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Standardisierung von Hochspannungsprüfungen mit zusammengesetzten und kombinierten Spannungsformen

Support for standardisation of high voltage testing with composite and combined wave shapes

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Kurzfassung

Bei der Zulassung von Geräten für den Einsatz in Hochspannungsnetzen werden zwingend zuverlässige Hochspannungsprüfungen gefordert. Mit diesen Prüfungen wird verifiziert, dass diese Hochspannungsgeräte den Betriebsbedingungen standhalten können. Solche "Stehspannungsprüfungen" können mit kombinierten bzw. zusammengesetzten Spannungen durchgeführt werden, bei denen Blitzstoß- (LI) oder Schaltstoßspannungen (SI) mit Wechsel- oder Gleichspannung überlagert werden. Bisher fehlen ein umfassendes technisches Verständnis und Vorschriften für die Erzeugung und Messung von solchen zusammengesetzten Hochspannungen. Auch die Regulierungen in internationalen Normungsgremien sind für die heutigen Anforderungen nicht ausreichend. Im Mai 2020 startete ein europäisches Metrologieprojekt mit Industriepartnern, Universitäten und sieben europäischen Metrologieinstituten (NMI), das in drei technische Arbeitspakete unterteilt ist. Zum Projektstart wird vorab der metrologische und normative Bedarf ermittelt. Zunächst werden Einflüsse von Impulsspannungen auf AC- bzw. DC-Messung zuverlässig bestimmt. Darauffolgend werden für die kombinierten bzw. zusammengesetzten Spannungsformen neue Messinstrumente, Auswertesoftware und Niederspannungsgeneratoren entwickelt, aufgebaut und in Betrieb genommen. An den NMIs werden rückführbare Hochspannungsmesssysteme und Kalibrierdienste für diese Spannungsformen mit einer Amplitudenunsicherheit von weniger als 2 % entwickelt und aufgebaut. Diese werden mit Hilfe eines Vergleichstests aller Komponenten der beteiligten NMIs in der PTB bestätigt. Bei den Prüfungen mit zusammengesetzten bzw. kombinierten Spannungsformen werden die Messunsicherheiten bestehender Spannungsteiler und Messketten genau bestimmt. Abschließend werden die Forschungsergebnisse in die laufende Überarbeitung der IEC 60060-Reihe auf internationaler Ebene eingebracht

Abstract

As part of the production of equipment for high voltage electricity grids, high voltage tests are performed to verify that the equipment can withstand the operational voltage stresses. Such ‘withstand tests’ are performed using combined and composite waves, where lightning impulse (LI) or switching impulse (SI) waves are superimposed on AC or DC. Both the technical understanding of the generation and measurement of such high voltage wave forms and the regulations in international standards are not sufficient for the current requirements. Therefore, a European metrology project with industrial partners, universities and seven European metrology institutes (NMI) is started in 2020. In three technical work packages the metrological and standardisation need will be issued. First, the relationship between impulse voltages with AC or DC

measurement, and related detrimental effects due to combining wave shape tests will be reliably determined. New measurement instruments, low voltage generators and measurement evaluation software will be created. Traceable high voltage measurement systems and calibration services for composite and combined wave shapes, with a target amplitude uncertainty of less than 2 % will be developed at the NMIs. The capabilities of these NMIs will be confirmed with aid of a high voltage comparison campaign at PTB. The uncertainty of existing voltage dividers and measuring systems used in tests with composite and combined wave shapes will be accurately determined. Finally, the research results will be forwarded to the ongoing revision of the IEC 60060 series.

