Experiences with UHF PD detection in GIS using external capacitive sensors on windows and disk-insulators

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Abstract: Experimental investigations of mobile ultra high frequency (UHF) partial discharge (PD) sensors for external installation to a GIS are discussed. The sensitivity of couplers for fitting to disconnector inspection windows and to casting apertures at metallic disk insulators flanges has been tested and compared to conventional internal UHF sensors.
While the existing literature reports of many successful applications of external UHF sensors, there are restrictions and error sources related to this technique, which are treated in this paper.
The authors found that the sensitivity and the usable bandwidth are strongly dependent on the type of sensor and the kind and size of apertures in the GIS. Whereas small inspection windows did not prove to be a suitable coupling device, disk insulator delivered sufficient high signal amplitudes for PD detection in the GIS.
The experimental procedure for the sensitivity evaluation of external sensors was analyzed and some common problems related to the assessment of the sensor characteristic are explained.
The significance of parasitic signal coupling outside the GIS enclosure and the requirement of an effective electromagnetic sealing are demonstrated.

1 INTRODUCTION

UHF PD detection is a common on-site insulation diagnostic technique for GIS. This method has been developed during the eighties of the last century [1], [2] and was practically implemented during the last two decades. However, elder GIS are not equipped with the required UHF sensors. Conventional internal UHF PD sensors consist generally of an insulated plate electrode mounted inside the GIS, The plate electrode is connected to an HF connector by a more or less coaxial conductor arrangement.

For GIS not equipped with internal sensors, different types of couplers to capture HF signals at apertures of GIS enclosures have been designed in the past [3] - [5].

In order to assess the insulation condition of a 30 years old GIS of the power utility of the city of Zurich, ewz, different external coupling devices for on-line PD diagnosis have been designed and applied, together with commercial ones.

The criterion for the usability of the sensors is based on the sensitivity check of the CIGRE Task Force 15/33.03.05 recommendation [6]. Four different mobile mountable UHF PD sensors have been tested with respect to their suitability for PD detection. Among the commercial sensors, only the results of the most sensitive one are documented in this paper (Tab. 1).

2 EXAMINATION METHODS

In a first step, the sensors were investigated in the laboratory of ABB Switzerland in a GIS test chamber. These tests included:

1. Sensitivity check with a real PD source in a laboratory test setup
2. Measuring of the frequency characteristic in a double cone GIS chamber

Finally, the sensors were tested on site on a 30 years old GIS, selected for the insulation condition assessment. Signal transfer measurements between sensors as well as PD detection with the externally mounted UHF couplers (listed in Tab 1) have been performed.

Tab. 1: List of the tested mobile mountable UHF PD sensors for external application and of the internal reference sensor.

Sensor	Type	Origin
No. 1	Window type sensor	self-designed
No. 2	Insulator type sensor	self-designed
No. 3	Insulator type sensor	commercial
No. 4	Internal sensor	reference

3 LABORATORY MEASUREMENTS

3.1. Test set-up for sensitivity check with PD source

The sensitivity verification corresponding to the recommendation of CIGRE TF 15/33.03.05 [6] was accomplished with a real 5 pC PD source (needle electrode).

These tests were carried out in a GIS test arrangement according to Fig. 1 and Fig. 2.

Fig. 3 shows the two sensors designed by FKH: No. 1 for a disconnector inspection window and No. 2 for the casting aperture of a disk insulator. In order to prevent external signal coupling between the sensors during signal transfer measurements by means of a test generator, the sensors had to be electromagnetically sealed with self-adhesive copper tape.

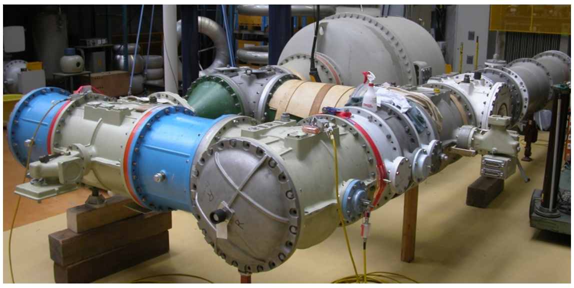

Fig. 1: GIS test chamber for sensitivity check with a real PD source (needle on the high voltage conductor)

Fig. 2 shows that in the used chamber, within a relatively short section, 5 possible locations for external UHF PD sensors exist. Similar to standard substation configurations, the sensor density of possible external sensor locations is significantly higher compared to standard internal UHF PD-Sensors.

