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Challenges to perform standardized dielectric tests of UHV arrangements

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SUMMARY

The voltage stresses over the external insulation can be in various waveforms, such as lightning impulses, switching impulse, AC and DC voltages. The strength of the external insulation is influenced by ambient parameters such humidity, air density, pollution, among others. To be able to fulfil such requirements equipment and support insulator arrangements of the size of tenths of meters with large corona top electrodes are required for UHV applications. Consequently, several technical challenges emerge when standard dielectric tests of external insulation of UHV equipment and/or connection arrangements are going to be executed. The aim of this paper is to outline the difficulties and limitations to perform standardized dielectric tests for UHV arrangements.

Some of the critical challenges to perform standardized tests of UHV arrangements are: to find high voltage laboratories designed to provide the voltage level required for the different tests, like, switching impulse, lightning impulse, AC and DC tests, the size of the laboratory, the capability of the generators to withstand breakdowns, the repeatability of the tests, among others. For UHV applications, the laboratory should count with a Marx generator able to generate switching impulse voltages of the order of 2700 kV, high lightning impulse voltages, and direct current generators designed to withstand breakdowns. The size of the laboratory shall be enough to warrant clearance distance towards walls or any nearby objects that are not part of the set-up to test. For outdoor installations standardize rain tests under different voltage stresses are required. Therefore, the rain ramp shall be capable to wet the total size of the UHV arrangement with the vertical and horizontally intensity recommended by the standards.

Due to limitations of size of the laboratories and the high voltage levels to test, it is required to implement new methods to perform and analyze the test results. Those methods can be the use of cameras to identify breakdown points, to determine the acceptability of breakdowns towards and from other objects within the laboratory, to accept tests at different higher rain intensities than the recommended in the standards. However, the major challenge to be overcome is the lack of repeatability and reproducibility of the tests.

KEYWORDS

Generator, high voltage, methods, testing.

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1. INTRODUCTION

The high demand of electricity and the remote location of energy sources respect to feeding points have increased the installation of ultra-high voltage transmission systems (UHV). UHV systems can be either AC systems with voltages above 800 kV or DC transmission systems with voltages up to 1100 kV. The equipment and clearance distances designed to operate on such a high voltage transmission levels shall be able to withstand higher dielectric stresses.

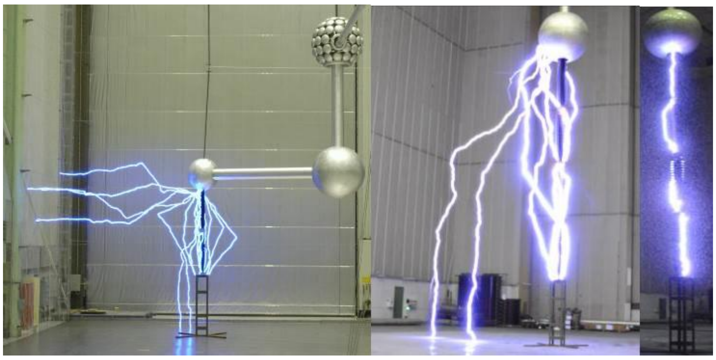
The voltage stresses over the external insulation can be in various waveforms, like lightning impulses, switching impulse, AC and DC voltages. The strength of the external insulation is influenced by ambient parameters as humidity, air density, and pollution, among others. To be able to fulfil such requirements, equipment and support insulator arrangements of the size of tenths of meters with large corona top electrodes are required. These arrangements to be used in outdoor stations will be subject to natural precipitation as rain, ice and snow. Consequently, technical challenges arise when standard dielectric tests of external insulation of UHV equipment and/or connection arrangements are going to be executed. The aim of this paper is to outline the difficulties and limitations to perform standardized dielectric tests for UHV arrangements.

2. UHV REQUIREMENTS AND LIMITATIONS

Some of the critical challenges to perform standardized tests of UHV arrangements are: to find high voltage laboratories designed to provide the voltage level required for the different tests, like, switching impulse, lightning impulse, AC and DC tests; the size of the laboratory; the capability of the generators to withstand breakdowns and the repeatability of the tests, among others.