1 Introduction

The reliability of high voltage electricity grids and their ability to support renewable energy sources crucially depends on the adequate testing of grid components. One of these tests involves the application of composite and combined wave shapes. As part of the production of equipment for high voltage electricity grids, dielectric testing is performed to verify that the equipment can withstand the operational environment. Such tests are performed using composite and combined waves, where lightning impulses (LI) or switching impulses (SI) are superimposed on HVAC or HVDC. However, at present, there is inadequate traceability for these wave shapes which may result in incorrect test results. The current IEC 60060 standard permits the voltage dividers and measuring systems that are used in test laboratories to be qualified by separate calibrations with HVAC, HVDC, LI and SI. However, these separate calibrations do not provide evidence for the ability of such voltage dividers and measuring systems to measure composite and combined wave shapes. Furthermore, there is currently no scientific evidence that HVAC/HVDC and LI/SI generation circuits do not interfere with one another. Thus, their relationship needs to be determined in order to provide traceable calibration services and input to the revision of the IEC 60060 series of standards. [1], [2]

The insufficient standardization for test systems, the lack of calibration services at the metrology institutes and test laboratories as well as the insufficient technical understanding of the interrelationships in composite and combined wave shapes led to a normative research project funded by the EMPIR programme co-financed by the participating states and from the European Union's Horizon 2020 research and innovation programme. [3] In this project, which has been running since May 2020, the aspects described below are researched and prepared for implementation in standardization. With the help of the project partners and members of the IEC TC 42, the results will flow directly into the ongoing revision of the IEC 60060 series. [1], [2]

2 State of Art

There are multiple areas of applications for high voltage test with composite and/or combined wave shapes. Tests of transformers, gas insulated systems or high voltage cables are the most important examples.

Compared to the necessary tests for HVAC cable systems, HVDC cable systems require additional new tests. One of them is the "superimposed impulse withstand test". This test is essential for HVDC cables and is differentiated according to the converter type (voltage source converter VSC and Line Commutated Converter LCC). As shown in [4], cable systems are already being tested with superimposed voltages. In [5] is described which test combinations of HVAC / HVDC and LI / SI are required for the different converter types.

As another example, there are phenomena that occur especially when testing gas insulated high voltage systems with combined wave shapes. These phenomena result in a reduced breakdown voltage. Insulation systems like gas insulated substations and transmission lines will likely play an important role in the application of HVDC transmission and the integration of renewables within the energy grid [6]. The current IEC 60060 standard describes the following two cases: combined voltage shapes and composite voltage shapes.

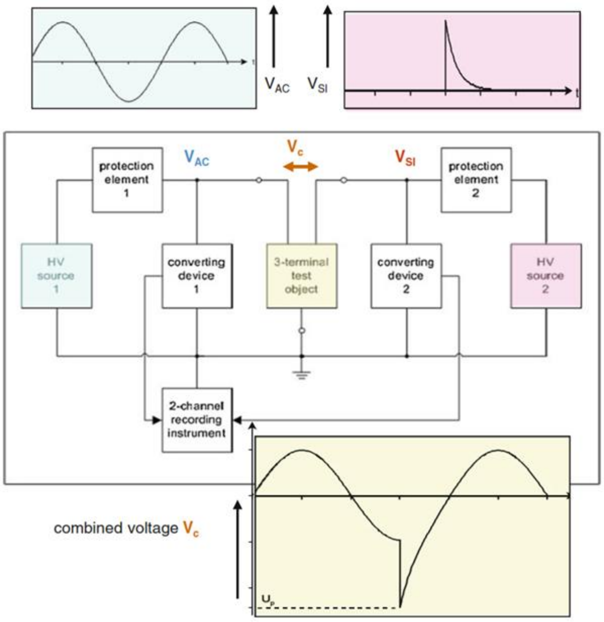

Figure 1 Setup for combined voltages [7]

In figure 1 the setup for combined voltage shapes is shown. The combined voltage V_C appears between two high voltage terminals of three-terminal (three-phase) test object, while the third terminal is grounded. The single voltage sources are protected by a protection element in case of a breakdown of the test object. However, a coupling of the different voltages via the equipment under test should be considered. Typical test objects are disconnectors, circuit breakers, GIS systems, etc. A usual measurement of combined voltage is difficult because there is no earth potential involved, it is allowed therefore the calculation of the combined test voltage (V_C) from the measurement of its two voltage components.