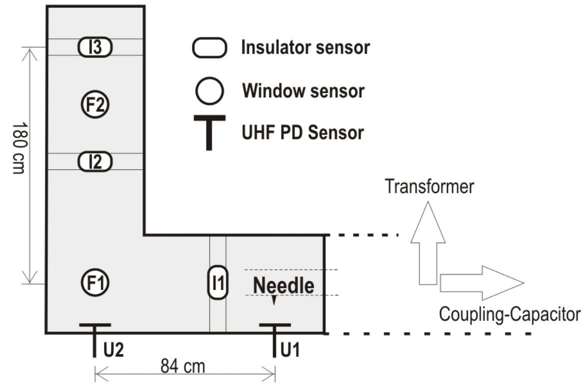

Fig. 2: Schema of GIS test chamber with sensor locations

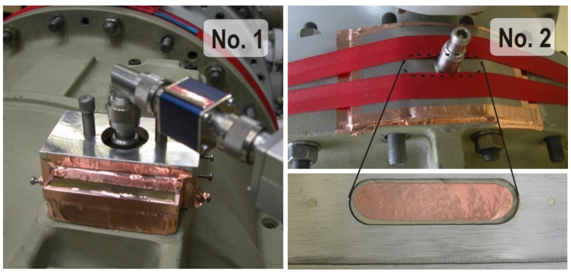

Fig. 3: External sensors, FKH design No. 1 and No. 2

For all measurements a spectrum analyser HP 8591E with tracking generator was used. The amplitude axis in the following signal spectra is scaled in dBm, where 0 dBm corresponds to 1 mW i.e. 224 mV on a load of 50 Ω. The lower curve in all spectra denotes the noise level without presence of a PD or a test signal. The upper curve shows the measured PD or test signal level.

3.2. Results of sensitivity check

Fig. 4 to Fig. 6 shows the spectrum of the 5 pC PD signal of the needle electrode at the internal sensor U1. The internal sensor shows the highest sensitivity followed by the commercial sensor No. 3 (Fig. 5). The inspection window sensors detects practically no PD signal (Fig. 6). Evidently, the window diameter of 40 mm and the position in the GIS enclosure affect the sensitivity in a unfavourable way.

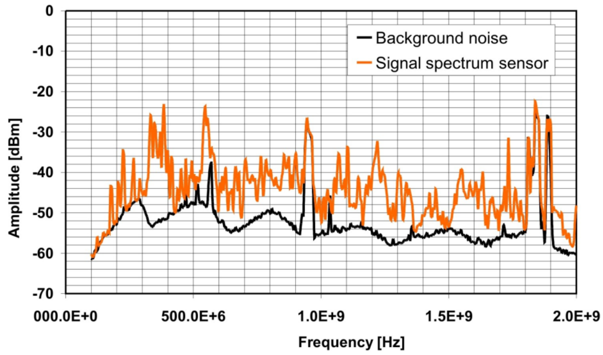

Fig. 4: Signal spectrum of a 5 pC PD source measured at sensor U1 (internal UHF PD sensor No. 4)

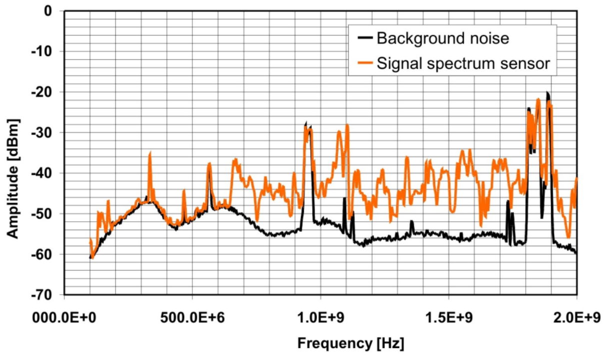

Fig. 5: Signal spectrum of a 5 pC PD source measured at sensor I1 (external insulator sensor No. 3)

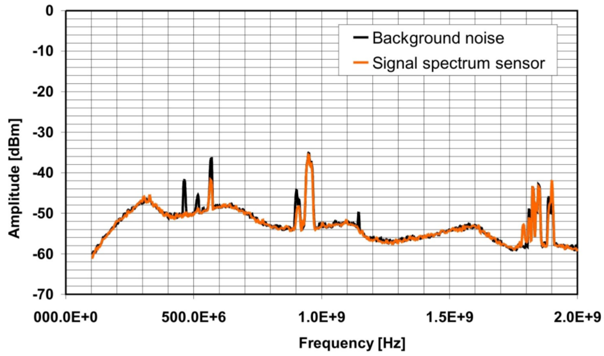

Fig. 6: Signal spectrum of a 5 pC PD source measured at sensor F1 (external window sensor No 1)

3.3. Measurements of the frequency response of the sensors

In order to characterize the frequency response of the investigated sensors, the transfer function was measured in a double cone test chamber according to Fig. 7 and Fig. 8.

