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Introduction

Nowadays the components of high voltage direct current (HVDC) transmission systems are tested with composite voltages. These are generated by superimposing a DC and an impulse voltage. Therefore, two voltage supplies are connected via coupling and blocking elements to one test object (DUT). The coupling and blocking elements should couple both voltages as uninfluenced as possible to the DUT and at the same time protect each voltage supply from the other voltage. For superposition of DC and impulse voltages often either a spherical spark gap or a blocking capacitor is utilized on the impulse voltage generator side. On the DC voltage supply side a blocking resistor or inductor can be used. Unfortunately, the generation and evaluation of the composite voltages is not completely standardized yet, but this is necessary to ensure comparability of dielectric tests.

Which parameters require a more precise specification?

During the dielectric tests, various parameters of the test voltage have to be evaluated according to IEC 60060-1 from the recorded voltage waveforms. These parameters and their evaluation processes are standardized for the lightning (LI) and switching (SI) impulse voltage. Important parameters for LI voltage are the value of the test voltage U_t, the front time T_1 and the time to half-value T_2 and the relative overshoot β'. Those for SI voltage are the value of the test voltage U_p, the time to peak T_p and the time to half-value T_2. These parameters are also applied to a composite voltage. While the voltage values (U_t, U_p) do not present a difficulty for the evaluation process, the time parameters do. [1]

The evaluation process for LI voltages first identifies a possible DC voltage offset of the recorded curve and removes it. After a few further steps the recorded data is fitted to a mathematical function, whereof the so-called base curve is constructed. Then the residual curve is determined by subtraction of the base curve and the recorded curve. A digital filter is applied to the residual curve, resulting in the filtered residual curve. Finally, the filtered residual curve is added to the base curve to obtain the test voltage curve, which is necessary to evaluate the parameters mentioned above. [1]

Especially, if a spherical spark gap (SG) is utilized as coupling and blocking element, a steep voltage rise occurs in the waveform of the composite voltage after its ignition (Figure 1, dark blue line). If the evaluation procedure is applied to this composite voltage, it can be seen that the evaluated test voltage curve does not contain any information about the steep voltage rise (Figure 1, light blue line). Thus, the front time parameter T_1 also lacks this information [2]. The evaluation for the SI parameters is simpler, but there is also a lack of information in the time to peak parameter T_p about the steep voltage rise after the SG ignition [3]. Furthermore, TC42 is discussing to utilize the LI voltage evaluation procedure for SI voltages in the revision of IEC 60060-1. The question arises whether the definition of additional parameters and their limits is necessary to describe the steep voltage increase after the ignition of the SG.

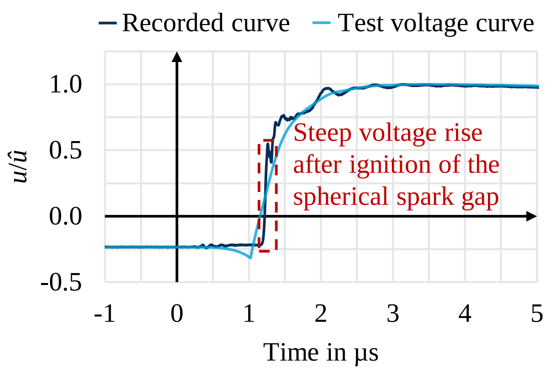

Figure 1 Composite voltage from DC and impulse voltage generated with a spherical spark gap as coupling and blocking element

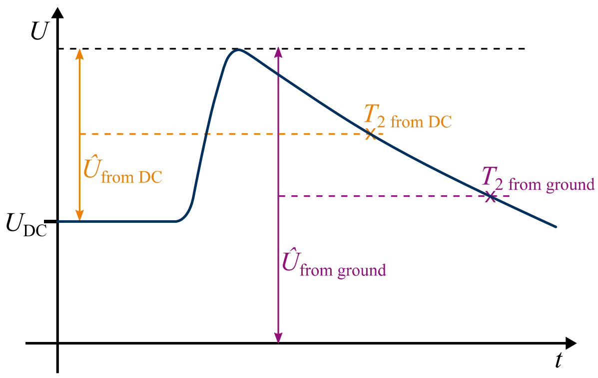

Figure 2 Determining the time to half-value T_2 using the ground or DC potential as the base value for evaluation