Test voltages for UHV equipment and arrangements can be up to 2700 kV for switching impulse, and 2500 kV for lightning impulse and DC and AC generators able to withstand up to 1.6 times the nominal voltage. Therefore, voltage sources with high rated voltages and measuring systems capable to handle such measurements are required.

To be able to withstand high over-voltage stresses, equipment and electrode arrangements of size of tenths of meters are designed on UHV applications. The increase of the size of the test object and the test voltages leads to an increment of the whole test set-up. The size of the laboratory shall be enough to warrant clearance distance towards walls or any nearby objects that are not part of the set-up to test.



(a) (b) (c)

Figure 1. Photograph of UHV indoor test under switching impulses. From left to right: (a) 1.6 m diameter sphere with 10.6 m insulation, and (c) sphere of 2.0 m diameter with 8.5 m insulation under rain condition, all over pedestal of 2.4 m. Notice that the proximity effect of grounded planes is observed on the trajectory of the discharges.

Due to the physical size of the test set-up, the total inductance may increase and therefore the required front time of a standard lightning impulse can in many cases only be reached by acceptance of a higher overshoot value.

The size of the test set-up influences also the rain test. The generation of artificial rain under the conditions indicated in the standards is very difficult. The rain ramp shall be capable to wet the total size of the UHV arrangement with the vertical and horizontally intensity recommended by the standards. In addition, the ramp should be located at sufficient clearance distance to not affect the testing object.

2.1 HIGH VOLTAGE EQUIPMENT AND MEASUREMENT

2.1.1 IMPULSE GENERATOR AND MEASUREMENT SYSTEM

The generation of lightning and switching impulse voltages is usually performed by a Marx generator. The output voltage of the generator is generally restricted by the size of the generator, i.e. number of stages, as well as, the distance between the top electrode and the external surroundings of the generator. For indoor testing, such a clearance distance will be restricted by the size of the laboratory, i.e., distance to walls and roof. Even though the equipment is designed to generate very high voltages, shorter clearances, and unevenness and/or under dimensioning of the top electrode of the Marx generator can generate undesirable breakdowns during testing.

(a) (b) (c)

Figure 2. (a) and (b) Impulse generator and voltage divider. Limited distances to walls, roof and ceiling marked. (c) Breakdown to ceiling from Marx generator top electrode during testing and toroidal electrodes type voltage divider.

Measurement System

Impulse voltages are measured with dividers such as damped capacitive dividers or resistive. For UHV testing the dimensions of the test object are usually very large, require large distances between test object and the grounded parts of the test area and large test loops with a high inductance. For practical reasons the inductance cannot be reduced by means of low-inductive connections. Furthermore, in indoor laboratories the available space is limited and therefore the proximity effect shall to be taken into account.

The calibration of the measuring system requires comparative measurements with a reference measuring system as recommended by IEC 60060-2 [1]. The voltage divider to be calibrated is connected in parallel with a reference divider; the rated voltage of the reference divider could be only 20% of the rated voltage of the voltage divider under test. For test voltages of above 2400 kV for switching impulse voltage and about 3500 kV for lightning impulse, requires reference measuring systems for 500 kV or 700 kV. However, the rated voltage of reference measuring system is limited worldwide and/or may not exist, therefore other non-standardize test methods shall be used to be able to calibrate and test the linearity of the divider.

According to IEC 60060-2 [1] in order to use the voltage divider up to its nominal voltage a linearity test of the whole system under conditions that represent the real test field is required. Due to the high test voltages, the relative low voltage of the reference measuring system and the possible discharges within the voltage divider may lead to a change of the voltage divider ratio. Therefore, it might be required to check the linearity of the measuring system before testing.

The use of a field probe could be a solution for the linearity check of the measurement system. The field probe 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.

Due to the reduce space in the laboratory and the large size of the test set - up, at times, it is required to move the divider in the test area. To move the divider may influence the transformation ratio of the impulse voltage divider due to the proximity effect. The large dimensions of the test system components and the test object proximity shall be taken into account during the calibration and the measurements. The measuring device shall be calibrated at a certain position in the laboratory and should be kept in this position in order to take care of the proximity effect.

