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Wide and narrow band PD detection in plug-in cable connectors in the UHF range

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***Abstract*--Experience in on-line UHF partial discharge detection on high voltage plug-in cable connectors (terminations) for GIS and transformers are presented. Narrow vs. broadband, as well as zero-span measurements were carried out using a spectrum analyzer on a laboratory setup with a built-in artificial PD defect of variable intensity. A sensitivity below 5 pC turned out to be detectable by the presented UHF method. The results of the laboratory experiments demonstrate high effectiveness of the on-line UHF PD detection in plug-in cable terminations. The method can be applied to proof the quality of assembly work during commissioning as well as on a regular basis after many years in service to detect aged and risky terminations as a part of the condition-based maintenance.**

***Index Terms*--Cable termination, on-line diagnostics, partial discharge, UHF, wide/narrowband.**

I. INTRODUCTION

A failure of a high voltage power cable causes a service interruption, costly location, repairs and loss of revenues. Utility experience shows that poor termination and jointing is a major cause of cable failure. This is due to the fact that, in contrast to the cable itself, these components have more complex structure, sometimes even with several dielectrics, and increased field gradients. But moreover they are assembled and installed under on-site conditions and thus exposed to the higher risk of defects and contaminations.

Modern plug-in cable connectors (terminations) for GIS and transformers are made from silicone rubber. The electrical life span of this high polymeric material normally exceeds 40 years, but only in absence of PD activity that inevitably causes material degradation. Several IEC standards, e.g. IEC 60840, prescribe routine tests on the prefabricated components of HV cable accessories to be carried out by manufacturers. The conventional IEC 60270 method, which can be calibrated, is always applied during quality assurance testing on the components in the factory in those cases. Unfortunately, there are no standards for testing a complete accessory yet. But an improper assembly done under on-site conditions can strongly affect the long-term performance of the complete accessory. Therefore, to make sure that the assembly was done immaculately, a quality check on-site is often desired by utilities. Although there are several well known off-line on-site test techniques, which are successfully applied to diagnose long power cables including their accessories, they all need grid switching and a separate voltage source to energize the cable line apart from the network. The on-line test approach overcomes these difficulties allowing sensitive measurement on the terminations, while the cable is in normal operation. This contribution discusses the experiences in on-line UHF PD diagnostics of high voltage cable terminations.

II. PRINCIPLE OF PD DIAGNOSTICS IN UHF RANGE

Partial discharge measurement is a well established criterion for the condition assessment and quality control of the high voltage electrical insulation. 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. As mentioned above, cable accessory manufacturers usually apply the conventional PD measurement method in accordance with IEC 60270 to test their components in the factory. However, such low frequency (up to 1 MHz) PD detection methods are not suitable for field application as a result of excessive interference from other substation equipment and electromagnetic interference [1]. To detect the PD activity under conditions of on-site on-line testing, the ultrawide band PD (UHF PD) diagnosis principle can be used. This method is based on sensing the electromagnetic emissions from discharge sites in the insulation. The coupling sensors should be placed possibly close to the test object and effectively screened against outside interferences as shown in Fig.1.

The occurrence of partial discharges in electrical insulation is always associated with the emission of electromagnetic pulses. A typical PD pulse has a rise time of less than 1 ns and a pulse width of several ns, implying in frequency-domain a bandwidth of several hundreds of MHz. The electromagnetic emissions propagate in all directions from the PD source. Different materials impose different attenuation rates to the travelling waves. In general, the attenuation of the PD pulses is a function of frequency [2]. The higher frequency components will be attenuated rapidly when they travel along the cable. Therefore, detecting PD in the UHF band (300-3000 MHz), that has only a few known discrete interferences, also has the advantage of the distance selectivity of only several meters. This can be perfectly used for the diagnosis of the concentrated equipment such as transformers, GIS, machines

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and cable accessories. The distributed equipment, e.g. cables, can be effectively diagnosed in HF and VHF bands.

Fig. 1 demonstrates the principle of UHF diagnosis of the plug-in cable connectors. A portable metallic housing is clamped on the cable behind the connector and fulfills two functions: firstly, as a housing for field couplers (antennas) and secondly, as a grounded screen against the disturbances from outside.

