

Mastering High Voltage: The Importance of Accurate Test Equipment

Author: Bryan Withers, Vice-President, Engineering - Vitrek, LLC



INTRODUCTION

Accurate definition and measurement of critical electrical performance parameters is essential for ensuring the reliability and safety of high-voltage equipment and cabling. For applications which can involve tens of thousands of volts, safety risks are high, as are the demands on the test equipment used to measure the equipment and cables.

Proper calibration of the test instruments themselves is critical to achieving the strict performance needs of many equipment types. Calibration results must often meet national and international specific standards and calibration measurements are typically conducted by certified laboratories with traceability to national standards, like those maintained by the National Institute of Standards and Technology (NIST).

This article delves into the importance of high-voltage test equipment calibration and the meticulous considerations required to ensure measurement accuracy.

HIGH-VOLTAGE MEASUREMENT TECHNIQUES

Each of the various techniques for high-voltage measurement has unique advantages and needs to be calibrated using different techniques:

- **Step-Down Transformers** reduce high voltage to lower, more manageable levels for measurement.
- **Capacitive and Resistive Voltage Dividers** divide the voltage proportionally.

HIGH-VOLTAGE MEASUREMENT TECHNIQUES (CONTINUED)

- **Series Resistance (Microampere Measurement):** Measures current through a high resistance in series with the voltage source.
- **Analog Style Measurement Devices:**
 - Sphere Gaps measure the voltage by observing the breakdown voltage between two spheres.
 - Electrostatic Measurement quantifies the electrostatic force between two plates.



Figure 1. Many types of equipment are used for high-voltage measurement.

WHY MEASURE HIGH VOLTAGE?

Measuring high voltage is increasingly important as technology advances. High-voltage systems reduce current carrying requirements and minimize energy loss. Also, in many cases, voltage values determine system performance. This means the voltage sources must be accurate and reliable in order to meet systems specifications. Also, monitoring systems need to be in place to ensure that the systems perform reliably from end-to-end and year-to-year.

HIGH-VOLTAGE APPLICATIONS BY INDUSTRY

High voltage, defined here as 1 kV to 150 kV (AC or DC), is used across various fields, including:

- **Analytical Instruments:** Mass spectrometers and photomultiplier tubes.
- **Defense and Aerospace:** Radar systems, CRT displays, and flight simulators.
- **Homeland Security:** Baggage inspection and explosive detection equipment.
- **Inspection and Non-Destructive Testing:** Systems that ensure the integrity of materials and structures.
- **Manufacturing Processes:** Like electron beam welding and electrostatic coating applications.
- **Medical and Biotechnology:** X-ray and radiographic equipment.
- **Research Laboratories:** Products like detectors, accelerators other large scale analyzers.

HIGH-VOLTAGE APPLICATIONS BY INDUSTRY (CONTINUED)

- **Semiconductor Equipment:** Essential for ion implantation and sputtering processes.
- **High Voltage Power Supplies:** Fundamental in many industrial applications.
- **RF Generators and Matching Networks:** Used in telecommunications and broadcasting.
- **Power Distribution:** Critical for corona detection and cable insulation testing in electrical cables and harnesses be they in utility networks, manufacturing plants or campuses.

Accurate high-voltage measurement is essential in these sub-systems to ensure operational efficacy and safety. Devices requiring high-voltage measurements include:

- **Hipot Testers:** Ensure the integrity of electrical insulation.
- **X-Ray Power Supplies:** Validate performance for medical and industrial imaging.
- **Ion Implantation Systems:** Regulate electrical systems for precise particle acceleration.
- **Energy Transmission Sub-Station:** High voltages in power grids enhance efficiency and reduce losses.

Safety Considerations

Calibrating high voltages is important for safety considerations:

- Establishing appropriate earth ground conductivity prevents dangerous ground loops.
- Ensuring sufficient clearance avoids unintended flashovers.
- Proper barrier positioning protects people from high voltage areas under all conditions.
- Means to discharging stored energy in voltage systems ensures safe adjustments.
- Following Manufacturer Guidelines: Adherence to recommended practices minimizes risk.

HIGH-VOLTAGE TEST EQUIPMENT CALIBRATION

Calibration Standards and Accreditation

ISO/IEC 17025:2017 outlines the general requirements needed for calibration and test laboratories to be deemed technically competent to perform calibrations. Additionally, standards like ANSI/NCSL Z540-1-1994 are also recognized in the industry by defining measurement uncertainty criteria. Accredited labs undergo regular assessments to maintain their certifications. These ensure that their procedures, environment, and personnel meet high standards of competence.

