

AGING TEST OF SILICON HYDROPHOBICITY WITH NON-IDEAL DC UNDER INFLUENCE OF VOLTAGE PARAMETERS

M. Hilbert^{1*}, C. Guca¹, M. Kurrat¹

¹ Institute for High Voltage Technology and Electrical Power Systems, Technische Universität Braunschweig, Schleinitzstraße 23, 38106 Braunschweig, Germany

*Email: m.hilbert@tu-braunschweig.de

Abstract: Nowadays high voltage direct current transmission (HVDC) is gaining more importance. So the assigned components and materials have to deal with the new challenges of this technology. Using DC different stresses and effects are dominating compared to AC applications, e.g. polarization and surface charges. However, the DC voltages occurring in the reality are not ideally smooth, and show different voltage contents as mostly small ripples. These voltages are superimposed harmonic waves and combinations of it. These conditions can lead to unexpected phenomena which are difficult to explain, if only ideal DC voltages were considered.

Many testing methods for systems or materials, which were established under AC load, need modifications to apply to the new DC conditions. One of the used material testing methods is the dynamic drop test (DDT), which was developed in the Cigré working group D1.14. With this procedure a defined AC voltage is applied over a diagonally clamped test specimen. A certain quantity of a solution with a defined conductivity drops from the upper to the lower electrode across the specimen. During the material test the leakage current is measured. The switch-off criterion is reached, if the leakage current rises above specific amplitude for a specific time. For the state evaluation of different materials the time until the disconnection occurs is compared with other materials under the same test parameters. To use the dynamic drop test for HVDC insulation materials, the switch-off criteria must be re-specified. Many other criteria can be varied like the conductivity of the solution, the voltage level, the current amplitude and duration for switch-off criterion and also the voltage shape.

In the paper the modified test set-up is presented. Herein a rectified voltage is used with a specific ripple factor. The ripple factor dependency and the energy content were determined in relation to the switch-off criterion.

1 INTRODUCTION

For the evaluation of insulation materials for DC-applications, like high voltage direct current transmission (HVDC), few established testing methods exist [1]. Using DC different stresses and effects are dominating compared to AC applications, e.g. polarization and surface charges. Many testing methods for systems or materials, which were established under AC load, need modifications to apply to the new DC conditions. However, the DC voltages occurring in the reality are not ideally smooth and show mostly small ripples. These conditions can lead to unexpected phenomena which are difficult to explain, if only ideal DC voltages were considered. These may have an influence on the behaviour of the electrical insulation [2].

Compound insulators show a better performance opposite to ceramic or glass cap insulators in DC application ([1], [3]). The dynamic drop test (DDT) is a method for the investigation and comparative evaluation of non-ceramic insulators under alternating voltage. It was developed in the Cigré working group D1.14 "Material Properties for Non-ceramic outdoor Insulation" ([4], [5]).

2 TEST SET-UP

2.1 Basic Set-up

The test set-up used in this work was developed in the Cigré working group D1.14 [5]. Herein the test specimen is characterized by a comparative procedure. A liquid solution with a defined conductivity (1500 $\mu\text{S}/\text{cm}$) runs from a high voltage electrode down to a ground electrode with an electrode gap of 50 mm across an inclined test specimen with a 60° inclination angle. The basic structure can be seen in Figure 1.

The original test is planned for measurement with alternating voltage. Therefore, voltage supply for this work had to be adapted by using a half-wave rectifier circuit application (see Figure 2 and [7]). The transformer feeds over a diode a smoothing capacitor C_G which DC voltage is applied to the test specimens. Over the variation of this capacity and a high impedance resistance (10 M Ω) the form of the voltage and the ripples can be changed. The leakage current over the test specimen is measured with an overvoltage relay. If this current stays above a defined value for a certain time the switch-off criterion is reached and the test specimen is separated from high voltage. This is

done with electromagnets, which hold a swivel arm in contact with a bus bar during the test.

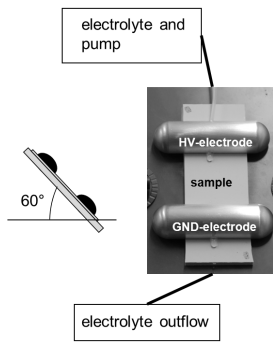


Figure 1: Schematic set-up of the dynamic drop test with shown inclination angle

The time between voltage connection and reached criterion is considered to be the evaluating benchmark of the test specimen. Test specimens in this work were silicon rubber test samples (SIR-RTV) with a roughness of $R_z = 9 \mu\text{m}$.

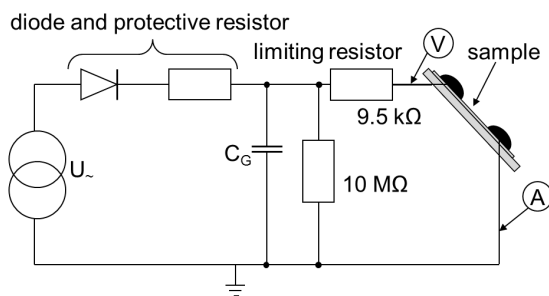


Figure 2: Equivalent circuit diagram of the dynamic drop test for DC voltage

2.2 Ripple generation

A DC voltage is characterized by its mean value. Furthermore, the half difference between minimum and maximum voltage is called 'ripple' related to the arithmetic average value it is called 'ripple-factor'.

