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ONLINE PARTIAL DISCHARGE MONITORING AND DISCHARGE LOCALIZATION ON TRANSFORMERS BY MEANS OF UHF METHOD

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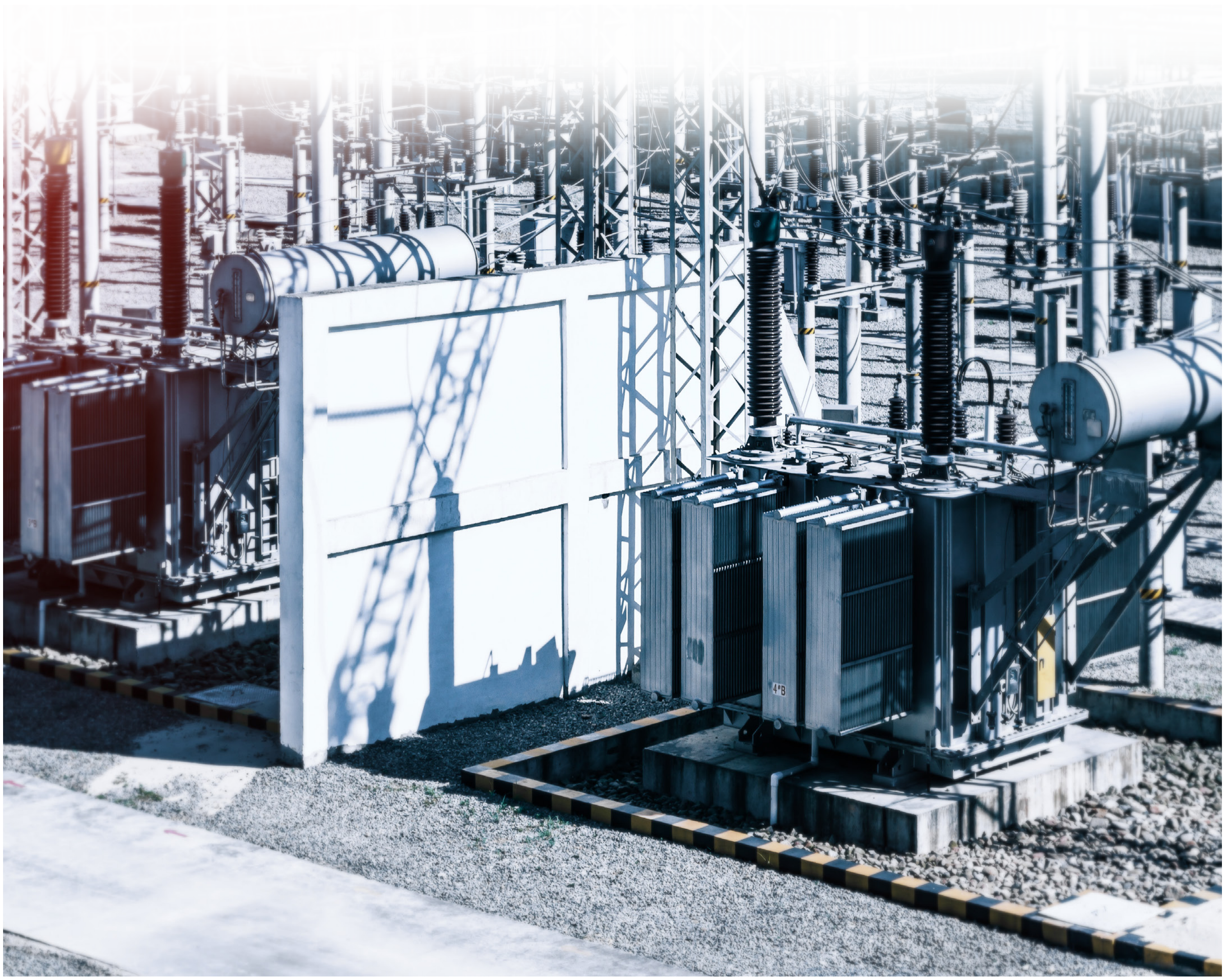


ABSTRACT

Dead Tank Breakers (DTB) are used since decades to integrate reliable GIS technologies into Air Insulated Substations (AIS). Despite UHF PD measurement and UHF PD online monitoring is successful used for GIS substations since more the 20 years for condition assessment and onsite commissioning tests, it is very rarely applied for Dead Tank Breakers. One of the main reasons for that is, that the Dead Tank Breakers are not fully encapsulated (openings at the SF6 filled bushings) and therefore prone to disturbances coming from external discharges, like surface discharges on the bushings for example.

