Upgrade of a High Voltage Laboratory

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ABSTRACT: In Graz (Austria) exists a High Voltage Laboratory for more than 40 years which belongs to Graz University of Technology. Beside a shielded hall there is also an outdoor test field for simulation thunderstorms with artificial rain. In the original version it was possible to generate AC voltages up to 1200 kilovolts, DC voltages up to 1100 kilovolts and lightning strikes up to 6 meter length. With the indoor dimensions of 35 meter length, 25 meter width and 21 meter height it was possible to handle all these voltages safe and without problems. In the last ten years countries like China, India or Brazil starts to install UHV (Ultra High Voltage) overhead lines which must be protected against lightning hazards of course. The necessary test levels for such components exceed the mentioned voltage levels. This increasing demand for high voltage testing in the UHV range was the reason for the upgrading of the laboratory to AC voltages up to 1500 kV, DC voltages up to 1500 kV and also the impulse generator was modified to produce lightning strikes up to 10 meters length. This paper will show the challenges of this upgrade and present examples for using these voltage levels.

INTRODUCTION

During the last 10 years the demand for testing high voltage equipment increased steadily. Especially the need for UHV (Ultra High Voltage) tests plays an important role since countries like China, India or Brasilia want to install UHV overhead lines. Many of the High Voltage Test Laboratories (indoor test fields and outdoor test fields) in Europe were built in the 1960 and 1970 and usually they were sized to test high voltage equipment up to the 765 kV three-phase AC range. Because in that period nobody thought that this voltage level will be exceeded, especially in Europe. The size of High Voltage Laboratories is determined by the positive switching impulse level due to the biggest clearances which is needed for this voltage shape. According figure 1 for air gaps larger one meter the positive switching impulse leads to the lowest breakdown voltage (even lower than the AC system voltage!). Additional to that the standardized positive switching impulse voltage (250/2500 µs) is the critical dimensioning parameter only up to 7 meter insulating height of a device. For higher equipment the lowest breakdown voltages will be reached with positive switching impulses and time to crest Tcr divergent from the standard switching impulse with 250 µs time to crest Tcr, figure 2. If we look into the standard (IEC 60071-1, insulation coordination) the highest test voltages for 765 kV AC transmission equipment are 2100 kV for lightning impulse (1.2/50) and 1550 kV for switching impulse (250/2500).

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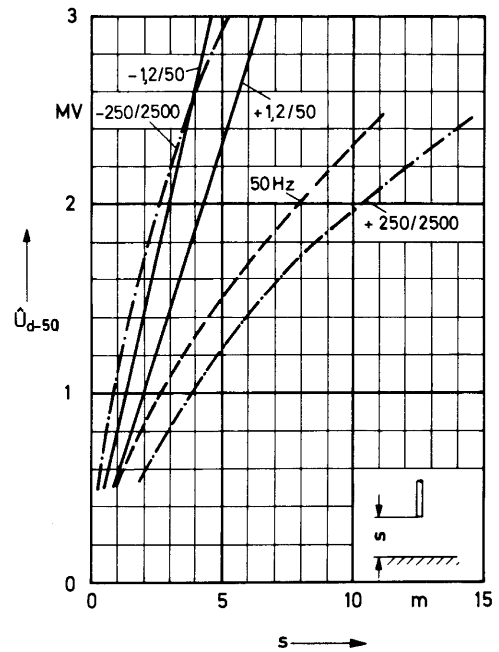

Figure 1: 50 percent breakdown voltage $\hat{U}_{d-50}$ versus gap distance s for different voltage shapes (rod-plate arrangement), according [1]

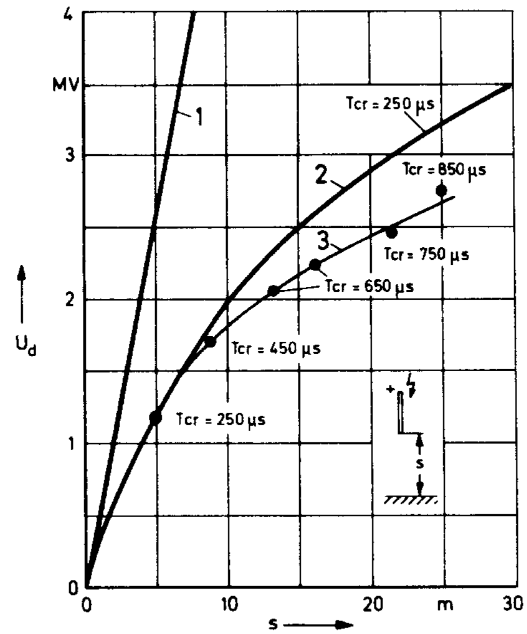

Figure 2: 50 percent breakdown voltage U_d versus gap distance s for rod-plate arrangement, according [1]
1…+1.2/50 µs, 2…+250/2500 µs, 3…curve with minimum strength

