10939
B1 Insulated cables
PS2 Future Functionalities and Applications

Session 2022

Identification of Partial Discharges in Cable Terminations using Methods based on Acoustic, Electromagnetic and Electrical Measurements

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SUMMARY

In this paper, the identification of partial discharges in outdoor cable terminations is studied using electrical, electromagnetic and acoustic measuring devices. The purpose of this study is to investigate whether it is possible to measure partial discharges accurately and cost-effectively from outdoor cable terminations with the measuring devices used in this study. Partial discharges in cable terminations give a straightforward indication of the condition of the devices, which makes measuring them an effective method of preventive maintenance. Due to the electromagnetic radiation and ultrasound generated by partial discharges, they can be recognized with methods based on acoustic and electromagnetic measurements.

Artificially created defects causing internal, surface and corona discharges are examined in heat shrink medium voltage (24 kV) and oil-filled high voltage (123 kV) outdoor cable terminations. Cable terminations are measured in high voltage laboratories with an acoustic camera, RFI (radio-frequency interference) surveying tools and a mountable continuously measuring RFI based IoT (internet of things) device. In addition, accurate galvanic partial discharge measuring systems are used for reference. Emphasis of the study is on the recently developed continuously measuring and cost-effective RFI based IoT surveying tool, which provides real time information regarding the condition of the cable terminations. The other RFI surveying tools than the RFI based IoT tool are well-known measuring devices with known partial discharge identification capabilities. Nevertheless, it is still unknown which kind of fault types these devices can detect in cable terminations and how sensitive these devices are to the different fault types.

The measurements showed promising results as the partial discharges were identified in each of the test samples with the measuring devices of the study. However, some of the devices performed better in the identification of partial discharges than the others. This paper considers the suitability and limitations of the measuring devices for the condition monitoring of cable terminations in more detail and present ideas for further development.

KEYWORDS

Partial discharge - Cable - Termination - Acoustic measurement - RFI measurement

1 INTRODUCTION

It is widely known in the industry that partial discharges can drastically decrease the lifetime of a substation asset and in the worst-case scenario, lead into a dielectric breakdown and therefore cause dangerous situations and transmission interruptions. Ongoing partial discharges emit electromagnetic radiation and sound, from which partial discharges can be measured and recognized. Partial discharges have been measured for decades but even so, cost effective and scalable solutions for monitoring and measuring partial discharges on-line from a large substation asset fleet are rare and not well-established. However, large varieties of different methods and techniques are available for this purpose, for example, acoustic cameras, RFI (radio-frequency interference) surveying tools and mountable sensors, but their capability of detecting and measuring partial discharges requires further research. This paper investigates whether it is possible to measure partial discharges accurately and cost effectively from outdoor cable terminations with the measuring devices used in this study.

Cable termination is a cable accessory, which terminates the cable, offers the same insulation and dielectric strength as the cable, and creates a connection to an overhead line, for example. Favourable conditions for partial discharges arise in cable terminations due to installation errors, material and manufacturing defects, mechanical stresses, overvoltage and environmental stresses. Studies have shown that a substantial number of faults in cable systems are due to cable terminations [1] [2]. Moreover, according to CIGRE Technical Brochure 815 [1], published in 2020, the failure rate of XLPE (cross-linked polyethylene) land cable terminations has increased 300 percent compared with the previous review from 2009, presented in CIGRE Technical Brochure 379 [3]. Therefore, the improvement of condition monitoring and preventive actions for cable terminations are necessary.

In this study, partial discharges are examined in heat shrink medium voltage (MV, 24 kV) and oil-filled high voltage (HV, 123 kV) outdoor cable terminations. Defects causing partial discharges in cable terminations are artificially created, for example by drilling the insulation of the cable, by scratching the surface of the insulation screen or by simulating a dry band surface discharge. Artificially created defects are measured with an acoustic camera, RFI surveying tools and a mountable continuously measuring RFI based IoT (internet of things) device, and for reference with accurate galvanic partial discharge measuring systems. These devices, excluding the galvanic partial discharge measuring systems, are on-line measuring devices which can be used or installed without transmission interruptions. However, the installation of a mountable RFI based IoT device might need special arrangements depending on the structure of the substation. Experimental measurements were performed in two different high voltage laboratories: one on university premises and the other at a cable manufacturer's factory.

Outdoor cable terminations have been measured on-line with these devices before but the results could not be confirmed to certainly be partial discharges and it has not been fully verified which type of partial discharges the devices can detect. There are several reasons for this and one of the main reasons is that RFI-measurements are very sensitive to interference because the electromagnetic radiation from discharges in other high voltage assets and from the environment interferes with them. Other reasons are, for example, attenuation in different materials, the differences between the measuring devices and the uncertainty from which type of partial discharges the fault originates from. The study was carried out without interference in high voltage laboratories. In a substation environment, the electromagnetic interference will have an effect on the RFI-measurements, and the applicability of the measurement devices in environments with interference will be discussed in the paper. This study was conducted as a part of Master's Thesis [4] published in July 2021 and the measurement results of the thesis are discussed in this paper.