Another issue to be discussed is the removal of the offset in the recorded data prior to the evaluation of the LI and SI voltages, since this offset is equal to the applied DC voltage of the composite voltage. Hence, the evaluation procedure calculates the time parameters for the composite voltage waveform without the applied DC voltage. For the time to half-value T_2 only the difference between the DC and the peak of the composite voltage is considered (Figure *2*, orange). Another way to determine the time to half-value T_2 of a composite voltage is to use the ground potential as base value for determination of the peak value of the composite voltage (Figure 2, violet). Both options result in different time to half-values T_2 for the identical composite voltage (Figure 2). It must be noted, that both options for the base value of the evaluation procedure are utilized nowadays. The first one for utilization of a blocking capacitor as blocking and coupling element and the second for the SG. The evaluation leads to identical time to half-values T_2 for the tests with either blocking capacitor or SG although the composite voltage waveforms are different. [2], [3]
However, it is questionable whether the two evaluation procedures with different base value are necessary for the testing of HVDC components with composite voltages. It has to be discussed which base value for the evaluation procedure is more suitable for the test execution and more critical for the insulation system.

Which parameters in the superimposed voltage waveform have proven to be particularly critical?
As described, there is a lack of information about a possible steep voltage rise in the evaluated parameters of a composite voltage if a spherical spark gap is utilized. However, this steep voltage increase could be significant for the electrical strength of an insulation system. It is known that gas-insulated arrangements have higher breakdown voltages with decreasing rise time (T_1, T_P) of a transient overvoltage, due to the voltage-time characteristics [4].
Also, the different evaluation respectively the different generation of the tail of a composite voltage and therefore different time to half-value T_2 could have an impact on the electrical strength of insulation. For example, the dielectric strength of a liquid insulation is growing with decreasing time to half-value T_2 [5].
It should be noted that the different types of insulation materials (gaseous, liquid and solid) react differently to transient stresses. Therefore, it is necessary to investigate the dielectric behaviour of the insulating materials under composite voltage stresses originating from different coupling and blocking elements.

How can the generation of composite voltages be optimized?
Especially if DC and switching impulse voltages are superimposed with a spherical spark gap (SG) as coupling and blocking element it can be shown that a forced triggering of the SG can increase the reproducibility of the composite voltage waveform. On the one hand, the scattering of the SG ignition can be reduced. On the other hand, it is possible to minimize the steep voltage rise during the front time of a transient voltage after SG ignition by appropriate selection of the trigger time. [6]
Additionally, the so-called "crocodile tail" which is caused by extinguishing and re-ignition of the SG during the test execution can be reduced or prevented if the capacitance on the test object side is increased. This ensures a higher current flow through the SG and thus prevents it from extinguishing. [7]

Literature

[1] IEC 60060-1:2010, "High-voltage test techniques - Part 1: General definitions and test requirements" (2010-09).
[2] A. Dowbysch, T. Götz, H.-P. Pampel et al., "Influence of the Blocking Element on the Front of a HVDC-Lightning Impulse Composite Voltage", (22nd International Symposium on High Voltage Engineering (ISH), Xi'an, 2021).
[3] A. Dowbysch, T. Götz, H.-P. Pampel et al., "Impact of Different Blocking Elements on the DC-Impulse Composite Waveform", (CIGRE Session 2022, 11116, Paris, 2022) (to be published).
[4] R. Arora, W. Mosch, "HIGH VOLTAGE AND ELECTRICAL INSULATION ENGINEERING", (IEEE Press, John Wiley & Sons, New Jersey, 2011).
[5] Q. Liu, J. Xiang, Z. Wang, O. Lesaint, "Streamer and Breakdown Characteristics of Dielectric Liquids Under Impulse Waveforms With Different Tail-Times", (IEEE Transactions on Dielectrics and Electrical Insulation, vol. 29, no. 3, pp. 1103-1110, 2022).
[6] A. Dowbysch, T. Götz, S. Schlegel, "Generation of Reproducible HVDC-Impulse Composite Voltage Waveforms Using a Triggered Spherical Spark Gap", (VDE Fachtagung Hochspannungstechnik, Berlin, 2020) (to be published).
[7] M. Hallas, C. Dorsch, V. Hinrichsen, "Discharge optimization of spark gaps during superimposed voltage testing", (VDE Fachtagung Hochspannungstechnik, Berlin, 2018), (in German language).