UHF PD-DIAGNOSIS AT HIGH VOLTAGE CABLE TERMINATIONS – INTERNATIONAL CASE STUDIES

D. Götz*, H.T. Putter*

*Megger Germany

INTRODUCTION

High voltage termintions are essential components in high voltage cable systems. A high reliability is given by high manufacturing quality and claimed company final testing. However onsite installation represent a considerable uncertainty for successful service of the system. Commissioning testing of cable systems according to IEC60840 and IEC62067 should allow a save, undistributed service. The cable can be put into service after passing successfully a commissioning test, which is increasingly accompanied by partial discharge measurement. While a cable is in service periodically performed offline testing and diagnostic measurements rarely take place due to the fact of high efforts for switching off the cable system. Online diagnostic methods, which could be used while a cable is in service, are valuable sources for information and represent a reasonable compromise between costs and benefit. UHF PD Diagnosis has proven to be a valuable and effective method for doing so at high voltage assets (cables, GIS, transformer), because this online measurement is performed at frequencies which are not affected by environmental noise.

THEORETICAL BACKGROUND

Different partial discharge defects show a different distribution in the frequency spectrum. These typical characteristics could be used in combination with the appropriate phase resolved partial discharge pattern (PRPDP) for the analysis of partial discharge defects. The classification of the partial discharges allow an assessment of the defects in terms of its criticality. For demonstration purposes a variety of artificial partial discharge defects were evaluated at their frequency distribution.

UHF Measurements of Artificial Defects

Three typical types of partial discharge defects were evaluated in their frequency spectrum for better interpretation of onsite tests. Beside the frequency distribution, the phase resolved pattern were captured at typical frequencies. Results by C. Nyamupangedengu [1] could be confirmed of different types of discharges in their "initial phase", which means at almost un-aged condition of the defect. The measurements were performed with 50Hz operating frequency . The applied measurement bandwidth was given by 5MHz at the appropriate centre frequency.

Corona discharges. The following captured corona discharge in air were emulated by a pointed wire, which was placed on high potential electrode. The electrode was set to a test voltage of 4kVrms and exceeds herewith 2 times the partial discharge inception voltage.

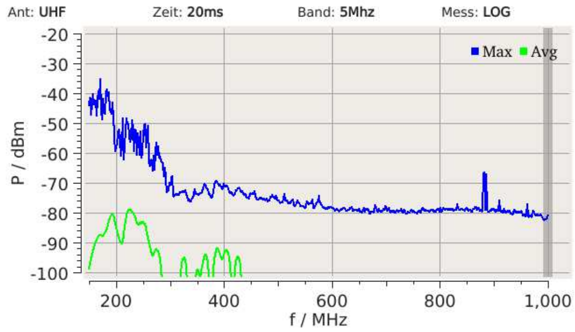

Figure 1 Spectrum of corona discharge

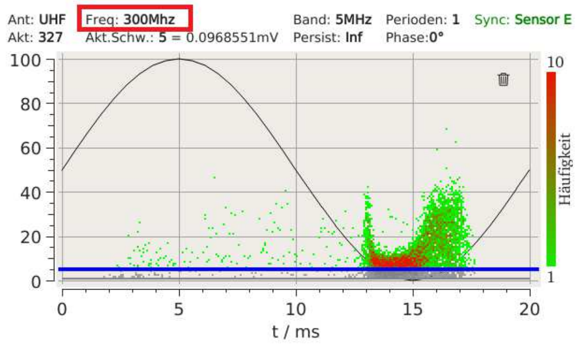

Figure 2 PRPDP at 300MHz centre frequency

Figure 1 shows the complete frequency spectrum and figure 2 the PRPD pattern at 300MHz. The corona discharge shows its typical behavior in the PRPDP, stabile discharge value located at negative maximum of the voltage period. The effective frequency spectrum of this discharge is limited to 300MHz.

Interfacial- / surface discharges. For demonstration of a surface discharge a setup according to Toepler was used. A high voltage electrode with a diameter of 2.5mm was placed centralized on a PVC plate. The measurement was performed at 4kVrms, this represents about 1,7 times higher than the partial discharge inception voltage.