2 METHODOLOGY

Partial discharges occur in dielectric materials where the dielectric strength of the material is temporarily exceeded, for example in a gas bubble inside an insulation or in a wet dirt on a surface of an insulation. Because partial discharges are electrical charges in accelerating motion, they generate electromagnetic radiation. In addition, partial discharges cause surrounding material to expand rapidly due to thermal expansion which produces sound over a broad frequency range, both audible and ultrasonic. Due to these phenomena, partial discharges can be measured with methods based on acoustic and electromagnetic measurements.

In this study, the partial discharges are measured from cable terminations with an acoustic camera and with three different RFI surveying tools. The first is a mountable, cost-effective and continuously measuring RFI based IoT device, the second is a handheld and portable measuring device meant for single on-site measurements with a human operator and the third is a well-known RFI-based surveying tool developed by a cable manufacturer. Hereafter these three RFI surveying tools are referred to as continuously measuring RFI surveying tool, handheld RFI surveying tool and portable partial discharge analyser in the same order as mentioned before.

The handheld RFI surveying tool is a well-known measuring device which has been used for years to detect partial discharges from instrument transformers, for example. Nevertheless, the suitability of the handheld RFI surveying tool for the partial discharge measurements of cable terminations has not been studied so extensively. The continuously measuring RFI surveying tool is a recently developed measuring device to achieve cost-effective and continuous partial discharge measuring. The portable partial discharge analyser is widely used and tested RFI surveying tool, which is used principally as a reference for the other measurements. These three RFI surveying tools are tested beside each other also to compare the performance of these devices. The acoustic camera, on the other hand, is known to perform well locating external faults causing ultrasound, for example, the corona in the power lines. Now the focus in this study is the capability to detect especially internal partial discharges related to the cable terminations.

The continuously measuring and the handheld RFI surveying tools used in this study are swept-tuned spectrum analysers. With superheterodyne receivers, these surveying tools capture incoming electromagnetic radiation in the frequency range of 50–1000 MHz in handheld and 100–1000 MHz in continuously measuring RFI surveying tools. The intensity of the radiation is measured in decibel-milliwatts dBm. The continuously measuring RFI surveying tool uses a narrow bandwidth to sweep the frequency spectrum compared with the wider bandwidth of the handheld RFI surveying tool. Due to this, the measurement results of the continuously measuring RFI surveying tool are filtered with a digital Savitzky-Golay filter (order = 3, frame length = 11) to smoothen the data into a more readable form. Both RFI surveying tools are operated with the peak detector mode.

The portable partial discharge analyser is a well-known measuring device developed by a well-known cable manufacturer. The analyser has been used for years to detect and classify partial discharges in cable systems. It is an on-line measuring tool that is placed on the proximity of the object being measured. Since the portable partial discharge analyser is placed always on the proximity of the test sample, the mentioned measurement distances in this paper will not apply to this device.

Although the portable partial discharge analyser is also a swept-tuned spectral analyser, it uses different kind of sensor to capture the electromagnetic radiation. The device has a very sensitive antenna with 100 MHz bandwidth and an integrated acquisition and processing system. It can also detect the phase of the supplying voltage and thus the phase-resolved partial discharge (PRPD) patterns can be produced. In this study, the portable partial discharge analyser is used merely as a verification and to produce reference measurements, thus it is not discussed in detail in this paper.

The handheld acoustic camera used in this study has a compact array of 124 microphones. A heatmap showing the intensity of incoming sound from different directions is calculated by means of beamforming and overlaid on top of the video image from an optical camera. The acoustic camera thus shows the location of different sound sources, in this case partial discharges, in real time on the display.

Partial discharges emit sound over a broad frequency range, but common noise sources produce sound mainly at lower frequencies, typically below 10 kHz, which is effectively filtered out. The acoustic camera then focuses on the strongest sound source within the passband and inside the field of view, and extracts the sound coming from that source, isolating it from the sound from other sources. Based on this sound signal, an acoustic PRPD pattern is calculated and shown in real time on the display. Snapshots of the image and signal can be taken and further analysed to assess the severity using the accompanying cloud solution.

3 TEST SAMPLES AND MEASUREMENT RESULTS

This chapter introduces the selection of artificial faults created in laboratory circumstances for both MV and HV cable termination test samples. The goal was to create test samples causing both internal and external partial discharges, and therefore, different internal and external fault types were introduced accordingly. Moreover, the purpose of the artificial faults was to produce the partial discharges of different types to test the measurement equipment. Thus, some of them might not correspond to an actual real-life fault found or expected in the terminations.

3.1 General

The measured RFI results from the test samples were compared with the background radiation of the environment measured before applying the test voltages. The difference between the background radiation and the actual measurement is caused by the partial discharges and this is how the partial discharges are recognized from the RFI results. Although the measurements were made inside Faraday cages, some electromagnetic radiation will leak through which emphasizes the importance of background measurements before actual measurements. In addition, telecommunication signals can cause strong yet narrow spikes to the frequency spectrum, which can be neglected in the analysis of results.

