TESTING LABORATORIES FOR HIGH-VOLTAGE POWER EQUIPMENT - ASPECTS AND REQUIREMENTS TO ENSURE RELIABLE ENERGY SUPPLY

Mark Kuschel Michael Gerlach Jörg Gorablenkow Andreas Kloos
Siemens AG, Energy Sector, Nonnendammalle 104, 13629 Berlin, Germany
mark.kuschel@siemens.com

Abstract:

The paper gives an overview about the testing requirements to verify the product integrity and capability for high-voltage power products. Testing approaches respectively examples from the high-voltage, high-power and mechanical testing laboratory are presented and important testing aspects are discussed. Moreover, other general laboratory requirements aspects such as accreditation or environmental requirements are discussed as well. Finally, the testing capabilities of the switchgear factory Berlin are presented.

1 INTRODUCTION

High-voltage power products and solutions such as circuit-breaker or gas-insulated switchgear systems (GIS) are important elements within the energy supply chain and therefore subjected to an extraordinarily high standard of availability and reliability (Figure 1). Quality assurance and life cycle considerations during development, production, commissioning and operation are the key elements to fulfil these requirements and ensure reliable energy supply.

However, the foundation for product quality is laid during the development. Experiences from earlier development projects and return of service are to be considered for the design and the choice of suitable materials. The verification of the approaches are done by calculation (e.g. FEM calculation of heat distribution) accompanied by intensive material and component qualification tests to verify the product specification for short- and long-term behaviour including the relevant environmental influences.

Figure 1: Example of a 145 kV substation with gas- and air-insulated high-voltage components

Figure 2: Overview of the main research and testing laboratories of the switchgear factory Berlin

In the end the final technical verification of the new design is determined by various type tests defined in different general and product related standards, e.g. IEC 62271 series. Basically, mechanical, power and high-voltage tests are carried out to prove the product characteristics.

The aim of this paper is to give an overview of the capabilities of the testing laboratories in Berlin and the testing requirements for high-voltage power products. Based on examples the most important testing influences are discussed. Moreover other laboratory aspects such as accreditation according to ISO/IEC 17025 or environmental effort are discussed as well.

2 BACKGROUND

The laboratories in the Siemens switchgear factory Berlin (Figure 3) have been established in parallel to the development of medium and high-voltage switchgear products at the beginning of the 20 century. The high-power laboratory e.g. was founded in 1928 (Figure 3, [1]). Since then, a lot of experience has been gained and implemented for the various laboratory developments and improvement steps, as well as product developments.

Since 1960, the laboratories in Berlin have become a part of PEHLA association [2], which currently collect 8 different testing laboratories in Germany and Switzerland under one roof to establish common testing and quality guidelines. Pehla enables the carrying out independent third party manufacturer tests. At the international level, Pehla is a member of the Short-Circuit Testing Liaison (STL) and contributes to the STL guides. STL is the body responsible for STLA the EOTC (European Organization for Testing and Certification) agreement group No. 0007 regarding testing and certification of high-power equipment for the European market.

International requirements for laboratories to prove their ability for testing are defined with ISO/IEC 17025 [3]. The laboratories of the Berlin switchgear factory have been accredited since 1992 by DATech and nowadays DAkks (the German technology accreditation centre). The main target of ISO/IEC 17025 is to guarantee reliable results. In particular, the following main items are to be implemented:

1) Management system acc. to ISO 9001 and its continuous improvement
2) Quality manual including definition of basic rules and targets as well as conformance commitment
3) Documented processes for testing and calibration; guidance for documents, records and nonconformities; clear responsibilities
4) Independent competent testing employees protected from external influences with impartiality and the ability to judge test results
5) Technical precondition (calibrated state of the art testing devices, awareness of measurement uncertainty, measurement traceability)
6) Data and property protection of the customer

The accreditation according to ISO/IEC 17025 and especially the extensive experience of the laboratories means the laboratories obtain reliable results that meet the requirements of the latest quality guidelines.

