

# Experience from First 800 kV UHVDC Long-term Test Installation

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**Abstract**--With one 800 kV UHVDC transmission project already in execution phase, second in bidding and third one in preparation of bidding; it can very well be concluded that 800 kV DC is now a established voltage level for bulk power transmission over long distances. Already realising such a need, ABB not only started with the development for 800 kV equipment to make this possible; but also planned for a long time test circuit installation to establish a confidence in such a voltage step, the new technology and the newly developed equipment. The long term test circuit installation has been energised at 855 kV<sub>DC</sub> since November 2006 at STRI, Sweden and has served well its purpose in providing final qualification for the newly developed products and boosting confidence in 800 kV UHVDC technology with several utilities around the world. This paper presents the experience from this first 800 kV UHVDC test installation in the world.

**Key Words**--800 kV, Bulk Power Transmission, Experience, HVDC Transmission, Test Installation, UHVDC, UHV Transmission.

## I. INTRODUCTION

Due to involved economics, interest in application of higher DC transmission voltage than presently used (i.e. 600 kV<sub>DC</sub>) has increased considerably in recent years to meet demand for clean and renewable energy from remote hydro-generation plants. 800 kV Ultra High Voltage Direct Current (UHVDC) Transmissions are economic attractive for bulk power transmissions, say above 5000 – 6000 MW, over long distances, say above 1000 – 1500 km. [1]

Xiangjiaba – Shanghai  $\pm$ 800 kV UHVDC Transmission project rated for 6400 MW to transmit power over a distance of 1935 km by State Grid Corporation of China is presently (July 2007) in bidding phase. Yunnan – Guangdong  $\pm$ 800 kV UHVDC Transmission project of China Southern Power Grid, rated for 5000 MW to transmit power over a distance of 1418 km has recently moved under execution phase; while Power Grid Corporation of India is currently preparing for bidding of NER/ER – NR/WR Interconnector I  $\pm$ 800 kV Multi-terminal UHVDC Transmission project rated for 6000 MW to transmit power over a distance of around 2000 km to feed power into Agra area.

## II. EQUIPMENT DEVELOPMENT

In order to meet the demands for such large projects, ABB has been running an R&D program, well in advance, with the goal to develop and test equipment needed for 800 kV UHVDC. The R&D work had focused on equipment connected to the pole voltage, with special attention to converter transformers, bushings and external insulation [2, 3]. The most significant difference between equipment for UHVDC compared with equipment for HVAC is the need for proper DC grading.

When applicable, UHVDC equipment is built up by modules where each module is provided with a proper resistive voltage grading resistor as well as an AC/transient grading capacitor. With a proper voltage grading, the voltage stress in the modules will be the same, regardless the module is part of an 800 kV<sub>DC</sub> apparatus or a 500 kV<sub>DC</sub>

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apparatus. For oil/paper insulation systems the situation is more complicated, since it is not possible to arrange the DC grading with physical resistors: the DC grading must be secured by other measures.

For outdoor equipment exposed to pollution and rain/fog, the coordination between the internal and external voltage grading is an important issue. Bad coordination can result in damage of the insulators due to radial voltage stress.

Not just designing or making prototype or testing these 800 kV<sub>DC</sub> equipments, ABB has installed them in an energised test circuit to obtain first hand long term 800 kV<sub>DC</sub> operational experience [4]. This was to obtain the confidence in the new technology as well to gain the time to resolve if any unforeseen problem is revealed and to verify the dimensioning of various parameters. In ordinary conditions, newly developed equipment is qualified by a series of type tests. Most of the dielectric type tests are short duration tests. Supported by operational experiences of earlier products at similar voltage level, such qualification has been proved to be sufficient. However, as for equipment for 800 kV UHVDC, there is no existing experience at this voltage level. To verify the design, it is of importance to examine the equipment in a relatively long time span. A good example is the need to verify the internal and external electric field design.

