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Influence of the pulse voltage injection configuration on the electromagnetic distortion in space charge measurements using the PEA method

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***Abstract*—The Pulsed Electroacoustic Method is one of the most common methods for space charge measurements in solid dielectrics. This method involves applying a voltage pulse across the dielectric under test, which modifies the electrostatic force balance across the dielectric, creating an acoustic signal that can be measured externally. This work analyzes the influence of the pulsed voltage circuit connection location at the PEA test towards the generated distortion due to the electromagnetic interaction between the pulsed voltage and the acoustic sensor by means of experimental tests. From the tests, it can be observed that the connection locations of the pulsed voltage circuit directly connected to the test cell have a significant influence on the distortion magnitude. In practice, this means that the generated distortion can be significantly diminished by modifying the physical location of the connection to the PEA test cell of the pulsed voltage injection electrodes. The results of this paper could serve as a guideline for the construction of PEA measurement setups to minimize the signal distortion caused by the pulsed voltage, which can also reflect in simpler post-processing.**

***Keywords*—space charges, pulse electro-acoustic method (PEA), electromagnetic compatibility (EMC), high voltage cables, piezo-electric sensor**

I. Introduction

Space charge measurements in High Voltage Direct Current (HVDC) cables have become more relevant during the last years due to the increased use of polymers as a dielectric material. Space charges trapped in solid dielectrics distort the overall electric field and may lead to local overstresses resulting in accelerated aging and, in the worst cases, even breakdown [1]–[3].

Nowadays, acoustic and thermal methods are the most common non-destructive methods for space charge measurements in HVDC cables [4], [5]. Much research has been done to improve these measurement methods, especially for flat samples and mini cables. Nevertheless, successful space charge measurements in full-size HVDC cables have been performed since the 1990s [6], [7].

The objective of this work is to analyze construction aspects for the pulsed electro-acoustic method in full-size HVDC cable, specifically the influence of the physical location of the pulsed voltage connection at the PEA test cell. This work shows that the electrical location of the voltage pulse connection impacts the current distributions across the test cell during the pulse injection, inducing a disturbance in the sensor-amplifier circuit. This disturbance may superimpose with the relevant PEA signal, potentially creating errors during post-processing and analysis.

The influence of the pulse connection location is analyzed by means of experimental tests in which PEA measurements with three different pulsed voltage injection positions are compared.

II. Experimental setup

The experimental test setup is briefly described in this section. A more detailed description of the setup can be found in [8].

A. PEA test cell

The PEA test cell used for the experiments uses a flat electrode configuration to facilitate a uniform contact with the HVDC cable. The electrode consists of a 120 mm thickness aluminum to avoid overlapping of the signal due to reflections, considering the dimensions of the HVDC cable sample [9]. The minimum required aluminium thickness has been calculated according to the following equation.

$$d_{Al} > d_d \frac{v_{Al}}{2v_d} \tag{1}$$

Where d_d and d_{Al} are the thicknesses of the sample dielectric and the aluminum electrode, respectively. Meanwhile, v_d and v_{Al} represent the average acoustic propagation velocities of the dielectric sample material and the aluminium electrode, respectively.

The acoustic sensor consists of a 52 µm thick polyvinylidene fluoride (PVDF) piezo film backed with 20 mm thick of nonpolarized PVDF. The piezo film is connected to a 30 dB charge amplifier with 1.6 kΩ input resistance, in series with two more 20 dB amplifier stages. Then, the amplified signal reaches a 40 MHz bandwidth oscilloscope. The amplifiers and oscilloscope are all battery-powered without connection to ground. Fig. 1 shows a representation of the PEA test cell.

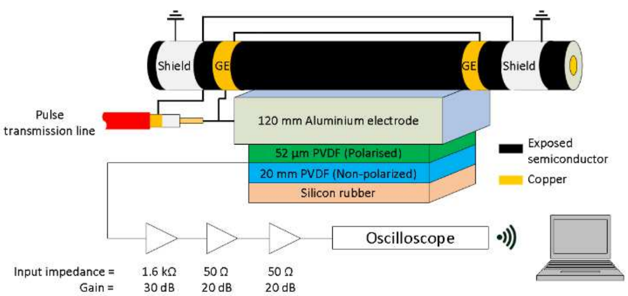

Fig. 1. Representation of the PEA test cell.

B. HVDC cable under test.

The sample is a 320 kV HVDC cable with cross-linked polyethylene (XLPE) as dielectric material. For the experiments, the outer semiconductor was exposed at the middle of the cable length, which is in contact with the electrode of the test cell. The semiconductor was kept continuous for the whole length of the cable. Guard electrodes (GE) were used at the HVDC cable at each side of the PEA test setup, as shown in Fig 1.

