Flashover Behavior of Semiconducting Glazed Insulators Under Positive Lightning Impulse Stress at Different Climatic Conditions

O. Elsässer, K. Feser
Institute of Power Transmission and
High Voltage Technology
University of Stuttgart
GERMANY

F. Messerer
Institute of High Voltage Engineering and
Electric Power Transmission
Technical University Munich
GERMANY

Abstract

The flashover voltages of a porcelain and a semiconducting glazed insulator are compared. The test samples are stressed with positive lightning impulse (LI) voltage (1.2/50) at four different temperatures (10°C, 20°C, 30°C, 40°C) in an environmental chamber. In each temperature step the relative humidity is varied between 10% and 90%. The test results are evaluated over the absolute humidity. A temperature correction is applied to the flashover voltage, to compare the values of the two insulator types over the absolute humidity.
The potential distribution along the insulators is investigated by numerical field calculation. The distribution for different frequencies of the driving voltage and for impulse voltages is shown. The flashover behavior of the two different insulator types can be explained by their potential distribution.
The flashover voltages obtained with lightning impulse stress are compared to results measured earlier with switching impulse (SI) voltage (250/2500). The differences in the flashover behavior can be described with the potential distribution at lightning respectively switching impulse stress.
The advantages and limits of the semiconducting glazed insulator, compared to a porcelain insulator, are described for LI and SI stress.

Introduction

Insulators are importent components to guarantee a reliable power transmission of electrical energy. Various insulating materials have prooved to be suitable for different climatic conditions and pollution areas. Composite insulators can reduce service cost in surroundings with heavy pollution or salt fog contamination. Because of their hydrophobic behavior, pollution layers can’t build up as quickly as on porcelain insulators. The risc of dry band arcing is also reduced by the hydrophobicity transfer to the pollution layer. Another possibility to avoid dry band arcing is the use of semiconducting glazes on porcelain insulators.
The flashover performance of different insulating materials under switching impulse stress for several temperature and humidity levels has been investigated earlier [1,2]. For clean conditions no differences in the flashover voltage for porcelain and composite insulators could be observed. The semiconducting glazed insulator showed higher values.
The tests presented in this paper investigate the flashover voltage of a porcelain and a semiconducting glazed insulator under lightning impulse stress at different climatic conditions. The flashover behavior is described by the potential distribution along the insulators.

Experimental Setup

The experimental setup is shown in figure 1. The same setup has been used in earlier experiments [1,2] with switching impulse stress.

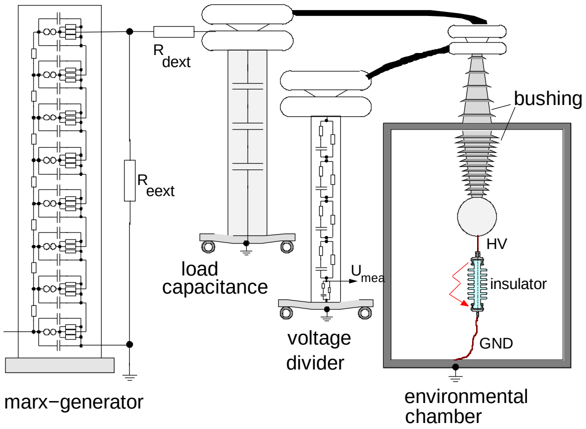

Fig. 1: Experimental setup

The voltage is generated with a marx generator and shaped to standard lightning impulse voltage (1.2/50) with external resistors. The test samples are located in an environmental chamber. The voltage is applied through a bushing.

The characteristic data of the voltage (U_p, T_p, T_2 or T_c) is measured with a voltage divider and analysed with a digital impulse analysing system (Haefely DIAS 730).

The climatic conditions in the test chamber are measured with a psychrometer.

Test Samples and Test Methods

The test samples are shown in figure 2. A porcelain and a semiconducting glazed porcelain insulator with the same design are used for the tests. The flashover distance is about 280 mm.

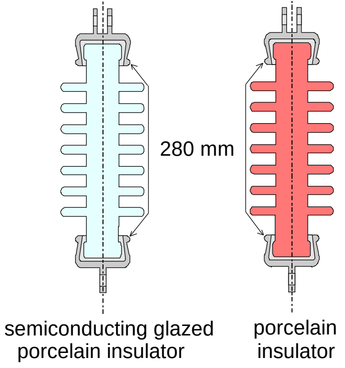

Fig. 2: Test samples

The test voltage is applied in steps. About 15 steps are used in each test series, 20 impulses are applied per step. The results are evaluated in a probability paper. The 50%−flashover voltage is derived from a linear regression through the measured values.