In AC, the field distribution is determined by the dielectric permittivity ( $\epsilon$ , epsilon) of the insulation materials, while in DC the steady state field distribution is controlled by the resistivity ( $\rho$ , rho) of the insulation materials. In real service operation an equipment, typically the bushings, will be exposed to both DC and transients of varying frequency. When switching on the voltage, an AC-like voltage distribution will occur, and after a certain time (corresponding to the “overall time constant” of the insulation system,  $\tau = \rho * \epsilon$ ), the DC-like field distribution will be obtained. Due to the complex nature of the insulation system, the geometry and position of the different parts, the transition from “AC to DC” may occur very differently in different locations inside and outside the bushing.

The resistivity of the insulation materials of a bushing is of course very high. As a result, the typical overall time constant will vary orders of magnitude and can be very long. In fact, hours, days, or weeks are quite typical. Furthermore, the resistivity is normally a function of the temperature, which means that the resistivity may vary several orders of magnitude, with varying temperatures. It is therefore important to verify the electric field distribution also in its “natural” environment, e.g., at a valve hall temperatures of up to 40-50 degrees C.



Fig. 1. 800 kV UHVDC outdoor equipments in long term test circuit installation at STRI, Sweden.

Though the test location is Sweden, however the equipment design is made for the site pollution conditions.

### III. LONG TERM TEST CIRCUIT

In order to verify the long term behaviour of the 800 kV UHVDC equipment, all relevant pieces of equipment are installed in a long term test circuit at STRI in Ludvika, Sweden (see Fig. 1 & 2), and energized at 855 kV<sub>DC</sub>, since November 2006.



Fig. 2. 800 kV UHVDC long term test circuit installation at STRI, Sweden.

The test circuit includes a “valve hall” where the temperature is kept at over 50 °C, to simulate the actual operating conditions for the bushings. The transformer bushing protrudes inside the “valve hall” and is connected to the wall bushing that is installed in the wall. The remaining equipment as listed below, are installed outdoors, together with the voltage generator. The layout for the test circuit is given in Fig. 3.

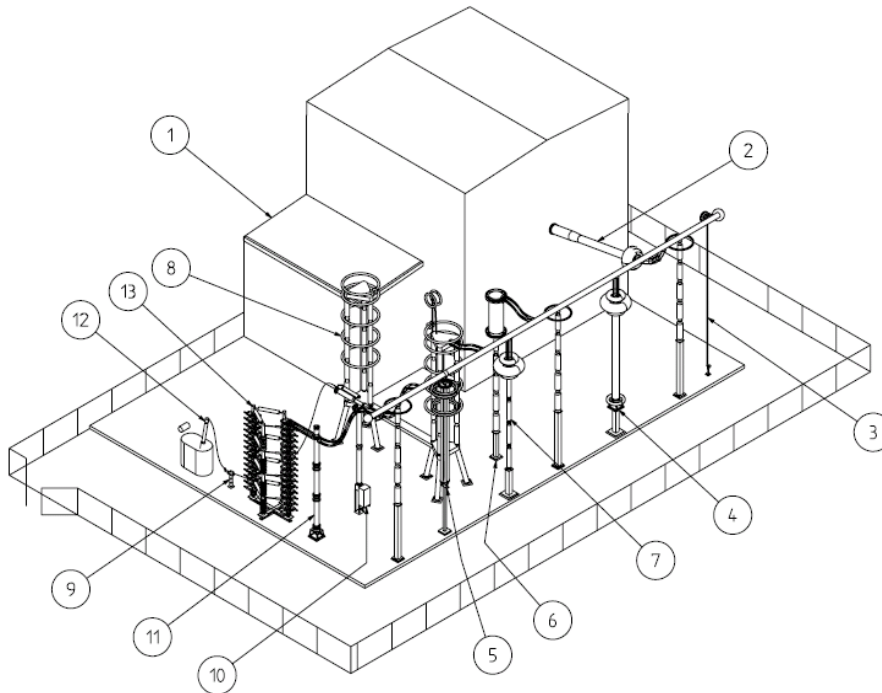


Fig. 3. 800 kV UHVDC long term test circuit layout.