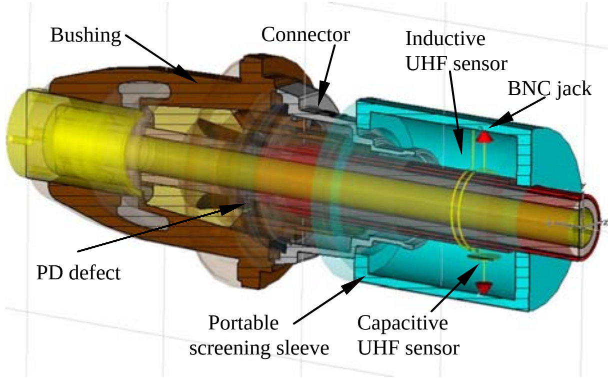

Fig. 1. Object and principle of the UHF PD diagnostics

The sensors are mounted inside the housing and terminated with BNC jacks. The capacitive sensor represents a copper disc with the diameter of 2.5 cm, placed about 2 cm above the cable sheath surface. The inductive sensor is a two-turn coil made from an insulated copper wire and winded around the cable. One end of the coil is grounded; the other end is connected via BNC jack to a measuring coaxial cable RG-214.

III. LABORATORY SET-UP

Fig. 2 presents an experimental arrangement built in a laboratory. It includes a single-phase XLPE insulated power cable (1) connected to the commercial 550 kV GIS via healthy connector on one side and terminated at the SF_6-filled test joint using the connector (2) with an artificial PD defect on the other side. An UHF PD detection circuit, shown also in Fig. 3, contains the portable screening sleeve (3) with capacitive and inductive sensors inside, coaxial cables, a 40 dB pre-amplifier (4) and a spectrum analyzer Anritsu MS7117A (100k-7.1GHz)

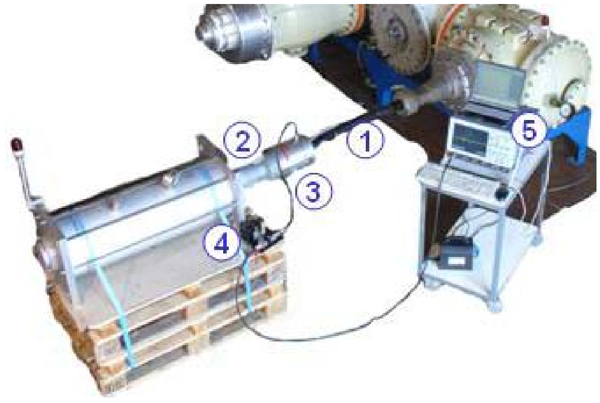

Fig. 2. Laboratory test setup: 1.single-phase cable 35/60 kV; 2.connector with an artificial fault; 3. screening housing with the UHF sensors; 4. Pre-amplifier 40 dB; 5.spectrum analyzer & Notebook

connected to a notebook (5). Power supply of the measurement circuit is realized via an insulating transformer to reduce interference coupling. An artificial PD defect was built into the termination to initiate a discharge at interfaces between 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 a stress cone. The intensity of PD is influenced by changing the penetration depth of the lath. The GIS is equipped with a coupling capacitor and the conventional IEC 60270 PD measurement system MPD540 from Mtronix, which is able to plot a color-coded PRPD pattern of a defect used as a reference for the UHF measurements.

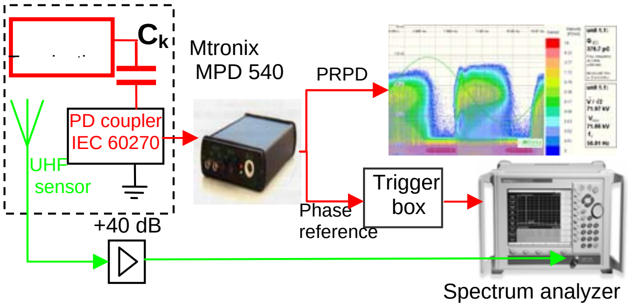

Fig. 3. Structural diagram of the measurement circuits

IV. WIDE/NARROW BAND MEASUREMENT TECHNIQUES

The main advantage of a spectrum analyzer (SA) over a digital oscilloscope, used to solve the same problem in [3], is its flexible frequency range. Thus, broad / narrow band and even zero span measurements, i.e. tuned on a single discrete frequency, are possible. This gives us an option to suppress external noises and disturbances by selecting a frequency range with a sufficient signal-to-noise ratio and lowest influence of disturbances [4]. Speaking of its disadvantages, it should be mentioned that, due to the measurement principle, a long time observation (up to several minutes) is needed when working with SA.

The frequency range of the SA used is 100 kHz-7.1 GHz. The spectrum is measured during several sweeps of the SA over a period of 3 min and is composed of the maximum amplitudes at each frequency, so called “hold max” mode. Other settings were set as following: RBW 3 MHz, VBW 300 kHz.

