ON-SITE CONDITION ASSESSMENT OF HV CABLE TERMINATIONS IN SERVICE

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ABSTRACT

The ultra-high frequency partial discharge detection method described in the paper is successfully applied on-line to assess the insulation condition of plug-in cable connectors. A portable screening housing with the UHF sensors inside is clamped around each tested termination in turn. PD signals recorded in the time-domain by a programmed oscilloscope are plotted as a function of the phase angle. FFT transforms of the PD pulses are used to differentiate between internal and external (corona) PDs. Experiences from a field testing are reported as well. Results of the visual inspection of the connectors retrieved from the field proved the effectiveness of the method. The diagnostic system can be applied as a quality check on just assembled terminations, as well as for the purposes of the condition assessment of insulation integrity after years in service.

INTRODUCTION AND PRINCIPLE OF UHF PD DIAGNOSTICS

Today's transmission and especially distribution of the electric power in the urban areas relies completely on the underground cable networks. High concentration of the population and industry in modern cities requires high availability of power and reliability of all components of the system. Recently conducted liberalization of the monopolistic services, such as electric power, gas and communications created new market incentives for the utilities and encouraged them to look for competitive asset management strategies. Therefore existing corrective or time-based maintenance approaches will be replaced by the condition based maintenance in the future. The latter requires the current condition assessment (diagnosis) for each part of the electric power system. This paper proposes a solution for the on-line on-site condition assessment of the cable terminations, which are the second weakest group (after joints) in the underground cable networks in terms of reliability [1]. In fact, the accessories are designed to possess the same integrity as their associated cables. But they are assembled and installed under on-site conditions and thus exposed to the higher risk of defects and contaminations.

Partial discharge (PD) is defined as an electrical discharge, which only partially bridges the insulation between two conductors. PD, originated from a microdefect, incepts periodically according to the ac cycle of the operation voltage and gradually degrades and erodes the polymeric material, eventually leading to breakdown. Cable accessory manufacturers usually apply the conventional PD measurement method in accordance with the IEC 60270 standard to test their components in the factory. However, the PD detection at the recommended frequency below 1 MHz is often not suitable for the field application as a result of excessive interference from other substation equipment and electromagnetic interference [2]. Recently the UHF PD testing has earned wide acceptance in the diagnosis of HV apparatuses in service due to higher signal-to-noise ratio onsite and thus increased detection sensitivity compared to the classical IEC 60270. The UHF band (300-3000 MHz) has only a few known discrete interferences (e.g. DVB-T and GSM). As well it has the advantage of the distance selectivity of only several meters due to high attenuation of RF waves. This can be perfectly used for the diagnosis of the concentrated equipment such as transformers, GIS, machines and cable accessories. The method is applied on-line, i.e. the PD detection is done on the HV plant in normal operation and. no disconnection or external voltage source is needed.

Nanosecond pulses emitted from the PD site and captured with the specially developed UHF sensor are consequently pre-amplified, filtered and recorded by an oscilloscope. The coupling sensor should be placed possibly close to the test object and effectively screened against outside interferences as shown in Fig.1. A copper disc with the diameter of 2.5 cm serves as a capacitive sensor, placed at a tangent to the cable sheath close to it. Various sensor geometries such as rectangular, bow-tie, diamond, and the Archimedean spiral and circle monopole were considered as well, without substantial gain in the detection sensitivity though [3]. The sensor is terminated via BNC jack that is connected to the coaxial cable.
On-site PD measurements were made in the manhole of GIS, while the cables were in service. The portable screening sleeve equipped with a set of UHF sensors was clamped around each phase in turn as shown in Fig. 2.

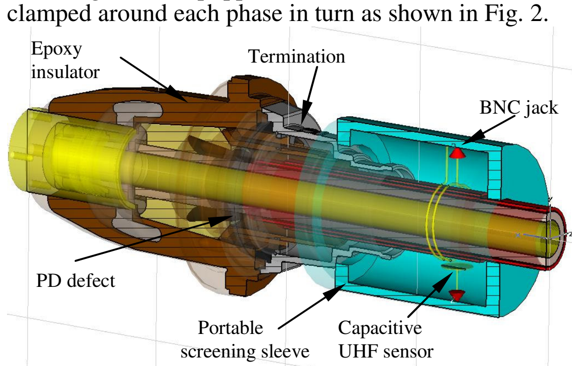

Figure 1. Object and principle of the UHF PD diagnostics

Figure 2. On-site application of the method

TEST ARRANGEMENT

Fig. 3 presents a structural diagram of a test setup built in the laboratory. An artificial PD defect was built into the termination to initiate a discharge at the interface between different dielectric materials. This kind of fault is very typical for defects in cable accessories. For that purpose a plastic lath covered with some silicon grease was introduced along the boundary between the cable insulation and stress cone.