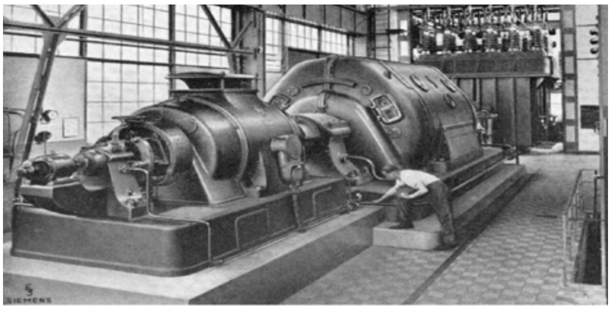

Figure 3: Machine house of the high-power laboratory (plant 1, 1928) with a generator of 40 MVA and a short-circuit power of 400 MVA [1]

3 HIGH-VOLTAGE LABORATORY

In the high-voltage laboratory, basically the insulation level of the components is verified and dielectric tests on auxiliary circuits are performed. AC-, DC-, impulse- and combined voltages are applied to the equipment to check insulation properties to ground respectively across the open contacts if applicable. The maximum output voltage of the AC transformer in our laboratory is 1200 kV (indoor) respectively 1800 kV (outdoor). The maximum voltage of the impulse generator is 3000 kV, for the DC generator 1200 kV. The voltage tests can be also performed in dry respectively wet condition. In parallel to the AC voltage tests for some products sensitive partial discharge or RIV measurements are needed according to the standards. Due to the shielded high-voltage laboratory (Figure 4) partial discharge measurements with a noise level < 1 pC can be obtained up to 1000 kV as recently carried out during 1200 kV component tests. In addition to the standard partial discharge measurement according to IEC 60270, also acoustical or UHF partial discharge measurements in the range 400 MHz…2000 MHz can be performed.

Above and beyond the standard voltage tests also other special qualification tests for e.g. the grading capacitors are important and performed. In this case, also sensitive capacitance and dissipation factor measurements are to be taken. These special tests are not only to test the short-term performance, but some of these tests address the long-term performance. For example, special care is to be taken for parts which are permanently under voltage stress in service operation, such as solid insulators or grading capacitors. In this case, long-term voltage aging tests are performed to verify the life-time behaviour (Figure 6). The service-life of 50 years can be simulated in a few months [4]. The long-term voltage tests enable the choice of the right design and material for the products. In fact, service experience so far has confirmed the outstanding reliability of the insulation components.

Figure 4: Example of a high-voltage type test of a 145 kV GIS in the high-voltage laboratory

Figure 5: Example of a long-term high-voltage test setup

4 MECHANICAL LABORATORY

In the mechanical laboratory, the mechanical integrity of the components is in focus. The following main tests are basically to be carried out for high-voltage components:

1) Mechanical operation and endurance tests including test of the kinematic chain
2) Temperature-rise tests on main as well as on auxiliary and control circuits
3) Gas-tightness tests
4) Strength of enclosures and other mechanical parts
5) Tests at limit temperatures (low and high), Figure 6
6) Thermal performance tests and ice condition tests
7) Airborn noise measurements
8) Degree of protection
9) Vibrations tests, Figure 7

Figure 6: Example of a mechanical test at limit temperatures of a 145 kV GIS

Figure 7: Example of a transportation test of a 145 kV DT-Breaker

For these tests modern precise tools are available in our laboratory, basically:

1) Temperature-rise testing system for 50/60 Hz up to 7000 A including discrete temperature measurements and automatic resistance measurements, additionally a thermal camera continuous plotting (768 x 576, Figure 8)
2) Several temperature cabinets (-60 °C…200 °C)
3) Several mechanical operation and endurance test set-ups including a high speed exposure camera (up to 20.000 fps)
4) Vibration test set-up with horizontal and vertical cylinder (max. traction 250 kN, max. stroke 100 mm, max. acceleration 100 m/s², frequency range 0,1...200 Hz) enabling
    i) tensile and bending tests
    ii) oscillation tests
    iii) shock- and impulse tests
5) Three-axial force measurement facilities to evaluate the impact of fundaments