The internal or external partial discharges of the test samples were verified with galvanic partial discharge measurement systems accurately, so that the magnitude of partial discharges was known in pico- or nanocoulombs. Taking into consideration the experimental nature of the test samples and the safety aspects of the MV and HV measurements, most of the test samples were tested with test voltages under the rated voltage of the cable and cable termination. Voltages were raised to a level that caused realistic partial discharges in the test sample or to a level which was safe enough to maintain.

The Master's Thesis study conducted in 2021 included a total of seven MV and four HV cable termination test samples. Only the most interesting and unique test samples and results are presented in this paper. For example, the study included multiple types of external fault test samples, but the measurement results were very similar, and thus this paper presents only some of them.

Each sample was tested multiple times, but only one measurement is presented from each sample in this paper. The selected results describe the average result from all of the measurements made for the sample. The results which are not shown in this paper, have small magnitude differences for example, but the overall shape of the frequency spectrum is somewhat similar in each of the measurements made for the sample. It is also noteworthy to mention that some of the measurements were interpreted as failed due to inexplicable deviations in the measurements. Some of the random deviations could be pinpointed to a specific reason, such as turning on the lights during measurements, the antenna getting disconnected from the device and the measuring devices being too close to the voltage supply.

The portable partial discharge analyser detected the partial discharges in all measurements and classified them as critical. An example of the results produced by this device is given in Section 3.3.1, but other results for this device are not shown in this paper.

3.2 MV cable terminations

Measurements of MV cable termination test samples were carried out in the high voltage laboratory on university premises. Artificial faults were introduced in multiple separate heat shrink 24 kV cable terminations. This section presents two of the test samples, one with an internal fault and one with an external fault.

3.2.1 Internal MV fault

Figure 1 shows the test sample with an internal fault, where a 0.5 mm layer of insulating tube was heat shrunk around the cable to extend the semiconducting layer. This layer of tape was punctured with a hole and another same type of insulating layer was wrapped around it. Another hole was punctured through both insulating tape layers and a layer of semiconducting tape was applied over the insulating tape layers. Finally, some stress controlling tape was applied as the last layer at the end of semiconducting tape layer and everything was sealed under a heat shrink sleeve.

FIGURE 1: THE TEST SAMPLE WITH AN INTERNAL MV FAULT WITH TWO HOLES IN THE INSULATING TAPE INSERTED BENEATH THE SEMICONDUCTING TAPE LAYER.

A total of five different tests were performed for the test sample with an internal MV fault with test voltages of 17–17.1 kV. The tests produced partial discharges with magnitudes of 250–740 pC. The tests were performed from a distance of 3–5 m with RFI surveying tools and 0.6–1.2 m with an acoustic camera. The first measurement was chosen to represent the results of the RFI and the acoustic measurements of the internal MV fault test sample. The results are presented in Figure 2.

The measurement was performed with the RFI surveying tools from a distance of 3 meters and with an acoustic camera from a distance of 1.2 meters. The magnitudes of the partial discharges in this measurement were 160–250 pC and the used voltage was 24 kV. The handheld RFI surveying tool recognized the partial discharges at frequency ranges of 50–150 MHz and 350–500 MHz. The continuously measuring RFI surveying tool recognized the partial discharges at the frequency range of 325–400 MHz, however, not as sensitively as the handheld device. The acoustic camera recognized the partial discharges from the distance of 0.6 m, where the highest measured signal level was −6 dB. From the distance of 1.2 m, which is shown in Figure 2, the acoustic camera recognized the partial discharges only in one snapshot, where the highest measured signal level was −13 dB. Hereafter only the PRPD pattern part of the acoustic image is presented from the measurements.

It is to be noted that the other three medium voltage test samples with faults causing internal partial discharges were recognized with RFI surveying tools with somewhat similar results, but not all the faults were recognized with the acoustic camera. The acoustic camera did not recognize two of the samples which had internal partial discharges of higher magnitude than in the test sample discussed above. Two of the samples that were recognized with the acoustic camera were barely recognized from the distance of 1.2 m.