Following equipments (test objects) are included in the test circuit installation at STRI, Sweden:

1. Transformer prototype
2. Wall bushing
3. Optical current transducer

4. Voltage divider
5. Pole arrester
6. Smoothing reactor prototype
7. RI Capacitor
8. Disconnecter
10. By pass breaker

In addition to the above, following test equipments associated with the voltage source can also be seen on the above layout:

9. Voltage transformer
11. Voltage divider
12. Transformer
13. DC voltage generator

#### IV. EXPERIENCE AND MEASUREMENTS

All equipments in the test circuit have been operating as expected and no failure has been reported so far. The polarity of test circuit was changed from positive to negative on May 4, 2007; after several months of successful operation. While making stop at positive polarity, measurement for the electrical field strength around the transformer bushing at 300 kV were performed and as well while starting at negative polarity.

During these times when all these equipments are kept energised at 855 kV<sub>DC</sub> in the test circuit installation, several measurements are continuously being recorded. These include

- Leakage current on the insulators during different weather conditions
- Surface charges on the insulators during different weather conditions
- Corona on the equipment and buses during different weather conditions
- Dissolved gas in oil for the transformer prototype

It is planned that after the long term testing, equipment shall be subjected routine tests again.

##### A. Ambient Measurements

Regular measurements are made for the ambient conditions. These include temperature, humidity, rain fall, wind speed, wind direction, UV-B intensity and dew-point temperature. In the below Fig. 4, Fig. 5 and Fig. 6, recorded temperature, humidity and wind speed is shown for period May/June 2007.

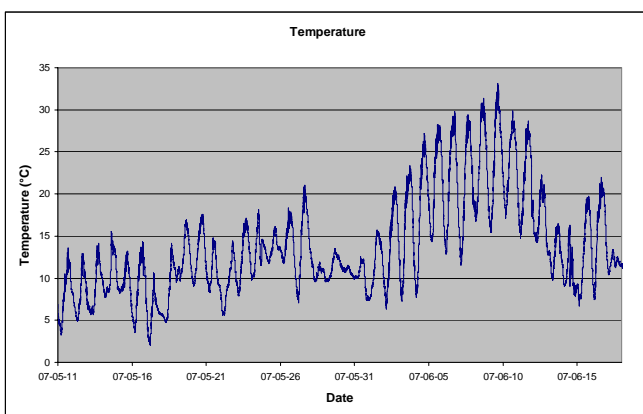


Fig. 4. Record of ambient temperature during May/June 2007

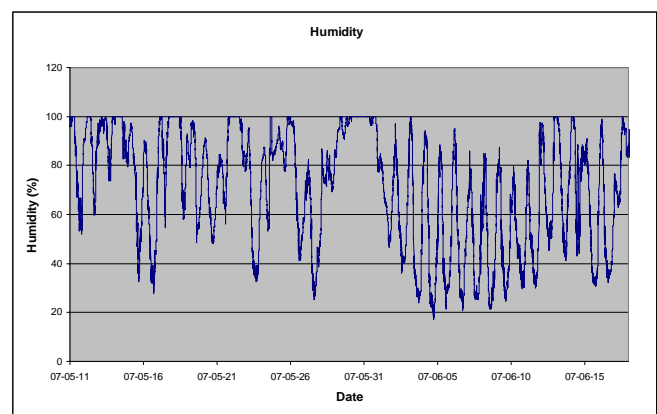


Fig. 5. Record relative humidity during May/June 2007

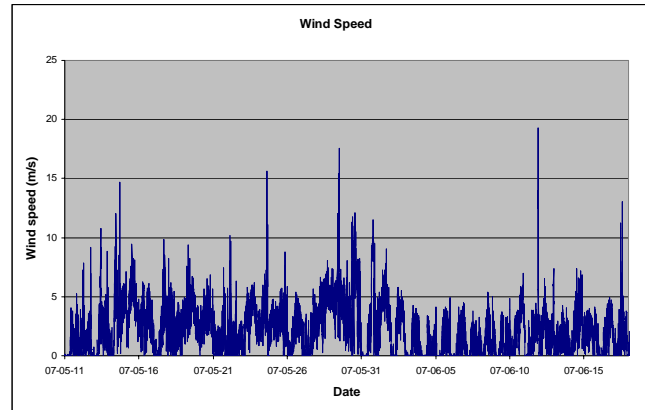


Fig. 6. Record of wind speed during May/June 2007.