Today the request for reliable PD measurement and monitoring approaches is increasing and forcing the technology development to find adequate solutions for Dead Tank Breakers.

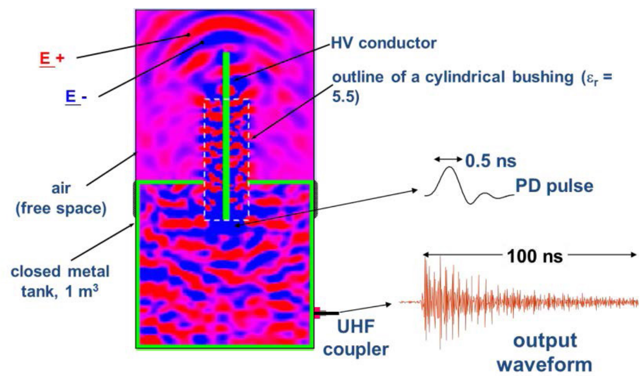
This paper will show how the UHF PD measurement can be applied for permanent online UHF PD monitoring and periodic UHF PD measurements for Dead Tank Breakers and how the external discharges and disturbances can be prevented to disturb UHF PD measurements on DTB's. Furthermore the behavior of free particles, busbar corona and chamber corona will be shown. The time- of- flight method in order to localize the discharges will be discussed.

INTRODUCTION

Ultra High Frequency (UHF) partial discharge measurements are common practice for GIS for high voltage site testing after erection and for partial discharge continuous monitoring for more than 20 years. The UHF techniques has proven its efficiency in high frequency waves are traveling and experiencing attenuation and reflections along its way. An antenna inside of the electromagnetic wave field will receive this electromagnetic waves and will provide a signal output for further signal processing.

UHF PD DETECTION PRINCIPLES IN TRANSFORMERS

Electrical impulses caused by partial discharges, have an order of less than 100ps rise time and those produce RF signals extending to several gigahertz. The wave propagation, the original PD pulse shape and the output signal at the UHF sensor is shown Figure 1. The partial discharge source is acting like an antenna and emitting these high frequency signals into the environment.



As UHF sensors, flat metallic plates with a certain shape and a certain diameter can be used. Preferable these sensors are being installed during manufacturing (special flanges are needed to be added to the transformer tank wall) or being installed as retrofit (drain valve or hatch cover sensors) – see Figure 2.