The DC testing voltage must not exhibit a maximum ripple-factor of 3% according to the German standard DIN IEC 60060-1 [6]. In this work the influence of different ripples is examined. The measured DC voltages with the different ripples are shown in Figure 3.

A maximum ripple-factor of 50% can be achieved without the 10-M Ω -Resistance (see Figure 2). Here, the self-capacitance of the test set-up with approx. 500 pF without the capacity C_G serves as smoothing capacity, which discharges over the non-ideal elements, e.g. the diode over its parasitic parts (Figure 3 a).

The minimum ripple-factor is reached using a capacity (C_G from Figure 2) of approx. 7 μF . Here, the 10-M Ω -resistance provides the voltage drop and thus the ripple-factor of 1.5% (Figure 3 c and d).

Measurements with a ripple-factor of 1.5% were also done using a limiting resistor (9.5 k Ω) in series to the test specimen. The large smoothing capacitor with 7 μF has stored a high energy (max. 56 J). When the test specimen with the running down electrolyte becomes conductive, the stored energy of the 7 μF -capacitor discharges across the sample. The protective resistor is implemented to reduce the current and so the energy, which stresses the sample.

The ripple-factor with 15% (Figure 3 b) is reached by a smoothing capacity C_G of 6000 pF in connection with the 10-M Ω -resistance.

Measurements with 50-Hz AC were also done for a comparison.

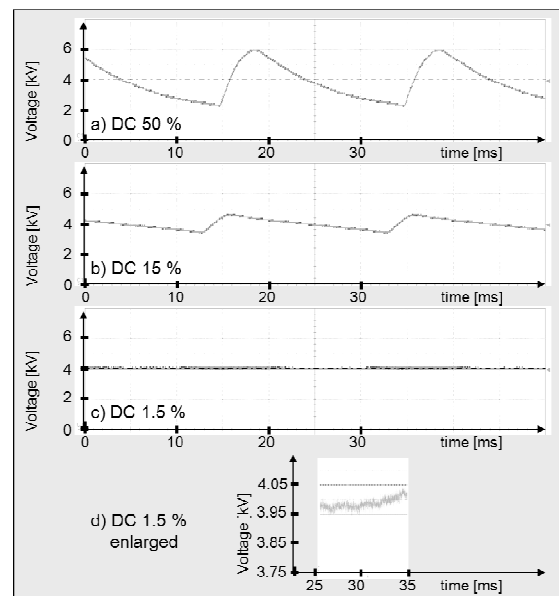


Figure 3: Measured DC voltage with different ripple-factors

2.3 Other parameters

Further parameters which can be selected are the values for the switch-off criterion. Usually this criterion is set to a current of 2 mA \pm 0.5 mA over a time of 4 s \pm 0.5 s [5]. Regarding the tolerance a current of approx. 2 mA for 3.5 s as criterion is selected. The voltage is chosen to 4 kV (root mean square value for AC voltage and mean value for DC voltage, respectively), which is within the centre of the AC specifications (3 kV/4 kV/5 kV).

The set-up is conceived as parallel arrangement. Few measurements were done in parallel, the others in single tests. Detailed explanations of the set-up can be found in [5] and [7].

3 RESULTS

3.1 Formation of conductive channels

During the examination the hydrophobicity of the test specimens changed: It begins with individual drops and leads among other phases with electrolyte residues to a continuous hydrophilic water film. By an interruption of the running down drops with still hydrophobic characteristics of the test specimen the switch-off criterion in the intermediate phase is not reached [8]. However, the test specimen in this phase already shows an occasionally existing conductivity.

A hydrophilic channel on the samples appears after a certain testing time (Figure 4). Finally this leads to a current flow that leads to a separation of the test specimen from high voltage reaching the switch-off criterion. Reaching the switch-off criterion a sizzling noise is usually heard which is caused by the energy of the discharges.

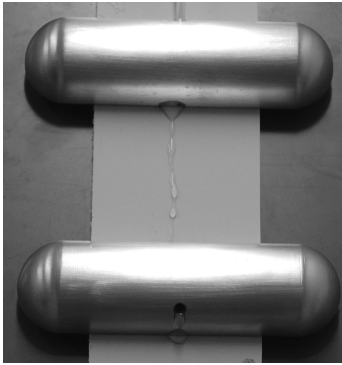


Figure 4: Hydrophilic channel on test specimen with DC voltage and ripple-factor of 1.5%

Also clearly visible brownish traces can be seen on some test specimens. The development of these traces by DC and a ripple-factor of 1.5% on one of the samples can be seen in Figure 5. Measurements with additional limiting resistor show the same brownish traces.

