CHALLENGES FOR HIGH VOLTAGE TESTING OF UHV EQUIPMENT

Ernst Gockenbach
Schering-Institut, Leibniz Universität Hannover, Hannover, Germany
*Email: Gockenbach@si.uni-hannover.de

Abstract: The increase of voltage level for AC and DC transmission systems requires some changes in the high voltage testing for Ultra High Voltage (UHV) equipment. After a short description of the coordination work in the standardization bodies the requirements for UHV equipment are mentioned. The main points concerning high voltage testing of UHV equipment are the impulse shape of standard lightning impulse voltage, the evaluation of the test voltage for impulses with oscillations or overshoot near the peak and the time parameter of switching impulses. The linearity check of the measuring devices, the proximity effect and the wet tests are further points to be discussed concerning testing of UHV equipment.

1. INTRODUCTION

The increase demand of electric energy and the long distances between energy sources and energy consumption places require a transmission of electric energy over long distances. To keep the losses of the transmission systems under control, two alternatives are possible:

- AC transmission systems with voltages above 800 kV
- DC transmission systems with voltages up to 800 kV

The increase of the voltage level requires an adaption of the existing standards not only for the equipment, but also for the testing and measuring techniques. The International Council on Large Electric Systems (CIGRE) and the International Electrotechnical Commission (IEC) have established a coordination group (JICCG) in order to define the standards which should be adapted to the higher voltage level and which should be elaborated [1].

2. RESULTS AND DISCUSSION

The UHV equipment has large dimensions and therefore voltage generators with high rated voltage are required. This leads also to large dimensions of the test equipment and in consequence large inductance of the complete test set-up. The requirements on a standard lightning impulse voltage concerning front time and acceptable oscillations and overshoot may be not reachable at the same time. Therefore a compromise concerning extension of the front time and allowed have to be fined.

The time to peak for switching impulse was defined according to so called V-curve where the flashover voltage of large air gaps has a minimum dependent on the time to peak. A test with the actual standardized switching impulse voltage will be outside this minimum and it should be decided if the time to peak should be extended for tests of UHV equipment with switching impulse voltages.

The increase of the voltage level requires also larger voltage dividers. The preferred calibration method is a comparison between a reference divider and the divider under test. Taking into account a lightning impulse voltage of about 3000 kV requires a reference divider of 600 kV assuming the 20 % as minimum voltage level during the calibration. This could be solved, but the linearity check will be a problem. The charging voltage of the impulse generator of the voltage measurement by an electric field probe will be the solutions for this topic.

The wet test of UHV equipment is a big challenge due to the size of the equipment, the required distance between the rain equipment and the test object due to the high voltage and the requirements on the rain. The rain should not provided in a sharp jet, which may lead to a flashover, but probably necessary to reach the test object. The rain should be droplets with an angle of 45 °deg related to the test object, but these droplets can not generated over the large distance between rain equipment and test object.

3. CONCLUSION

The development of UHV equipment should be combined with the development of the related test techniques. Most of the existing standards need only an extension up to the voltage level of the UHV equipment [2-5]. For some particular points research work are necessary like extension of the front time or the acceptance of a large overshoot for lightning impulse tests, the adaption of the time to peak for switching impulse tests, linearity test for high voltage dividers and wet test for UHV equipment with large dimension.

4. REFERENCES

[1] JOINT IEC-CIGRE COORDINATION GROUP (JICCG) see Internet website of CIGRE and IEC
Challenge for High Voltage Testing of UHV Equipment

Ernst Gockenbach
Schering-Institut
Leibniz Universität Hannover
30167 Hannover, Germany
gockenbach@si.uni-hannover.de

Abstract—The increase of voltage level for AC and DC transmission systems requires some changes in the high voltage testing for Ultra High Voltage (UHV) equipment. After a short description of the coordination work in the standardization bodies the requirements for UHV equipment are mentioned. The main points concerning high voltage testing of UHV equipment are the impulse shape of standard lightning impulse voltage, the evaluation of the test voltage for impulses with oscillations or overshoot near the peak and the time parameter of switching impulses. The linearity check of the measuring devices, the proximity effect and the wet tests are further points to be discussed concerning testing of UHV equipment.

I. INTRODUCTION
The increase demand of electric energy and the long distances between energy sources and energy consumption places require a transmission of electric energy over long distances. To keep the losses of the transmission systems under control, two alternatives are possible:

- AC transmission systems with voltages above 800 kV
- DC transmission systems with voltages up to 800 kV

The increase of the voltage level requires an adaption of the existing standards not only for the equipment, but also for the testing and measuring techniques. The International Council on Large Electric Systems (CIGRE) and the International Electrotechnical Commission (IEC) have established a coordination group (JICCG) in order to define the standards which should be adapted to the higher voltage level and which should be elaborated [1]. At first this group tried to define a definition for the highest voltage level and came to a conclusion, that these future voltage levels should be mentioned Ultra High Voltage (UHV). For AC voltage this means rated voltage level above 800 kV, for DC voltage it means voltages in the range from 600 kV to 800 kV.