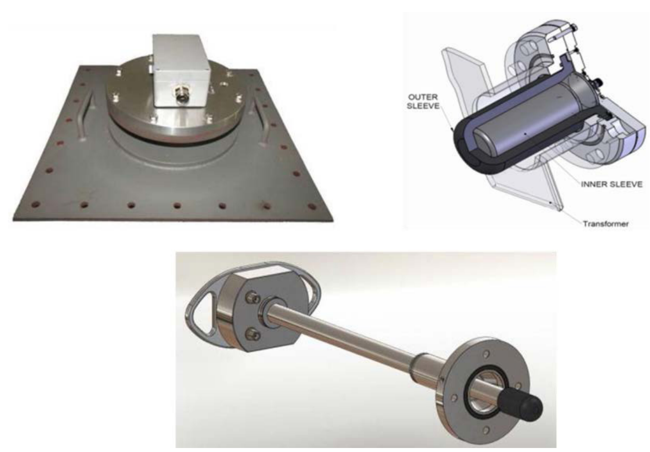


Figure 1: Different types of UHF transformer sensors

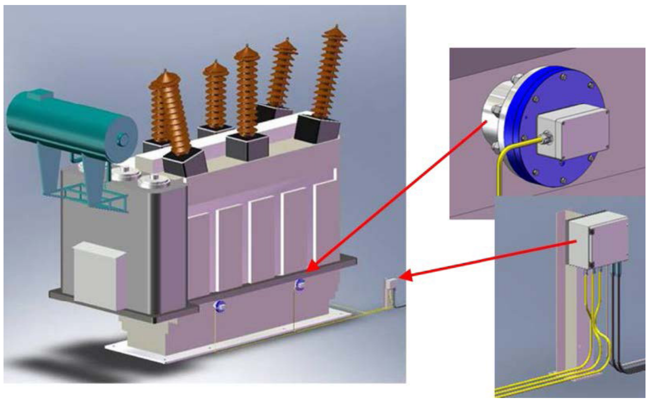
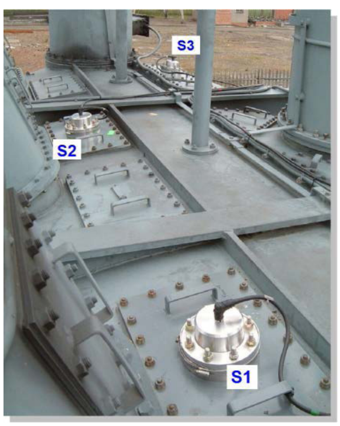


Figure 2: Examples for Sensor positions on transformer tank



- Replacement hatch covers were prepared before the installation
- Sensors fitted on top of tank to the replacement hatch covers
- Oil was only drained to a few cm below the hatch level
- Outage time was kept to a minimum

Figure 3: Sensor retrofit example and installation procedure

Figure 3 is showing a sensor placement on a new transformer and Figure 4 and example for a sensor retrofit, using the hatch covers. In Figure 4 the installation procedure is roughly described.

Considering the UHF PD measurement, the closer the PD source is to the sensor, the bigger the output signal is at the sensor, which is different to the signal behavior of the conventional PD measurement according to IEC 60270. This is the result of the attenuation along the propagation way. Also the captured signal shape is not identical with the original impulse, which is due to the multiple reflections and overlapping of the waves inside of the transformer tank according to high frequency signal behavior.

Assuming a certain discharge position and a certain sensor position the following two statements are always true:

> A higher PD intensity is creating a higher UHF output signal at the sensor.

> The travel time from the PD source to the sensor is always the same.

An additional factor to assess the condition of a transformer is the type of defect. According to (2) the differentiation is between the following defects:

> Sharp point causing void
> Sharp point embedded in insulator
> Punctured paper increasing stress
> Loose paper causing void
> Winding movement
> Conductor to conductor discharge
> Surface discharge
> Void adjacent to insulator
> Void on conductor surface
> Corona gas discharge

The differentiation is based on the partial discharge patterns, witch according to the experience are identical for the conventional IEC 60270 method and the UHF method.

UHF MAGNITUDE TO PC CONVERSION

According to (3) the defect classification in terms of its magnitude is described as following:

Defect free: 10-50 pC

Normal deterioration: <500 pC

Questionable: 500 -1000 pC

Defective condition: 1000-2500 pC

Faulty (Irreversible): >2500 pC

Critical: >100,000-1,000,000 pC

The most asked question is how to access the values by the use of the UHF method?

In order to find an answer to that question, several measurements with different transformer models were carried out. All of the measurements are done at Strathclyde University by the team of Prof. Martin Judd as a joined project between Strathclyde University and Qualitrol DMS. All of the results are summarized in (4).

In order to create real PD impulses, a test cell with an adjustable gap was used (see Figure 5). By changing the gap, the discharge magnitude and the inception voltage could be changed. The generated discharge is independent from transformer/ test chamber/ transformer model. The voltage needed to create PD depends on the gap distance and is relatively low and can be supplied separately, without energizing the whole transformer/ transformer model (see Table 1).