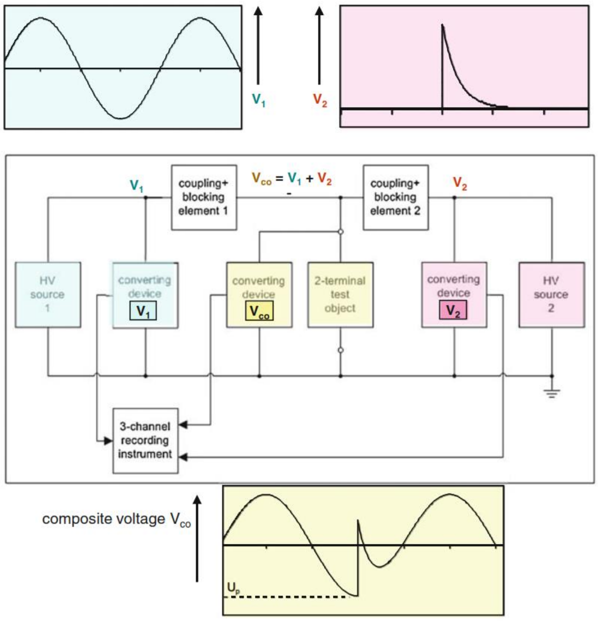

Figure 2 Setup for composite voltages [7]

In figure 2 the setup for composite voltage shapes is shown. The composite voltage V_{CO} is the superimposed voltage on the test object. Test is performed on the one terminal of test object.

The test circuit for composite wave shapes contains a measuring device which measures directly the voltage across the equipment under test. On both sides are coupling and blocking elements and further measuring devices for the adjustment of the single components of the composite wave shape. This means that depending on the coupling and blocking elements the stress on the equipment under test and the generating components can differ. The coupling and blocking element should have a low impedance for the coupling purpose of the relevant kind of voltage and a high impedance for the other kind of voltage of the composite test voltage.

2.1 Test and calibration parameters

The evaluation of the individual signal forms, AC, DC, LI and SI, is described in IEC 60060 1 [1]. So far, there have not been any standardised evaluation routines for superimposed signals, so the evaluations of the individual voltage forms are currently combined as required during tests. Therefore, with the same signals, completely different results can be achieved in different laboratories.

In a superposition of a HVDC with LI, the evaluation does not seem to be complicated. However, in cases such as the superposition of an HVAC with SI, there are problems in determining the time parameters. It is currently up to the creativity of the test personnel to develop adequate evaluation routines for superimposed voltages. This unsatisfactory condition is due to the lack of definitions and evaluation routines in the current standards.

2.2 Low voltage generators and instruments

Low voltage generators for the generation of both precise direct voltages and alternating voltages have been in the form of e.g. calibrators available on the market. In the case of impulse voltages, there are also generators of different types. There are analogue impulse voltage sources that can generate a resonance circuit with the help of changeable capacitors and resistors in such a way that a standard impulse can be generated. There are also calculable impulse generators that can generate a calculable impulse curve, considering the input impedance of the measuring instrument and the resistive and capacitive elements measured beforehand. Another alternative are digital-to-analogue converters that generate a programmed curve. However, there are currently no low voltage generators for combined voltages. In the HV com² project, these will be developed and built either as a combination of several generators assembled in a circuit or as a single device. The developed devices will meet the requirements of the metrology institutes in order to ensure the traceability for accredited institutes and test laboratories.

2.3 Software and test data generators

IEC 61083 [8,9] deals, among other things, with the development of software for measuring instruments for impulse voltages. A test data generator was developed as part of this standard. This digital generator can be used to generate voltage and current pulses for the verification of measurement software. Due to the lack of standardized parameters for combined and composite voltages, there are currently no standardized evaluation software and no standardized error limits for evaluation software for such voltage types. As part of the HV-com² project, both measurement software for digitizers and a data package for evaluating this software are being developed and brought into the standardization bodies. The aim is to create a standardized approach for testing and calibrating high-voltage devices and measuring instruments.