The development of higher transmission system voltages requires also higher test voltages. At the moment there is need for testing with positive switching impulses up to 2000 kV and higher, AC voltages up to 1200 kV and higher and DC voltages up to 1500 kV and higher. If we look to figure 2 clearances of 10 meters and more are necessary for testing with 2000 kV positive switching impulse. But not only clearances have to be handled also the enormous dimensions of the test objects. For instance a wall bushing for 800 kV HVDC (High Voltage Direct Current) transmission lines has an overall length up to 22 meters and more. That means for switching impulse test up to 2000 kV of such a wall bushing there is a footprint of 40 meters to 20 meters necessary at least. And this only for the test object and for clearances additional space is needed for the impulse generator.

HIGH VOLTAGE LABORATORY GRAZ

Our High Voltage Laboratory in Graz/Austria (Graz University of Technology) has indoor dimension of 35 x 25 x 21 meters (Length x Width x Height) and a footprint of 50 x 25 meters (Length x Width) for the outdoor test field. It was built in the late 1960s at the southeast outskirts of Graz, photo1.

Photo 1: High Voltage Laboratory, Graz University of Technology

It was originally equipped with a 1300 kV, 10 mA DC generator, photo 2, a 1200 kV, 800 kVA (15 minutes) AC generator, photo 3 and an impulse generator with 3250 kV charging voltage, 162,5 kJ for generating lightning flashes up to 6 meters, photo 4.

Photo 2: Former 1300 kV DC generator, Graz University of Technology

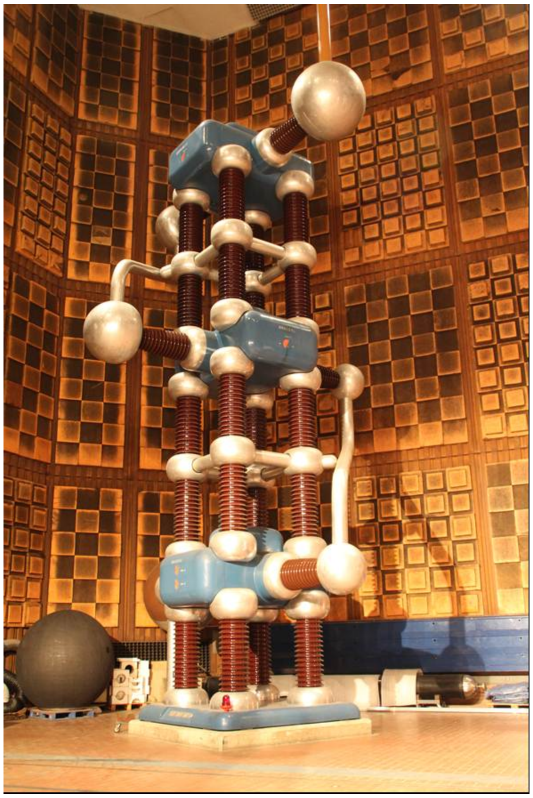

Photo 3: Former 1200 kV AC generator, Graz University of Technology

Photo 4: 3250 kV impulse generator, Graz University of Technology

For 30 years all test inquiries could be done. Then the demand for testing with higher test voltages increased. Therefore we made considerations how to install generators with higher voltage and power in the given laboratory with its limited dimensions. This refurbishment process start with the DC generator in 1999, then we made the upgrade of the impulse generator in 2010. Finally the AC generator was replaced in 2013.

UPGRADE OF DC GENERATOR

Due to the request for higher DC test voltages than +/-1300 kV and also the demand for fast polarity reversal tests we replaced the old DC generator. As our floor is not suitable for air cushion movement we used the trolley of the old plant and built up the new DC plant on it. This trolley moves the DC generator from the parking position to the test position on rails and vice versa. The features of the new DC plant: +/-1500 kV, 20 mA (continuous) and 30 mA (short-term), polarity reversal within 5 seconds up to +/-1000 kV. Photo 5 shows the new DC generator in test position.