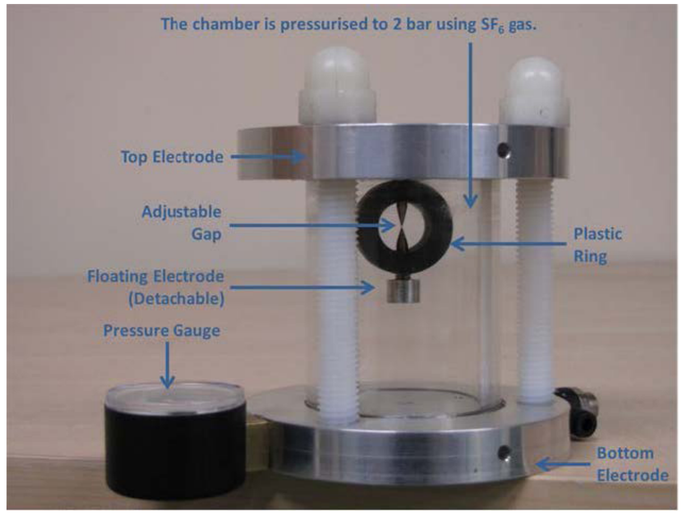


Figure 4: PD test cell

Gap Size / mm	PD Inception Voltage / kV
0.05	4.8
0.10	7.3
0.15	8.8
0.20	10.9

Table 1: PD inception voltage

To prove the PD pulse repeatability the test cell was placed in an empty quadratic test chamber with an edge length of 1m and a UHF sensor installed in the chamber wall.

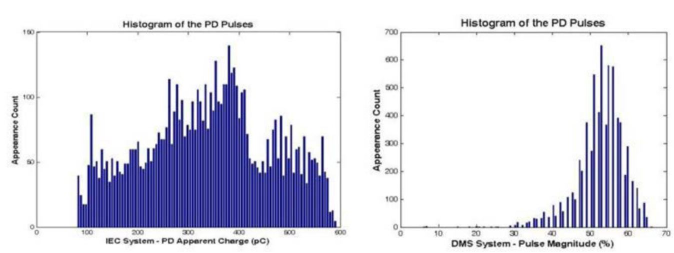


Figure 5: PD pulse distribution (conventional and UHF method)

As shown in Figure 6 (even the left histogram is more stretched) both histograms are looking quite similar. Additionally it can be seen, that the discharge magnitude is fluctuating between 100 and 600 pC for the same discharge source. The calculated mean value is 417pC, as the mean value for the UHF measurement is 50.5% scale. Just in an empty test chamber, the PD pulses measured by the conventional method and by the UHF method are correlating quite well. It can be concluded, that also in a real transformer tank, PD impulses from the same source, detected at the same UHF sensor are correlating too.

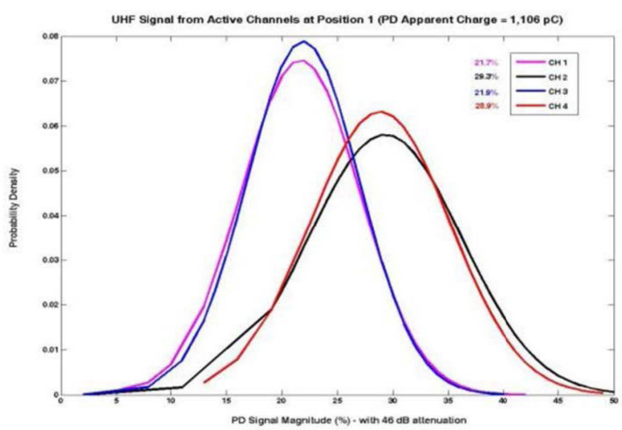


Figure 6: PD pulse distribution of all four installed sensors

Figure 7 is showing the pulse distribution for four different UHF sensors installed in a more realistic transformer model (Figure 8). Also these results are showing a similar distribution of the PD impulses as recorded for the empty test chamber.

