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Influence of the impulse voltage on the residual charge

***Abstract**. Results of measurements and simulations of the charge accumulated on the surface of composite insulator models after applying to them standard high voltage impulse (1.2/50 – positive polarity) are presented in the paper. Studies have shown that the residual charge deposited after applying the impulse with a positive polarity does not exceed 8nC and should not noticeably affect the flashover voltage tested models.*

***Streszczenie.** W artykule przedstawiono wyniki badań ładunku zgromadzonego na powierzchni modelu izolatora kompozytowego po przyłożeniu do jednego z okuć standardowego udaru wysokonapięciowego (1.2/50) o biegunowości dodatniej. Badania wykazały, że wprowadzony w ten sposób ładunek resztkowy nie przekracza 8nC i nie powinien wpływać w zauważalny sposób na wartość napięcia przeskoku badanych modeli (**Wpływ napięcia udarowego na ładunek resztkowy**).*

Keywords: high voltage, impulse voltage, composite insulators, residual charge.
Słowa kluczowe: wysokie napięcie, napięcie udarowe, izolatory kompozytowe, ładunek resztkowy.

Introduction

Development of DC power distribution systems [1,2,3] requires determination and understanding of physical processes leading to a generation and distribution of electrical charge (or related quantities) deposited on insulator surface.

The charge deposited on surface of the insulator may potentially affect both, the DC [4,5] and impulse [6,7] flashover voltage value U_f. So far carried studies show that surface discharge can result in charging the insulator surface [8-10]. Previous studies have been performed on models equipped with electrodes that their shapes differ from the typical fittings used on insulators [4-10].

Models

The investigations of the residual charge distributions were carried out on a composite insulator models. Each of models consisted of cylindrical dielectric core and silicone elastomer housing, both made of different dielectrics. The insulating cores with diameter equal to 20mm, were made of epoxy/glass composite (signed EG), basalt/epoxy composite (B) and polyamide PA6 (PA). Two types of silicone coverage were applied, i.e. made using Liquid Silicone Rubber technology (signed LSR) and using High Temperature Vulcanization (HTV). Finally there were 6 types of models signed as follows:

- EG-LSR, EG-HTV – models with EG core and LSR or HTV housing;
- PA-LSR, PA-HTV – models with PA core and LSR or HTV housing;
- B-LSR, B-HTV – models with B core and LSR or HTV housing.

Each of models was equipped with typical, industrially used metal fittings, mounted on its ends. Distance between the fittings was kept constant for all of models and equal to 270 mm. The outer diameter of the insulating part of the model (insulating cylinder) was equal to 25 mm. There were 3 samples of each core-housing combination.

Electrical properties of used materials, i.e. the relative permittivity ε_r and electrical volume resistivity ρ_v (core and covering materials) are shown in Table 1. For all of the models the charge decay time was greater than 200 s [11].

The models were stressed by standard lighting pulses (1.2/50 μs) with amplitude lower than or equal to the flashover voltage. Potential distributions were measured just after application of the voltage stress, in a time shorter than the charge decay time.

Table 1. Resistivity of materials applied in models constructions

Material	Relative permittivity ε_r [-]	Volume resistivity ρ_v [Ωm]
HTV	3,8	$1,9\times10^{12}$
LSR	2,6	$2,1\times10^{13}$
PA	4,5	$3,8\times10^{11}$
EG	5,5	$1,2\times10^{12}$
B	5,2	$2,2\times10^{11}$

Expermiment

The research consisted of two parts: simulation and experimental.

Insulating surface each of models was depolarized before each test. Depolarization was carried out by cleaning whole surface of the insulator (model) by an earthed, ethanol soaked cotton tampon. The potential value, measured on the surface of depolarized models did not exceed ±50 V.

During the experiment standard lighting impulse voltages (1.2/50 μs) was applied. Simplified scheme of the insulator attachment is shown in Fig. 1.

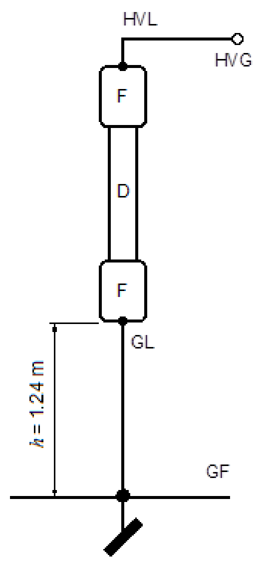


Fig. 1. Simplified scheme of insulator attachment. Symbols: GF – grounded floor, GL – grounding line, HVL – high voltage line, HVG – connection to high voltage generator. Not scaled

Surface potential and its distribution (along the model generatrix) was measured using an AC compensating voltmeter TREK – Hand-Held Electrostatic Voltmeter Model 520, placed in a distance of 7 mm above the model surface and operating in the direct, non-contacting mode. During the measurements, fittings of the model were supported by earthed, conducting supports. The first measurement was done after time t = 40±10 s, from the moment of application of the voltage pulse. It should be noted, that the completed procedure of potential distribution measurements along the insulator generatrix took about 60 s.