### B. Leakage Current Measurements

Regular measurements are made for the surface leakage current on the RI Capacitor, Arrester and Wall bushing. In the in Fig. 7 below one of such typical recoding is shown for period May/June 2007 for the RI Capacitor.

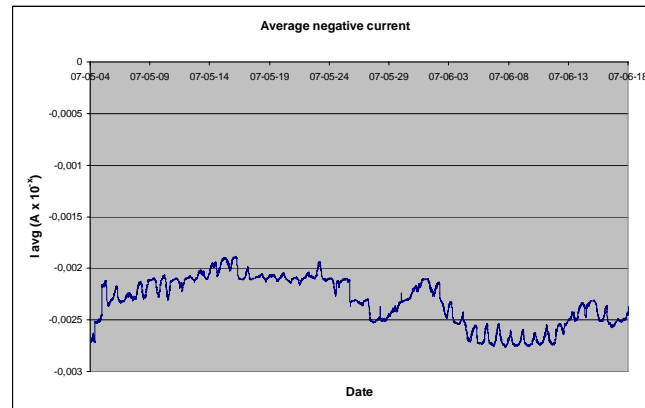


Fig. 7. Record of average negative current on 800 kV RI Capacitor.  
(Note: above measurement is with out correction of initial offset).

These measurements have been as expected and have not revealed any problem with any of the equipment installed in the test circuit.

### C. Electrical field strength Measurements

In DC applications, the voltage is constant over time and the impact of this constant electric field strength is a continuous driving force on charges and charged particles. These are drawn towards and accumulated on the bushing and these charges will have an impact on the total field distribution, not only on the outside of the bushing, but also on the internal parts of the bushing. It is the electric field distribution, and the lack of “electric field hotspots”, which determines the dielectric performance of the bushing. It is therefore of vital importance to know where those charges will and should be accumulated when designing the internal parts of the bushing.

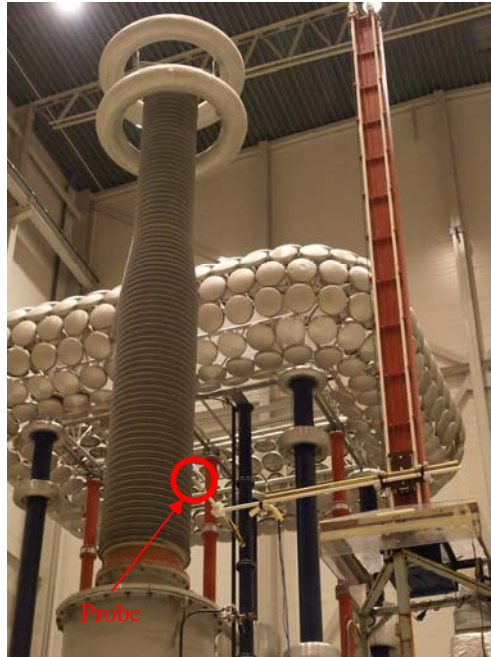


Fig. 8. Test set-up for DC electric field measurements along a 500 kV<sub>DC</sub> transformer bushing.  
The field probe is in the middle of the red circle.

Initially, the field distribution was studied along a 500 kV<sub>DC</sub> transformer bushing. The test set-up for the electric field measurements is shown in Fig. 8.

The rotating field probe measures the axial and radial field along the bushing, by moving the white horizontal rod, holding the probe, along the vertical (brownish) robot pillar. A typical field plot is shown in Fig. 9, measured after the bushing was grounded and thus indirectly showing the amount of charges left in and on the bushing. It is clear that charges are present and that they will influence the field distribution during normal service conditions. Under certain conditions, residual field strengths of up to 500 kV/m were measured locally along the bushing. To integrate this phenomenon into the design of the bushing is a requirement for any UHVDC bushing in order to guarantee a life-long problem free operation in service.