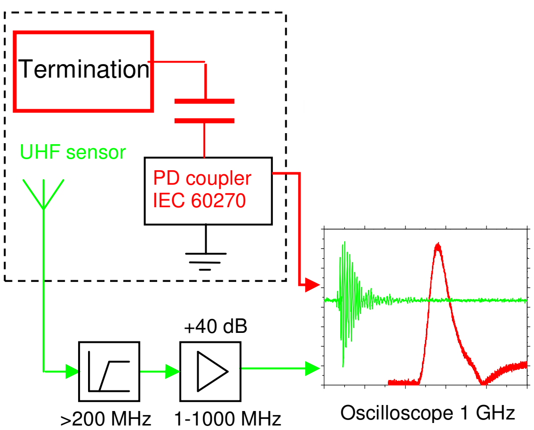

Figure 3. Structural diagram of the comparative measurement between an UHF and IEC60270 PD detecting methods

The laboratory GIS was equipped with a coupling capacitor and the conventional IEC 60270 PD measurement system MPD540 from Mtronix. The latter was able to plot a color-coded PRPD pattern of a defect used as a reference for the synchronously conducted UHF measurements. The phase reference signal in the laboratory was obtained via the capacitive divider built into the test transformer.

SPECTRAL ANALYSIS OF UHF PD PULSES

Fig. 4 shows the UHF PD pulse of 5 pC (measured synchronously acc. IEC 60270) in time and frequency domains captured on the laboratory termination with the built-in artificial defect. The frequency spectrum on the right side was obtained as a result of the FFT transform of a PD pulse length only. Besides some DVB-T carrier frequency spikes there is a clear broadband increase in the spectral density in a range of 500-1000 MHz that indicates the presence of the PD activity [4].

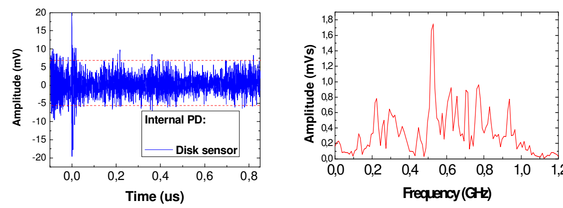

Figure 4. UHF PD pulse of 5 pC (acc. IEC 60270) from the artificial defect in the termination in time and frequency domains

Often in a noisy on-site environment some repetitive pulse activity picked up by the diagnostic system can be falsely interpreted as possible PD. In this case the FFT transform can be a good key to the PD/noise differentiation. Fig. 5 shows the differences in FFT waveforms of an internal PD inside the termination compared to the corona discharge at the protrusion in air and SF_6. The protrusion was placed within the test joint sealed with the termination under test. The waveforms were obtained in result of the FFT transformation of the PD signals captured in the time-domain at similar pC values by the same broadband capacitive sensor. It is visible that the internal PD comprises the spectrum of higher frequencies than that of the corona discharge in air and SF_6.

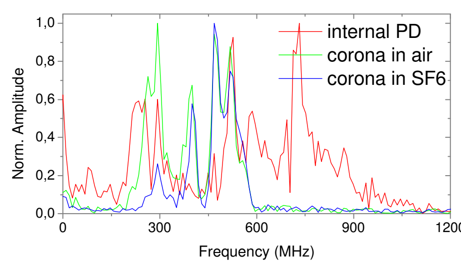

Figure 5. Differentiation between internal and external PDs based on FFT transforms

PHASE-RESOLVED UHF PD IMAGING

Another way to distinguish the internal defect from noise is to collect the cumulative picture of PD pulses and plot it against the phase angle of the test voltage. The basic idea of the phase resolved interpretation of PD is that PD pulses are distributed statistically with a strong correlation to power frequency and noise is not. In PRPD pattern the information on the phase angle of the pulses, as well as magnitude and repetition rate are plotted in one 2D-diagram. To enable an automated acquisition of UHF PRPD patterns a software was written, which remotely controls the oscilloscope and collect the key parameters of UHF pulses, such as peak amplitude, integral energy, phase angle reference and the IEC 60270 system output (available in the lab only) as shown in Fig. 6 into one database. The control software triggers the oscilloscope in the "single" mode for the number of PD pulses given by the user. The UHF signal is used to trigger the measurement.