Ensuring Measurement Uncertainty

When calibrating high-voltage test equipment, it's essential to account for all sources of measurement uncertainty, including:

1. **Equipment Accuracy and Precision** — Every measuring instrument has a specified accuracy, often expressed as a percentage of the reading or a fixed value. Precision, on the other hand, refers to the instrument's ability to produce consistent readings over repeated measurements. Regular calibration ensures that both accuracy and precision are maintained, aligning instrument performance with its specified tolerances.

HIGH-VOLTAGE TEST EQUIPMENT CALIBRATION (CONTINUED)

2. **Signal Type and Frequency** — High voltage measurements can be affected by the type of signal (AC or DC) and its frequency. AC signals, especially at high frequencies, can introduce additional errors due to reactive components in the measurement system. It is crucial to ensure that the measurement accounts for this reactivity so that its accuracy is maintained.
3. **Calibration Procedures** — Calibration involves comparing the instrument's measurements to a known standard by making necessary adjustments. This process must be performed in controlled environments to minimize external influences. Calibration intervals depend on the instrument's usage and the criticality of its measurements. Optimal intervals are usually recommended by the manufacturer.
4. **Environmental Effects** — Environmental conditions such as temperature, humidity, and altitude can significantly impact measurement accuracy. For instance, temperature fluctuations can cause expansion or contraction of materials, affecting the physical dimensions of components and thereby the measurement. Humidity can influence the conductivity and dielectric properties of insulating materials, while altitude changes can alter the air density, affecting high-voltage discharge characteristics.
5. **Cabling and Connections** — High-quality cables and secure connections are essential for accurate high-voltage measurements. Poor connections can introduce resistance, leading to voltage drops and inaccurate readings. Additionally, cables should be chosen based on their voltage rating and insulation properties to prevent leakage currents and ensure safety.
6. **External Influences** — Uncontrolled variables, such as EMI and corona discharges, can introduce significant errors in high-voltage measurements. EMI can be mitigated by using shielded cables and maintaining proper grounding. Corona discharge, caused by ionization of the air around conductors, can be reduced by using smooth, rounded connections and avoiding sharp points that can concentrate the electric field.

Corona and Connections

Corona discharge is a common source of error in high-voltage measurements. It occurs when an electrical discharge ionizes the surrounding air, often at sharp points or within air gaps in insulation. To minimize corona:

- Smooth out connection points to reduce the risk of discharge.
- Use larger diameter wires to reduce electric field strength around conductors.
- Maintain ample separation between high-voltage components.
- Use continuous insulation without gaps to prevent internal discharges.



Figure 2. What Not To Do — Loose Wire Ends, Different Wire Thicknesses, Sharp Wire Bend.

HIGH-VOLTAGE TEST EQUIPMENT CALIBRATION (CONTINUED)

Fields and Interference

High voltages generate substantial electrical fields which can be influenced by nearby objects, including the operator. External electrical interference from sources like radio stations and military installations can also impact measurements. To mitigate these effects:

- Keep measurement setups away from potential sources of interference.
- Employ proper shielding techniques to protect against external fields.
- Avoid movement of objects or personnel near the measurement area during testing.