Photo 5: New 1500 kV DC generator in test position, Graz University of Technology

The challenge for this DC generator exchange was the limited clearance (about 4.5 meters). To withstand +/-1500 kV with the mentioned limitation it was necessary to oversize the head shielding of the new DC generator. Furthermore this heavy head shielding had to be stabilized with straining rods to allow the movement between parking and test position.

UPGRADE OF IMPULSE GENERATOR

The impulse generator is the only plant which can be moved to the outside test field also by means of rails. As the inquiries for testing with switching impulses up to +/- 2000 kV increases there was need for upgrading of the generator. This was achieved by using a head shielding, photo 6.

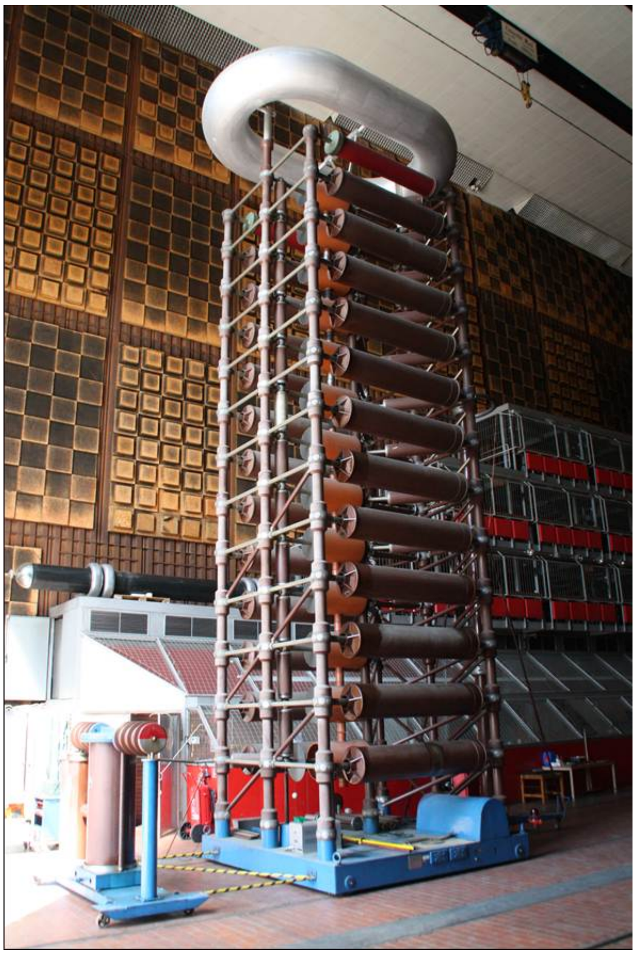

Photo 6: Impulse generator with head shielding, Graz University of Technology

The challenges for this impulse generator upgrading were on the one hand the limited weight what could be put on the head of the generator, to let him be movable (drive to the outside test field through the doors). On the other hand for generating lightning flashes up to 10 meters (with 2000 kV positive switching impulses 250/2500 µs) there is need of sufficient clearances. So we had to remove some trees in the outsides test field. Like many other cities Graz want to improve its air quality ("Fine-dust-problem"), therefore it is not allowed to remove healthy trees with particular size. It was really a hard task to convince the responsible people to do this!

UPGRADE OF AC GENERATOR

The former three stages 1200 kV AC generator was well designed to allow in a space-saving manner:

1) Generating up to 1200 kV in cascade connection (one phase), photo 7.

2) Higher output power up to 400 kV with the help of parallel connection (one phase).

3) Three-phase high voltage generation up to 693 kV (phase to phase) in triangle connection.

4) Generating of high AC voltages in the frequency range 16 Hz to 150 Hz.

5) No footprint for the measurement by fixing the capacitive divider on the ceiling.