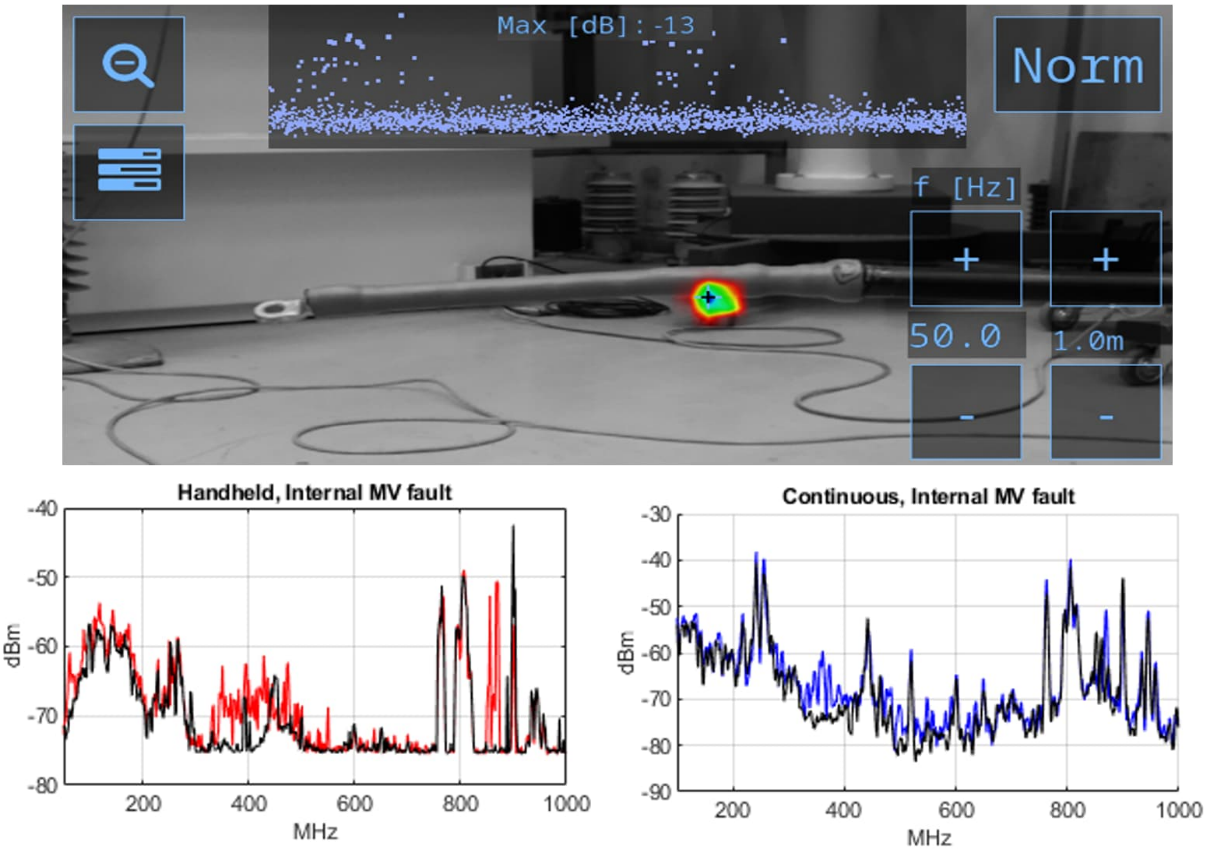

FIGURE 2: THE MEASUREMENT RESULTS OF THE ACOUSTIC CAMERA (ON TOP), THE HANDHELD RFI TOOL (BOTTOM LEFT) AND THE CONTINUOUS RFI TOOL (BOTTOM RIGHT) FROM THE TEST SAMPLE WITH AN INTERNAL MV FAULT.

3.2.2 External MV fault

Test termination for the sample with an external MV fault was prepared according to the termination manufacturer's instructions. However, the flashover distance of the termination surface was reduced by applying copper tape and a few rounds of semiconducting tape according to Figure 3. The goal was to simulate dry band type surface discharges. The dry band fault can occur, for example, when a leakage current dries an area on a temporary conducting surface due to pollution and wet conditions. The dried area no longer works as a conductor, which creates favourable conditions for surface discharges over the dried spot.

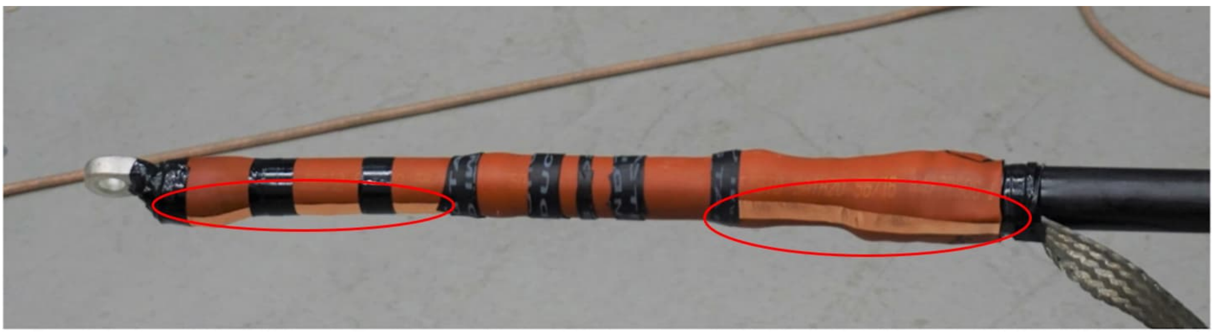

FIGURE 3: TEST SAMPLE WITH AN EXTERNAL MV FAULT, WHERE CLEARANCE BETWEEN LIVE AND GROUNDED PART WAS REDUCED BY INSERTING TWO SECTIONS OF COPPER TAPE (HIGHLIGHTED BY RED CIRCLES) AND ROUNDS OF SEMICONDUCTING TAPE.

A total of four different tests were performed for the test sample with an external MV fault with test voltages of 9.2–11 kV. The tests produced surface discharges with magnitudes of 2.5–6.5 nC. The tests were performed from a distance of 3–5 m with RFI surveying tools and 1.2–5 m with an acoustic camera. The second measurement was chosen to represent the results of the RFI and the acoustic measurements of the external MV fault test sample. The results are presented in Figure 4.

