

2D axi-symmetric multi-component electrical insulator traction simulation and measurement comparison

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Abstract

Toughened glass insulator is a key component of a high-voltage overhead transmission and distribution lines, supporting mechanically the conductors and insulating them electrically from ground potential. Insulators units are assembled in strings of different length and configuration ensuring a reliable mechanical connection between the transmission tower and the conductors.

Thus, SEDIVER places specific emphasis on evaluating the mechanical performance of the insulator.

Mechanical tensile test is carried out using a test-rig designed to simulate the predominant service-induced stress acting on this component under operational conditions. In addition, SEDIVER and SIMTEC developed a 2D axi-symmetric numerical model of the insulator itself with COMSOL Multiphysics® and use numerical testing to further improve the insulator design.

This paper reports the experimental measurements realized with the test-rig and the numerical predictions of the 2D axi-symmetric model. While the comparison with experimental results confirms the validity of the model, numerical results provide local insights on the behaviour of the insulator under stress.

Keywords: Traction test, Contact, Plasticity, Insulator, Overhead transmission line.

Introduction

Glass insulators have been used for more than a century, but the modular suspension toughened glass insulators have allowed for developing high voltage transmission lines [1]. It breaks down the voltage drop progressively and prevents various failure modes while being very reliable and robust [2].

To further improve their mechanical strength and refine the design, an experimental and numerical approach is employed.

Tensile loading is applied between the cap and the pin using an MTS testing machine.

This approach provides an evaluation of the numerical model. Thanks to the model developed and evaluated, it becomes possible to investigate the influence of various design parameters on the insulator behaviour by making available otherwise invisible variables like stress and displacement inside the cap.

I. Methodology

To address the need described in the introduction, one insulator geometry is selected. Experimental and numerical approaches are combined and described in this section.

a) Insulator geometry and loading description

The insulator investigated is the reference F120PB from SEDIVER which design complies with IEC

60305 standard [3]. Its geometry is represented in Figure 1, with the pin in blue, the toughened glass in transparent turquoise, the aluminous cement in grey and the cap in dark grey. Insulators are assembled in strings, where the pin of one insulator is inserted and locked in the top part of the cap of the next insulator.

This specific insulator can undergo a traction between the bottom of the pin and the top of the cap of at least 120kN without failing. Therefore, the present study focuses on the insulator behaviour up to the limit guaranteed by SEDIVER (120kN) and does not address its behaviour under larger load or its ultimate failure.

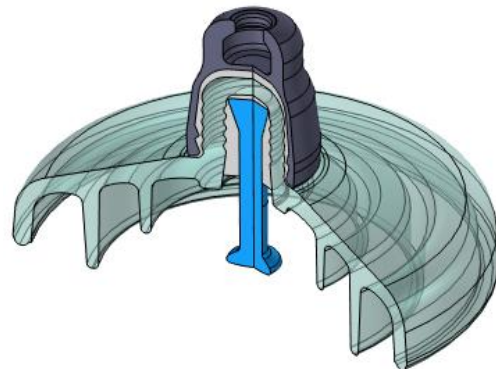


Figure 1. Insulator type F120PB geometry

b) Traction test description

The tensile tests were performed using a servo-hydraulic MTS universal testing machine equipped

with dedicated pin-like and cap-like connectors. Figure 2 represents the toughened glass insulator under load together with its connectors in the MTS. The machine applies a controlled axial tensile load (maximum load is 250kN) while continuously recording the applied force and the crosshead displacement. Because the measured displacement includes not only the deformation of the specimen but also the compliance of the testing frame and connector system, a machine compliance correction was applied before analysing the mechanical response of the insulator.



Figure 2. Toughened glass insulator in the MTS.

Tensile test procedure

The experimental procedure consisted of two successive steps:

i. Machine compliance characterization. A complete loading–unloading cycle was first carried out without an insulator. The pin-like connector and the cap-like connector were directly attached to each other, so that the measured displacement

originated solely from the deformation of the testing machine and the connector system. The resulting displacement at a given applied load F , denoted $w_{\text{MTS}}(F)$, represents the compliance of the MTS machine and its fixtures.

ii. Tensile test on the glass insulator. The glass insulator was then mounted between the same connectors and subjected to a conventional tensile test with controlled steepness. The total measured displacement, $w_{\text{total}}(F)$, includes both the deformation of the testing system and that of the insulator. The actual displacement of the insulator was therefore obtained by subtracting the machine compliance from the total measured displacement:

$$w_{\text{insulator}}(F) = w_{\text{total}}(F) - w_{\text{MTS}}(F).$$

This correction isolates the mechanical response of the glass insulator from the elastic deformation of the testing machine and connector assembly, providing an accurate load–displacement relationship for the insulator specimen.