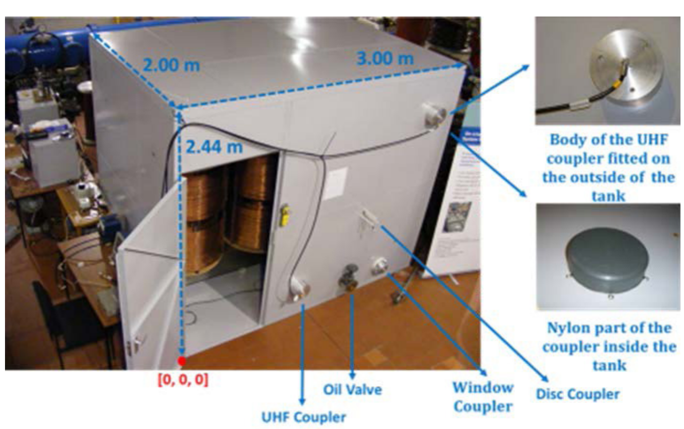


Figure 7: Transformer model with winding and core model

The next question, which needs to be answered, is: How to convert the measured mV/ dBm/ Scale percentage to a pC value?

Figure 9 is showing different partial discharge magnitudes compared with the UHF signal output. A nonlinear relationship can be discovered, but corresponding ranges between UHF output and apparent charge for that certain configuration can be assumed. Taking that into consideration, the following statement can be made:

If the location of the source is known and sensitivity/ amplitude verification was done, the estimation of the magnitude of the apparent charge based on the range of the UHF output (mV/ dBm/ % of scale) can be done.

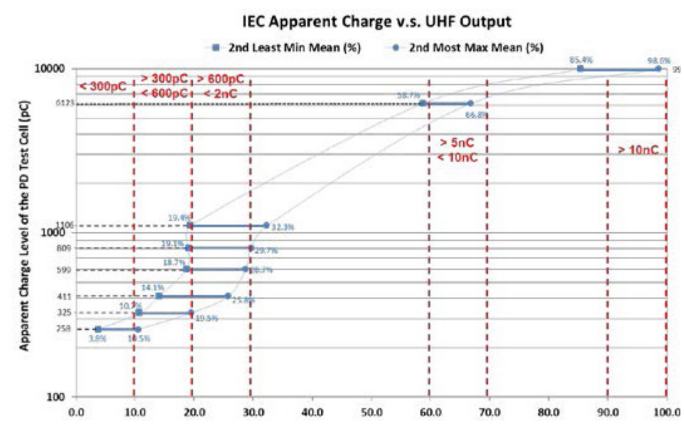


Figure 8: IEC apparent charge vs. UHF output

Considering the statement above, it can be concluded the following: To determine the range of IEC 60270 discharge magnitude and to assess the condition of the transformer regarding PD by the reading of the UHF PD magnitude, that:

> The location of the PD source needs to be known
> The type of defect needs to be known
> The sensitivity/ amplitude verification similar to the proposed method by CIGRE for GIS needs to be applied
> The propagation way of the UHF waves needs to be known

The location can be assessed by means of triangulation. With the complex construction of a transformer, it will need more than only 3 sensors, in order to reach a satisfying accuracy. Localization will be discussed more in detail in the next section.

The type of defect can be assessed by using phase resolved patterns, which are similar for the conventional and the UHF method.

The application of the sensitivity/ amplitude verification today is not common practice and not commonly defined. Therefore further development and discussions in that area are needed.

Out of the design information/ drawings, the propagation way can be assessed.

PD SOURCE LOCALIZATION BY MEANS OF THE UHF METHOD

The localization of a PD source by means of the UHF method is based on the different travel times of the UHF signal from the source to the sensors. In terms of a complex transformer design, reflections and travel ways along the surface of conducting material has to be considered. Therefore more than only 3 sensors are necessary for an accurate localization. Bigger transformer units would require 6 UHF PD sensors and smaller units 4 UHF PD sensors. The placement of the sensors should be in a way that the sensors are having the maximum possible distance to each other. An example is shown in Figure 10.