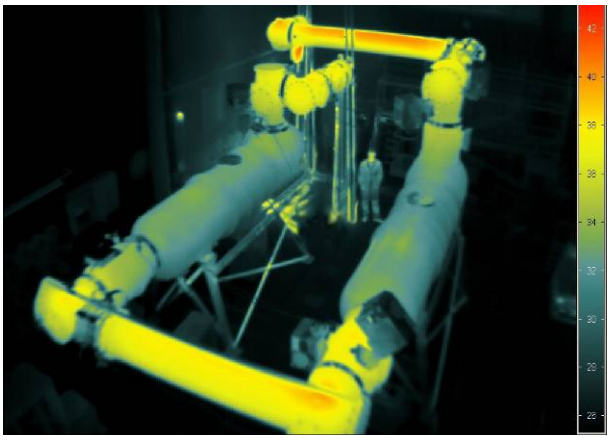

Figure 8: Example of a thermal record of a temperature rise test of 550 kV GIS at 5000 A and 60 Hz

5 HIGH-POWER LABORATORY

In the high-power laboratory, medium- and high-voltage products are tested with respect to their short-circuit withstand capability, their dynamic strength, their switching capacity, their insulating property and their performance characteristics.

Three generators are available to generate tripping currents of up to 120 kA at 35 kV. In synthetic tests, in current or voltage-injection circuits, testing power levels of up to 114 GVA can be achieved. Figure 9 shows the synthetic circuit enabling full pole tests with up to 550 kV rated voltage, which was modernized in 2005.

The whole circuits are equipped for each phase with the necessary elements; in particular safety and making switches, tappable coils, short-circuit transformers, tension section bay enabling variable connection to the individual test bays. The three generators can be connected either in parallel or separately to the test bays. The connection is realized by a safe busbar. Strategically placed surge arrestors protect the connection to avoid any flashovers in the test circuits. More details about the high-power laboratory and the other laboratories can be found in [5].

Moreover, a synthetic circuit test laboratory is available for basic investigation of switching capabilities of a circuit breaker without involving the costly testing generators. The testing current is generated by a capacitor bank which can be charged up to a level of 10 kV and provides two half-waves with RMS values of up to 63 kA. In case of short line fault experiments, an additional oscillating circuit (current injection circuit) provides the extremely high rate of rise of the transient recovery voltage following breaking of the current. Voltage rates of rises of up to 10 kV/µs and peak values of transient recovery voltage of up to 150 kV can be attained by this method.

Figure 9: Synthetic circuit with a peak voltage of up to 1050 kV equipped for 2- and 4-parameter TRV circuits.

Figure 10: Example of a making test on a 245 kV CB (middle) with spark path tower (right) and charging unit (middle right) and voltage divider (left)

Modern transient recorder measuring equipment with a high level of accuracy (0,1 %) a resolution of 14 bit, a sample rate of up to 100 MS with a memory of up to 1 GB per channel and fast transmission via optical fibre connections, input range +/-50 mV to +/-250 V enable precise measurements. Automated evaluation tools to prepare the reports support effective and high quality documentation.

Furthermore, also the total measuring path including voltage divider for voltage measurement and the current shunt needs to be calibrated carefully [6]. In addition to calibration, the experience of the influences of these elements because of capacitive or inductive coupling from the different potentials and currents need to be taken into account as well.

Special care is to be taken for the maintenance of the components such as generators, transformers, making and auxiliary switches. Especially in this case maintenance is needed to achieve a high availability rate of the testing devices enabling effective and fast testing.

