Development of a new PEA Cell for model cables

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Abstract- **In this work, a prototype of a new PEA cell configuration has been built and its principle of operation investigated and described. The reasons that led the authors to this work are due to the fact that the traditional cell still presents some issues. In particular, it known that that for cable specimens the reflection phenomenon and the signal attenuation are the main responsible factors that affecting the main output signal. Concerning the acoustic wave attenuation phenomenon, it was found that the signal magnitude can increase by replacing the metallic ground electrode with a polymeric acoustic coupler and the PVDF absorber with a metallic block. Based on this, after a description of the classic and the new PEA cell structure, in the present paper the acoustic wave behavior in the sensor/absorber interface has been simulated by means of a previously developed model. Simulation results show that in the new PEA cell the signal sensed by piezoelectric sensor is doubled in comparison with that detected in the traditional configuration. However, in the first experimental test carried out with the built PEA cell prototype in a model cable specimen it has been observed that the magnitude of the space charge profile needs to be further improved.**

Keyword: HVDC, Full-size cables, New PEA, PEA, Space charge.

I. INTRODUCTION

In the last years, due to the ever-increasing use of High Voltage Direct Current (HVDC) links, the space charge accumulation phenomenon has been widely considered [1]. The presence of charges in the insulating material constituting the DC cables generates an additional electric field which distorts the nominal one with the consequence of promoting the dielectric aging [1-4].

To measure the accumulated space charge different measurement techniques were developed. In particular, the Pulsed Electro-Acoustic (PEA) method has been the most successful [5-6].

Recently, a recommendation named "IEEE Recommended Practice for Space Charge Measurements on High-Voltage Direct-Current Extruded Cables for Rated Voltages up to 550 kV" was issued [7]. It proposes to introduce the space charge detection by means of the PEA or the Thermal Step Method (TSM) in full-size cables before and after routine tests. Both measurement techniques are well described in [8], where a protocol to be followed for the charge detection in full-size cables is reported.

For the reasons above, cables manufactory industries have shown strong interest in the research activity related to the space charge accumulation phenomenon and its measurement by means of the PEA method. However, despite the applications of the PEA technique since the 90s [9], it still has some critical issues. In particular for measurements on full-size cables, where the dielectrics thickness is high, the reflection and attenuation of acoustic waves represent the main disturbance phenomena. With the aim to solve the problem related to the reflection phenomenon, different studies were made [10-12].

In [13] the authors developed able to simulate the behavior of the acoustic waves travelling within the PEA cell. To avoid multiple reflections in main output signal it was found that particular attention should be paid in the PEA cell components materials and thickness, as well as in the features of the specimen under test.

Concerning the issue related to the acoustic wave attenuation phenomenon, which is more significant for PEA tests on full-size cable, or on flat specimens with high thickness, a solution has been proposed by Zahra et al in [14-16]. In particular, they have modified the material types employed in some components of the PEA cell in order to change the acoustic impedances of it and increase the signal detected by the piezoelectric sensor. In the classic PEA cell, the ground electrode is made of aluminium, while in the new configuration it is replaced by a block of XLPS material. The latter, with features similar to the cable's insulation shows an acoustic impedance close to the insulation itself and therefore in the cable/XLPS interface the transmitted part of the incident wave is greater in comparison of that transmitted in the classic cable/aluminium interface. Another change has been made in the sensor/absorber interface. In the classic PEA cell version, the absorber, with the main task of absorbing the waves that pass through the sensor, is made of the same sensor material. Therefore, considering that the sensor and the absorber have the same acoustic impedance, the signal in their interface is totally transmitted. In the new configuration, instead, the classic material used for the absorber has been changed in a metallic block. This last component shows a higher acoustic impedance compared to the sensor material with a consequence that the signal travelling from the sensor to the absorber is partially reflected. Thanks to this wave behaviour the pressure signal at the piezoelectric sensor is now given by the sum of the incident wave and its reflection, with a result that the total pressure at the sensor is almost doubled in comparison with the incident one [14].

II. THE CLASSIC PEA CELL FOR CABLE SPECIMENS

The measurement setup for the space charge detection in cable specimens is depicted in Fig. 1. The model cable under test is stressed by a DC voltage provided by a High Voltage generator, while the accumulated charges are detected by means of a pulse voltage applied through two electrodes placed near the PEA cell. In our laboratory, pulses with width of 700 ns are generated at a frequency of 110 Hz, the pulse train acts in the accumulated space charge causing them to vibrate. From the charge vibration the resulting pressure waves are travelling within the PEA cell where a piezoelectric sensor is placed. Finally, the voltage signal generated by the piezoelectric sensor, after its amplification, is send to the oscilloscope to be visualized [6].