Test Results

All flashover voltages presented in the following paragraphs are corrected to a pressure of 101,3 kPa.

Influence of the Absolute Humidity on the Flashover Voltage and Temperature Correction

The influence of the absolute humidity on the flashover voltage is presented in figure 3 and 4. An increase of the flashover voltage with rising absolute humidity can be observed for both insulator types and all temperature steps. Differences can be seen in the gradient of the increase.

A flashover voltage drop can be recognized at a certain humidity level for rising temperatures.

The sole influence of the absolute humidity on the flashover voltage can be seen after applying a temperature correction to the data.

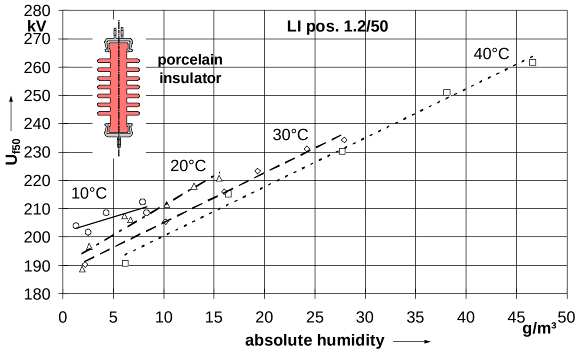

Fig. 3: Dependence of the 50%−flashover voltage (LI pos.) on the absolute humidity at different temperatures for a porcelain insulator

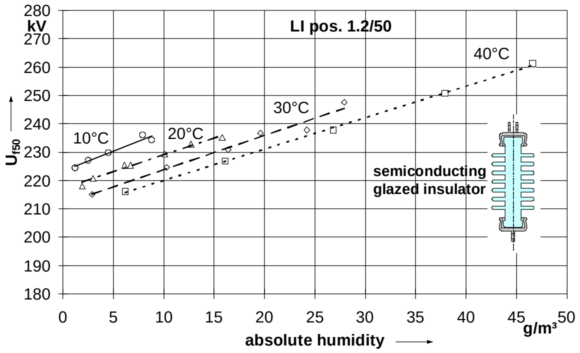

Fig. 4: Dependence of the 50%−flashover voltage (LI pos.) on the absolute humidity at different temperatures for a semiconducting glazed insulator

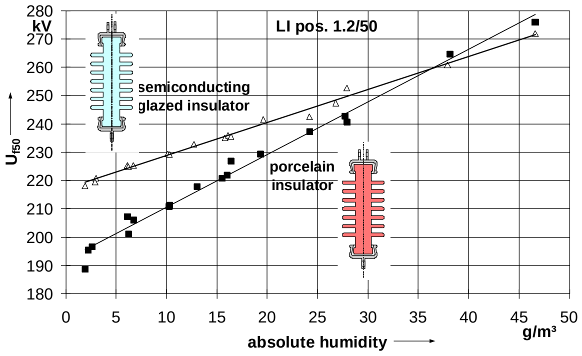

Fig. 5: Influence of the absolute humidity on the 50%− flashover voltage (LI pos.) of a semiconducting glazed and a porcelain insulator (temperature corrected values)

The values can be corrected with the following equation:

$$U_{dcorr} = \left(\frac{273{,}15°\mathrm{C} + \vartheta_{st}}{273{,}15°\mathrm{C} + \vartheta_0} \right)^m \cdot U_{dmeas} \qquad (1)$$

The exponent $m = 0.7$ is determined from the experiments.

Figure 5 shows a relative flashover voltage increase of 0.9%/(g/m³) for the porcelain and 0.5%/(g/m³) for the semiconducting glazed insulator. The absolute flashover values for the semiconducting glazed insulator are higher up to a humidity level of 37 g/m³.

Field Calculation

The numerical field calculations are based on the Boundary−Element−Method (BEM). The boundary conditions are modified to calculate capacitive−resistive fields with surface and volume resistivity [3,4].