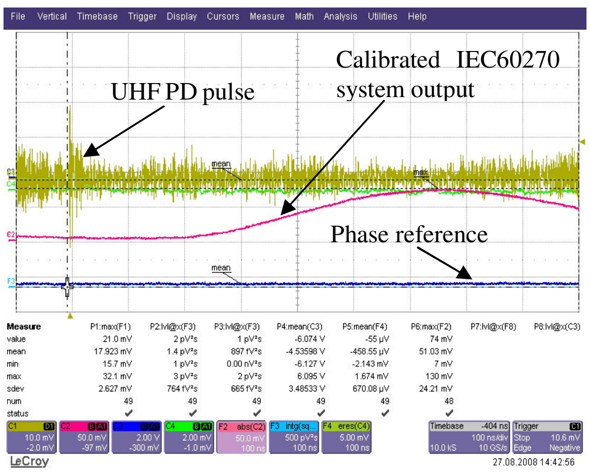

Figure 6. Oscilloscope screenshot

Fig. 7 presents the simultaneous measurement on the lab setup by both the IEC 60270 and the UHF methods. The images shown stand for an inner PD activity in the cable termination recorded over 5 min. The UHF PRPD image counts over 2500 triggered PD pulses. The shape and phase position of both patterns are very similar. Thus, based on the UHF PRPD images one can use on-site the same pattern recognition techniques developed for the laboratory testing in accordance with IEC60270.

In the laboratory the applied high voltage was measured directly via capacitive divider. The exact phase angle at the moment of pulse acquisition is calculated using the output value of a ramped voltage generator as shown in Fig. 8. A ramp is generated in sync to the sinusoidal test voltage to avoid an uncertainty if it is a rising or falling part of a sine wave in a short timeframe as can be seen in Fig. 6. Regarding the on-site testing in the GIS substations there are very few possibilities to extract the corresponding phase signal of the line voltage. First, if available, the use of an electrode, embedded into the epoxy insulator, for voltage indication purposes. In this case it is a voltage divider with the capacitive impedance in the HV arm and the capacitive-resistive load in the LV arm. The ramped output voltage is then shifted by a certain degree found experimentally in the lab. But unfortunately this embedded electrode is optional and not often available. The second approach was to use a Rogowski coil clamped around the cable core at the place where earth strap lead out of the termination. Thus the phase of the cable conductor current is measured. In the strict sense the unknown power factor (cos φ) will cause a phase angle error. Usually the power factor is close to 1 in the city cable networks. But the approach will not work on cables with no load current. The third way is to simply use the mains supply voltage of the oscilloscope. It is enough to proof the AC cycle correlation of repetitive pulses. But the pattern is then shifted to an unknown degree with respect to the original.

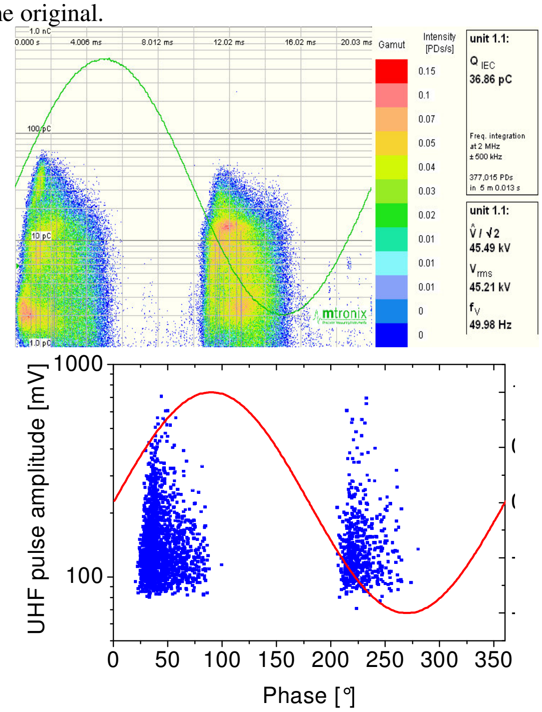

Figure 7: PRPD images of an internal PD (<80 pC at 45 kV) recorded synchronously acc. IEC60270 (left) and using the UHF signal from the oscilloscope (right)

