# OHIO STATE UNIVERSITY MEASURES UP FOR HIGH-VOLTAGE LABORATORY TESTING

By Professor Stephen E. Sebo

In the U.S.A., only a handful of high voltage laboratories can be found that are operated by universities. The High Voltage Laboratory at The Ohio State University was designed and constructed in the 1990s. Its major facilities are related to the generation and measurements of high voltage AC, DC and surges.

The laboratory has high-voltage DC sources (up to 150,000 volts), high-voltage AC sources (up to 250,000 Vrms), a 1,000,000 volt surge generator, and a high-voltage Tesla transformer (up to 3 million volts). Test capabilities include withstand-, partial discharge- and breakdown tests on gases, liquids and solids, electric and magnetic field tests, reduced-scale model tests, fog chamber tests (accelerated aging), and shielding and attenuation experiments. The laboratory is used for education (teaching high voltage courses), research and independent testing.

## 1. HISTORICAL DEVELOPMENT

The Department of Electrical Engineering of The Ohio State University (OSU) has offered electric power engineering courses continuously since 1895. The HV activities were started in the 1950s by Prof. Neal A. Smith. The initial building of the HV Lab was an old structure with brick walls and saw-tooth roof, without any electromagnetic shielding. Its neighbor in the same building was the studio of the OSU Radio Station. The area occupied by the HV Lab became much larger after the Station moved to a building dedicated to radio and TV communication functions.

Since the initial building was in poor condition and it was scheduled for demolition, a new location for the HV Lab had to be found. When the HV Lab had to leave the initial building in 1990, another brick building was found (also without electromagnetic shielding) and used for four years as the temporary home of high voltage activities.

Its floor area was significantly smaller than that lab in the initial building. The temporary HV Lab was in service for four years. Planning and design of the new HV Lab started in the early 1990s. Several design and operation ideas could be tested in the temporary HV Lab. Construction of a new building, used jointly by the Departments of Computer and Information Science, and Electrical Engineering, started in 1992. The building and the new HV Lab in it have been in service since 1994.

Figure 1. View of the 250 kV transformer, current limiting resistors and high voltage buses.

## 2. MAJOR EQUIPMENT IN THE HIGH VOLTAGE LABORATORY

The laboratory has two DC sources. Their maximum voltages are 60 kV and 150 kV. There are several AC sources in the laboratory. The highest voltage is supplied by a 250 kVrms, 25kVA transformer. Other transformers available are at 69, 34.5 and 20 kVrms. A high voltage three-phase system is available with the interconnection of three potential transformers. The maximum voltage supplied is 69 kVrms, line-to-line. The 250 kV transformer is connected to two high voltage buses, suspended at 3.6 m elevation. There are two current limiting resistors between the transformer and the high voltage buses. The buswork and the resistors are suspended by composite insulators. The 60 Hz test area of the HV Lab is shown in Fig. 1.

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The surge generator (donated by American Electric Power Co.) has ten stages. Its ratings are 1000 kV, 25 kjoule, maximum charging voltage output 100 kV. The surge test area of the HV Lab is shown in Fig. 2.

A unique source is a Tesla transformer (donated by Battelle Memorial Institute), whose maximum rating is 5000 kV. For safety reasons, the Tesla transformer is used “only” up to 3000 kV. Its test area is shown in Fig. 3.

A fog chamber has been built (sponsored by The Ohio Brass Co.) for polymer insulator testing purposes. Its volume is 9.5 m3, its maximum voltage is 69 kVrms. Either clean fog or salt fog (at the desired conductivity) can be applied in the chamber. Steam fog generation is also available. The fog chamber test area of the HV Lab with the supply transformer is shown in Fig. 4.

Other main facilities available for high-voltage experiments: a 50 kV partial discharge detector, a transformer ratio arm (ε and tan δ) bridge, a 50 kV oil tester, sphere gaps, potential dividers, cylindrical corona testers, oscilloscopes, instruments, etc.

### 3. EDUCATIONAL ACTIVITIES

Lectures and laboratory experiments related to High Voltage Engineering are available for undergraduate and graduate students. Special projects, individual studies, master’s thesis and dissertation topics are also parts of the educational activities.

### 4. TEST CAPABILITIES

Withstand-, partial discharge- and breakdown tests on gases, liquids and solids can be performed. Special instrumentation, including scale models, are available for electric and magnetic field distribution measurements. Facilities are available for fog chamber (insulator accelerated aging) tests, shielding and attenuation tests. Some thermal tests can also be performed.

### 5. CONSIDERATIONS OF THE PLANNING AND DESIGN OF THE NEW HIGH-VOLTAGE LABORATORY

Many papers, studies, reports and books related to the planning and design of high-voltage laboratories were reviewed first. Also, discussions with many fellow engineers interested in high voltage activities and visits of several operating high-voltage labs have been very useful. By 1990, it was relatively easy to list the basic requirements for the new HV Lab. It had to be large enough to house major facilities already owned and planned, it had to be an indoor lab, of course. Ground level location, air cleaning and conditioning, complete electromagnetic shielding, accessible grounding, safety, a suitable number and level of auxiliary services were all items that were discussed during the planning and design stage.

Figure 2. View of the 1000 kV surge generator.

### 6. DESCRIPTION OF THE HIGH VOLTAGE LABORATORY

Floor area of the HV Lab is 18.3 x 18.3 sq. m (60 x 60 sq. ft). The ceiling-to-floor clearance is 8.5 m (28 ft). It has an adjacent upper level observation room, and an adjacent floor level storage room. The main hall (high bay area) is completely shielded electromagnetically. That was essential not only because of the high level of use of computers and instruments literally everywhere around the HV Lab, but also because the next-door neighbor is a division of the OSU Computer Center. The power supply lines are filtered. The laboratory has its own “internal” shielded enclosure to protect the computers and sensitive instruments used. The entire area (laboratory and observation room) is air conditioned. Departmental shop facilities are available in the building next door, but the laboratory is equipped with an appropriate number of tools and small parts. A pneumatically operated person-lift is available. The mechanical load capability of each one of the 20 suspension points is about 1 ton (2000 pounds).