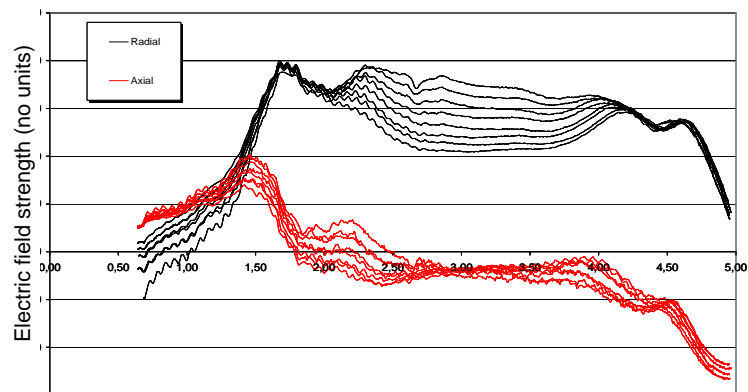


Fig. 9. Axial (red) and radial (black) electric field along 500 kV<sub>DC</sub> transformer bushing after grounding ( $U_{\text{applied}}=0$ ).  
The different curves represent different measurements in time. Time step is about 1 minute.  
Y-axis: Axial and radial field strength in arbitrary units;  
X-axis: length along bushing in meter.

The field distribution inside and outside the bushing is controlled not only by the deposited charges on the outside, but of course also by the inner structure of the bushing, the external flanges, the corona rings and the properties of the surrounding air.

During the long duration tests, the electric field was measured along the transformer bushing to monitor the transition from purely capacitive AC-field distribution to a steady state resistive DC field distribution, including the impact of accumulated charges, see Fig. 10. The measured electric field distributions also confirm the calculation models based on the resistivity of the insulation materials used.



Fig. 10. Measurement of 2-dimensional DC electric field along transformer the bushing, during the long duration test. The wooden structure is used to put the robot in parallel with the bushing. The position of the probe is indicated by the red circle and it is remotely moved along the bushing..

#### D. Corona

No audible or visible corona has been found except on optical current transducer (OCT) and on DC voltage generator itself. This was already expected as the shielding design for OCT was used from 500 kV without modifications.

The test installation has proved the satisfactory design for the electrode arrangements and bus bars.

### V. CONCLUSION

800 kV UHVDC is economically attractive for bulk power transmission over long distances. With the present progress of R&D converter equipment for 800 kV UHVDC is fully qualified.

Test installation has been operating satisfactorily since November 2006, without any problems and has provided confidence in ABB's design for 800 kV UHVDC equipments including design of electrode arrangements and bus-bars. With the confidence gained with satisfactory operation of the long term test circuit, the conclusion is that 800 kV UHVDC will account for a significant part of world growth in power transmission capacity over the next several years.

### VI. ACKNOWLEDGMENT

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### VII. REFERENCES

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**Brief Biography:**

**Abhay Kumar** was born in Delhi, India in 1961. He obtained his degree in Electrical Engineering from University of Roorkee (now IIT) in 1982. He joined National Thermal Power Corporation Ltd. (NTPC) in 1982 and worked until 1995 as Deputy Chief Design Engineer. He has been involved in the design of Vindhyachal B2B HVDC and Rihand - Delhi HVDC Projects and many other EHV substations. He has also been consulting engineer for Chandrapur – Padghe HVDC Project. From 1995 to 2000 he worked for ABB Ltd. New Delhi as Senior Manager at Power System Engineering and Business Development department. Since May 2000, he has been working for ABB AB in Sweden as the Technical Manager for the Three Gorges - Changzhou  $\pm 500$  kV DC Transmission Project. At present he is working as the Lead Engineer cum Project Manager for The Three Gorges - Shanghai  $\pm 500$  kV DC Transmission Project and is deeply involved with new  $\pm 800$  kV UHVDC projects.