The scheme of the system applied for measuring the potential distributions is shown in Fig.2.

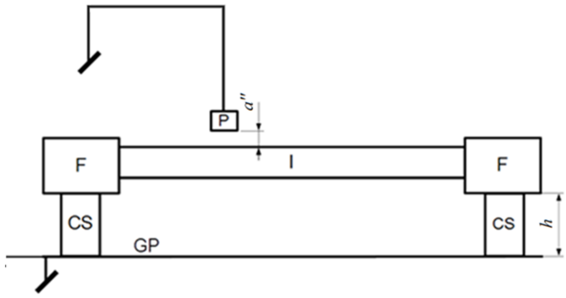


Fig. 2. Potential distribution measurement system. I – insulator; F-fittings; P – voltage probe (Trek 520); CS – conducting support; GP - grounded plate, distances: a'' = 7 mm, h = 20 mm

Measurements of the total charge Q_t, stored on the insulator model, were made using the Faraday cage and the RFT- 6305 electrometer - operating as a voltmeter.

Results

Typical potential distribution measured for the models subjected to impulse flashover is presented in Fig 3. This is also distribution with highest value of U_{max} obtained during the tests.

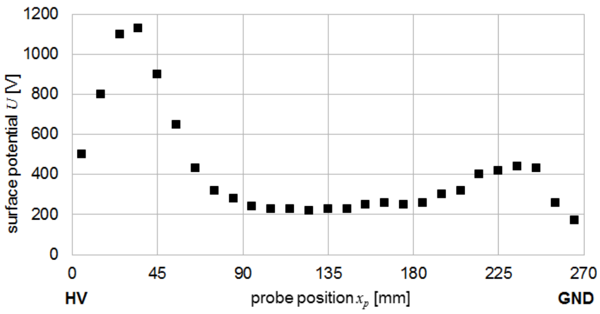
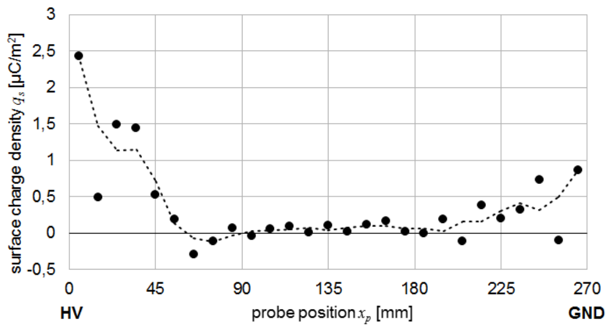


Fig. 3. Surface potential distribution measured after positive impulse flashover (U_f = +201.5 kV). HV and GND refer to high voltage and grounded fittings respectively. Model: EG-LSR



flashover (U_f = +201.5 kV). HV and GND refer to high voltage and grounded fittings respectively. Sample: EG-LSR

The Φ-matrix method [12] was applied to determine an effective charge density distribution on the insulator model. In order to simplify the calculation process, the Φ-matrix was created with assumptions: 1) the charge density is constant around the insulator perimeter, 2) the relative permittivity of all dielectric parts of an insulator is constant and equal to ε_r = 5. The results of surface charge distribution calculations are shown in Fig. 4.

Surface charge integration over the whole surface of the insulator allows calculating the total charge stored in the insulator. For the charge distribution presented in Fig. 4 the total charge was found to be Q_t = 7.2 nC.

Potential distributions measured on the insulator model after being subjected to impulse voltage, with and without the following flashover, are shown in Fig. 5 and 6 - measured and relative values, respectively.

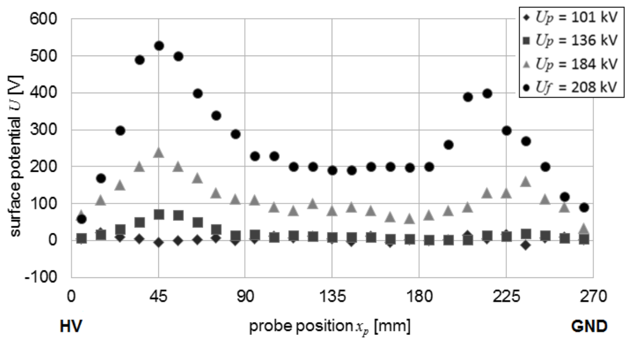


Fig. 5. Surface potential distributions measured after applying positive impulse voltage with (U_f) and without (U_p) flashover occurrence. HV and GND refer to high voltage and grounded fittings respectively. Model: B-HTV