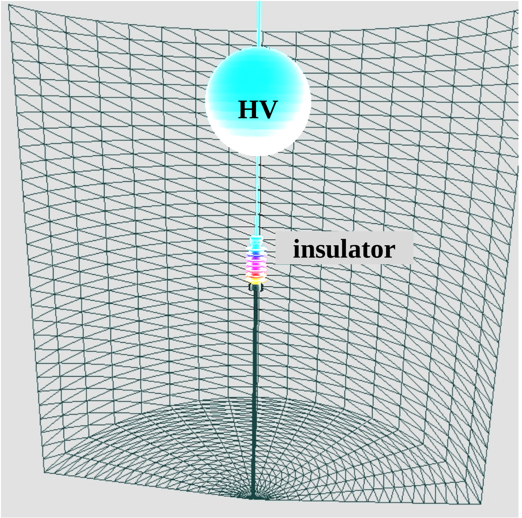

Fig. 6: Model of the test setup for the field calculation

For capacitive−resistive field calculation the system of equations obtained for both known and floating potential conductor boundaries is the same as those for capacitive field calculation with the only difference that the potentials and the charges are complex quantities.

Fig. 6 shows the test setup as a 3D−model. Numerical calculations can be made for 2D and 3D−axissymetric geometries. The environmental chamber is described as a cylinder which does not have significant influence on the field distribution of the insulator.

Potential Distrubution along a Semiconducting Glazed Insulator

Figure 7 shows the potential distribution along the semiconducting glazed insulator for different frequencies of the driving voltage. The values are obtained by the numerical field calculation. For the semiconducting glazed insulator a value of $2.841 \cdot 10^6\,\Omega$ for the surface resistivity is applied ($\kappa = 0.352\ \mu S$).

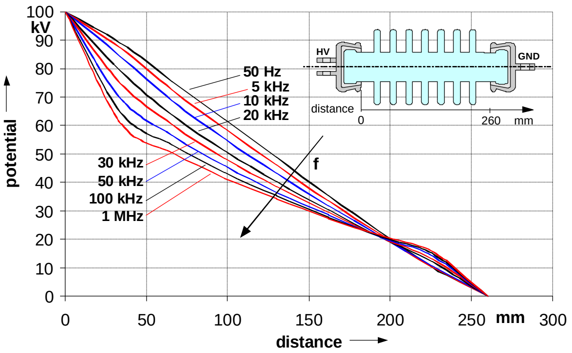

Fig. 7: Potential distribution along a semiconducting glazed insulator for different frequencies of the driving voltage (derived from field calculation)

For low frequencies the potential shows an ohmic distribution according to the conductivity of the semiconducting layer. For rising frequencies the potential distribution shifts over to a capacitive behavior, which corresponds to the potential distribution of a porcelain insulator.

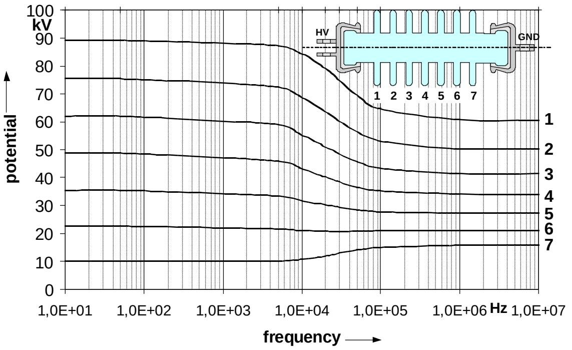

Fig. 8: Frequency response for the tip of each insulator shed for a driving voltage of 100 kV

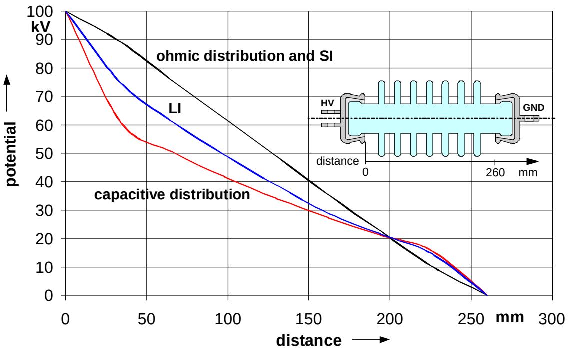

Fig. 9: Potential distribution along a semiconducting glazed insulator under LI and SI stress

Another possibility to illustrate the frequency dependence of the potential distribution is given in figure 8. Each curve gives the frequency response on the tip of the seven insulator sheds. A simple equivalent RC−circuit for the semiconducting glazed insulator can be developped, which results in the same frequency response. Figure 9 presents the results from a PSPICE simulation with impulse voltages on the RC−circuit. For switching impulse voltage the potential distribution is still ohmic, whereas the distribution for lightning impulse voltage is between the ohmic and the capacitive distribution.