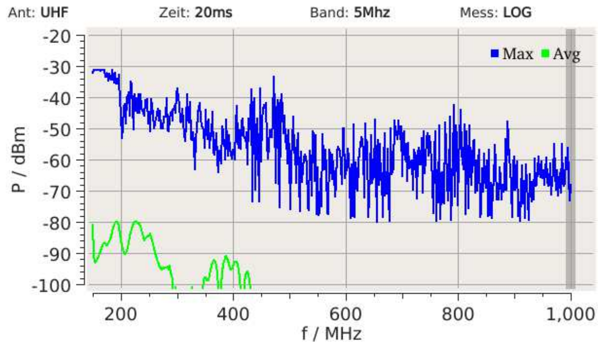

Figure 3 Spectrum of surface discharge

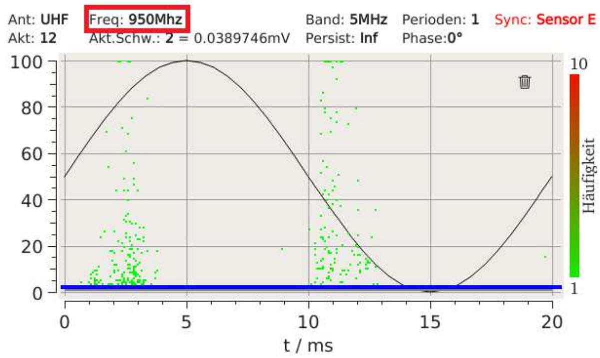

Figure 4 PRPDP at 950MHz centre frequency

Figure 3 shows the complete frequency spectrum and figure 4 the PRPD pattern at 300MHz. The surface discharge shows a continuous distribution in frequency, see figure 3. The immediate subsequent discharge vary strongly in its values. Therefore the standard deviation is rather high in comparison to e.g. a corona discharge. The characteristic PRPDP prove this fact due to the typical scattering of the discharge value within the cluster.

Discharges in „small“ voids. An epoxy plate containing several voids (air) with an approximated diameter of 500µm was placed between two electrodes, for creating a discharges in these voids. The voids are located nearby the high voltage electrode. The test voltage was 4kVrms. The voltage exceeds 1,4 times partial discharge inception voltage.

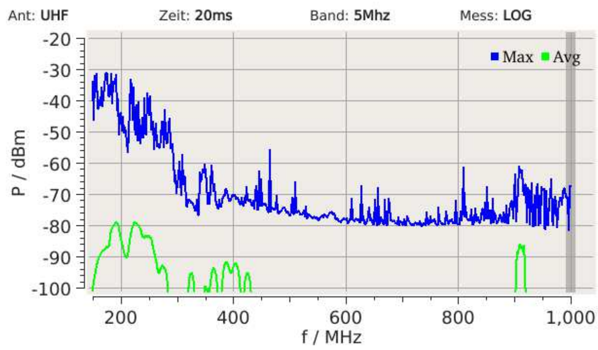

Figure 5 Spectrum 500 µm void diameter

It is necessary to differentiate between aged and un-aged defects studying a void discharge. The following experiment uses an un-aged void defect. Analyzing the spectrum signal fractions at high frequency can be observed, see figure 5. At this stage the discharges are called „Streamer-like“ [2]. The spectral distribution changes by increasing aging condition [1]. The sporadic, not continuous distribution in the spectrum is seen to be an important criterion for differentiation. This means there are frequency bands, in which the partial discharge shows no signal.