The JICCG elaborates a road map to define the work which should be done within CIGRE and IEC and to allocate the different tasks to the relevant Technical Committees of IEC (TC) or the relevant Study Committees of CIGRE (SC). One of the outcome of this work was, that for AC systems the existing standards cover most of the points relevant to UHV, but some adjustments or amendments are necessary in particularly for the insulation coordination [2 - 3] and testing and measuring techniques [4 - 5]. For DC systems the situation was quite different, because only a limited number of standards exists and therefore a new TC within IEC was created titled as High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV, with the scope of standardization in the field of HVDC transmission technology above 100 kV, dealing with general standards, design, technical requirements in the field of HVDC equipment, construction and commissioning for acceptance, operation and maintenance as well as system control and protection.

However the JICCG agrees that all tasks which are dealt with in existing Technical Committees should be handled under their responsibilities, and therefore the values of the test voltages regarding insulation coordination of UHV were defined in IEC TC 28 [3] and IEC TC 42 established a new Working Group WG 19 with the title “Adaptation of TC 42 standards to UHV test requirements”. Also in CIGRE new Workings Groups within SC C4 System Technical Performance and SC D1 Materials and Emerging Test Techniques were established to elaborate the scientific basis for the IEC standards.

The following contribution will be related only to the challenges concerning testing and measuring techniques for UHV equipment.

II. UHV REQUIREMENTS
The test voltages for UHV equipment are very high and this requires test voltage sources with high rated voltage. The increase of the test voltage is combined with the increase of the physical size of the equipment even for gas insulated
The increase of the equipment and test voltages leads to an increase of the whole test set-up and its inductance. Particularly for the generation of a standard lightning impulse the inductance of the complete test circuit is very important relating overshoot and front time of the impulse.

The large dimension of the equipment influences also the wet tests, because the generation of an artificial rain according to the requirements in the standards is very difficult. The water jet should not be concentrated in order to prevent a flashover but the large distance between the rain equipment and the equipment under test could not be coped with a sprayed jet. Here some solutions are required taking into account the feasibility of the tests, the costs of the test equipment and the reliability of the test results.

Another subject is the impulse shape of standard switching impulse voltage. The increase of the voltage level and the limited ratio between rated power frequency voltage and required switching impulse voltage asks for a careful evaluation of the switching impulse shape, because the breakdown voltage of large air gaps depends on the time to peak of the applied switching impulse voltage.

III. LIGHTNING IMPULSE VOLTAGE

The actual version of IEC 60060-1 [4] will introduce a test voltage function which considers the influence of the overshoot on the test voltage level. The former version of the same IEC standard defines only a frequency or a time duration concerning the overshoot as parameter for the evaluation of the test voltage. Fig. 1 shows this definition.

The introduction of the test voltage function allows now to evaluate the test voltage as function of the frequency or time duration of the over shoot without this former sharp frequency limit. The test results of a European Research Project were the basis for this test voltage function as shown Fig. 2 [6]. However the discussion was going on concerning the allowed overshoot value. The former value was 5 % and now is changes to 10 % [4], but for UHV equipment this limits are mainly not achievable due to the large circuit and its inductance.

The revision of IEC 60060 also includes a description of the evaluation procedure for the test voltage taking into account that nowadays more or less all recording instruments are based on digital recorders. Now instead of a “mean curve” as shown in Fig. 1 a well defined base curve could be calculated, based an the assumption that the standard lightning impulse shape is given by the superposition of two exponential functions. The test voltage can then be calculated taking into account the influence of the test voltage function in such a way, that the superimposed oscillations is removed from the recorded curve $U(t)$, filtered according to the test voltage function and the filtered resulting curve added to the base curve according to the following equation:

$$U_{\text{test}}(t) = U_{\text{base}}(t) + k(f) \cdot (U(t) - U_{\text{base}}(t))$$  \hspace{1cm} (1)
The large dimensions of UHV equipment and the relevant test circuits asked again for a compromise between front time and overshoot value. Due to the increasing physical size of the test circuit the inductance increases and then the required front time of a standard lightning impulse can in many cases only be reached by acceptance of a higher overshoot value. Here the new established Working Groups within IEC and CIGRE may found a solution taking into account the different requirements concerning the steepness of the front time and the value of the test voltage depending on the equipment under test e. g. insulators or transformers.

IV. SWITCHING IMPULSE VOLTAGE

The peak time of a standard switching impulse was defined according to the breakdown voltage of air gaps. According to [2] the high voltage tests for equipment up to a rated voltage of 245 kV were power frequency and lightning impulse tests, above 300 kV switching and lightning impulse tests were required. The following experimental results were the basis for the determination of the standard time to peak for switching impulses [8].