2.4 Calibration of universal dividers

As described above, tests with combined and composite voltage forms are currently being carried out. Since there is currently no traceability for voltage dividers or measuring instruments for superimposed voltages, such tests are carried out with universal dividers that have been calibrated with separate voltage forms (HVAC, HVDC and pulses). However, there is no proof of the capability of these universal voltage dividers when subjected to superimposed voltage forms. One of the goals of the HV-com² project is to qualify the existing universal voltage dividers so that they can carry out the prescribed tests in a traceable manner. For this purpose, several measurement campaigns are carried out during the project. In the first measurement campaign, the reference measurement systems of the metrology institutes at PTB will be compared with each other and verified.

In the two subsequent measurement campaigns at TU Dresden and TU Graz, universal dividers that are already on the market are qualified using the newly built references. For this purpose, measurements with superimposed voltage forms of different combinations and voltages up to the megavolt range are carried out.

3 Calibration capabilities

The current IEC 60060 standard allows voltage dividers and measuring systems used in test laboratories to be qualified by separate calibrations with HVAC, HVDC, LI and SI voltage. Since no combined or composite wave shapes have so far been used to qualify the measuring systems of calibration and testing laboratories, the NMIs focus on reference measuring systems for HVAC, HVDC and pulse voltages. There are currently no calibration services or measuring devices for these voltage forms at the highest metrological level. However, these separate calibrations do not provide evidence for the ability of such voltage dividers and measuring systems to measure correctly combined and composite wave shapes. Currently, the traceability of composite and combined wave shapes is inadequate and can lead to incorrect test results. Therefore, there is an urgent need for traceable measurement systems for composite and combined wave shapes that can be directly attached to the device under test. Furthermore HVAC/HVDC and LI/SI generation circuits do interfere with each other. Thus, their relationship must be determined in order to provide traceable calibration services.

4 Project progress

The HV-com² project has been running with eleven international partners since May 2020. One of the first steps was to establish contact with the maintenance teams of the IEC TC42, especially the MT04. The revision of the IEC 60060-1 standard has included the creation of new definitions of the parameters of superimposed voltages. The results of the project will be incorporated in the course of the revision of this standard.

Furthermore, the design and construction of a low-voltage calibrator for superimposed voltage forms was started. The first attempts were made possible with a build-up of commercial voltage calibrators. Test calibration waveforms have been tested with a Fluke 5500 (AC/DC) calibrator, and calculable, battery powered impulse voltage calibrator with optical usb-connection. In figure 3 the setup of this composite voltage generator is shown.

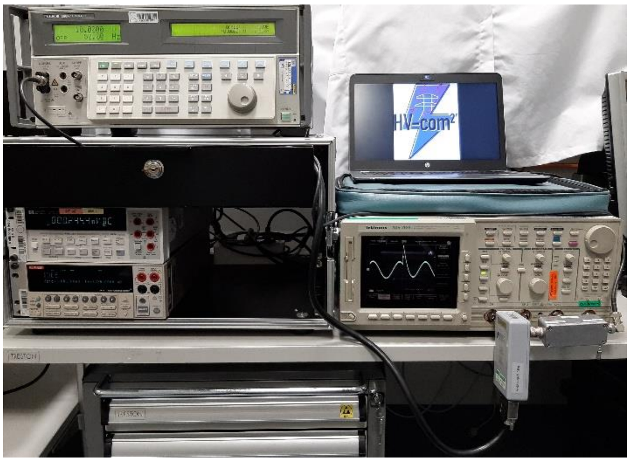

Figure 3 Low voltage generator for composite voltages

Furthermore, a first version of the design of a modular reference voltage divider for superimposed voltages was created using an RCR structure and modules up to 200 kV (figure 4).

First simulations show that a broadband voltage divider for use with DC voltages and at the same time LI can be set up in this way. Figure 5 shows the simulated frequency response of a 200kV module with a coaxial cable, a 1000: 1 attenuator and a digital recorder. In the next steps, detailed planning and the search for suitable components will be carried out. Thereafter, the prototype will be built and characterized.