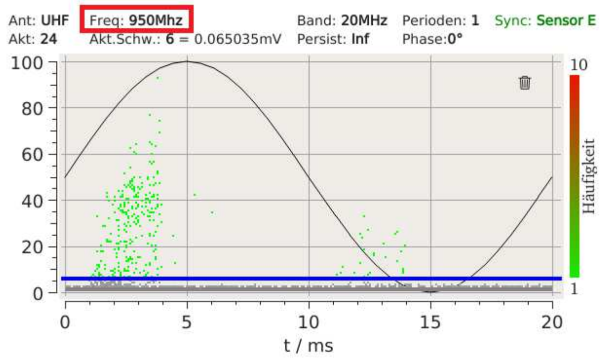

Figure 6 PRPDP at 950MHz center frequency

The PRPDP in Figure 6 demonstrates the asymmetric scattering, because the voids are immediate close by one electrode.

Discharges in „large“ voids. The Townsend type partial discharge is emulated by a „large“ void. This type of partial discharge appears not only at large voids. It can be observed after a certain aging of defects (small void) producing „streamer-like“ discharges. So, the „streamer-like“ changes while aging towards Townsend discharge type, see [1] for further details. This defect was also created by a centralized void of about 5mm diameter within a epoxy plate . The test voltage was 4kVrms. The voltage exceeds 1,4 times the partial discharge inception voltage.

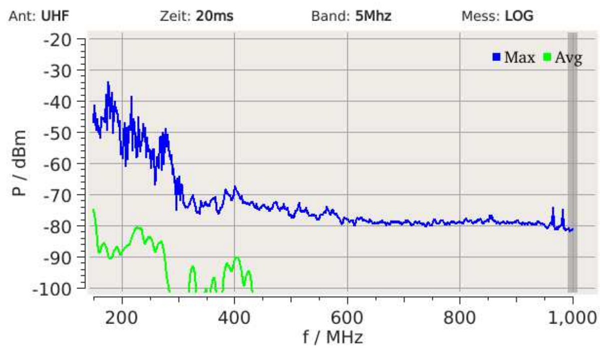

Figure 7 Spectrum discharge in large void

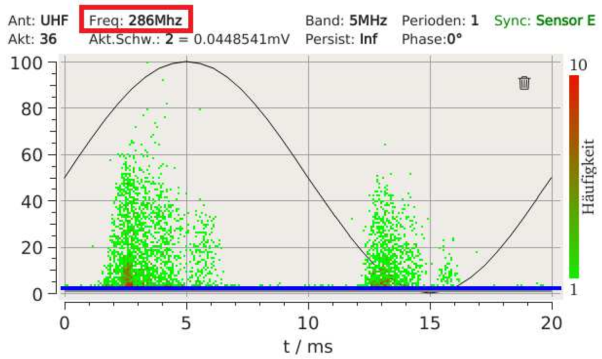

Figure 8 PRPDP at 286MHz center frequency

The frequency spectrum Figure 7 shows frequency contents up to 300MHz only. Hence it behaves similar to the frequency distribution of the corona discharge in Figure 1. The phase resolved partial discharge pattern (PRPDP), as can be seen in figure 8, nevertheless allows for a concrete differentiation between both discharge types.

Disturbances. For completion of the different types of PRPDP an example of disturbances is depicted in Figure 9. Disturbances could also built up clusters in PRPDP. They could be often identified by a rather sharp structure in the PRPDP. At high frequencies, beyond 400MHz, signal contents of radio frequencies (mobile, data broadcast, etc.) could appear. A diagnosis at those particular frequencies is not recommendable and not possible respectively.

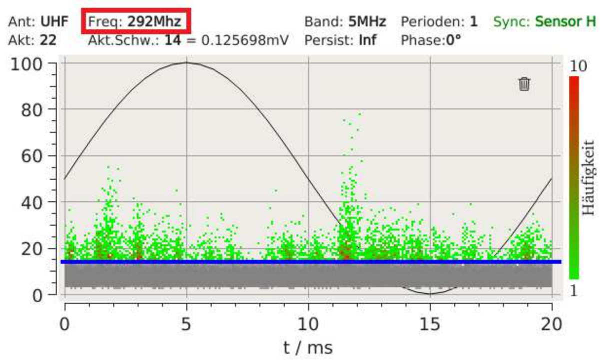

Figure 9 PRPDP at 292MHz center frequency

COMPARISON OF DIAGNOSTIC METHODS ON A HIGH-VOLTAGE CABLE

One phase of a 110kV cable system is used to compare the measurement methods. Sensors for UHF and HF coupling at the same cable termination were installed. The cable termination is connected to a high voltage transformer via bus bar. Consequently the transformer is located directly beside the object to test. The conventional offline partial discharge diagnosis were performed by a HV DAC (damped AC) source. The connection of the measurement system had to be performed on the opposite cable termination, due to space limitations at the local termination on which the sensor was placed.