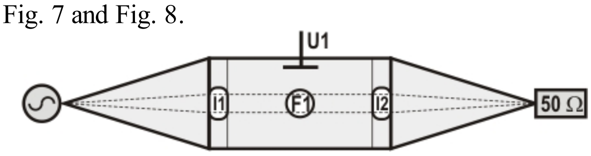

Fig. 7: Schematic diagram of double cone GIS test chamber

Fig. 8: Double cone GIS test chamber

In Fig. 9 the output spectrum of the internal sensor U1 for two configurations is compared: (1) the cone setup at an input power level of –60 dBm, and (2) the GIS test chamber at a PD signal level of 5 pC (see Fig. 4). It can be concluded that a signal power level of –60 dBm corresponds approximately to a PD-Level of 5 pC.

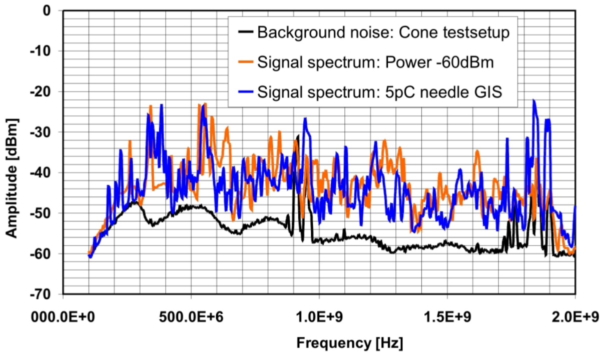

Fig. 9: Signal spectrum at -60 dBm input power measured at sensor U1 (conventional internal UHF PD sensor) compared with measured signal spectrum of a 5 pC PD source (Fig. 4).

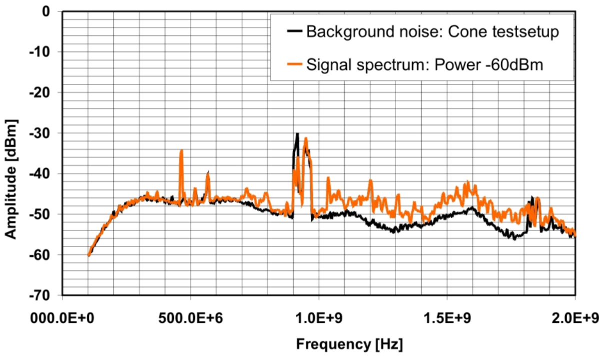

Fig. 10: Signal spectrum at -60 dBm input power at sensor I1 (external insulator sensor No. 2).

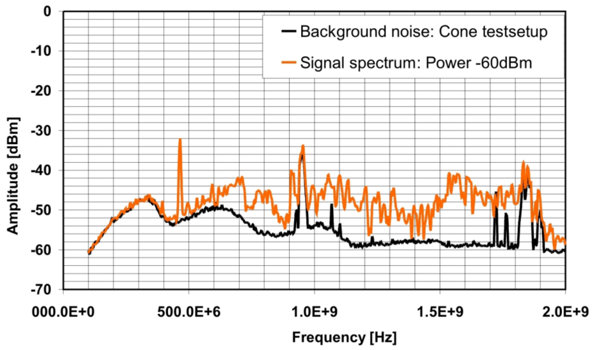

Fig. 11: Signal spectrum at -60 dBm input power at sensor I2 (external insulator sensor No 3).

The comparison of Fig. 10 and Fig. 11 shows clearly that the self designed coupler No. 2 has less sensitivity than the commercial sensor No. 3.

4 ON SITE MEASUREMENTS ON A GIS

4.1. Test configuration

The practical applicability of the investigated coupling devices was investigated at a 30 years old 150 kV GIS substation of the power utility of the town of Zurich (ewz).

Since the GIS was not equipped with internal PD sensors, the measurement of PD signals and the injection of test impulses had to be executed via external PD sensors. The positions of the three sensors A, B and C are shown in Fig. 12

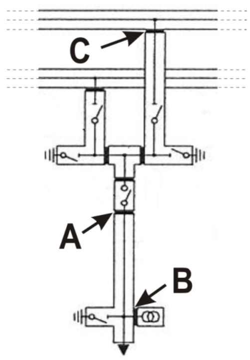

Fig. 12: Single phase diagram of investigated GIS section

Fig. 13: Positions of external sensors A and B

4.2. Test results

Due to the low sensitivity of the tested inspection window sensor No. 1, only results of the disk insulator sensors are presented. The used impulse generator had a maximum amplitude of 50 V with a rise time of 200 ps.

Fig. 14 to Fig. 16 show impulse spectra at the couplers of type No. 2 or No. 3, respectively. Repetitive voltage steps of 20 V or 50 V were injected to the adjacent coupler. In this way, the efficiency of the couplers and the attenuation between the sensors were determined.