The measurement was performed with RFI surveying tools from a distance of 5 meters and with an acoustic camera from a distance of 1.2 meters. The magnitude of the partial discharges in this measurement was approximately 5.5 nC and the used voltage was 11 kV. The handheld RFI surveying tool recognized the surface discharges right at the beginning of its frequency spectrum at 50–150 MHz. The continuously measuring RFI device did not perform in the recognition that well, which is most likely due to the frequency range of the device, which starts from 100 MHz. The handheld device measured most of the deviations under the frequency of 100 MHz. Nevertheless, small deviations can be noticed at frequency range of 100–115 MHz in the results of the continuously measuring RFI surveying tool. The acoustic camera performed well in the measurements, and it recognized partial discharges clearly from the distance of 5 m, where the highest measured signal level was 13.6 dB. The highest measured signal level was 24.7 dB from a distance of 1.2 meters, which is shown in Figure 4.

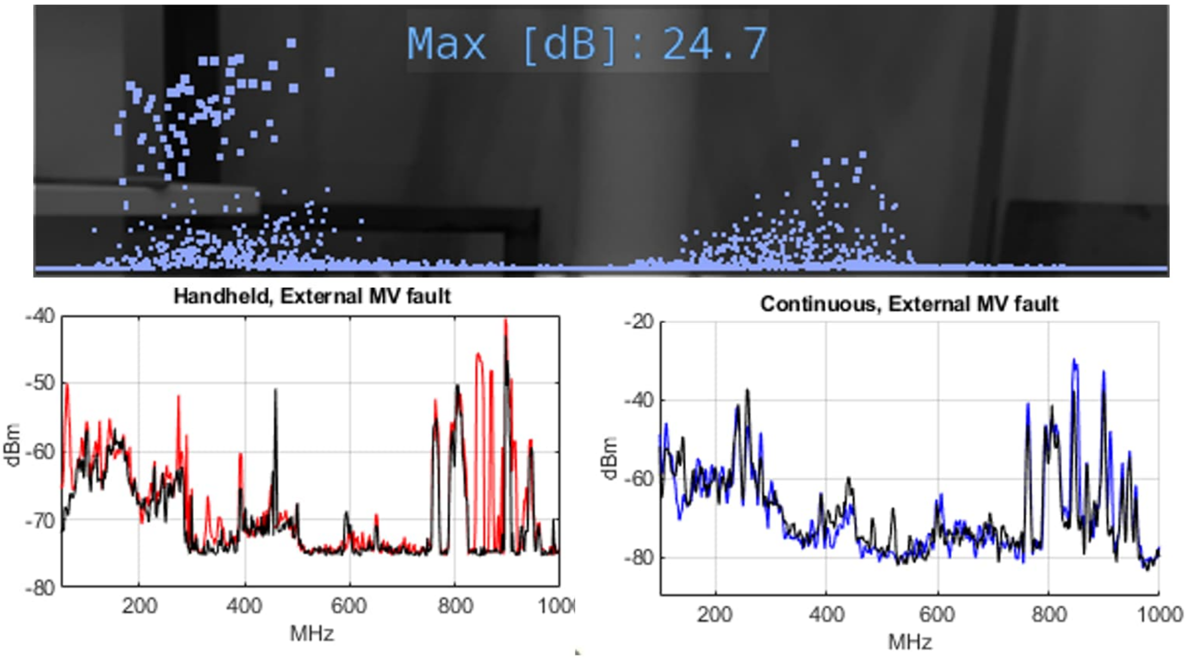

FIGURE 4: THE MEASUREMENT RESULTS OF THE ACOUSTIC CAMERA (ON TOP), THE HANDHELD RFI TOOL (BOTTOM LEFT) AND THE CONTINUOUS RFI TOOL (BOTTOM RIGHT) FROM THE TEST SAMPLE WITH AN EXTERNAL MV FAULT.

Other test samples causing external discharges were also recognized with the RFI devices with the exception of one test sample, which the continuously measuring RFI surveying tool did not recognize. The acoustic camera recognized all the external discharges exceptionally well.

3.3 HV cable terminations

Measurements of the HV cable termination test samples were carried out in a cable manufacturer's high voltage laboratory in Finland. Artificial faults were introduced into two separate 123 kV oil filled cable terminations connected to a 123 kV XLPE cable. After each set of measurements, the previously created fault was repaired, and another introduced for the next set of measurements. This section presents two of the HV cable termination test samples, one with an internal fault and one with an external fault.

3.3.1 Internal HV fault

In the test sample with an internal fault, the cable insulation was damaged by using a saw according to Figure 5. The introduced cut remained under the stress cone when termination was assembled. In service, this type of fault would present a coarse and very severe installation error.

FIGURE 5: TEST SAMPLE WITH AN INTERNAL HV FAULT, WHERE THE INSULATION WAS CUT IN A PART OF THE CABLE BENEATH THE STRESS CONE.

A total of seven different tests were performed for the test sample with an internal HV fault with test voltages of 44–110 kV. The tests produced partial discharges with magnitudes of 100–8000 pC. Tests were performed from a distance of 3–5 m with RFI surveying tools and 2.5–3 m with an acoustic camera. The sixth measurement was chosen to represent the results of the RFI measurements of the internal HV fault test sample. The results are presented in Figure 6.