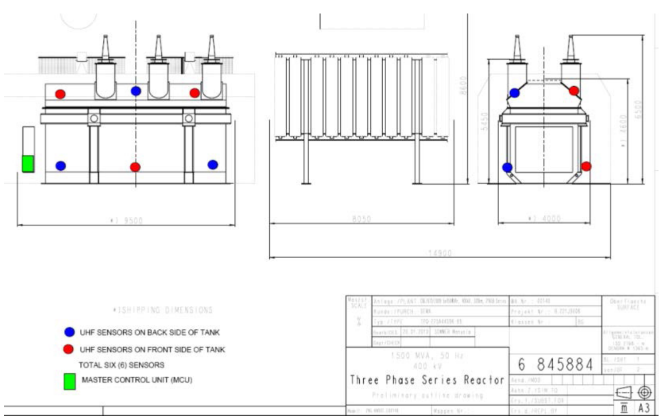


Figure 9: Example for sensor placement

The sensors at the back side of the transformer preferable are arranged as an opposite triangle compared to the front side.

With the information of the time difference of arrival of the UHF signal to the different sensor, the estimated localization can be calculated.

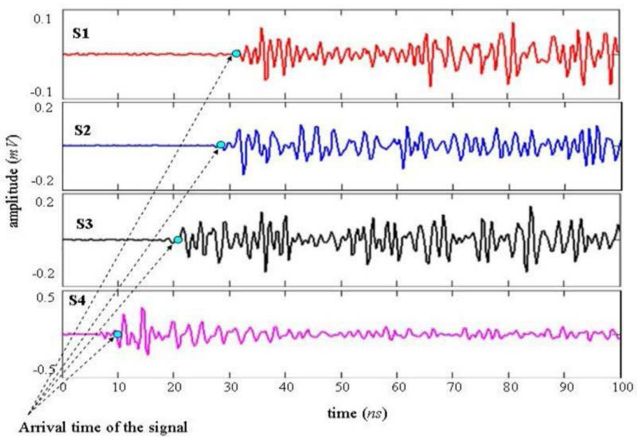


Figure 10: Example for time difference of arrival

In the below example, the transformer was equipped with four sensors and an impulse was injected at sensor 4. The time differences are shown in Figure 11. The time difference calculation has to consider the design of the transformer (basically to determine between metallic and nonmetallic parts – see Figure 12).

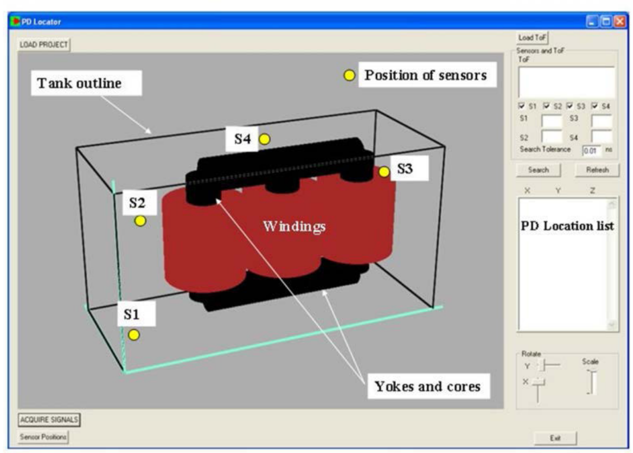


Figure 11: PD location calculation software

In order to measure the time difference of the arrival of the UHF signal at the different sensors a common oscilloscope with 4 channels with a sampling rate of 5Gs/s or higher can be used.

Following an example will be described, were the localization of a PD source was applied. A 132kV/ 25kV single phase industrial transformer was showing high DGA reading. Three UHF sensors were retrofitted into three hatch covers at the top cover of the transformer (Figure 13).

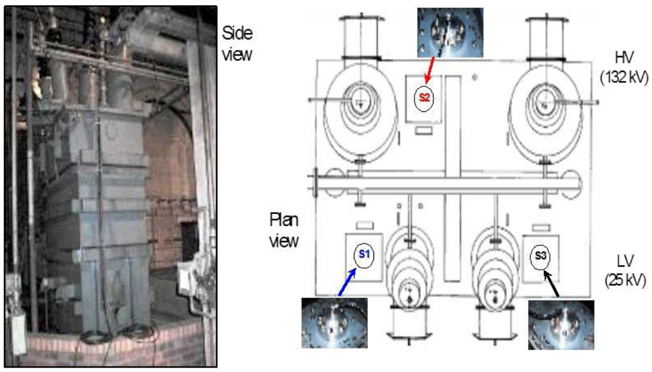


Figure 12: Single phase transformer with 3 hatch cover sensors

The PD was confirmed by detecting by means of the UHF method. As the next step, the time difference of arrival was measured (Figure 14).