TABLE I. HVDC CABLE PROPERTIES

Property	Value
Inner conductor (diameter)	62.3 mm
Inner semi-conductive layer thickness	1.9 mm
Insulation thickness (XLPE)	21.5 mm
Outer semi-conductive layer thickness	1.5 mm
Exposed semiconductor length	1.5 m
Total cable length	9 m
Cable weight	34.1 kg/m

The HVDC cable has been previously subjected to tests non-related to this work, in which HVDC has been applied. Due to this, the cable has pre-existing space charges. Nevertheless, the existence of space charges does not affect the results of this paper.

C. Applied voltage pulse

The voltage pulse is generated using a fast solid state switch which generates a 5.5 kV pulse of approximately 300 ns. The pulse travels along a 100 meters coaxial transmission line of 50 Ω characteristic impedance, which reaches the PEA test cell in a non-matched connection. Due to the length of the transmission line and the duration of the pulse, the voltage pulse generator is decoupled from the PEA test cell. Because of the impedance mismatch, the pulse is reflected, resulting in an enhanced applied voltage pulse at the test cell [10]. The pulse generator is properly terminated to avoid multiple reflections.

In Fig. 2, the measured voltage at the voltage divider of the pulse generator can be observed. The initial peak belongs to the outgoing pulse of the generator, and the reflected voltage waveform from the test cell arrives at 1 µs. Because the pulsed voltage at the test cell is the overlapping of the incident and reflected waves, it is possible to estimate the applied pulsed voltage by adding these two pulses.

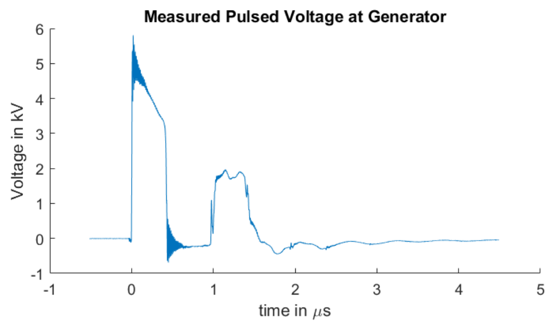

Fig. 2. The measured voltage at the voltage pulse generator. The signal from 0 to 0.3 µs belongs to the outgoing pulse; the signal after 0.8 µs is the reflected voltage at the HVDC connection

III. TEST EXPERIMENTS

The objective of the test experiments is to observe the impact of the pulsed voltage on the piezo-sensor distortion resulting from the current distribution across the PEA test cell during the pulse application. For this purpose, a set of three test arrangements were performed to demonstrate the relevance in the selection of the pulsed voltage connection location at the PEA test cell for the generated piezo-sensor distortion. Fig. 3 illustrates the selected locations for comparison used for Cases A, B and C. In these cases, there is a dielectric table between the metallic table and the PEA test cell to decrease the parasitic capacitance towards the ground.

- Case A: Pulse injection between the base of the PEA test cell and the HVDC cable shield. The test cell is ungrounded. The HVDC cable shield is grounded.
- Case B: Pulse injection between the lateral part of the PEA test, close to the upper surface of the aluminum electrode, and the HVDC cable shield. The test cell is ungrounded. The HVDC cable shield is grounded.
- Case C: Pulse injection between the clamping screws of the HVDC cable to the test cell and the HVDC cable shield. The test cell is ungrounded. The HVDC cable shield is grounded.

For the tests, a voltage of 200 kV DC was applied to the HVDC cable. Each of the measurements had a duration of approximately 30 seconds consisting of 100 averaged signals.

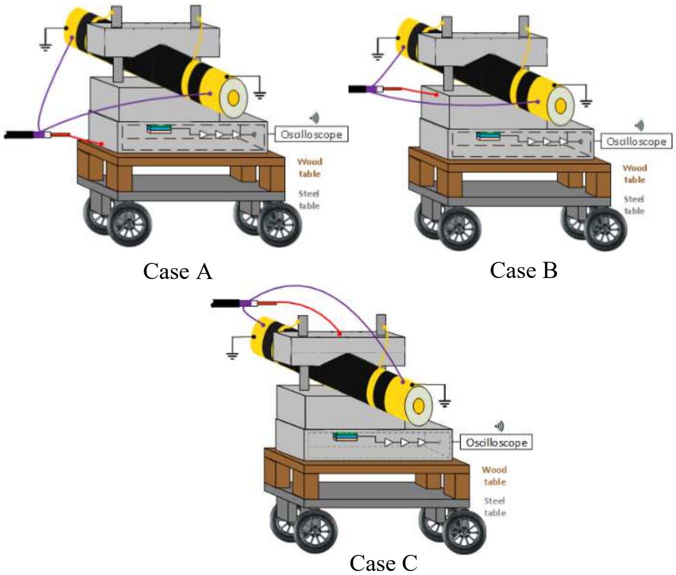

Fig. 3. Test setup 3D representation of the pulsed voltage connection locations. Each of these cases has a different current distribution across the PEA test cell with a different impact on the piezo amplifier interference. The connection between the test cell and the guard electrode is made through the yellow cables at the mechanical pressure screws.