During the measurement, the partial discharge level was momentarily at 300 pC and dropped to 120 pC. The test voltage was 70 kV and the measurement distance with RFI surveying tools was 5 m and with the acoustic camera 3 m. For the handheld tool, clear deviations caused by the partial discharges can be seen clearly at 50–300 MHz and for the continuously measuring tool at 200–500 MHz. The acoustic camera didn't recognize these internal partial discharges.

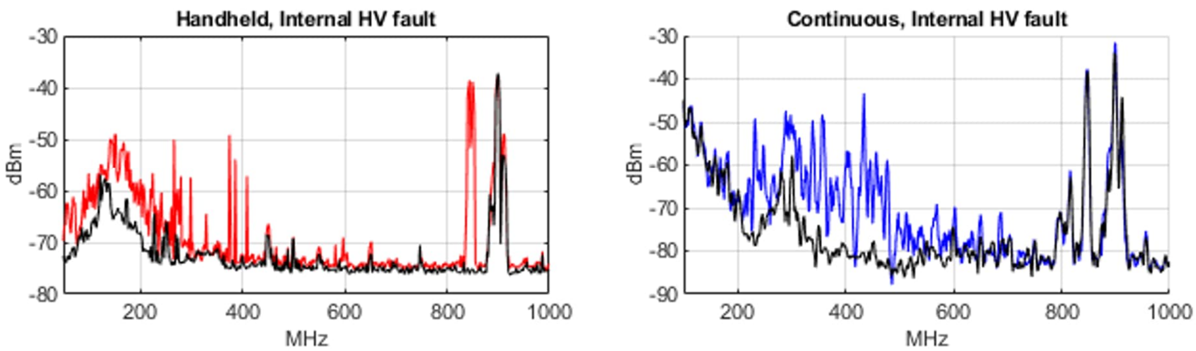

FIGURE 6: THE MEASUREMENT RESULTS OF THE HANDHELD RFI (LEFT) AND CONTINUOUSLY MEASURING RFI (RIGHT) TOOLS FROM THE TEST SAMPLE WITH AN INTERNAL HV FAULT.

Generally, both RFI tools performed similarly recognizing the partial discharges in this test sample. For each set of measurements, they both either measured or did not measure clear deviations. It can be concluded from the measurements that in this case, the internal partial discharges with the magnitude of 300 pC are visible with the RFI surveying tools whereas 120 pC discharge levels are not clearly visible.

In addition, an example of measurement results produced by the portable partial discharge analyser are shown in Figure 7. The PRPD indicates clear internal discharges as expected.

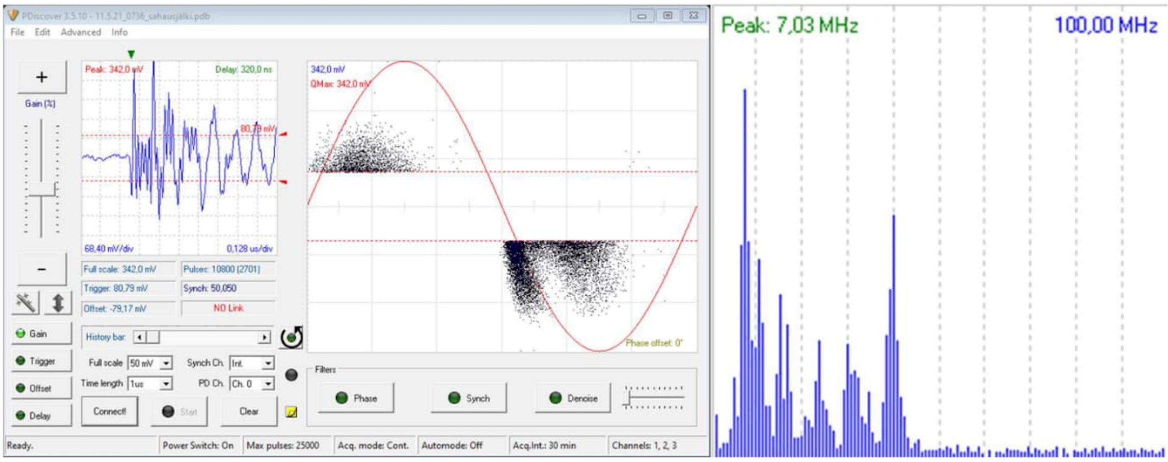

FIGURE 7:THE MEASUREMENT RESULTS OF THE PORTABLE PARTIAL DISCHARGE ANALYSER FROM TEST SAMPLE WITH AN INTERNAL HV FAULT. THE ANALYSER PRODUCES THE PARTIAL DISCHARGE WAVEFORM (LEFT), THE PRPD PATTERN (MIDDLE) AND THE FREQUENCY SPECTRUM (RIGHT).

3.4 External HV fault

The test sample with an external HV fault was prepared by wrapping semiconducting tape around the termination as shown in Figure 8. The idea was to reduce the creepage distance of the termination by by-passing the silicone sheds and thus creating surface discharges. In this test, only the area between two adjacent sheds was left unwrapped with the tape.