Figure 11: Control and measurement room of the high-power laboratory

6 CONTINOUS IMPROVEMENT

Continuous improvement is part of daily work based on the participation and commitment of all employees. It requires clearly defined structures and roles and enables outstanding performance results. Improvement targets are defined based on different strategic aspects balancing various perspectives, e.g. business development and quality targets, customer orientation and innovations. Defined and regularly monitored key performance indicators (KPIs) makes improvements visible and keeps the motivation for further steps.

As an example, the results of the reduction of SF_6 emission efforts of the last decade are presented. Different measures were defined and implemented such as i) better evacuation of SF_6 (< 1 mbar) using powerful state-of-the-art gas handling equipment, ii) less coupling points in the SF_6 gas supply and regular leakage tests of the SF_6 gas supply. Finally, arcing tests due to an internal fault are performed in that way that the contaminated SF_6 is absorbed (Figure 12). All measures helped to cut 50 % of the SF_6 emission in the last decade despite the higher testing load, Figure 13.

Figure 12: Arcing test of a 550 kV GIS component carried out in a testing vessel to absorb SF_6

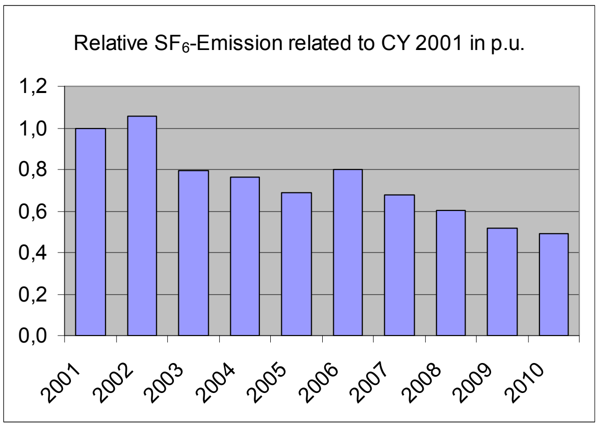

Figure 13: SF_6-Emission related to tests including internal and external testing laboratories

7 CONCLUSION

The testing laboratories are crucial to support effective development of new reliable high-voltage products and components. The highly diversified range of test facilities in Berlin supports all stages of development: from experimentation with basic principles, through initial testing of test units and checks on prototype products, to globally recognized type testing of first units for delivery. There are many advantages having these testing facilities so close to the development and production departments:

- Effective development because no additional effort for travelling and sample logistic is needed
- Higher frequency of use of the experienced testing laboratories during development, and consequently a higher level of quality for the finished products
- Higher severity of testing, thanks to 'multilayered' development using sensitive measuring and testing facilities perfectly tailored to the respective development task
- Immense knowledge base concerning all material properties and functional sequences, which enables the exploration of the limits of the stressing capacities, not only of materials but also of devices
- Ongoing integration of theoretical experiments into the development process
- Quick and uncomplicated verification of new technology or product ideas through experimentation

8 REFERENCES

[1] H. Knobloch: “Geschichte der Siemens-Prüf- und Versuchsfelder in Berlin-Siemensstadt”, Siemens brochure, Berlin, 2004

[2] http://www.pehla.com/

[3] General requirements for the competence of testing and calibration laboratories ISO/IEC 17025:2005

[4] K. Juhre and E. Kynast: “Long term performance under high voltage of mineralic filled and fiber-reinforced epoxy insulators used in GIS”, XIVth International Symposium on High Voltage Engineering, Beijing, 2005

[5] www.energy.siemens.com/hq/en/services/power-transmission-distribution/high-voltage-services/test-research-laboratories/

[6] J. Scharschmidt, D. Gebhardt, E. Kynast: “Estimation of the measurement uncertainty of tests and calibrations in high-voltage test laboratories”, Tagungsbericht 4. VDI-Fachtagung, Erfurt, 12./13.11.2008