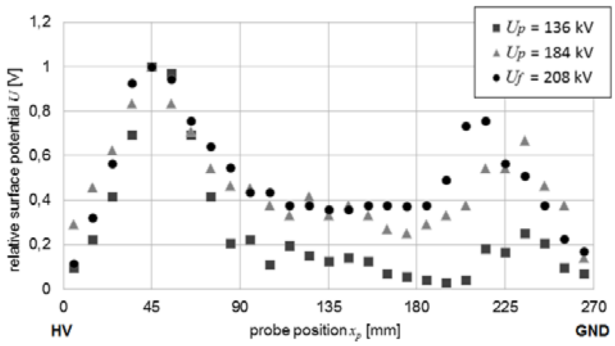


Fig. 6. Relative (related to the maximum value) surface potential distributions measured after applying positive impulse voltage with (U_f) and without (U_p) flashover occurrence. HV and GND refer to high voltage and grounded fittings respectively. Model: B-HTV

The shapes of potential distributions measured for all of cases (with and without flashover occurrence) seem to be similar. For models subjected to impulse voltage (1.2/50 μs), the surface potential in most cases exhibit mono-polar distributions with the same polarity as that of HV electrode. Determined charge distributions exhibit charge peaks near fittings, with higher peak near HV-fitting. The charge is deposited on insulator by a corona discharge occurring on the fitting.

Dependence of the average value of the surface potential on the impulse peak voltage U_p is shown in Fig. 7.

Since the value of the potential depends on the position and material of the insulator, the average potential has low diagnostic value. It can only serve as an indicator when the corona discharge starts and what the trend of changes in value of residual charge is.

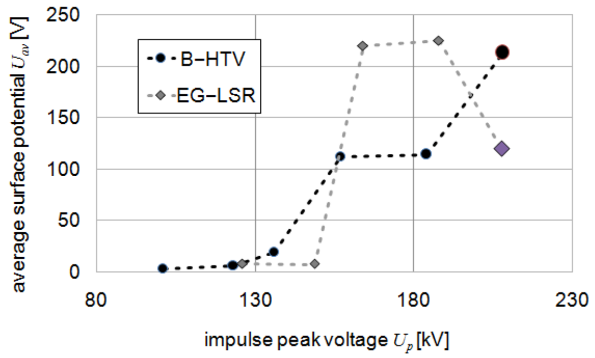


Fig. 7. Average value of the surface potential as a function of impulse voltage U_p. Points for highest voltages - for flashover.

Total charge Q_t, measured with a Faraday-cage, as a function of impulse voltage is shown in Fig. 8.

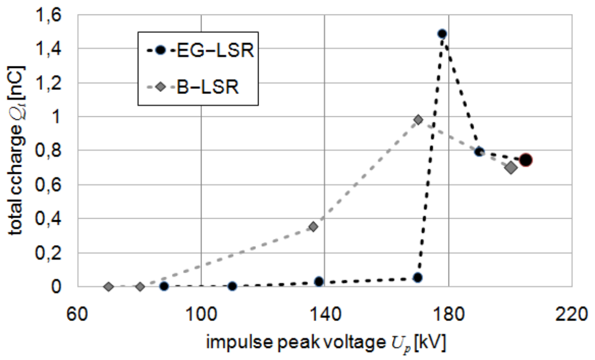


Fig. 8. Total charge as a function of impulse voltage U_p. Points for highest voltages - for flashover.

Different samples (insulators) are characterized by different corona inception voltage values. The total charge generally increases with the increase in U_p voltage, however some exceptions, mainly after flashover occurrence, were observed.

The measured value of the total charge Q_t does not exceed level of 1.6 nC. This value is 5 times lower in comparison to the value determined by integration of the surface charge density distribution shown in Fig. 4. However it should be noted that the estimated surface charge density was calculated for potential distribution with measured highest value of the surface potential U_{max} and with assumption that charge is uniformly distributed around the insulator perimeter.

Preliminary experiments were performed to determine whether the charge near the HV-fitting affects the value of the DC flashover voltage of tested models [13]. The insulator was electrified by corona discharge from a needle electrode placed in a distance of 40 mm from the HV fitting edge. The corona electrode was supplied from the stabilized DC HV power supply. The "point" electrification of the insulator was carried out in conditions: Corona voltage U_c=+32 kV, electrification time t_c=10 s. After electrification the potential distribution was similar to that presented in Fig. 3, with the maximum value on the level of 13 kV. The measured total charge accumulated on the insulator was on the level of Q_t =40 nC, it is the value greater by an order of magnitude in comparison to the values determined for the residual charge.