In the Master's Thesis study, this test was varied, for example, by adjusting the number of unwrapped silicone sheds. In addition, copper wire was used instead of semiconducting tape. However, in terms of partial discharges, all the variations produced similar results.

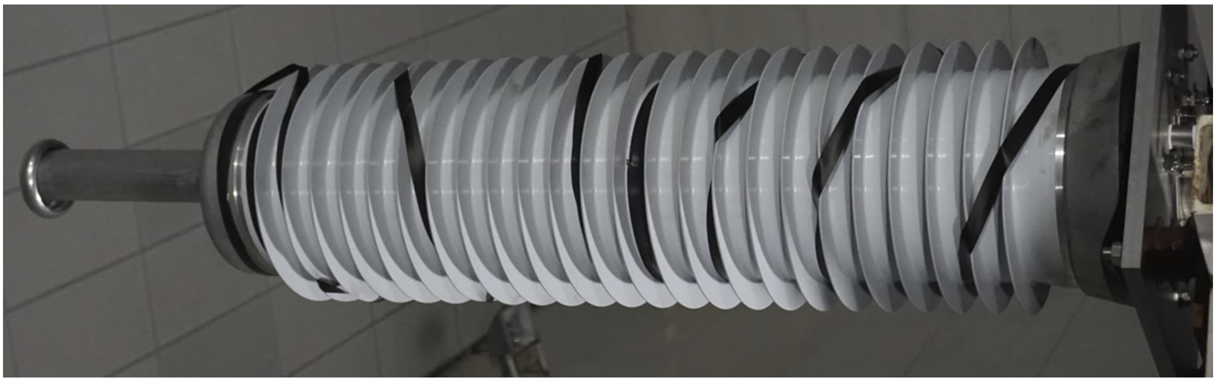

FIGURE 8: TEST SAMPLE WITH AN EXTERNAL HV FAULT, WHERE SEMICONDUCTING TAPE IS WRAPPED AROUND THE TERMINATION TO REDUCE THE CREEPAGE DISTANCE.

A total of three different tests were performed for the test sample with an external fault with test voltages of 20–32 kV. The tests produced partial discharges with magnitudes of 70–500 pC. The tests were performed from a distance of 3–5 m with RFI surveying tools and 3.5 m with an acoustic camera. The third measurement was chosen to present the results of the RFI and the acoustic measurements of the external HV fault test sample. The results are presented in Figure 9.

During the measurement, the partial discharge level was momentarily at 300–500 pC, the test voltage was 32 kV and the measurement distance with RFI surveying tools was 3 m. The RFI tools didn't produce any clear deviations apart from a narrow band below 100 MHz and some random spikes with the handheld tool. On the other hand, the acoustic camera performed very well with the highest measured signal level being 30.6 dB. In addition, it produced clear PRPD patterns which correctly indicate surface discharges.

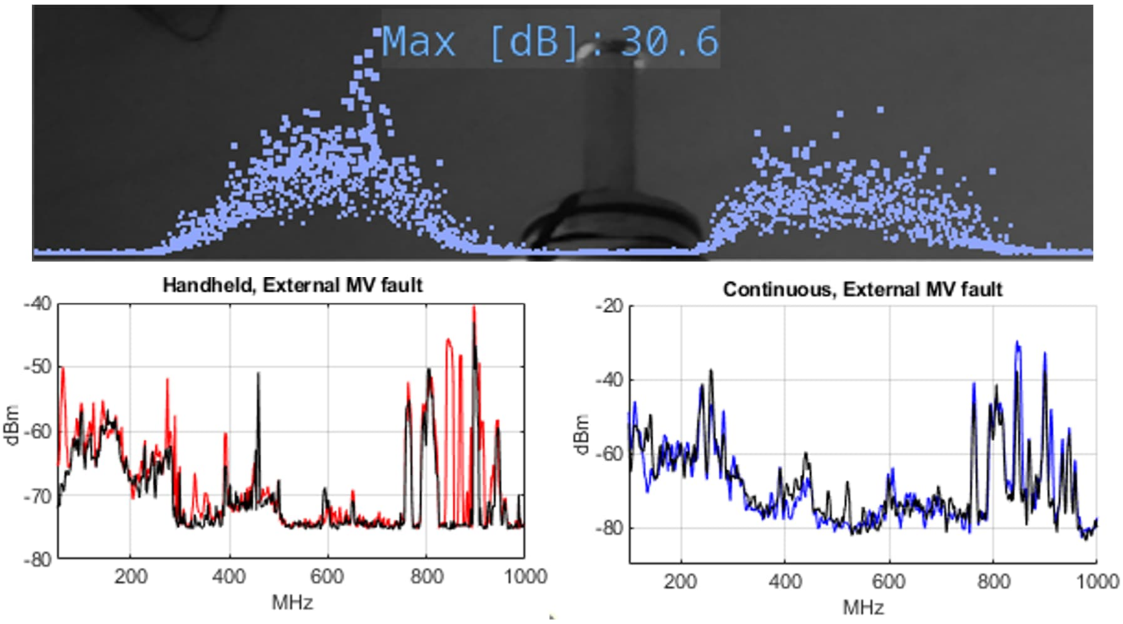

FIGURE 9: THE MEASUREMENT RESULTS OF THE ACOUSTIC CAMERA (ON TOP), THE HANDHELD RFI TOOL (BOTTOM LEFT) AND THE CONTINUOUS RFI TOOL (BOTTOM RIGHT) FROM THE TEST SAMPLE WITH AN EXTERNAL HV FAULT.