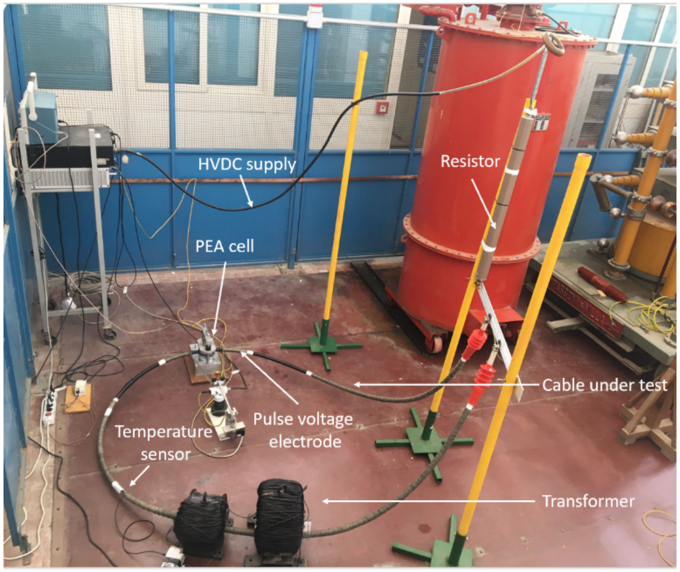

Fig. 1. Space charge measurement setup for model cable.

The classic PEA cell for cable specimens is shows in Fig. 2. The main components are the ground electrode which is made of aluminium material, the PolyVinyliDene Fluoride (PVDF) piezoelectric sensor and the absorber. The latter, to avoid acoustic wave reflections, is made of the same material of the piezoelectric sensors and it is used to absorb the waves passing through the sensor. However, the sensor and the absorber are not visible in the photo because they are just below with the ground electrode, inside the shield box.

Fig. 2. The commercial Techimp PEA cell for cable specimens.

In a previous work [17], the described measurement setup and the classic PEA cell were used to measure the accumulated charge in a model cable made of XLPE insulating material with thickness 5 mm. By stressing the cable with 70 kV/mm and by means of a pulse voltage with 5 kV, the obtained charge distributions are reported in Fig. 3.

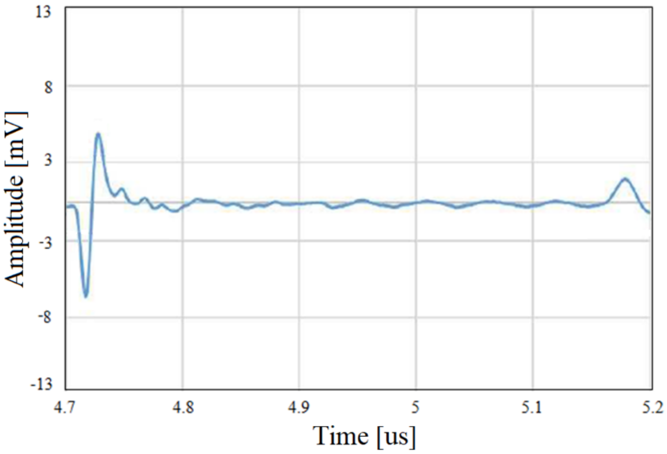

Fig. 3. Charge distribution acquired with the classic PEA cell.

As can be observed in the pattern above, the charge peaks are well visible and therefore no particular issues have been encountered in the measuring. However, this is true for model cables in which the thickness of the insulating layer is typically 5 mm. When the cable section increases, i.e. for full-size cables, difficulties in the charge detection may be encountered.

In fact, in an experimental test carried out in a full-size cable by using a PEA cell (that in Fig. 2) having the same structural configuration of that used for the model cables, the obtained charge distribution visualized in the oscilloscope results not easily interpretable, as shown in Fig. 4 [18].

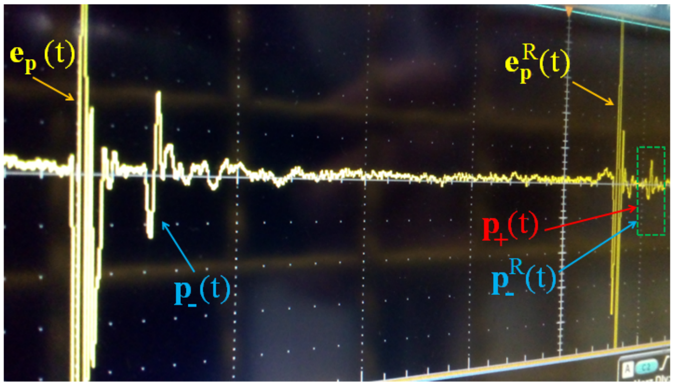

Fig. 4. Space charge profile observed in the oscilloscope during a test in a full-size cable.

