Calibration of High-Voltage Test Equipment

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1. Abstract

The main key for accurate measurements of voltages and currents in high voltage applications is the performance of the measuring system. It requires a precise calibration traceable to National Standards. International Standards, e.g. IEC 60060-2 or IEEE Standard no.4-1995 define the configuration of measuring systems (MS) and the demands on the performance as well as the principal calibration methods.

With respect to the acquisition of valid data during HV tests it must be in the interest of the operator to assure the correct performance of the HV measuring system; i.e. accurate calibration.

The scientific background of the calibration of HV measuring equipment has been considered in many publications. This paper is written especially for the users of MS as an introduction to some theoretical and practical aspects of calibrations.

2. Introduction to HV Metrology

The user of measuring equipment in general, and in high voltage applications in particular, is confronted with the requirements of technical and quality standards, that require the use of calibrated equipment. In addition the calibration must be traceable to National Standards /1 - 3/.

The term **traceability** is the property of a result of a measurement whereby it can be related to appropriate standards, generally national or international standards, through an unbroken chain of comparisons. The result is a calibration hierarchy, as shown in Figure 1. A measurement result is complete only when accompanied by a quantitative statement of its **uncertainty**. The uncertainty is required in order to decide if the result is adequate for its intended purpose and to ascertain if it is consistent with other similar results.

Typical uncertainty levels for high voltage quantities are 3 % for MS of test equipment /1/, 1 % for Reference Measuring Systems (RMS) /1/, 0.5 % for Reference Standards, < 0.5 % for National Standard (e.g. Germany PTB: DC 0.001 %, AC 0.02 %, LI/SI 0.3 %).

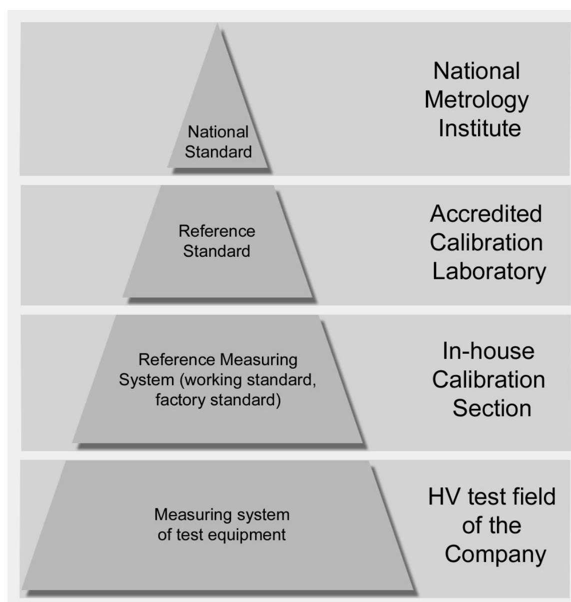

Figure 1: Calibration hierarchy /4/

Illustrated in table 1 is how different levels of the hierarchy interact with the metrological infrastructure.

For the MS used in the HV test field of a company at least the first calibration must be performed by an accredited calibration laboratory (see IEC 60060-2, annex A). If a company operates a large number of MS, the periodical re-calibration of the MS may be performed by an in-house calibration section, that operates RMS calibrated by a National Metrology Institute or an accredited calibration laboratory. Normally, this company's section is granted the right to calibrate the companies own systems after it is inspected by an accreditation body. The in-house calibration section must have a close cooperation with an accredited calibration laboratory to ensure the performance of the RMS.

Accredited calibration laboratories perform most of the routine calibration work for HV test fields of companies and in-house calibration sections. They operate reference standards which are industrial manufacture standards with the best possible characteristic.

	Tasks	Basis for the calibration or measurement	Documentation of the calibration or measurement
National Metrology Institute	To maintain and disseminate the National Standards	Statutory duty to represent SI units and ensure international compatibility	Calibration certificate for reference standard
Accredited calibration laboratories	To safeguard the metrological infrastructure of a country	Calibration certificate from National Metrology Institute or another accredited laboratory	Calibration certificate for working standard or factory standard
In-house calibration section	Supervision of measuring equipment for in-house purposes	Calibration certificate from National Metrology Institute or an accredited laboratory	Factory calibration certificate, calibration mark or the like for test equipment
HV test department	Measurements and tests as part of quality assurance measures	Calibration certificate from accredited laboratory or Factory calibration certificate, calibration mark or the like	Test mark or like

Table 1: Calibration system /4/

Accredited calibration laboratories issue calibration certificates with a predefined structure (calibration object, calibration method, measuring conditions, measuring results, uncertainty of measurement). The mutual recognition of these calibration certificates is ensured by multilateral agreements of the accreditation bodies.

National Metrology Institutes operate very special standards to achieve the lowest possible uncertainty. They are responsible for representing the SI units and have to assure the international compatibility.

3. Equipment for in-house calibration sections

The selection of the equipment for an in-house calibration section depends on the type of voltage to be measured and on the range of testing voltages applied for quality assurance measures. In general, the calibration should meet, if technically possible, the range of testing voltages. Because of the difficulties to meet the uncertainty level of 1 % for RMS at higher voltages, the standard IEC 60060-2 has made the compromise to allow calibrations at a lower voltage level. The voltage level can be as low as 20 % of the rated testing voltage (MS for 630 kV AC can be tested with a minimum of 126 kV).