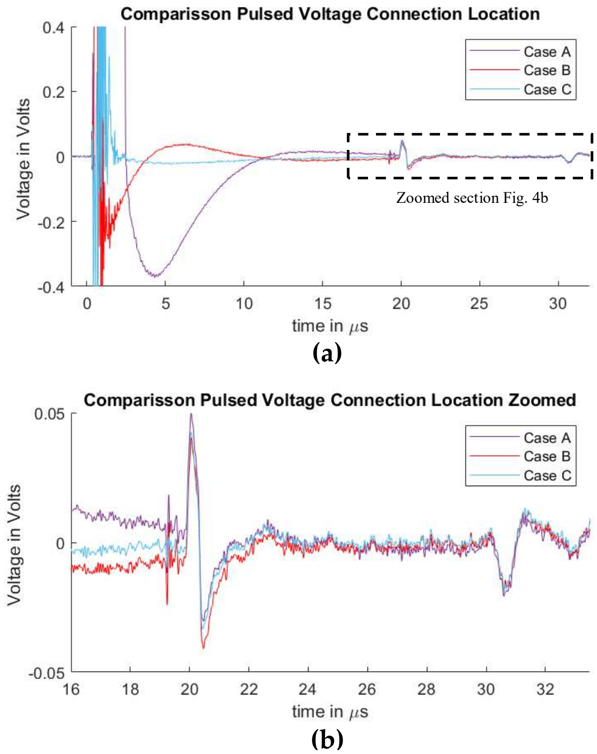

Fig. 4. Comparison of disturbances Cases A, B and C. (a) Full measured signal ranging from the instant of the pulsed voltage application up to 32 µs. (b) Zoom to the time instant of the acoustic signal arrival belonging to the acoustic measurements.

IV. Results and discussion

In Fig. 4 can be observed the comparison of the different measured signals between the different Cases. It should be noted that the disturbance at the beginning of the signals (less than 3 µs) has a peak value magnitude bigger than 1 volt, meaning that the amplifier got saturated and that the complete waveform cannot be observed. This disturbance is due to the interaction of the pulsed voltage with the piezo-amplifier. For this reason, the vertical scale of the graphs was adjusted, so the signals after 3 µs are better visible. The main objective of this work is to compare how the disturbance reaches and overlaps with the acoustic signal belonging to the space charges region. For this purpose, the focus is on the 19 µs after the acoustic time delay region of the aluminium electrode.

The shown measured signals have not gone through any post-processing to either compensate the piezo-amplifier response, geometric divergence or acoustic attenuation losses; meaning that the signal does not represent the actual charge distribution in the sample.

From Fig. 4, it can be observed how the pulsed voltage injection location has a different impact on the disturbance of the signal depending on the pulse current path across the PEA test cell. When the pulse injection is through the base of the PEA test cell (Case A), the pulse current path is closer to the amplifier, and this creates a higher electromagnetic interference in comparison to Case B and Case C. Between Cases B and C, the difference is not as remarkable. Nevertheless, in Fig. 4b can be observed that at the arrival time of the acoustic wave from the HVDC cable (19 µs), the signal from Case B is still more affected by the disturbance than Case C, adding error to the measurement.

V. Conclusions

The results of this work by means of experimental testing show the effect of the pulse injection connection location at the PEA test cell in relation to the electromagnetic distortion of the piezo acoustic sensor and the pulsed voltage interaction.

The use of a pulsed voltage in the PEA method produces an electromagnetic transient across the PEA test cell, interfering with the piezo-sensor and overlapping with the desired acoustic signal. The distortion resulting from the pulsed voltage can be substantially diminished by modifying the current distribution of the pulsed voltage across the PEA test cell in relation to the piezo amplifier position.

It must be noted that the measured disturbance is dependent on the specific piezo-amplifier circuit configuration, which differs between different PEA test cell designs. Nevertheless, the measured disturbance is related to the magnitude of the interference originated by the applied voltage pulse. This paper demonstrates the influence of the connection configuration of the applied voltage pulse and the resulting magnitude of the disturbance in the piezo-amp circuit. Therefore, it is advisable that for a given setup, the optimal location of the electrodes of the voltage pulse injection connection is found. In our particular setup, the minimum distortion was achieved when the electrodes were placed at the furthest possible distance from the piezo-electric sensor.

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