In the pattern above, $e_p(t)$ is the applied pulse voltage and $e_p^R(t)$ its reflection, $p_+(t)$ is the positive peak related to the charge deposited in the core/dielectric interface, while $p_-(t)$ and $p_-^R(t)$ are the negative peak due to the charge in the dielectric/outer-semicon interface and its reflection, respectively.

In this case, despite the applied DC stress was 350 kV and the pulse voltage magnitude equal to 8 kV, the $p_+(t)$ peak results very poor. Moreover, a signal reflection is present in the middle of the main PEA cell output signal. In particular, the positive peak $p_+(t)$ is anticipated by the pulse voltage reflection $e_p^R(t)$ and it is also overlapped by the reflection $p_-^R(t)$. The latter issues it was demonstrated that can be solved by increasing the ground electrode thickness [18]. However, this last solution is only useful for translating the wave reflection out of the main signal, but would make the second peak signal even weaker because it is subject to travel a longer path. With the aim to increase the second peak magnitude, as well as the amplitude of the first peak, Zahra et al in [14] propose a new PEA cell structure configuration which will be described in the next section.

III. THE NEW PEA CELL FOR CABLE SPECIMENS

As previously reported, to increase the amplitude of the PEA cell output signal a new PEA cell configuration has been proposed in [14].

In respect to the classic version, the ground electrode of aluminium material has been replaced with a piece of PMMA. This change has been made in order to bring the acoustic impedance of the ground electrode (now called "acoustic coupler") closer to that of the cable dielectric material. In this way the transmitted acoustic wave from the dielectric to the acoustic coupler is greater compared to the reflected one and therefore is it also greater in magnitude the pressure signal that reach the piezoelectric sensor. A further change has also been made in the absorber component, which in the classic PEA cell version is made with the same material of the piezoelectric sensor, such as PVDF. In the new PEA cell version, the PVDF material of the absorber has been replaced with a block of lead. As a consequence of this, the pressure wave passing through the sensor is in part reflected when it reaches the interface with the metallic absorber. Based on this, the pressure signal at the piezoelectric sensor is given by the sum of the incident wave (coming from the acoustic coupler) and the reflected wave (in the sensor-absorber interface), with a result that the total pressure at the sensor is almost doubled in comparison with the incident wave [14]. To demonstrate this phenomenon a PEA cell simulation model, developed by the authors in [13], has been used.

First of all, a mathematical evaluation of the transmitted and reflected acoustic wave in the sensor/absorber interface can be made. The acoustic impedance values, calculated as the product of the material density and the speed of sound, are equal to $4\cdot10^6$ and $22\cdot10^6$ Ns/m^3 for the PVDF and lead materials, respectively. Based in these values, the transmission K^T and reflection K^R coefficients, calculated as in [11], for the classic and the new version of the PEA cell are reported in Table I.

Table I. Comparison between the transmission and reflection coefficients for the classic and the new PEA cell configuration.

PEAVersion	**Sensor/abosorber**	K^T	K^R
Classic	PVDF-PDVF	1	0
New	PDVF-Lead	1.7	0.7

Considering the values of Table I, it is possible to observe that, in the classic PEA cell version, the signal coming out from the sensor is totally transmitted in the absorber. While, in the new version, when the pressure signal reaches the metallic absorber is reflected for 70% in the sensor direction.

The transmission part, instead, is equal to the 170% of the incident wave, this means that, due to the nature of the two materials involved in the interface, the pressure signal is also amplified.

The theoretical explanation above reported can be better understood by observing the simulation results reported in Fig. 5. However, it is important to highlight that the carried-out simulation has been made in order to observe the acoustic wave behaviour in the sensor/absorber interface. Therefore, to better visualize the acoustic wave within the sensor, its thickness has been increased.