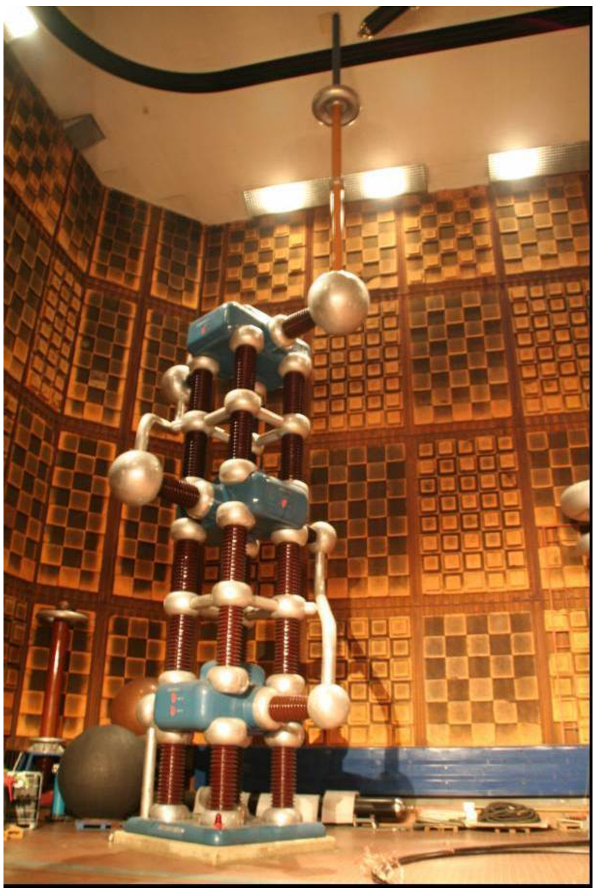

Photo 7: Former 1200 kV AC generator, Graz University of Technology

Over time various components failed and there were no spare parts available. Furthermore the demands of customers according partial discharge behavior, fast switching off in case of breakdown and higher output voltage and power increases and so the idea of replacing the old generator was born. The challenges for this replacement were manifold. It starts with the problem of weight. While the weight of the old generator was 41 tons a new generator with something more output voltage and power has about twice the weight. So the foundation had to be reinforced. The problem is the accessibility of this foundation, it is accessible only by an hole of 70 to 70 centimeters. Consequently all equipment must be small enough to be possible for binging in if you don't want to open the laboratory floor. The next item was the setup of the new AC generator. The common method of construction for "transformer-type" AC generators is to place the stages successively, photo 8.

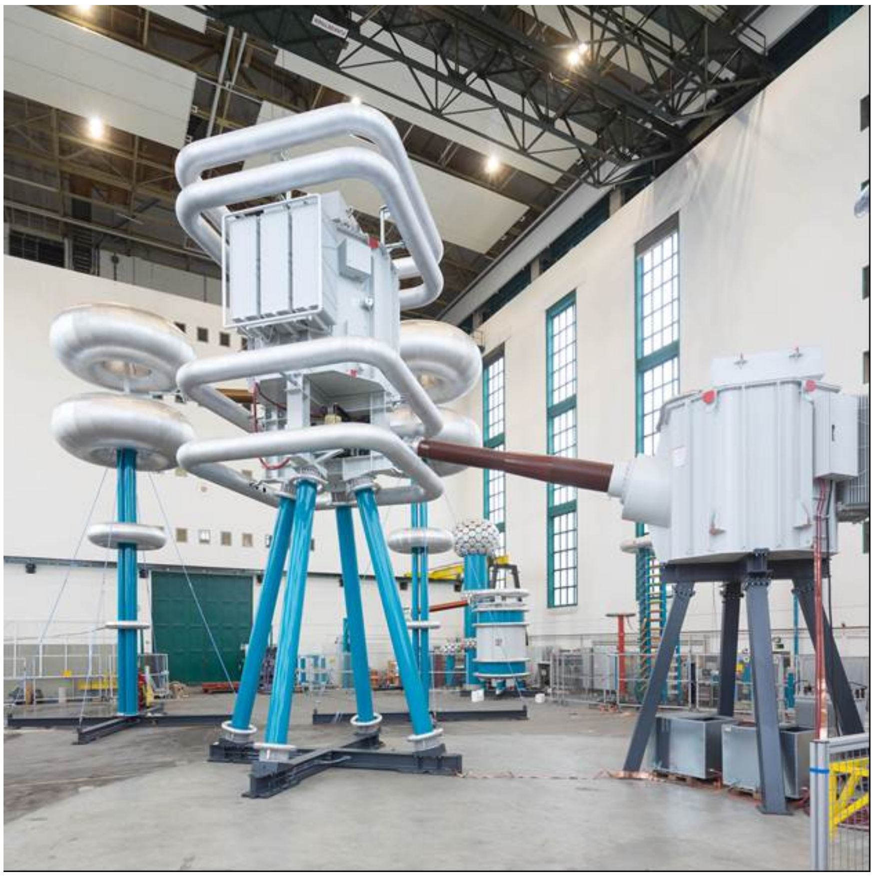

Photo 8: Common setup of two 750 kV AC transformers, Highvolt Prüftechnik Dresden, Germany

As can be seen in photo 8 the successively arrangement of the two stages needs a certain footprint. A reduction can be reached by setting one above the other. But this simple consideration needs an accurate calculation of the field distribution to avoid electrical field strength exceeding, especially when the clearances are limited. We also made the whole setup rotatable to allow the bushings looking to the back side of the laboratory in parking position. With this kind of arrangement it was possible to install a new AC generator with higher output voltage and power which needs not much more space than the original one, photo 9.