Online Unconventional Partial Discharge Diagnosis UHF versus HF

The measurements were performed subsequently, so influences such as a higher humidity or temperature can be excluded. The UHF diagnosis did not show any abnormalities of the termination under test as can bee seen in figure 10.

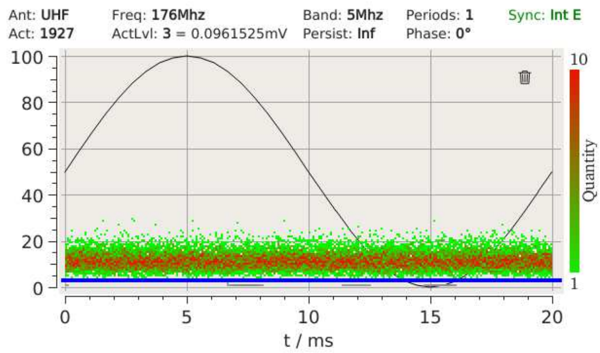

Figure 10 PRPDP of phase L3 at 176MHz

In direct comparison see the PRPDP of Figure 11, which uses a HFCT (high frequency current transformer). The evaluation was done at a frequency band (HF) or 100kHz to 20MHz.

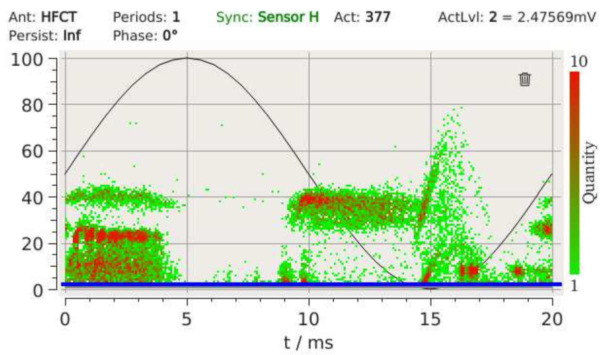

Figure 11 PRPDP of phase L3 at HF

It turned out a PRPDP with relative high activity. The pattern shows disturbances which are stabile in phase as well as several characteristic clusters, which could be evaluated like corona discharge type. In comparison to UHF measurements RF measurements can also detect partial discharges which are not close to the test point itself. This means that partial discharges initiated at connected bus bars, the transformer or the cable or components connected to its far end, could also be cause for a cluster in shown PRPDP. Furthermore it is likely that cross-talk of partial discharges to the measured phase could take place. Due to the fact, that corona discharge could not be detected at UHF measurement, it seems likely that the discharge was caused either from the far cable end or from the connected transformer.

Energy at this low frequency range (100kHz to 20MHz) could be distributed over long distances and could be captured at HF measurements.

Online Unconventional UHF versus Conventional Offline PD measurements

The offline HV DAC partial discharge measurement was performed by conventional coupling (couple capacitance according IEC60270) this in contrast to UHF measurement. The offline diagnosis confirms the result of being partial discharge free at nominal voltage. Nevertheless partial discharges were detected at both termination at inception voltages of 1.7 times nominal voltage. This PD activities were caused at the connection points of the HV DAC system to the object to test.

Discussion of UHF Measurements to both Comparable Methods

Partial discharge diagnosis by UHF allow high noise suppression and highly selective detection, because a suitable frequency can be chosen.
In condition of physics the UHF diagnosis is limited locally to the considered component of the test object, here the high voltage termination. This simplifies the evaluation of the measurement results, because they are not affected or have superimposed results by PD defects from e.g. cable joints or the far end termination point.

