# PD-Source Recognition in Generator Bars using a High-Voltage Coaxial-Type High-Pass Filter

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***Abstract*— A high-voltage coaxial-type high-pass filter is reconstructed and used to detect different impulse forms in generator bars. The test results of an old generator bar shows simultaneous occurrence of different discharge impulse forms. In this paper, the error of the band-pass filter used for PD measurement in delaminated aged bars is presented. It is essential to measure both discharge magnitude and discharge pulse forms to minimize the error.**

***Index Terms*— *partial discharge, impulse form, generator bar, delamination, high-pass filter***

## I. Introduction

Partial discharges induce measurable parameters by the inherent charge displacement. The internal discharge current has a shape similar to a narrow impulse, with a very short rise time and a longer tail. In many cases, PD pulse shapes suggest composite pulses possibly indicative of multiple discharge events within the void volume [1, 2]. Discharge pulses in atmospheric air provide current duration of about ten nanoseconds in general. Also both ringing and non-ringing pulses can be detected on the same test object. It has been observed that discharges in short gaps occurring under certain conditions may exhibit a pulseless or pseudo glow character [3]. By ignition the first PD in a flat cavity with plane-parallel geometry e.g. in delaminated generator bars, the total surface of cavity my not be discharged. A start-electron will be generated in another point of the cavity due to UV-radiation and photoemission of the first PD and parallel partial discharges can be activated simultaneously in different points of the cavity. These parallel partial discharges are in narrow intervals and can be detected separately with ultra wide bandwidth filters [2].

Test objects with inherent inductances or internal resonant circuit such as generator windings, will always cause oscillatory PD currents. A discharge signal from a discharge site will undergo attenuation and reflection on its passage to the measurement terminals [4]. In a PD-measuring system, the test configuration, the coupling capacitor, the coupling impedance and the coaxial cable to the recording-instrument are integral parts of the whole PD-measuring circuit that affect the measured PD-pulse time-constants.

The characteristics of the filters used in PD measurement are such that the current pulse signals are integrated to yield a pulse magnitude which is proportional to the charge in the PD pulse. Discharge detection problems arise from the fact that conventional PD pulse detectors do not respond exactly to all types of PD forms. For low frequency PD detectors, the filters have a bandwidth ranging from 30 kHz to 500 kHz [5]. The width of the current impulse generated by PD activity has an influence on the accuracy of PD measurement [6]. To characterize nanosecond pulses, a measurement bandwidth of ten MHz is required [7].

PD measuring systems which use an ultra wide bandwidth have been technically achieved [1]. The main advantage of using a wideband system is that the true shape of the PD current pulses can be detected [8].

Evaluation of the measured PD-signals in high voltage generator bars is complicated by the occurrence of multiple internal discharges in spherical/flat cavities inside the groundwall insulation, external discharges in the slots and surface discharges in overhang region, due to the restricted bandwidth of commercial PD-measuring systems.

Common measuring quantity such as peak value of detected PD pulse by semi integration can indicate false results because of multiple PD occurrences in a flat void inside of generator bars [8].

PD-activity of two old bars (bar "A" and "B") measured by a 50-800 kHz band-width system was given in [9]. They show that partial discharge activity of the bar B is higher than the Bar A. Obviously, the power factor tip-up tests on the bars shows reverse results (see Tables 1 and 2). So two subjects must be more studied:

- Probability of false indication of band-pass PD measuring device
- Containing the pulseless discharges in Bar A that are not considered

The first subject is examined here. With the help of a constructed coaxial-type high-pass filter, different PD sources in the generator bars are recognized. Discriminating of internal discharges in flat voids with their pulse form is examined too.

## II. Experimental Setup

The high voltage high-pass coaxial type filter (Fig. 1) has a surge impedance of 150 Ω and an output impedance of 50 Ω. The filter is reconstructed from Shwarz [10]. The output of the filter is connected to a 100 MHz PC-based oscilloscope through a 50 Ω coaxial cable. The filter has 30 MHz band-width; Fig. 2 shows band-pass of the filter with the test specimen.

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TABLE 1
POWER FACTOR VARIATION OF THE BARS

| | Tanδ (at phase voltage) | Tanδ (at nominal voltage) | Variation |
|---|---|---|---|
| Bar "A" | 0.040 | 0.085 | 112% |
| Bar "B" | 0.011 | 0.014 | 25% |

TABLE 2
TOTAL INTEGRATED CHARGE VARIATION OF THE BARS

| | Total integrated charge (at phase voltage) | Total integrated charge (at nominal voltage) | Variation |
|---|---|---|---|
| Bar "A" | 1400 nC | 8000 nC | 470% |
| Bar "B" | 2000 nC | 22100 nC | 1000% |