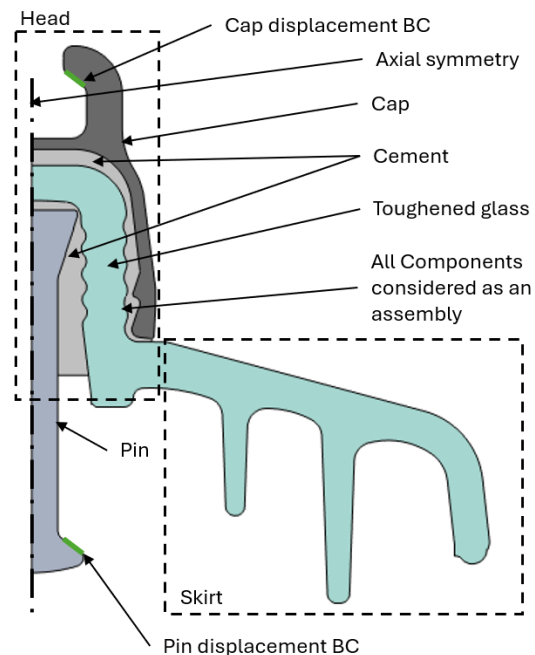


Figure 3. F120PB 2D axisymmetric description of the insulator and its boundary conditions (BC, green lines)

c) Numerical model description

In this study, the geometry, the load and the material behaviour can be considered as axisymmetric. Therefore, the solid mechanics equations are solved using the 2D-axisymmetric

framework. The geometry of the insulator and its components is summarized in Figure 3.

The solid mechanic equation applied here is the linear elastic description in the toughened glass and the pin, and elasto-plastic with linear hardening description in the cap and the cement. In both descriptions, geometric nonlinearity assumption is required to account for contacts; a total Lagrangian formulation with multiplicative strain decomposition is used. The stationary equation, solved for the displacement $\mathbf{u}$, is:

$$0 = \nabla \cdot (FS)^T$$

With $F = I + \nabla \mathbf{u}$ the deformation tensor, $S = S_{inel} + S_{el}$ is the stress tensor, S_{inel} is the inelastic stress tensor and S_{el} is the elastic stress tensor. Toughened glass has initial stress and cement is anisotropic. But in this study, all materials are supposed isotropic and free from initial stress. Material properties are defined in Table 1.

Property	Young Modulus	Poisson coefficient	Yield stress	Isotropic tangent modulus
Unit	GPa	-	MPa	GPa
Glass	72	0.23	-	-
Steel	210	0.3	-	-
Cast iron	110	0.28	240	1.2
Cement	50	0.24	25	20

Table 1. Material properties

The boundary conditions are as specified in Figure 3: the symmetry axis receives a zero radial displacement; the cap receives a zero vertical displacement at the contact location between the neighbouring pin (not represented) and itself; and the pin receives a varying vertical displacement w_{pin} at the boundary $\partial\Omega_{pin}$ situated between the neighbouring cap (not represented) and itself to apply the load on the insulator. Under the displacement w_{pin} , the load applied is

$$L = \int_{\partial\Omega_{pin}} reacf(w_{pin}, 1) dl$$

Mechanical contacts with Coulomb friction are defined between the different components since none of them are joined together. Contact pairs are defined, and a Nitsche incomplete formulation is applied.

In the present study, the friction coefficients were set according to the values reported in Table 2, and maximum tangential traction is infinite.

Interface	Friction coefficient (-)
Steel - cement	0.05
Glass - cement	0.1
Cast iron - cement	0.6

Table 2. Interface properties

II. Results

a) Experimental results

As described in Section I.b., the step i of the test is a machine compliance characterization. Three tests are performed and reported in Figure 4: MTS-1 to 3. A visual interpolation of the load-displacement curve without insulator is realized to be able to predict the MTS machine load at zero displacement and the machine compliance.