The almost linear potential distribution for switching impulse voltage on the semiconducting glazed insulator results in higher flashover voltage values compared to the porcelain insulator. The flashover voltage is about 20% higher at standard conditions (20°C, 101,3 kPa, 11 g/m³) according to figure 10. Under lightning impulse stress the difference in flashover voltage is about 8%.

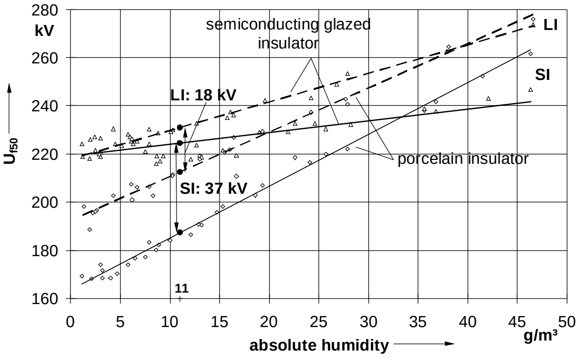

Fig. 10: Influence of the absolute humidity on the 50%−flashover voltage of a porcelain and a semiconducting glazed insulator under lightning and switching impulse stress

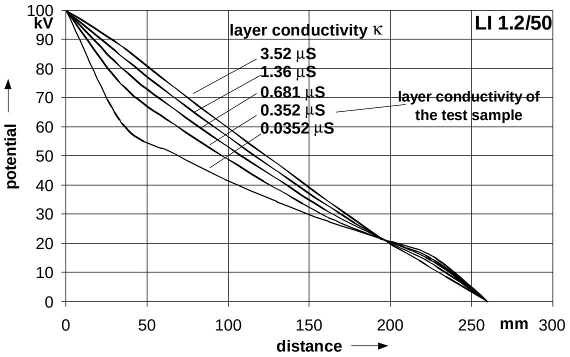

Fig. 11: Potential distribution along a semiconducting glazed insulator for different layer conductivities (LI stress)

A more linear voltage distribution under lightning impulse stress could be achieved by raising the layer conductivity of the semiconducting glaze. Figure 11 gives the influence of the layer conductivity on the potential distribution. For a more linear potential distribution the layer conductivity would have to be increased by a factor of 4−10.

Discussion and Conclusion

The relative flashover voltage (LI) increase with absolute humidity is about 0.5%/(g/m³) for a semiconducting glazed and 0.9%/(g/m³) for a porcelain insulator. For lightning impulse stress the semiconducting glazed insulator shows 8% higher flashover voltage values at standard conditions. For switching impulse stress the difference rises up to 20%. This can be explained by the linear potential distribution along the semiconducting glazed insulator at SI. The conductivity of this insulator would have to be raised 4 to 10 times to get a more linear potential distribution and higher flashover values at LI. This would cause 4 to 10 times higher leakage currents, which could lead to thermal stability problems, especially if you consider the negative temperature coefficient of the semiconducting glaze.

For this reason lightning impulse voltage is the limiting factor for the design of semiconducting glazed insulators. With an 8% higher flashover voltage compared to a porcelain insulator, the flashover length could be made 8% shorter, which wouldn’t result in a significantly more compact design.

References

[1] O. Elsässer, K. Feser: *Flashover behavior of different insulating materials under positive switching impulse voltage stress at different climatic conditions,* ISH 1999, London, conference puplication No. 467, Volume 4, pp. 4.119.S27−4.122.S27

[2] O. Elsässer, K. Feser: *Flashover behavior of semiconducting glazed insulators under positive switching impulse stress at different climatic conditions*, CEIDP 1999, Austin, annual report, pp. 711−714

[3] S. Charkravorti, H. Steinbigler: *Capacitive−Resistive Field Calculation around a HV Insulator using Boundary−Element−Method,*
ISH 1997, Montreal, Vol. 3, pp. 49−52

[4] F. Messerer, W. Boeck: *Field Optimization of an HVDC−GIS−Spacer*, CEIDP 1998, Atlanta, annual report, pp.15−18