Parasitic external coupling between the external sensors forced again to seal carefully the tested sensors with self-adhesive copper tape. The top curve in Fig. 16 shows the signal at location C, when neither the sensor at location A nor the other one at location C was electromagnetically sealed.

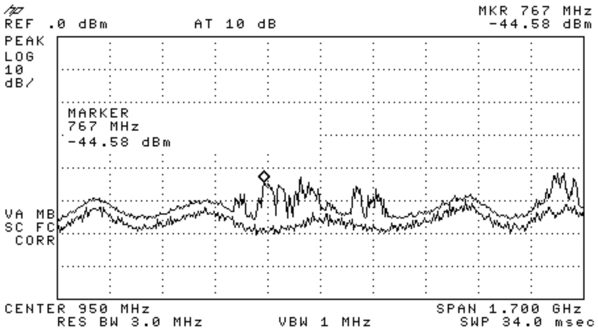

Fig. 14: Signal spectrum measured at location B with sensor No. 2; pulse injection of 50 V into sensor No. 3 at location A.

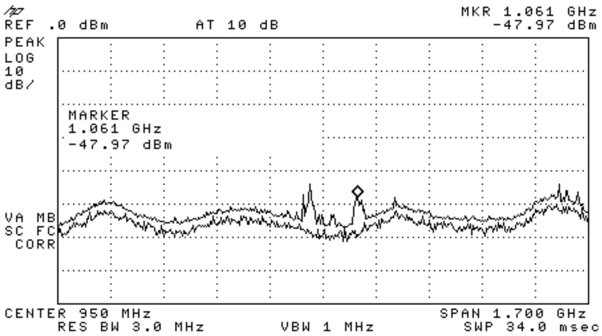

Fig. 15: Signal spectrum measured at location A with sensor No. 3; pulse injection of 20 V into sensor No. 2 at location B.

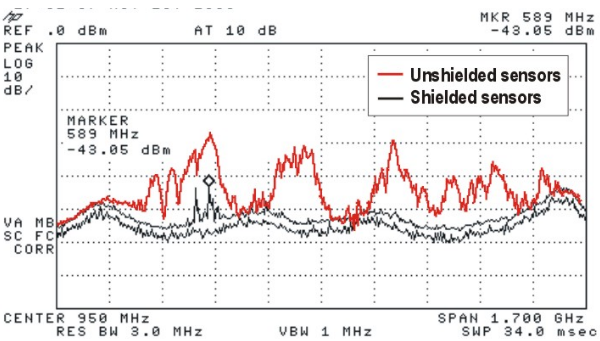

Fig. 16: Signal spectrum measured at location C with sensor No. 2; pulse injection of 50 V into sensor No. 2 at location A.

4.3. Discussion of on-site measurements at the GIS

The injection of an artificial PD pulse via an external sensor turned out to be very inefficient compared to conventional internal UHF sensors. The necessary pulse amplitudes for a specific response on a second external sensor were more than 10 times higher than with internal UHF sensors. Likewise, the transferred spectrum width was significantly reduced with external sensors. From a comparison of the output signal levels during on-site measurements and those obtained from the experiment with the real PD source (see Fig. 1), it can be concluded that the injected test impulse of 50 V corresponded to a PD level much lower than 5 pC.

5 CONCLUSIONS

The tests conducted in the laboratory and on-site with external UHF PD sensors for GIS lead to the following conclusions:

1. Sensors mounted on casting apertures of insulators showed a far higher sensitivity for PD signals than the sensors fitted to disconnector inspection windows, if the latter have small diameters (40 mm).
2. Standard internal sensors have been found to be generally more sensitive than external sensors in the frequency range below 700 MHz. In the range above 700 MHz optimized external sensors on insulator casting apertures can reach the sensitivity of internal UHF sensors.
3. Because of elevated signal attenuation in the higher frequency range (>700 MHz), the spatial range for PD detection with external sensors is limited to a few meters. Therefore, external sensors are not considered to be an adequate replacement for internal sensors in commissioning tests because numerous measuring locations (3…5 sensors per GIS feeder and phase) are necessary, resulting in high onsite test effort. However, external sensors may support the localization of a PD defect.
4. During an on-site sensitivity check at the GIS a reference impulse is injected to one sensor and received at another one. Because of the high attenuation for the signal through the GIS, the sensors have to be carefully screened to prevent external electromagnetic signal coupling.

6 ACKNOWLEDGMENT

This investigation has been financed by the electric power utility of the city of Zurich (ewz). The authors thank for the support and the permission to publish the results.

7 REFERENCES

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