Fig.4 presents the results of the wideband testing in a range of 200-1000 MHz with capacitive and inductive couplers. Beside the background noise measurement (0 pC), two other spectra for the artificial defect’s intensity of approx. 50 pC and 250 pC in average over a period of 3 min are shown. Beside a few discrete peaks at 225, 522, 706 and 940 MHz, which stand for well known interferences: digital radio, DVB-T and GSM 900 respectively, the spectral curve level uplifting at rising PD intensities can be revealed. The working range of

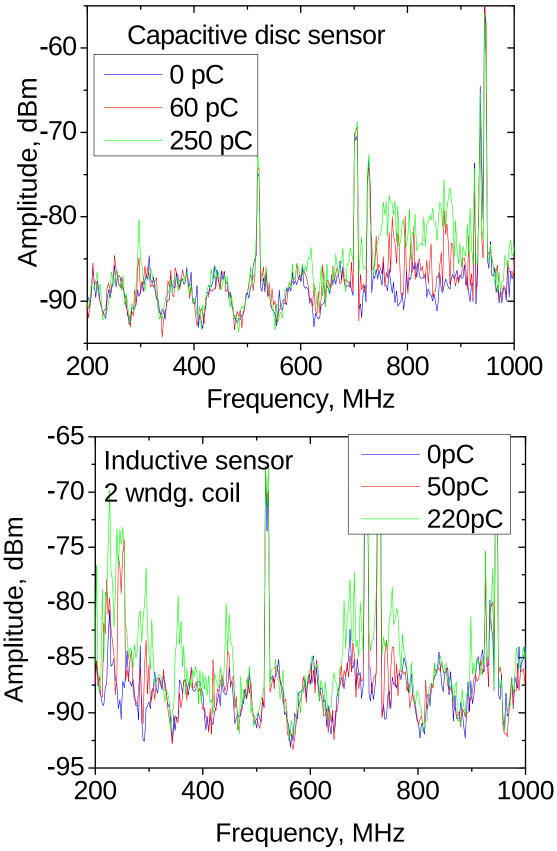

Fig. 4. Wideband spectra for the artificial PD defect of variable intensities and background noise picked up by capacitive (top) and inductive (bottom) couplers

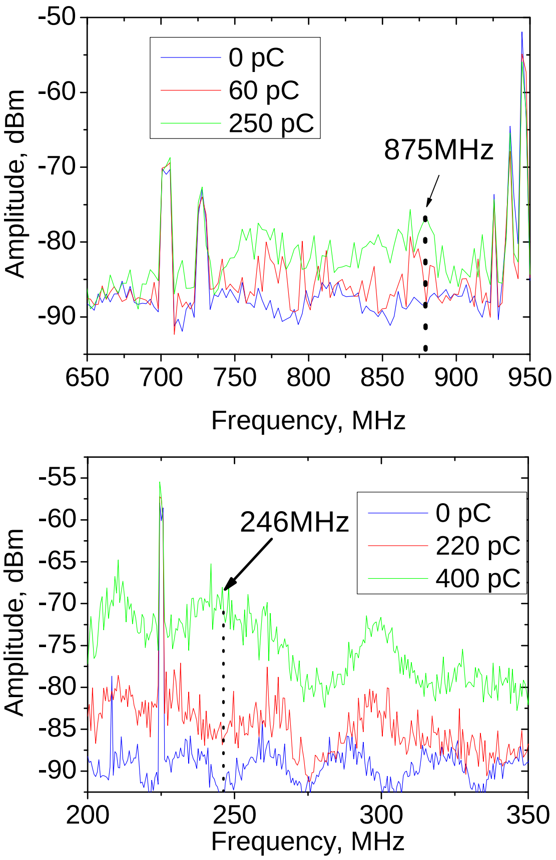

Fig. 5. Narrowband spectra for the artificial PD defect of variable intensities and background noise picked up by capacitive (top) and inductive (bottom) couplers

the capacitive and inductive sensors is clearly seen on these graphs.

The SA can be seen as a tunable narrow band bandpass filter and the center frequency of the tunable filter is swept across the desired frequency range [5]. Therefore, for the further narrowband measurements the frequency ranges, where PD spectra lies well above the spectrum of the background noise are selected. Those are 650-950 MHz for the capacitive and 200-350 MHz for the inductive ones as shown in Fig.5. The next step in finding a proper measuring frequency for the narrowband UHF PD measurement is the so called zero span measurement. For that purpose two discrete frequencies, at which the signal-to-noise ratio seems to be maximal, are marked in Fig.5, namely at 875 and 246 MHz.