![Figure 4. Flashover voltage at switching impulses as function of time to peak](image)

It can be clearly recognized that for a distance up to 7 m the standard time to peak of 250 μs is very closed to the time of the minimum flashover. In [3] the distances for rated voltages above 800 kV are much larger and therefore the actual time to peak for standard switching impulses does not correspond with the minimum flashover voltage of air gaps. The consequence could be the extension of the time to peak for testing of UHV equipment with switching impulses.

V. MEASURING TECHNIQUE

The test of UHV equipment requires according to [2] lightning impulse voltages up to 2700 kV and switching impulse voltages up to 1950 kV. Assuming a certain safety margin and development margin the UHV manufactures should be able to measure lightning impulse voltages up to about 3000 kV and switching impulse voltages up to about 2300 kV. The preferred calibration method for voltage measuring devices is the comparison method [5]. The voltage divider to be calibrated is connected in parallel with a reference divider, but the rated voltage of the reference divider could be only 20% of the rated voltage of the voltage divider under test. Today reference divider with a rated voltage up to 500 kV are available and therefore a voltage divider with a rated voltage of 3000 kV could not be calibrated according the relevant standard. The small difference may be acceptable, but a larger problem is the check of linearity of such a large divider. This problem is not now, but became again a point of interest with the testing of UHV equipment. In former times a solution was proposed by comparison the charging voltage of the impulse generator with the output voltage of the generator measured with the voltage divider under test. This ratio is usually named efficiency factor and if this factor will be constant over the up to the rated voltage of the voltage divider, it can be assumed that the voltage divider is linear. This is only valid if the impulse generator output voltage depends linear on the charging voltage within the required uncertainty of the voltage divider.

Another possibility is the calibration of the single components of a voltage divider up to its full rated voltage. But here again the linearity should be checked on the complete assembled device.

The use of a field probe may be a solution for the linearity check. The field measures the electric field and the field changes linear with the applied voltage assuming that no discharges influence the electric field distribution in the area of the electric field probe. In [9] such a device was used to check the transfer behaviour of a voltage divider, but it can also be used for a linearity check of a voltage divider up to the rated voltage.

The proximity effect on high voltage measuring equipment is well known and mentioned in the standard [5]. However due to the large dimension of the UHV equipment and the related generators and measuring devices it may be necessary to take the proximity effect into account in such a way, that the measuring device will be calibrated at a certain position in the laboratory and should be fixed in this position in order to take care of this proximity effect. In addition the equipment under test should have a distance from the measuring devices which is high enough to prevent an influence on the measuring uncertainty. These requirements could be not fulfilled in all laboratories, particularly if UHV equipment like transformers or disconnectors have to be tested. For DC equipment the voltage divider should be designed without any metallic flanges to prevent surface leakage.
VI. TEST TECHNIQUE

The points related to test techniques of UHV equipment are mainly related to the large dimensions of the UHV equipment. The generation of the test voltages are not difficult, however for combined and composite tests, e.g. switching impulse and lightning impulse on open contacts of a circuit breaker, the mutual influence of the different voltage sources may be taken into account.

The critical test is actually the wet test. The standardized procedure requires a rain with 45 ° deg, so that a rain equipment fixed on the ceiling will not be sufficient. Besides the required large dimension the generation of the correct water amount may be very difficult. The water should not be supplied in a jet, but in droplets. However the generation of droplets with an angle of 45 °deg related to the equipment under test over a large distance which is required due to the high voltage is very difficult. Fig. 5 shows a DC disconnector as an example to give an impression about the size and the required area which should be supplied by the rain test equipment.

![Figure 5. Dimension of a DC disconnector for 800 kV [8]](image)

According to Fig. 5 the area for the rain will be about 500 m² if the complete disconnector should be tested. A possible solution could be to test each insulator alone but again the test of the moving part of the disconnector requires at least the length of the rain equipment of more than 30 m. The problem with the distance between equipment under test and the generation of standardized rain within such large distance remains.

VII. CONCLUSIONS

The development of UHV equipment should be combined with the development of the related test techniques. Most of the existing standards need only an extension up to the voltage level of the UHV equipment. For some particular points research work are necessary.

It should be evaluated if the extension of the front time or the acceptance of a large overshoot for lightning impulse tests could be accepted without weakening the test requirements.

It should be evaluated if the time to peak should be adapted for test of UHV equipment with switching impulse voltages.

It should be defined a linearity test for high voltage dividers with very high rated voltage.

It should be defined a wet test for UHV equipment with large dimension taking into account the distance between the rain equipment and the equipment under test due to the high test voltage.

CIGRE and IEC Working Groups are dealing with these topics and will deliver some results in the future.

REFERENCES

[1] JOINT IEC-CIGRE COORDINATION GROUP (JICCG) see Internet website of CIGRE and IEC
[8] International Symposium on Standards for UHV Transmission, New Delhi, India, 2009