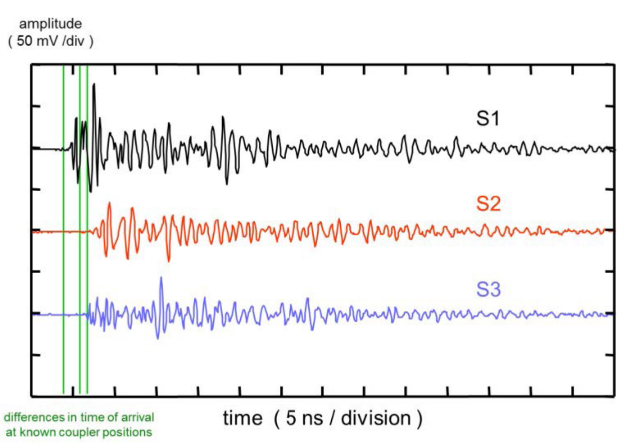


Figure 13: Time difference of signal arrival

The transformer model was setup in the localization software (light blue = nonmetallic/ light red metallic parts) and the location was calculated (Figure 15 and Figure 16).

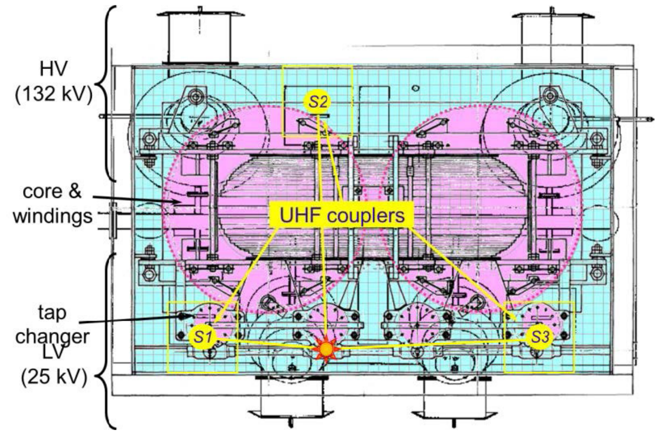


Figure 14: Transformer model

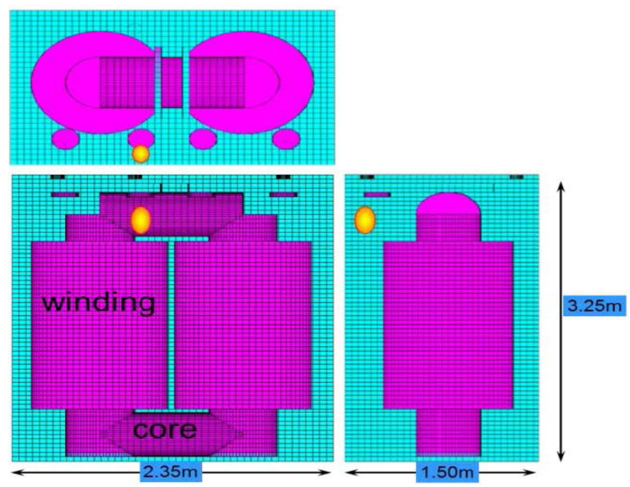


Figure 15: PD location display

After core disassembly the position of the discharge could be confirmed (see Figure 17).