V. ZERO SPAN MEASUREMENTS

In this case, the SA is tuned to a pre-selected measuring frequency (in our case 875 or 246 MHz), the measured span is set to the RBW, and the sweep time is set to 20 ms to obtain phase-resolved patterns related to the 50 Hz power cycle. To conduct such a measurement, a trigger signal from outside is needed in form of the repeatable TTL pulse. Thus, a trigger box (see Fig.3) was built to produce a TTL pulse repeating itself with a power frequency of 50 Hz and synchronized in phase with the AC test setup supply voltage. The zero span plots measured over 3 min are shown in Fig.6. In zero span mode the measured frequency band is determined by the resolution bandwidth (RBW) set to 3 MHz.

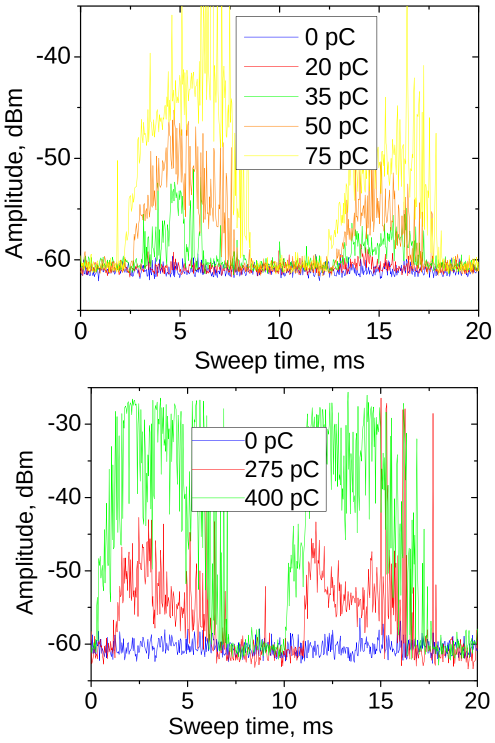

Fig. 6. Zero span plots for the capacitive (top) and inductive (bottom) sensors. Measured at 875 MHz and 246 MHz for various PD intensities respectively

Visual comparison of the zero span PD plots demonstrates a good phase correlation with classical PRPD patterns picked up in accordance with IEC 60270.

A. *Sensitivity issues and discussion*

To assess the sensitivity of the zero span method regarding the minimal detectable PD intensity, a series of comparative measurements was done on the laboratory setup with the defect of variable intensity. Peak values of the previously smoothed zero span PD plots, to avoid statistical fallouts, are shown in Fig.7. Maximal sensitivity of the zero span method comprises 5 pC for the inductive and 10 pC for the capacitive sensor. The saturation effect visible in case of capacitive sensor can be fixed by using a pre-amplifier with smaller gain, for instance 20dB. The inductive sensor reveals nearly linear behavior.

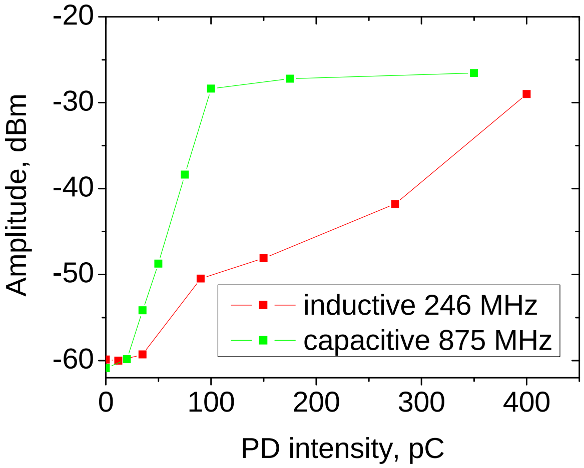

Fig. 7. Sensitivity lines at the zero span mode for the capacitive and inductive sensors

VI. CONCLUSIONS

The experiences in on-line wide/narrow band UHF PD detection in high voltage plug-in cable terminations under the laboratory conditions were discussed in the paper. Comparative study of capacitive and inductive sensors was conducted. As a result, used sensors are effective in the frequency range of 650-950 MHz for the capacitive and 200-350 MHz for the inductive ones respectively. Maximal sensitivity of the narrow band UHF PD method comprises 5 pC for inductive and 10 pC for capacitive sensor. Zero span UHF PD patterns give a good correlation with classical PRPD patterns measured according to IEC 60270.

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

VII. REFERENCES

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