Investigations of the influence of charge density on the flashover voltage for the insulators described previously have shown that this influence is on the level of 5% [13].

Simulation

In order to analyze the observed distributions, simulation of the electric field distribution around the insulator were carried out in COMSOL Multiphysics v.4.2. A 2D axisymmetric model, based on real dimensions of the tested insulator and high voltage equipment arrangement was considered. The shape of the fitting assumed in simulation is shown in Fig. 9.

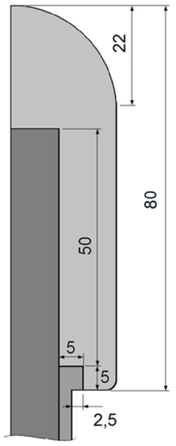


Fig. 9. Details of the fitting used in simulation

The highest values of the electric field intensity were found to appear at the edge of the fitting and at the point where the fitting connects to the insulator housing. Both of the points are placed on the "analysis" line A – see Fig. 10.

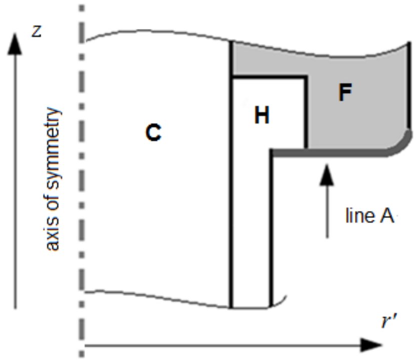


Fig. 10. Close-up of the fitting with defined line along which was calculated field distribution. C – core, H – housing, F – fitting

Result of simulation of the electric field strength along the line A is shown in Fig.11.

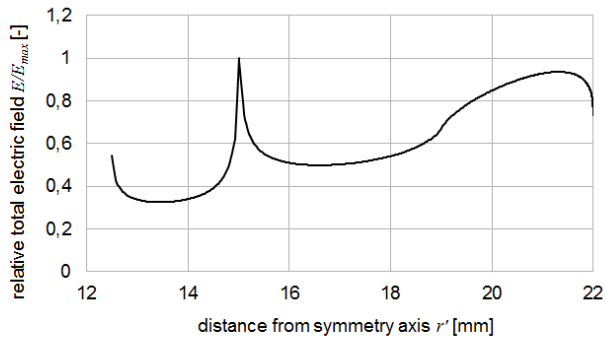


Fig. 11. Electric field (modulus value) distribution on line A (see Fig. 10).

Result of calculation of the electric field (modulus value) distribution between two points with highest electric field intensity (occurring on both fittings – i.e. between places where fittings contacts with housing) is shown in Fig. 12.

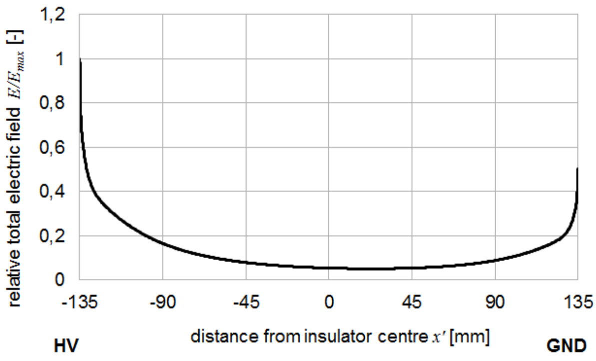


Fig. 12. Electric field (modulus value) distribution between fittings edges (sharpest part). HV – upper (high voltage) fitting, GND – bottom (grounded) fitting.

It is clearly seen that the highest electric field occurs near the upper fitting, i.e. the fitting to which high voltage was applied.

Conclusion

In case of application of an impulse voltage, the time of voltage stress is long enough to develop the local corona discharge from the sharpest parts of fittings. The charge is than deposited on the insulating surface of the model, where it is stored long enough for the measurements. Simulation indicates that the highest electric field occurs near the fitting to which high voltage was applied (upper fitting). The corona appears likely in the area of the sharpest parts of the upper fitting, That is probably the reason for which the residual charge has the same polarity like that of HV fitting. The charge peak observed near the HV fitting may be associated with capturing of the charge originating from the corona discharge. The other (lower) charge peak, observed near the GND fitting, may be associated with attracting of charges by mirror-charge on the grounded fitting.

There were no visible influence (occurrence of any regularity) of core and housing material on the flashover voltage, as well as on the value and distribution of the residual charge observed after the flashover.

The measured total charge introduced within the pre-breakdown processes (e.g. corona from the sharpest parts of the fittings) was (in case of the tested models of insulators) on the level of Q_t <8 nC (see distribution in Fig.4). According to conducted studies [13] such residual charge should not affect noticeably the flashover voltage on tested models.

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