The origin of these traces on the test specimens can be explained by dry band arcing discharges and loss of the hydrophobicity ([10], [11]): The drop flows from the high-voltage electrode down and produces a dry area by the energy of discharges in front of the drop. This leads to a deceleration of the drop. The short time current pulse, caused by the water drop reaching the earth electrode, leads to a non-continuous flow over the 3.5 s and thus to no disconnection. This is reached when the distance between the electrodes is sufficiently hydrophilic to produce a conductive channel and a steady current flow. The discharge channel with the traces is examined with a tree-dimensional profilometer. Height profile and a photo of this measurement can be seen in Figure 6a) and b), respectively. Due to the energy of the discharges peaks and

recesses on the sample of some μm can be detected. The hydrophobicity is thereby affected ([9], [10]).

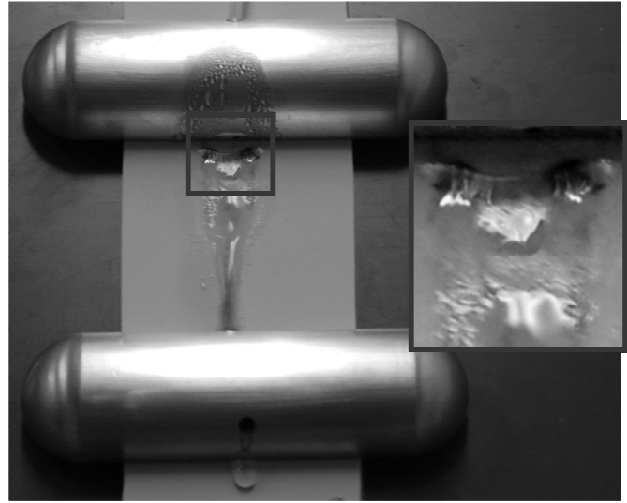


Figure 5: Discharges on test specimen with dry area in front of water drop with DC voltage and ripple-factor of 1.5%

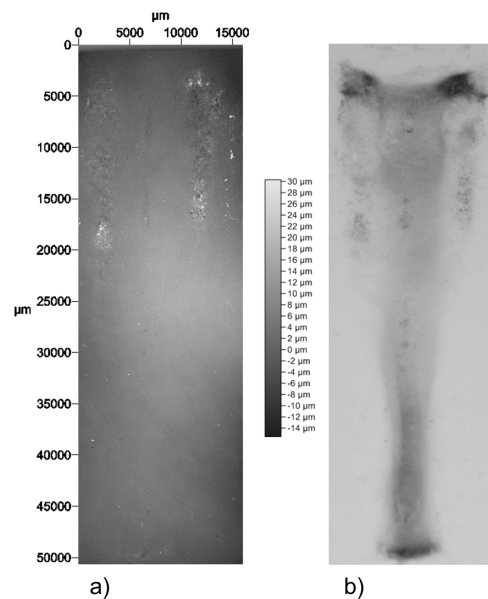


Figure 6: a) Height profile and b) photo of the test specimen from Figure 5 after switch-off

3.2 Time until switch-off

Figure 7 shows the median with the standard deviation of the time until switch-off for the different DC voltages. Generally, a strong scatter can be observed, which was also determined in [8] and in detail explained. In the conducted test it could be seen that the AC shows a longer time until disconnection than the DC (see also [7]).

Measurements with set-up variation by the limiting resistor (in Figure 7 'DC 1.5% LR') show nearly the same results as in the basic setup. Because of that not only the energy content of the discharges is

responsible for the early switch-off when using the 1.5% ripple factor DC voltage.

After testing the specimens with DC a high residual charge on the samples can be observed. This is caused by the unipolar polarization and leads to shorter durations until switch-off in relation to AC testing. A similar behaviour was found with other testing methods, in which DC voltage likewise leads to a faster reaching of the switch-off conditions [1].

A statement about the influence of the ripples and the voltage shape is not possible due to the measured value scattering.

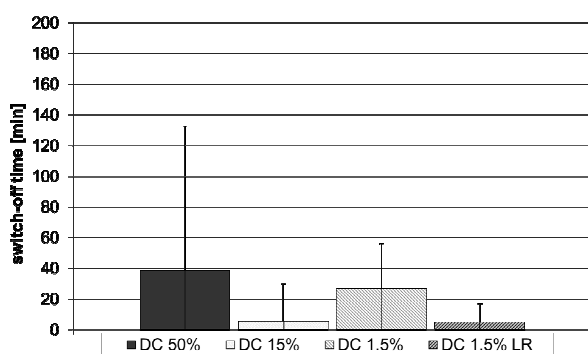


Figure 7: Median of the time until switch-off with standard deviation by the different voltage forms

4 CONCLUSION

The dynamic drop testing method was used for measurements with DC voltage. The voltage form was produced over a half-wave rectifier circuit with variation of the smoothing capacity. For the measurements with small ripple-factor the set-up was modified to reduce the current with no significant change in behaviour. Generally, investigations revealed a high value scatter for all considered voltage forms. This all well as small differences in the short switch-off times among the different voltage forms do not permit a statement of the ripple influence with the introduced parameters (e.g. switch-off criterion). However, it could be seen that the possible duration of voltage stress is longer with AC than with DC.

5 ACKNOWLEDGMENTS

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