Figure 3. View of the Tesla transformer.

### 7. SAFETY

Safety is one of the most important requirements in a high-voltage laboratory. Proper operation of the OSU HV Lab includes the presence of qualified personnel, the use of systematic procedures, safety ropes, signs, visual and audible warnings and alarms, the use of grounding rods, the periodic review of safety rules, the availability of fire extinguishers, emergency phone numbers, first aid kit, and smoke alarm system.

### 8. SHIELDING OF THE HV LAB

The walls, two supporting pillars and ceiling of the HV Lab are shielded with a system of interconnected modular steel sheet elements mounted on wood framework. It is a single shield system with the shielding sheets stretched over the outer surface of the wooden frames and bolted together. The thickness of the

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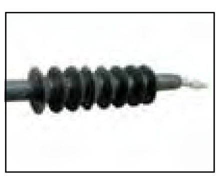

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steel sheet is 0.76 mm (22 gauge). The sheets are galvanized on both sides. The modular elements are tied to threaded bolts embedded in the concrete walls, pillars and ceiling of the high voltage hall. There is a fiberglass insulating element at each tie point, therefore, the shielding system is electrically insulated from the steel structure of the parent building. This modular shielding system is fully connected to the extended edges of the ground plane of the HV Lab along the wall/floor line. The ground plane is a copper sheet embedded in the concrete floor of the laboratory. Thickness of the concrete is 15 cm (6 in) over the copper sheet. The copper sheet is connected at one point to the grounding system of the building power supply.

### 9. SHIELDING INTEGRITY CONTROL

Each of the penetrations had special design and construction requirements. All doors are special precision metal clad doors with metal door frames. The door frames are tied to the shielding system. Spring temper bronze contact finger strips are used along the entire door/frame contact line. High visibility double radio frequency (RF) screens are built into the observation shielded windows. The screens are extended over the glass and connected to the window frame and to the shielding system. Honeycomb waveguide air vents are used in the air conditioning system intake and exhaust connections to maintain the integrity of the shielding system. Piping-to-shielding seals (insulation) or an insulating section in the piping are supplied at the points of penetration by the air ducts, water pipes and sprinkler system. Power line filters are used for full 60 Hz power supply of the HV Lab. The single-phase and three-phase power transformers and their switchboards are located inside the laboratory. Also, telephone line, data line, and fire alarm line filters are employed.

### 10. SHIELDED ROOM IN THE HV LAB

A Lindgren-type double electrically isolated RF enclosure (a Faraday cage) is available for the housing of the data acquisition computer and sensitive instruments. A see-through double copper screen system, a special RF door, a power line filter, incandescent lighting and a 20-terminal coaxial cable service panel are employed.

### 11. SHIELDING PERFORMANCE REQUIREMENTS AND MEASUREMENTS

Shielding efficiency requirements in the 14 kHz - 10 MHz range were specified as 80 dB for electric field strength (E) attenuation and 60 dB for magnetic flux density (B) attenuation for the main HV hall. These figures are 120 dB for E and 68 dB for B for the shielded room in the HV Lab. Measured attenuation values for the HV hall are 87 dB for E at 10 MHz, and 63-68 dB for B at 14 kHz - 10 MHz. For the shielded room, at 14 kHz, these values were 126 dB for E and 71 dB for B.


Figure 4. View of the 69 kV fog chamber.

### 12. LIGHTING

In order to minimize the electromagnetic noise emitted by light sources and their accessories, high intensity incandescent light bulbs are used for general purpose indoor lighting. A secondary red lighting system is provided in the HV Lab and in the adjacent observation room, for night adaptation purposes. A remote controlled spotlight is available in the HV Lab. There is an emergency lighting system in case of power failure.

### 13. UTILITIES, SERVICES

120 V and 240 V single-phase voltages are supplied at many receptacles in the laboratory. 208/120 V three-phase receptacles are also available at several places. Double sink with hot and cold water supply is available in the laboratory. A water deionizing system has been added. There are several floor drains that can be utilized in case of wet tests. High pressure air is available from a compressor located in the HV Lab. Telephone, clock and computer lines have been provided. There is an intercom between the main floor and the observation room. Storage shelves, storage cabinets and work benches are available.

### 14. FLOOR STATION SYSTEM

There are 12 floor stations in the laboratory. Each floor station is equipped with two 120 V and one 240 V receptacles, a connection bar to the grounding system, and two coaxial cable terminals. Each cable is located in a separate steel conduit. The coaxial cables of the 12 floor stations, as well as 3 cables from the observation room and 5 cables from the shielded room, end at a patch panel. The patch panel makes the interconnections of the floor stations with the shielded room (or with each other) possible, without employing a maze of cables above the floor.

### 15. ACOUSTIC PANELING

In order to eliminate the sound reverberation and echo in the HV Lab, acoustic paneling has been added to the walls and pillars. They are perforated, corrugated galvanized steel wall panels, with baked-finish epoxy paint, attached to the shielding system via noise absorbing pads. The performance of the paneling is excellent. The color of two walls and the ceiling is off-white. The color of two other walls, behind most of the experiments, is green, in order to make the observation of discharges easy.

*Dr. R. Malewski set up the design guidelines of the shielding system of the OSU HV Lab. His valuable contributions are appreciated very much. Dr. E. Sebo was the color coordinator for the HV Lab.*