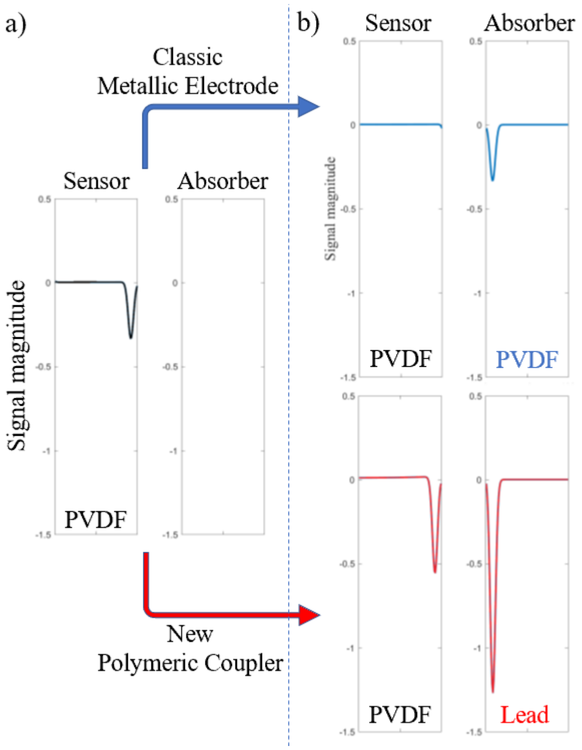

Fig. 5. Simulation of the acoustic wave behavior in the sensor/absorber interface for the classic and the new PEA cell configuration. a) before the pulse reaches the absorber b) after the pulse reaches the absorber.

Based on the benefits provided by the new PEA cell configuration, the authors built a PEA cell by following the instructions and suggestions given in [14-15].

The first experimental test carried out at the HV LEPRE Laboratory whit the new PEA cell prototype has been made in a 2 m long XLPE model cable stressed with a DC voltage from 20 to 80 kV. The measurement results visualized in the oscilloscope are reported in Fig. 6.

As can be seen, the obtained charge distribution is clear and easily interpretable, this because the two main peaks are well visible and no reflections occur between them. In addition, it is possible to observe that the second peak, corresponding to the inner interface between semicon and dielectric, have higher magnitude, in accordance with the Laplacian distribution of the electric field in a cable section. This also means that, with the new PEA cell configuration, the wave attenuation phenomenon can be neglected. By making a comparison with the profile observed in Fig. 3, which was provided by the traditional PEA cell, it is possible to notice that for a stress voltage equal to 70 kV the second peak magnitude is around 2.0 mV, while in the test of Fig. 6 it is approximately doubled.

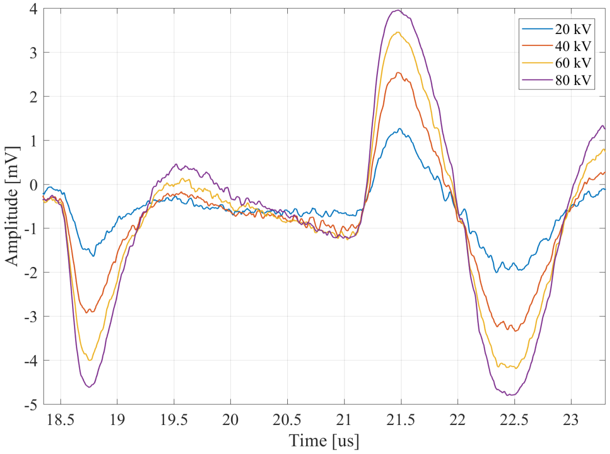

Fig. 6. Space charge profiles observed in the oscilloscope and obtained with the new PEA cell prototype.

V. CONCLUSIONS

In the present paper, a prototype of a new PEA cell configuration has been built. The main changes, compared to the traditional version, are related to the different materials employed for the ground electrode and the absorber. The first one, in the new version has been replace with a piece of polymeric material, such as PMMA. In this way the acoustic wave coming from the dielectric layer of the cable is almost totally transmitted when reaches the interface with the PMMA. This is due to the fact that the acoustic impedance of both cable dielectric and PMMA are similar. The absorber component, that in the previous version was made with the same PVDF material of the sensor, now is made of lead. Thanks to this change the acoustic impedance of the sensor and that of the lead are very different to each other and therefore the signal reaching the sensor/lead interface is almost totally reflected. In this way it was found in literature, and confirmed in this work by means of a simulation test, that the signal sensed by the sensor is doubled in respect to the precedent PEA cell version. In the first experimental test carried out with the new PEA cell prototype in a model cable specimen it has been observed that the space charge output signal is easily interpretable, the peaks are clearly visible and correctly positioned in the time scale. In future works the signals acquired with the oscilloscope will be processed with the deconvolution and calibration software. Particular attention will be paid to the calibration procedure in which the signal reflection in the sensor/lead interface must be also considered.

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