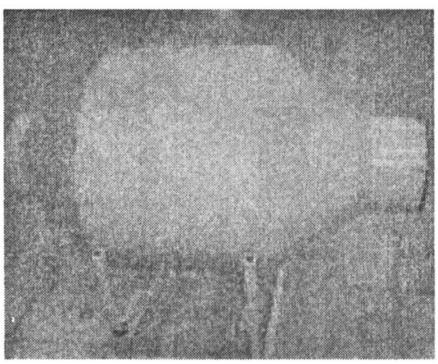

Figure 1. Photo of the high-voltage coaxial-type high-pass filter

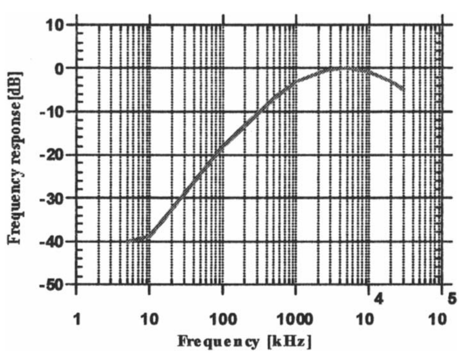


Figure 2. Combined frequency response of the filter and generator bar

## III. TESTS

### *A. Capability Tests of the Filter*

Capability of the filter is examined by detecting partial discharge impulse between two parallel insulated plates. Fig. 3 and 4 show two discharge signals detected in 1.0 mm and 0.2 mm air gap between the plates respectively. Both signals are indicative of the occurrence of multiple PD impulses inside the air gap in narrow intervals.

Internal discharge and external discharges in the slot and in the overhang region of a one meter test bar are detected using the high-voltage filter. Semi-conducting layer and field grading layer are manually damaged locally to produce external partial discharges. Fig. 5 shows the experimental setup and Fig. 6, 7 and 8 show detected pulses respectively. The PD arts can be recognized by signal processing in time and frequency domain [11].

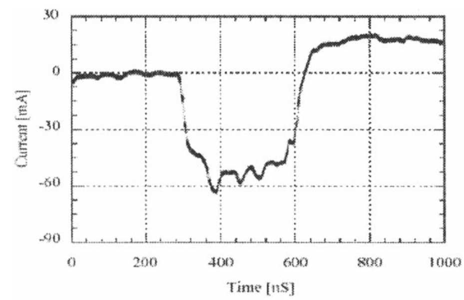


Figure 3. Discharge impulse between two parallel insulated plates, (d=1mm), detected by the high-voltage coaxial-type high-pass filter

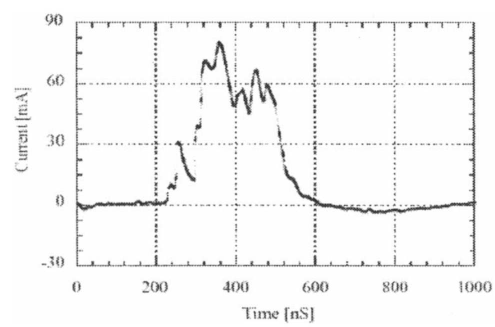


Figure 4. Discharge impulse between two parallel insulated plates, (d=0.2 mm), detected by the high-voltage coaxial-type high-pass filter

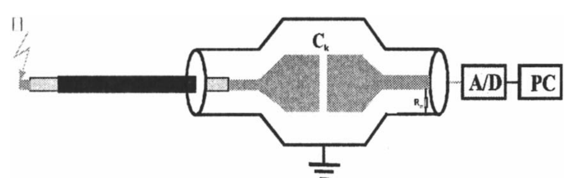


Figure 5. Partial discharge test on a generator bar using the high voltage, coaxial-type high-pass filter

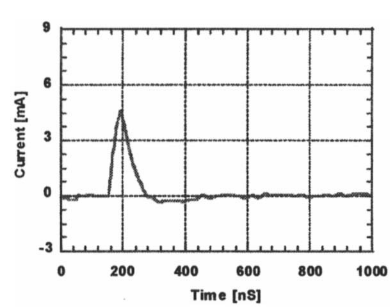


Figure 6. Detected internal PD of the test generator bar

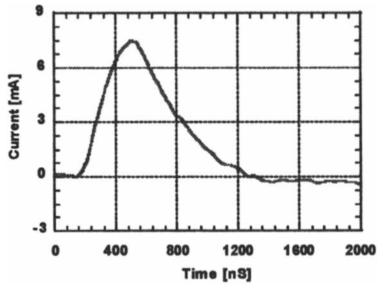


Figure 7. Detected surface discharge on damaged semi-conducting layer

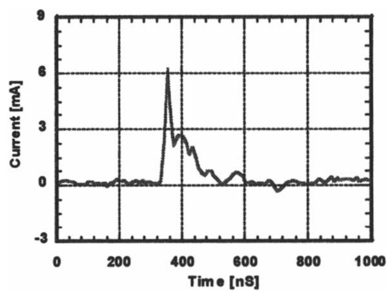


Figure 8. Detected surface discharge on damaged field grading layer

### *B. Main Tests*

The main tests are carried out on an old generator stator bar "A" with mica folium, polyester resin insulation and 13.8 kV nominal voltage [9]. The bar has a 220 cm slot section and 60 cm ends. It was complete with conducting and semi-conducting layers.