Photo 9: New 1500 kV AC generator in test position with the 1500 kV divider, Graz University of Technology

Another challenge is the measurement of AC voltages up to 1500 kV. As can be imagined a divider for this voltage range is a huge piece. To avoid the usage of this divider for voltages up to 1100 kV a new measurement technique was developed. Therefore the output voltage is calculated by measuring the voltage of the lower stage, with the help of a capacitive divider build in between the two stages, and coupling out of the voltage value of the upper stage by using the test tap of the upper bushing. The voltage value of the upper stage is transmitted with the help of optical fiber.

TESTING EXAMPLES

Since we use the new test equipment the test objects are getting bigger and bigger. Due to the limitation of laboratory dimensions we have to use sometimes tricky test setups for reaching sufficient clearances. Photo 10 shows a test setup of 820 kV transformer bushing. This long bushing had to be placed diagonally in the laboratory to reach enough clearances.

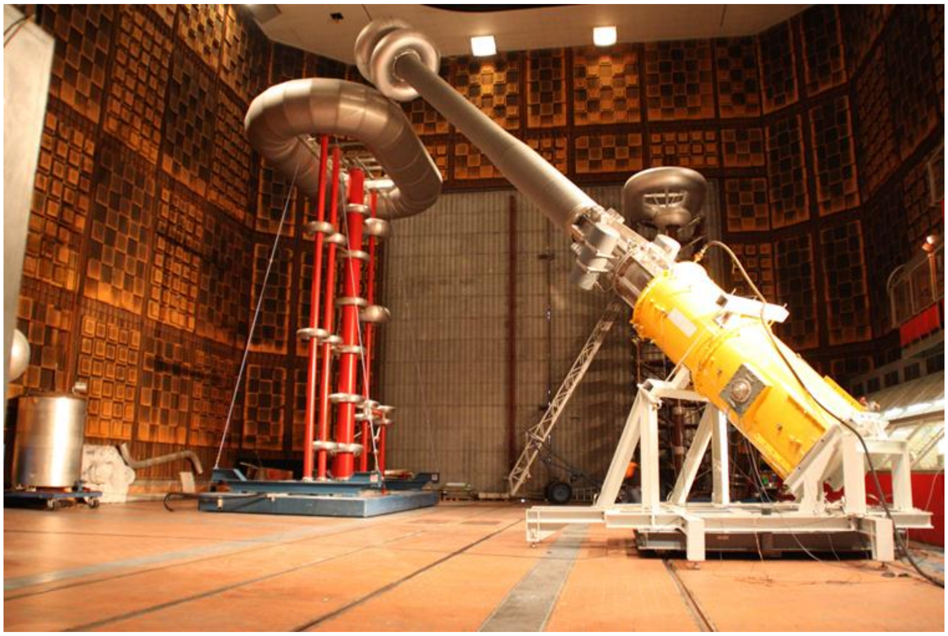

Photo 10: DC test of transformer bushing, Graz University of Technology

Another example is the switching impulse test of 800 kV wallbushing. As the clearances for positive switching impulses up to 2000 kV are about 10 meters, figure 1, we had to perform this test in the outside test field. In photo 11 the test arrangement for this switching impulse test can be seen. Due to the length of the test object (about 22 meters) the needed place for the generator and the required clearances the whole outdoor test field footprint was necessary.

Photo 11: Switching impulse test of wallbushing, Graz University of Technology

To demonstrate the protection effect of a faraday cage photo 12 shows a lightning strike of 2 million volts into a car with people. To avoid long reverberation times of the lightning strike the inner wall of the high voltage laboratory is covered with acoustic sheets.

Photo 12: Lightning strike into car, Graz University of Technology

CONCLUSION

Upgrading of an existing high voltage laboratory presents challenges in itself. Not only electrical problems like clearances have to be considered. Usually many mechanical problems must be solved. As new generators with higher output voltage and power have also higher weights the handling of this inside an existing laboratory with limited floor loading must be taken in account. And also non-technical issues (e.g. removing trees in an outdoor test field) can be a big problem.

REFERENCES

[1] D. Kind, H. Kärner “Hochspannungsisoliertechnik” ISBN 3-528-03812-8