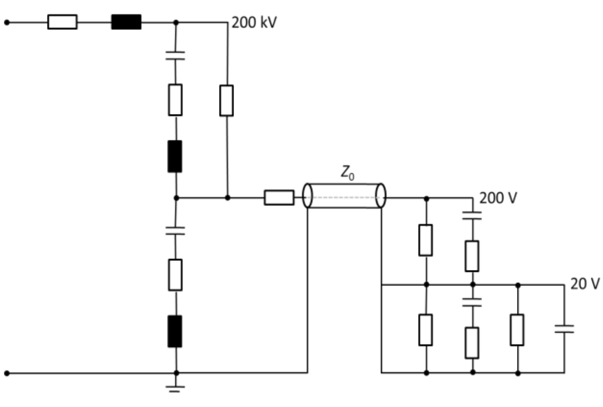

Figure 4 First design of a universal reference divider for superimposed voltages

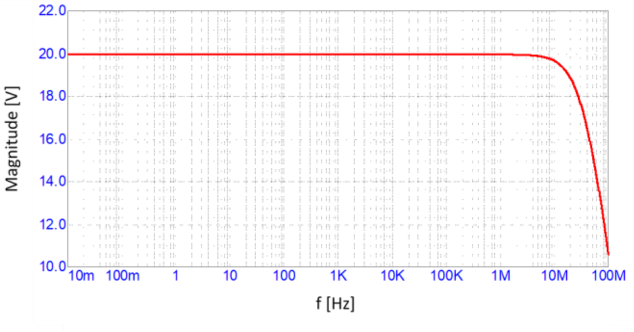

Figure 5 Frequency response of the first design of a universal reference divider for superimposed voltages

First tests with novel superimposed voltage dividers have been made at PTB. The following figure 6 shows a first reference setup for the generation and measurement of a composite HVDC and LI voltage using both the superimposed voltage divider as well as common LI and HVDC dividers.

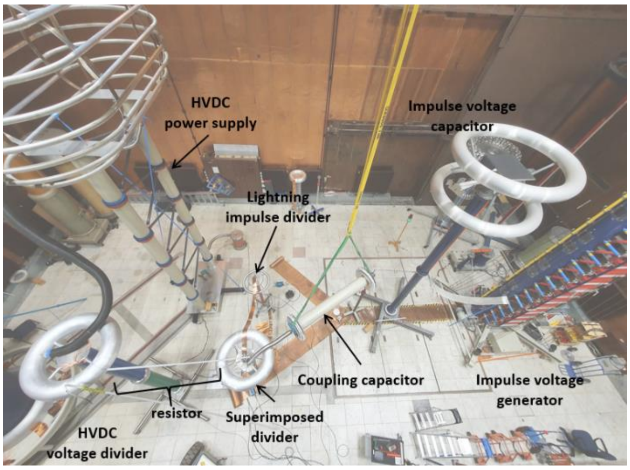

Figure 6 Setup for superimposed voltage generation

Between the superimposed divider and the LI part a coupling capacitor is installed. In this manner the influence of the coupling capacitor was examined.

After the setup of the new modular universal reference divider in the project the shown setup will be used for a comparison campaign at PTB. The aim is to adapt the measuring circuit so that HVAC and SI combinations with polarity changes should also be possible. In addition, the voltage level is expanded to at least 300 kV.

5 Conclusion

This paper describes the work already started in the project 19NRM07 HV-com² funded by the European Metrology Programme for Innovation and Research. After the completion of this project, a new metrological area for measurements, tests and calibrations with combined and composite high voltage forms will be established. This includes the measuring instruments, the voltage dividers and the software as well as the metrological feedback chain, the standardization and the creation of calibration services within Europe. First results of the design of the reference voltage dividers for superimposed voltages are presented.

6 Acknowledgement

This project (19NRM07 HV-com²) has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

7 Literature

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