The old generator bar is conducted to the input-terminal of the high voltage filter and its PD signals are detected at room temperature and nominal voltage. Fig. 9 shows a 2nC calibrating impulse detected at the terminal-end of the bar. PD signals shown in Fig. 10, 11, 12, 13and 14 are selected as PD impulse forms that are detected in the tests. The results show that less than 50% of PD pulses of the old bar have a single impulse form. This can be due to delamination of the groundwall insulation of the old bar and production of flat cavities inside the mica-folium insulation.

Computer modeling in "SPICE" shows that 5 to 10 PD pulses with narrow intervals ignited in a flat cavity can perform such form of pulses shown in Fig.11 and 12. Computer modeling shows that by using a conventional PD measuring system, in this situation, the apparent charge is often measured 20% more than the highest PD event in the cavity and the total integrated charge is measured lower than 50% of the total integrated charges of the cavity. It appears the band-pass measuring device and calibrating procedure loose their accuracy because of the occurrence of long-tail impulses with different time constants.

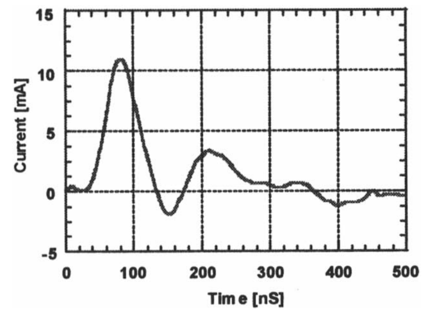


Figure 9. Detected 2nC calibrating impulse

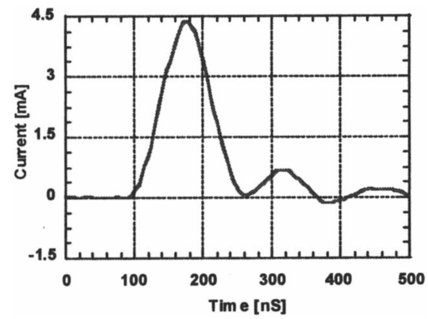


Figure 10. Detected single impulse

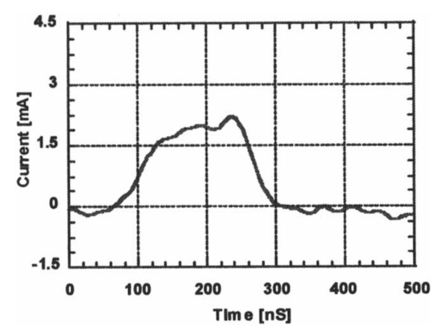


Figure 11. Detected multiple impulse (semi rectangular form)

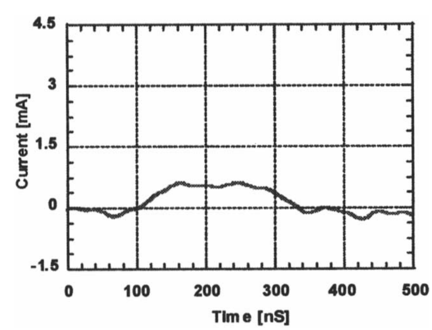


Figure 12. Detected multiple impulse (flat form)

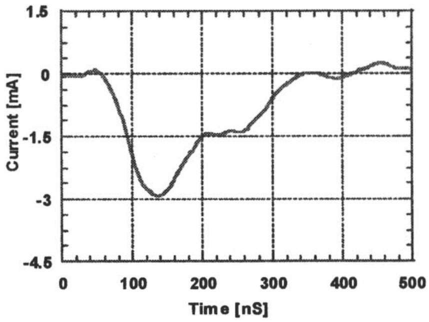


Figure 13. Detected single impulse (Townsend form)

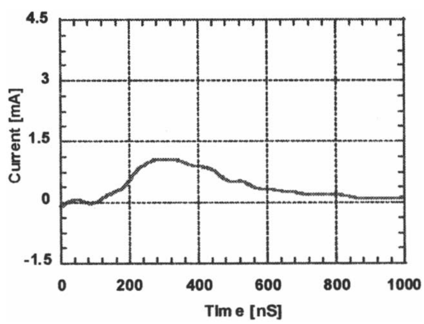


Figure 14. Detected impulse (long tail)

## IV. Conclusions

A high-voltage coaxial-type high-pass filter with 30 MHz bandwidth was examined for PD pulse detection in generator bars. The results of the tests on an old generator bar show that because of delamination of the insulation and production of flat cavities inside the groundwall insulation, various PD pulses can be observed simultaneously. The pulses are mostly not in single narrow impulse form. Semi rectangular form pulses that are due to combination of several single pulses, Townsend form pulses, flat form pulses and long tail pulses can not be correctly detected by conventional PD measuring systems. Thus using calibrator with adjustable width current impulse can not be useful too. Under these conditions PD measurement can be conducted to uncertainty of detected apparent charge and calculated total integrated charge of the bar. It is essential to measure both discharge magnitude and discharge pulse form to minimize the error. Based on this understanding of the PD sources, criteria can be found, which allow determining the number of different PD signals in a time-window and therefore enabling the quantification of the damage in an aged generator bar.

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