2.1.2 DC GENERATOR

DC test voltages for testing UHV set-ups are mainly produced indirectly by rectification of high AC voltage. In order to get a higher DC voltage than the peak of the AC supply voltage, DC generators are cascade rectifier e.g. Cookroft-Walton cascade. Such generators consist mainly of an AC transformer, two capacitor columns (grading capacitor and smoothing capacitors) connected with rectifier elements, a resistive and a capacitive voltage divider. The test object is connected via external damping resistors. The damping resistors are designed to protect the DC generator against transient overvoltage occurring after a possible breakdown of the test object.

For UHV test there is a high risk of breakdown of the test object, which may affect the damping resistor of the generator. In case of damage of the damping resistor, the reliability and repeatability of the test, such as continues voltage test or linearity test might be affected.

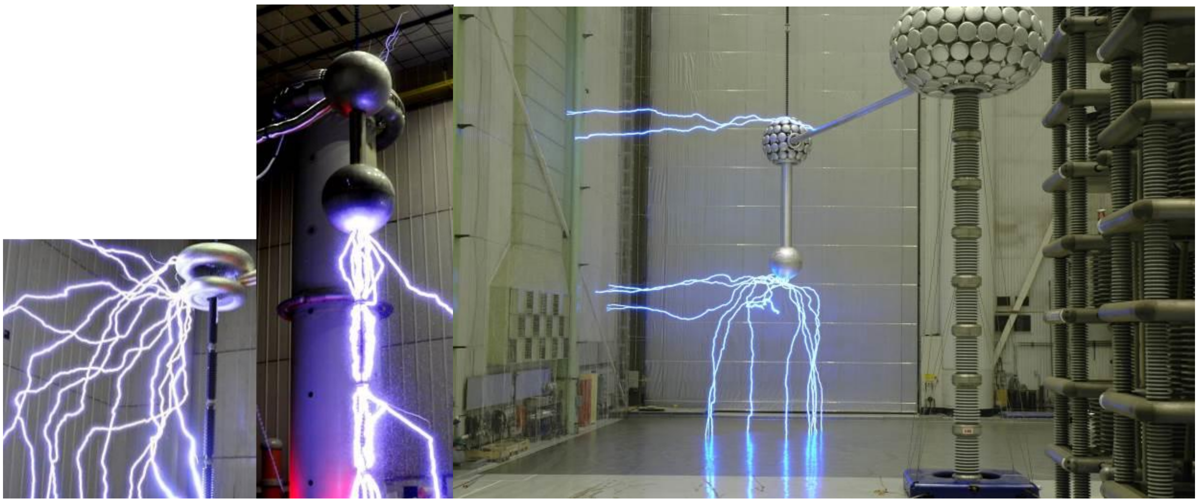
Furthermore, the electric field strength at the top of the generator shall be controlled by the dimension of the top electrode. The size of the top electrode is very important due to the long duration of the applied voltage. For UHV DC test special attention shall be given to the environment conditions, because the high DC field may attract particles or insects. These particles accelerate towards the highest electric field and can generate partial discharges as well as breakdowns.

Figure 3. DC generator and damping resistors. Critical distances to walls, roof and ceiling marked.

2.2 TESTING METHODS

High voltage laboratories perform breakdown or withstand tests to obtain the statistical distribution desired, e.g. “up and down method” and/or “constant voltage experiment”, [2] among others. Some test procedures have been automated and test equipment manufacturers offer complete measuring and control systems. For certain tests, the program is fed into the control equipment, preselection of rate of rise of voltage and the number of individual tests and the random values of the breakdown voltage are measured digitally. However, for UHV arrangements limitations described above, such as proximity of test object and testing equipment, partial discharges, streamers and/or breakdowns from other parts of the set-up different than the test object shall be taken into account because they might affect the test method, the results and the interpretation.

Testing methods to determine breakdown probability of UHV arrangements might be affected by the undesirable discharges and pre-discharges from high voltage Marx generator and/or divider. Therefore, the designer shall decide how to handle such events during the test procedure. In order to avoid interruptions on the test method and ensure a sample statistically valid the designer shall consider to increase the size of the sample, design smooth electrical connections capable to withstand the voltage stress and consider to improve all points that can generate electrical stresses different than the test object, among others. Electric static field calculations are a good tool to identify critical points of the test set-up that might need to be improved.