The demonstrated comparisons allows to conclude that all diagnostic methods, online or offline, in HF or in UHF frequency range have benefits and drawbacks. In general all studied methods are complementary and allow nevertheless a sophisticated analysis of the problem.

CASE STUDIES

For this publication UHF onsite measurements were performed. The study covers measurements at 110kV high voltage outdoor terminations only. The majority of this systems were XLPE insulted cable systems with different length. The results of the UHF diagnosis were analyzed statistically. Figure 12 shows onsite UHF measurements, the coupling was performed by preinstalled UHF sensors.

Figure 12 onsite UHF measurement

The statistical population is given by 27 UHF measurements at 18 high voltage terminations at different international sites. It was counted as UHF measurement, if it was any significant modification of the situation, like cleaning or treatment. 11 out of the 18 terminations had preinstalled UHF sensors. At first all measurements were analyzed regarding activity in the frequency spectrum. The classification of the particular partial discharge types, was done by means of PRPDP. PRPDP cluster, which could not be classified to any known partial discharge pattern were set to disturbances. Any signal not stable in phase was automatically classified to "no activity".

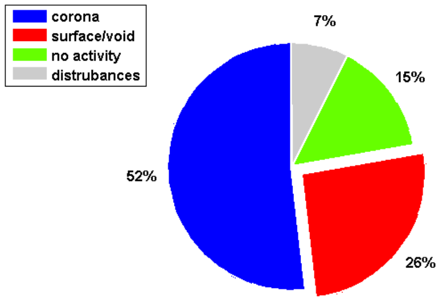

Figure 13 UHF captures in different categories

The diagram of Figure 14 shows the percentile of frequency contents of spectrum which belong to class surface or void discharge. These results are part of the measurement results classified as surface/void in Figure 13.

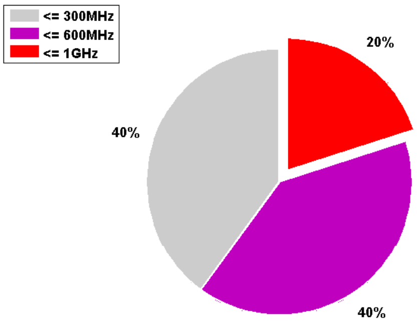

Figure 14 Frequency content of the PRPDP

The following criteria were used for categorizing measurement to „further study“:

1. the experience of the spectral behavior of the type of the partial discharge defect;
2. the absolute PD level;
3. the width of the distributed spectrum (frequency contents).

Figure 15 depicts the percentile of suspicious results of all terminations examined.

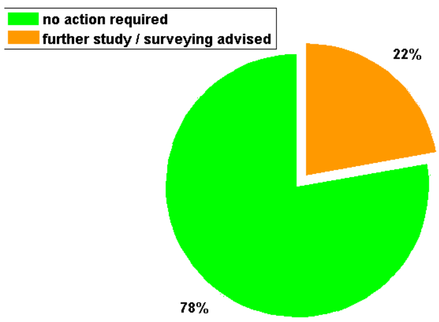

Figure 15 percentage of conspicuous terminations

A classification to „further study / surveying advised“ could be seen as recommendation for surveying this termination. Periodical surveying UHF measurements will give further knowledge about possibly changes in discharge activity (pulse per cycle), discharge level and spectral distribution. It is recommendable to keep identical setting and frequencies for repeating UHF measurement.

CONCLUSIONS

Different spectral distributions and their specialties of typical partial discharge defects were discussed. A comparison between unconventional methods in UHF/HF frequency range and conventional offline methods shows significant differences. The characteristic features of the UHF and RF measurement can very well be used as an interpretation aid.

The case study on 18 high voltage termination by UHF diagnosis resulting in 4 termination to be on further study due to classifying to surface or void discharge. It is recommended to follow up by surveying this objects Possible differences in level or frequency distribution should be noticed.

Beside the distribution in frequency spectrum and characteristic clusters in phase resolved pattern, the absolute level and the grade of activity (pulses per cycle) could be used for proper decision making criteria.

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