Based on all the test samples and measurements regarding faults producing external partial discharges studied, it seems that the RFI surveying tools cannot recognize external partial discharges that well compared to the recognition capability of internal partial discharges. However, the handheld tool seems to be slightly more sensitive in recognizing them than the continuously measuring tool.

4 CONCLUSION AND DISCUSSION

This paper presents highlights from a Master’s Thesis study concluded in 2021. The goal of the study was to test and validate a palette of different tools for partial discharge detection from high and medium voltage cable terminations in a laboratory environment. For this purpose, a set of artificial defects creating partial discharges was built in the cable terminations. The laboratory measurements revealed that these tools could detect partial discharges, but they performed very differently in the detection of different types of partial discharges.

The acoustic camera was very accurate in the detection of external partial discharges, i.e., corona and surface discharges, but it couldn’t detect internal partial discharges reliably. However, the main benefit of the acoustic camera is that it clearly indicates the exact location of any detected partial discharges together with the PRPD pattern, making the results easy to interpret. Compared with commonly used solar blind ultra-violet corona cameras, the acoustic camera is also more cost effective and does not require direct line of sight, but can up to a certain degree detect partial discharges that are obscured by objects or enclosures The continuously measuring and handheld RFI surveying tools were both able to detect internal partial discharges. The handheld tool was also able to detect external partial discharges, whereas the continuously measuring tool didn’t detect external discharges from every test sample.

It must be noted though, that all partial discharge deviations indicated by the tools were not perfectly unambiguous. Even though the defects were detected by the tools, the measured radio frequency-interference or the intensity of sound were not directly proportional to the measured apparent charge of the partial discharges. Furthermore, a long experience of utilities and manufacturers shows that the partial discharges in the substations may be detectable at one instant and extinguished at the other. The existence and magnitude of partial discharges depend e.g. on the environmental parameters, materials of the insulation structure as well as the location of the fault creating the discharges. Thus, it must be acknowledged that these types of measurements don't necessarily provide a clear severity classification of the faults but are merely an indication that something is wrong.

In reality, the measurements may be disrupted by acoustic and electromagnetic interference in substation environment. For example, high levels of corona discharges might disturb the RFI measurements by producing wide band interference concealing other and more severe types of partial discharges underneath. In addition to this, the measuring distances in substations might be longer due to high voltage safety distances which can amplify the attenuation phenomena of electromagnetic radiation and ultrasound. Pinpointing the most severe origins of partial discharges inside a substation is a difficult task due to interference and distance attenuation, and for this reason, these factors must be considered if the measuring methods are used in a substation environment.

In the future, the solution to overcome these challenges could be to use a combination of the different tools presented in this paper. The continuously measuring RFI tool could be used to monitor a large fleet of assets such as cable terminations comprehensively and cost-effectively. It could provide an early indication of a severe defect in a cable termination. On the other hand, it might not be able to indicate the accurate fault location or severity of the fault. However, the acoustic camera, the handheld RFI surveying tool and the portable partial discharge analyser could be used to verify the defect and to pinpoint the fault location more accurately. Finally, the necessary maintenance actions could be focused on the faulty termination.

The continuously measuring RFI tool still needs more development in the accuracy of partial discharge detection, and especially in the automatic analysis of the measurement results, since it will be used for a large-scale online monitoring. Furthermore, performing laboratory measurements for faulty high voltage cable terminations at their rated voltage or measuring faulty cable terminations in a substation environment with the tools presented in this paper, would provide the final confirmation of their capabilities. In the coming years, these tools will be used in the national main grid of Finland to gather more valuable knowledge of their performance and hopefully faulty components will be discovered as well.

BIBLIOGRAPHY

[1] Working Group B1.57 CIGRE “Update of service experience of HV underground and submarine cable systems” Technical Brochure 815, September 2020, 59 pages. Available at: www.e-cigre.org

[2] B. Van Maanen, C. Plet, P. Van Der Wielen, S. Meijer, F. De Wild and F. Steennis, "Failures in underground power cables – return of experience," in 9th International Conference on Insulated Power Cables (Jicable’15), Versailles, France, 2015.

[3] Working Group B1.10 CIGRE “Update of service experience of HV underground and submarine cable systems” Technical Brochure 379, April 2009, 85 pages. Available at: www.e-cigre.org

[4] T. Syrjänen, "Identification of Partial Discharges in Cable Terminations using Methods Based on Acoustic, Electromagnetic and Electrical Measurements", Master's Thesis, in Finnish, Aalto University, Finland, 2021, Available from: https://aaltodoc.aalto.fi/bitstream/handle/123456789/109369/master_Syrj%c3%a4nen_Tuukka_2021.pdf?sequence=1&isAllowed=y