(a) (b) (c)

Figure 4. Competitive gaps during UHV testing. (a) Breakdowns from shielding of equipment HV shield. (b) rain test – notice streamers and breakdowns from top electrode and marx generator. (c) weak connection tube HV testing

One option to perform breakdown test can be the use of cameras. To be able to determine the validity of each shoot of the test, the designer can install cameras or video system to identify for each applied impulse if breakdown or pre-discharges happened. The camera system shall be capable to give information about the origin of the breakdowns, i.e., starting and ending points and the presence of pre-discharges. In case discharges happened in locations different than the test object, the shoot shall be repeated under the same voltage conditions as the previous one. At the moment to calculate breakdown probabilities, breakdowns from generator, divider or connections shall be removed from the test sample. In case the generator, divider or connections provides several breakdowns, it shall be considered to improve the top electrode geometry and its connections before continue testing. A limited number of breakdowns shall be accepted during test to ensure the continuity and repeatability of the test.

Pre-discharges especially streamer discharges from the generator or divider towards any ground point of the test area behave as competitive discharges with the test object. In previous investigations performed by the authors of this manuscript [3], it has been reported that the effect of competitive gaps may reduce the streamer inception voltage of the test object; however it does not significantly affect the breakdown voltage of the test arrangement. Therefore, if the interest of the test is to study the breakdown voltage probability of the arrangement, there is not significant effect from the other competitive gaps; however if the study is focus on partial discharges and/or streamer inception, the results can be misled by the test set-up.

2.2.1 RAIN TEST

As the simulation of natural rain in the laboratory is concerned, at present only tests under standard rain conditions (rain intensity rate 1.5 mm/minute, water conductivity 100 µS/cm) are covered in the present edition of IEC 60060 [4], while higher intensities were mentioned in the previous editions, even if limited to AC tests. Standardized rain tests under switching impulses are rather complicated especially for UHV levels. Investigations of wet positive switching impulse breakdown of support insulators and pedestal with and without top electrode arrangements are summarized in [5]. From the experimental point of view, difficulties were observed to obtain a standardized rain for set-ups larger than 10 m in a conventional high voltage laboratory. Unfortunately, rain tests are rather complex to carry out and it is not straight forward to control all the parameters which can affect the results, such as circuit parameters, test object size, type of nozzle, droplet size, surface conditions, water resistivity, water temperature, tolerance, intensity and specially the uniformity and repeatability of wetting. All this uncertainties can influence the results, affecting especially the repeatability and reproducibility of the test. The lack of repeatability and reproducibility of wet tests due to the difficulties for testing and measuring procedures is well known and remains as a critical step for acceptance test or performance test.

According to [5] to perform the tests according to IEC standards for arrangements longer than 10 m raised the following difficulties:

1. To be able to reach the test object located at a distance from the ramp, the rain intensity must be increased and it can become rather high.
2. The longer the test object, the more difficult to control the distribution of the spray intensity along it. To obtain a uniform distribution of the vertical and horizontal rain components along the test object is not easy to regulate.

A possible solution for UHV tests would be to increase the required tolerances. According to the work performed at CIGRE Working group D1.50 [6], the increase of the tolerances on the precipitation rate from 1 mm/minute to 3 mm/minute for both the average and individual measurements was proposed, assuming that this condition could be reached more easily by the laboratories. However, breakdowns towards the rain ramp shall be handled by the test designer.

3. CONCLUSIONS

Testing methods of UHV arrangements and equipment are still under development. There are several challenges that need to be taken into account and that do not have standardized solutions yet. Improvements are required not only from test equipment manufacturers on the design of DC generators capable to withstand breakdowns, the improvement on top electrodes of generators to be able to work in its limit in restricted size laboratories, calibration of measurement equipment, but also on the international working groups on standardization, in proposing testing and calibration methods and study how to warranty the reliability and repeatability of the tests, e.g., rain tests.

The testing methods shall be re-evaluated taking into account the conditions of high voltage laboratories worldwide, for instance taking into account the competitive gaps on indoor tests, on how to handle breakdowns from points different than the test object during breakdown probability tests, on accepting higher intensity of water on rain test, on increasing tolerances of wet testing, among others.

It is important to outline that to plan, execute and analyze UHV tests of equipment or arrangements, the knowledge of skill high voltage engineers are required.

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