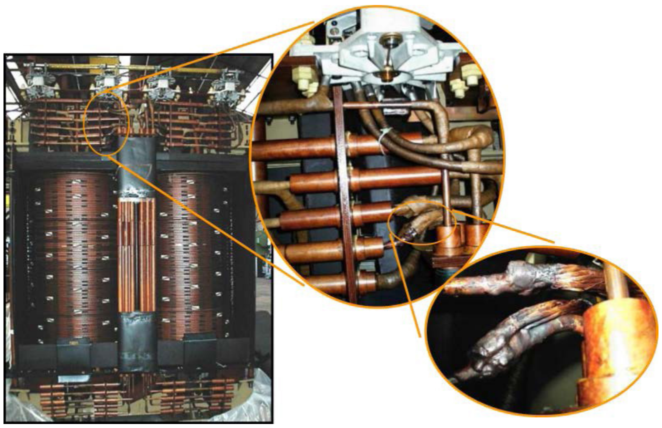


Figure 16: Confirmation of discharge location

CONCLUSION

The UHF technique is effective for detection and localization of partial discharges inside of transformers. The installation of UHF sensors is simple for new transformers. To retrofit UHF sensors to existing transformers, hatch covers can be used, but requires an outage. Drain valve sensors can be installed without outages, but in most of the cases only one drain valve sensor can be installed.

An estimation of the IEC PD magnitude range is possible, but requires localization of the PD source and a sensitivity/ amplitude verification preferable during manufacturing. No common agreed method is available today. Further investigations and discussions are required in that field. In regards to that, the new CIGRE JWG A2/D1.51 was established in August 2014, which is dealing with the non-conventional PD measurement techniques for transformers.

UHF PD monitoring on transformers offers new possibilities to assess continuously the condition of a transformer and support the approach to detect changes in its behavior. Nevertheless further research and development needs to be done to assess the health condition of transformers adequate to the given guideline as per (3).

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ABSTRAKT (D)

Es ist zu beobachten, dass der Energiesektor weltweit über die letzten 10 – 15 Jahre immer mehr durch die Entwicklung hin zu intelligenten Netzwerktechniken und steigende Ansprüche an die Zuverlässigkeit und Stabilität der Kernkomponenten der elektrischen Netze beeinflusst und getrieben wird. Diese Entwicklung wird auch in den nächsten Jahren anhalten. Zusätzlich sehen sich die hoch industrialisierten Länder, zum Beispiel in Europa, den USA und Japan konfrontiert mit dem möglichst störungsfreien Betrieb einer alternden Flotte der Key- Netzwerk- Komponenten, welche effizient und bis zu ihrem eigentlichen Lebensende betrieben werden sollen. Sanierungs- und Modernisierungsprogramme, basierend auf den Ergebnissen periodischer und kontinuierlicher Messungen, wurden entwickelt um gealterte Teilkomponenten zu erkennen und zu überholen und damit die Lebensdauer der Key- Komponenten zu erhöhen. Weiterhin führte die Deregulierung des Energiemarktes dazu, dass Kostenfaktoren eine immer größere Rolle spielen.

Transformatoren sind eine der Key- Komponente der elektrischen Energieverteilung. Als solche gewinnt die permanente Zustandsüberwachung in Form des Online Monitorings von Parametern wie zum Beispiel Teilentladungen, eine steigende Bedeutung. Das konventionelle Teilentladungs- Monitoring, hauptsächlich unter Nutzung des Messanschlusses der Durchführungen, ist heute allgemein verbreitet. Diese Form des TE Monitorings leidet allerdings an der fehlenden Aussage über die Herkunft der gemessenen Entladungen. Neuere Methoden, wie zum Beispiel die Nutzung der UHF Technologie im TE- Monitoring werden heute auch im Transformatorenbereich zum Standard.

Als Folge von schnellen Entladungsvorgängen werden UHF Signale ausgesendet und können durch eine UHF Antenne (Sensor – Antenne, in einer ähnlichen Form wie eine flache, abgerundete Platte, installiert im Transformator) empfangen werden. UHF Sensoren für Transformatoren ragen in den Transformator hinein und werden am besten schon während des Engineerings und der Produktion des Transformators integriert bzw. installiert. Die Vorteile der UHF Technik sind die hohe Störfestigkeit und die gute Empfindlichkeit. Weiterhin kann beim Einsatz von mehreren Sensoren (4 bis 6) die TE Quelle lokalisiert werden. Auch wenn diese unkonventionelle TE- Messmethode nicht kalibriert werden kann, erlaubt die Lokalisation und eine Art vorgängiger Empfindlichkeitsnachweis die Abschätzung der TE Amplitude in einem Pico Coulomb Bereich.

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