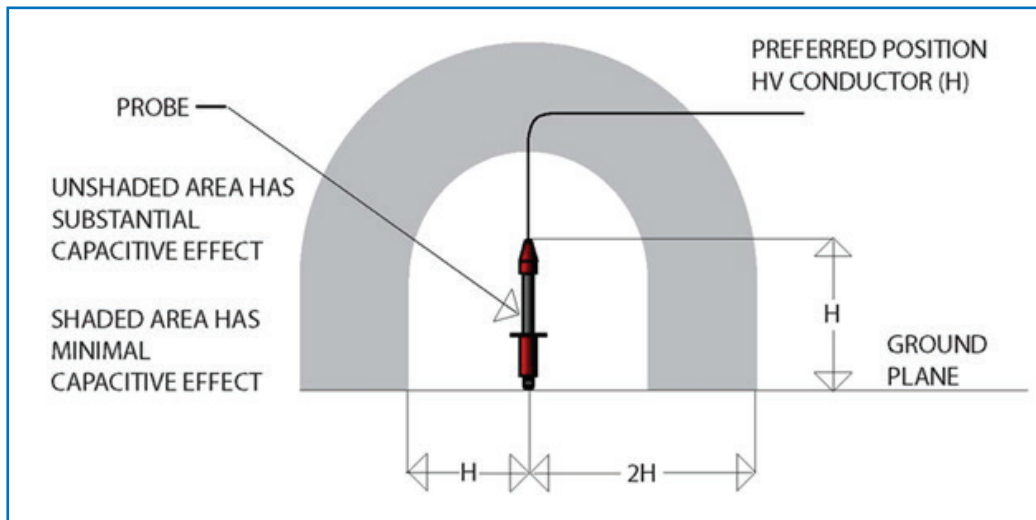


Figure 4. Diagram Showing Influence of External Fields on High Voltage Probe.

Total System Uncertainty

Total system uncertainty encompasses all potential sources of error in a measurement setup. This includes:

- **Device and Divider Errors:** Each component in the measurement system introduces its own level of error.
- **Operator Bias and Location Effects:** The experience of the operator and the measurement environment can affect results.
- **Software Influence:** Ensure the software used for data collection and analysis is accurate and reliable.

HIGH-VOLTAGE TEST EQUIPMENT NEEDS TO FIT THE APPLICATION

The types of devices used in standards and calibration labs worldwide can provide simultaneous AC/DC voltage, frequency, peak-to-peak, and crest factor readings. In commonly used equipment like the Vitrek 4700, the meter measures up to 10kV directly and up to 150kV with their proprietary Smart Probes. It also provides a chart mode for graphic documentation of high voltage drift, ramp time, overshoot, and sag — key variables that can define failure.

HIGH-VOLTAGE TEST EQUIPMENT NEEDS TO FIT THE APPLICATION

Accuracy calculations for equipment like the Vitrek 4700 are valid for one year from calibration. The accuracy specifications include the measurement uncertainties in the standards and methods employed by the manufacturer during calibration of the tester and probes. Measurement accuracy specification comprises base accuracy, floor, resolution, and high voltage self-heating specifications. For direct measurements, no additional calculations for accuracy at the terminal are required.

EXAMPLE @ 5kVDC DIRECT INPUT:

$$\begin{aligned}
 & \text{BASE ACCURACY} \quad \text{FLOOR} \quad \text{RESOLUTION} \\
 & (0.03\% * 5000V = 1.5V) + 0.03V + 0.05V \text{ (1/2 0.1 V Resolution)} \\
 & \text{SELF-HEALING} \quad \text{TOTAL} \\
 & + ((1.5\text{ppm} * 5^2) * 5000 = 0.1875V) = 1.7675V
 \end{aligned}$$

Performance and Automation

The best of the available test equipment utilizes Digital Signal Processing (DSP) technology that can provide outstanding AC and DC voltage accuracy, stability, and resolution. A simple example of such DSP is signal averaging, which can improve measurement precision or stability. Ideally the device should support test automation with built-in Ethernet and high-speed serial communication ports, making it fully programmable for tailored testing requirements. Some equipment, like the Vitrek 4700, include a USB printer port for capturing readings and obtaining hardcopy printouts of high voltage plots. The This meter and its SmartProbes come with an ISO17025 accredited calibration certificate, ensuring accuracy and traceability.

The Role of Accredited Laboratories

Accredited laboratories play a crucial role in maintaining measurement accuracy. These labs provide traceability to national and international standards, ensuring consistent and reliable calibration. For instance, Vitrek's calibration lab is accredited by the American Association for Laboratory Accreditation (A2LA) to ISO 17025:2017 and ANSI/NCSL Z540-1-1994 standards. This ensures that all measurements are traceable to the International System of Units (SI) via national metrology institutes like NIST and NRC.

CONCLUSION

The calibration of high-voltage test equipment is not just a technical necessity but a cornerstone of safety and reliability. By adhering to rigorous standards and meticulously accounting for all sources of measurement uncertainty, we can ensure that high-voltage systems operate with precision and dependability. Accredited labs play an indispensable role by providing the expertise and traceability needed to uphold high standards.

As technology advances, the importance of accurate high-voltage measurements will only grow, making it essential for industries to invest in proper calibration practices. Ultimately, mastering high-voltage measurement is about safeguarding both the equipment and the people who rely on it, ensuring a safer and more efficient future for all.

For information on Vitrek's High Voltage Test Equipment visit us online at www.Vitrek.com, email info@vitrek.com or call (815) 838-0005.