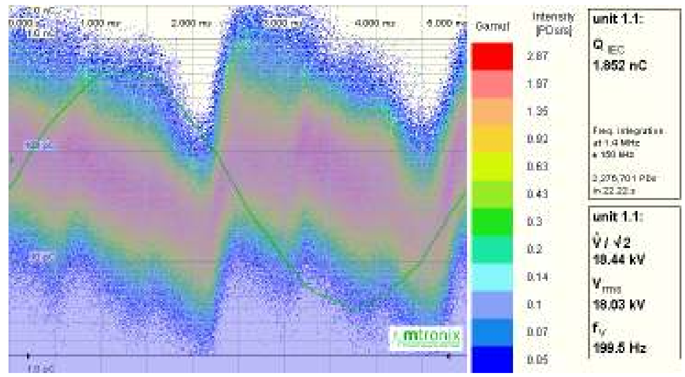
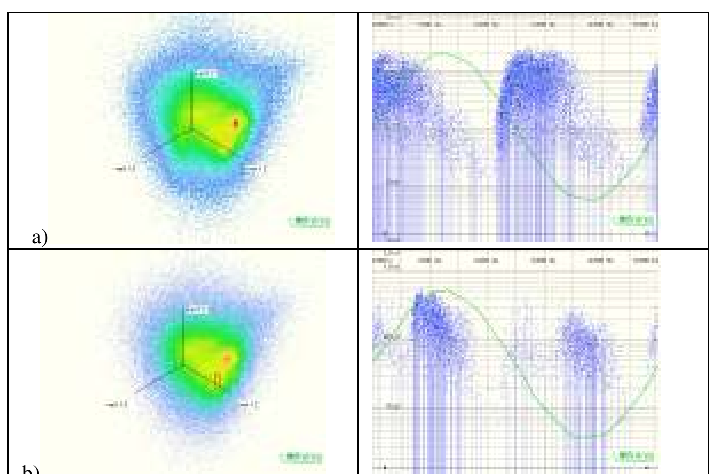


Fig. 16. PRPD pattern @1.8V_N, superposition of all detected signals

For 3FARD use the PDs were decoupled by a single coupling capacitor (no measuring tabs at bushings available). The measuring impedance was connected to three MPD600 acquisition units with different filter settings (unit 1: band pass center frequency f_c=1.4 MHz, bandwith bw=300 kHz; unit 2: f_c=2.4 MHz / 300 kHz; unit 3: f_c=2.0 MHz / 300 kHz). Due to different signal attenuation of PD pulses propagating from different locations inside the transformer the measurable amplitudes differs at the selected center frequencies. Therefore areas with high PD activity represent single PD fault locations.

Figure 17 shows the real-time calculated 3FARDs of the PD activity with the referring PRPD pattern (fingerprints) generated within the measuring time.



3FARD clustering	back transformation to PRPD pattern (fingerprint)

Fig. 17. PD fault separation by 3FARD

Areas with PD activity are clearly identifiable as red colored clusters. Cluster a) shows a PD fault at the connected phase (surface discharges, transformer terminals not designed for 1.8 V_N), cluster b) refers to a similar PRPD pattern with a 120 degree phase shift (related to the test voltage recorded at phase L1). Here the surface discharges from the terminals of the neighbor phase (phase L2) cross talk to phase L1.

4. Conclusions

Synchronous multi-channel PD data acquisition provides new and advanced options of real-time PD evaluation as 3PARD (3 Phase Amplitude Relation Diagram) and 3FARD (3 Frequency Amplitude Relation Diagram) for PD measurements on power transformers. Therefore a powerful hardware is needed to allow synchronous PD acquisition in a frame of some nanoseconds. The presented digital PD measuring system MPD600 is capable of performing this kind of measurement, as proven in many PD tests in the laboratory and especially under noisy on-site conditions. The 3PARD evaluation method to separate different PD sources inside a transformer as well as to separate PDs from noise already is widely accepted [10] as a powerful software tool based on the PD data provided by the synchronous multi-channel PD measurement system. 3FARD as an enhancement of 3PARD is still in the state of research activity with promising results in laboratory and as well in first field tests.

5. References

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