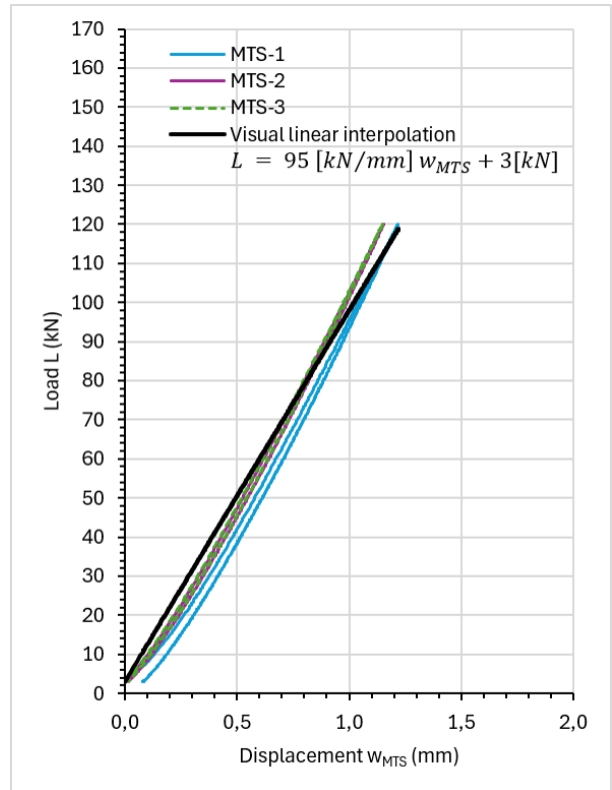


Figure 4. Machine compliance characterization

Step ii. of the test is the actual tensile test on the insulator. Two tests are reported in Figure 5. The data reported is the loading until $L=120\text{kN}$. Most of the curve show a linear behaviour, while the beginning and the end slightly differ. The result is a faint S-shape curve. It must be noted that the curve reported in Figure 5 is not the insulator behaviour, but the joint behaviour of the insulator, the connectors and the MTS.

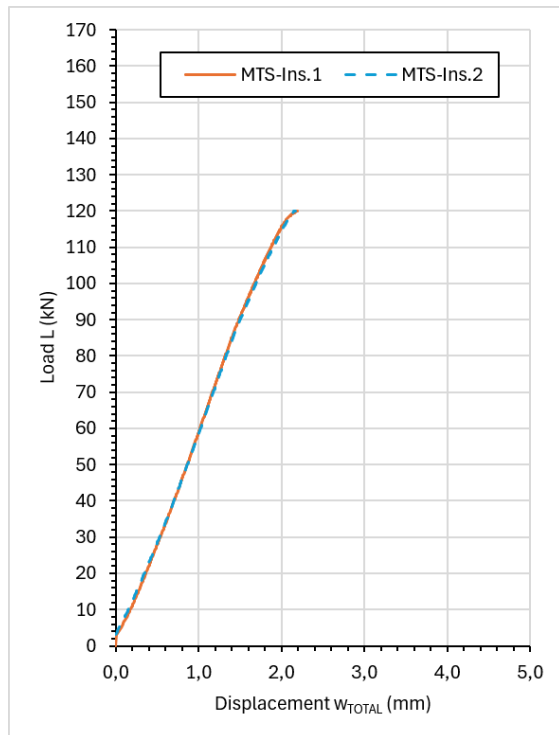


Figure 5. Insulator tensile test

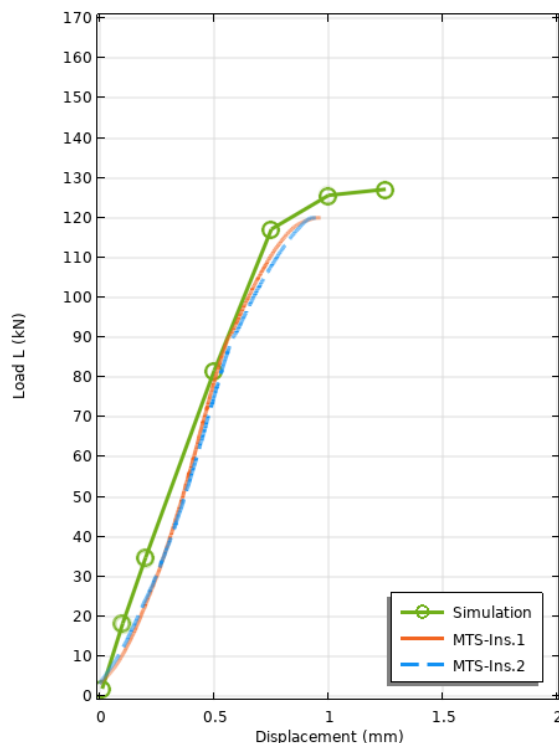


Figure 6. Comparison between simulation and corrected measurement

b) Numerical results and discussion

A displacement ramp is applied to w_{pin} , thus putting the insulator model under tensile load. The

load L is plotted against the displacement w_{pin} in Figure 6. It can be noted that the simulation result does not show the lower part of the S-shape curve. However, the top part of the S-shape curve is visible.

The displacement of the insulator alone $w_{insulator}$ is computed from w_{MTS} and w_{TOTAL} and displayed in Figure 6 for the two insulator tensile tests. The overall behaviour is very similar between the simulation and experimental results. The displacement under maximum load and the device stiffness are well predicted by the numerical model. Ideally, independent friction test should be performed to assess the behaviour of each interface, and elasto-plastic behaviour of the specific grade of cement should be realized. However, the rather generic data used here shows reasonable agreement.

Conclusions

In this joint work between SEDIVER and SIMTEC, a mechanical numerical model and tensile measurements are realized on a F120PB toughened glass insulator.

Careful analysis of the MTS tensile test results shows a specific and reproducible behaviour which is rather well predicted by the numerical model. This agreement suggests that the simulation results are representative of the real insulator behaviour under load. While more comparisons could be performed on other insulators to further increase the confidence in the model, it is already possible to investigate insulator specific design parameters. By testing numerically various parameter combinations with limited time and computation power, more performant design can be identified and tested experimentally to validate their behaviour.

References

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