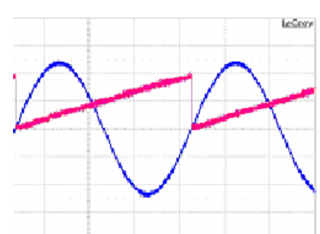

Figure 8. 50 Hz sine form of the applied voltage coupled on-site by the electrode, embedded into epoxy insulator, and a ramped trigger box output signal

ON-SITE TEST EXPERIENCE

Fig. 9 and 10 show the corona noise and internal PD patterns encountered during the on-site measurements. The UHF PRPD image of a suspicious termination in Fig.10 has

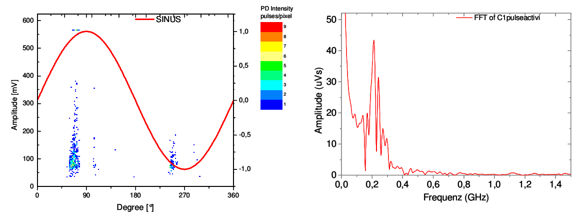

Figure 9. On-site test: corona (PRPD and FFT patterns)

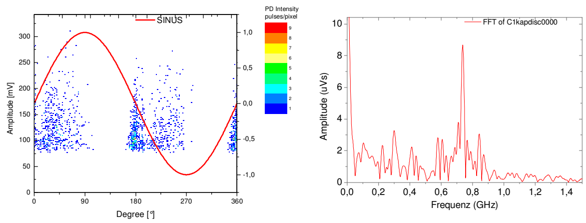

Figure 10. Internal PD defect (PRPD and FFT patterns)

a classical form of the internal insulation fault. This sealing end was taken out of service later and shipped to the lab for the visual inspection. In Fig. 11 the dismantled termination is shown. Two major black spots were found on the surface of the cable and adjacent surface of the stress relief cone. Black (carbonized) colour of the spots and yellow colour of neighbouring area of XLPE cable insulation point out to the heavy arcing process taking place across the border "cable-stress cone".

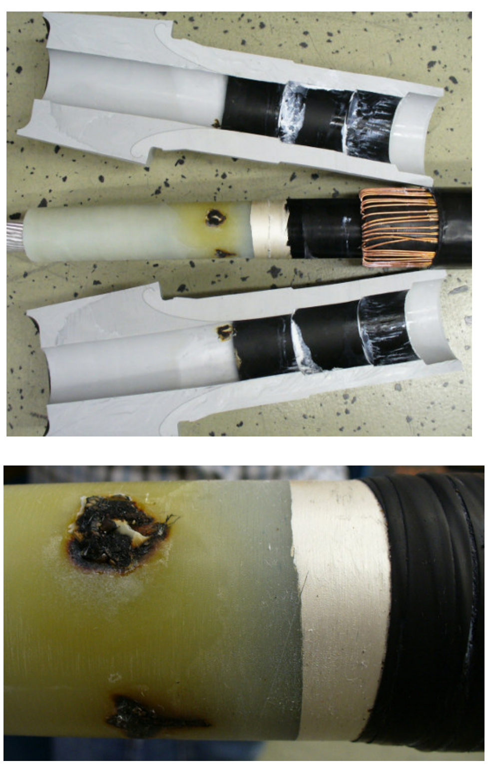

Figure. 11: A faulty 72 kV cable termination qualified onsite and dismantled in the lab

CONCLUSIONS

The experiences in the on-line on-site UHF PD detection in high voltage plug-in cable terminations were discussed in the paper. Maximal sensitivity on the UHF method that could be achieved in the laboratory comprises 5 pC for the capacitive sensor.

FFT transforms of PD pulses can be used to differentiate between internal and external (corona) PDs. UHF PRPD patterns give a good correlation with classical PRPD patterns picked up according to IEC 60270. The technique can also be used to recognize different types of possible PD defects on-site, if a database of typical defect PRPD patterns is previously collected in the laboratory. The method was successfully applied under on-site conditions and enabled us to find damaged terminations.

The presented UHF PD detection method can be applied to prove the quality of the assembly work during the commissioning, as well as on a regular basis after years in service to detect aged and risky terminations in terms of the condition-based maintenance.

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