The questions are: is there only one type or are there more types of voltage to be measured and what kind of RMS should be chosen? The following recommendations are intended to answer some of those questions:

RMS for single types of voltages:

300 kV-DC RMS with Precision Divider and Peak Voltmeter (MR 0.5/300, MU 15)

- For the HV arm of the divider highly stable, non-inductive HV resistors are used. The low voltage arm is designed as a tap of the high voltage part. Therefore the high voltage and the low voltage arms have the same temperature coefficient of voltage of 0.005 % and consequently the scale factor may be considered as temperature stabilized.
- The divider is arranged inside an insulating glass fiber reinforced tube. Creepage currents over the tube are flowing directly to earth and have no effect on the scale factor of the divider.
- Creepage currents over the surface of the divider, e.g. in case of high ambient humidity, are avoided by the self heating of the divider (temperature on the surface during operation, approx. 60 °C is much higher as the ambient temperature).

200 kV-AC RMS with special Measuring Capacitor and Peak Voltmeter (MCF 600/200, MU 15)

- Voltage dependent non-linearity is low due to the use of an advanced capacitor technology CDCT
- Low temperature coefficient because of compensation of the temperature coefficient of high voltage arm and low voltage arm
- The proximity effect may be neglected because the stray capacitances are much lower than the capacitance of the measuring capacitor.

700 kV-LI RMS with Controlled Resistive Lightning Impulse Voltage Divider and Digital Recorder (SMR 10/700, TR-AS 100-10)

- The proximity effect is compensated by the capacitive grading of the voltage distribution over the divider.
- The construction and the materials of the divider ensure the compensation of the temperature influence on the scale factor and avoid aging of the divider resistors.
- As digital transient recorder the type TR-AS 100-10 (100 Ms/s, 10 bit, 2 channels) is used.

RMS for more than one type of voltages

Universal RMS based on a Damped Capacitive Divider with parallel resistive path and Digital Recorder (MCR 600/500spec, TR-AS 100-10)

- Adapted system for 500 kV LI and SI, 200 kV AC and 200 kV DC
- Only one instrument to measure the relevant voltage quantities at LI, SI, AC and DC

Calibrators

In addition to the RMS, calibrators are required for calibrations and adjustments of the instruments. For AC/ DC, precision Fluke calibrators (uncertainty < 0.05 %) and for LI/SI, the impulse calibrator Dr. Strauss KAL 1000 (uncertainty 0.7 %) are recommended.

Software and know-how package CALLAB

The package contains the software for calculation of measuring deviations, scale factors, uncertainty of measurement and the working instructions to perform calibrations.

4. Calibration procedure

For the user of a measuring system the question arises; what does he have to know about the calibration procedure? The answer depends on the kind of system.

New manufactured MS

The first calibration of a new manufactured MS may be performed by an accredited laboratory at the factory (manufacturer), because in most of the cases the conditions at the factory are similar to the conditions at the user's location. Only in cases where the MS will be built into existing test equipment (e.g. AC cascade transformers) the calibration has to be performed on-site at the user's location.

Existing MS

With the exception of small transportable MS, the calibration has to be performed on-site at the users location.

Preparing the calibration, first it is necessary to check if the MS is ready for calibration. It needs to be checked if the configuration of the MS meets requirements of IEC 60060-2 and if the instrument is functioning properly. For support and help you might contact a accredited laboratory.

To ensure a successful calibration the voltage generators must fulfil the demands on the voltage shape according to IEC 60060-1.

The HV test field must have sufficient space for the arrangement of the RMS.

Ambient temperature and humidity on-site must be within a range for which the metrological behavior of the RMS is known. Especially high humidity (> 80 %) should be avoided.

If all conditions are fulfilled you can proceed with the calibration. Average duration times for the calibration are: systems up to 1 MV one day, systems > 1 MV two days.

After the calibration the user gets a calibration certificate which contains a conformity declaration as described in IEC 60060-2. If the conformity was proved by the measurements the MS is considered as an “Approved Measuring System” (AMS) for the applied conditions.

The calibration certificate is valid for the moment of calibration. No calibration laboratory can foresee the long term stability. Therefore the user is responsible for the determination of a suitable re-calibration period. The maximum re-calibration period is 5 years according to IEC 60060-2, if performance checks demonstrate that the long term stability is within the range of ± 1%.

5. Performance check of MS

For most of the users there are no additional AMS or RMS available to proceed with the performance check by using the comparison measurement method. Therefore the performance check has to be performed by measurement of the output voltage of the test system under well defined conditions. The results of this measurement have to be compared with the results of the first performance check.

Conditions

- Test system: without load or with defined load, defined input voltage
- Measuring system: defined measuring range and setting

Proceeding

- Observation and recording of the ambient temperature and humidity and of the output voltage of the test system (10 observations)
- Calculation of the mean value of the output voltage for the 10 observations
- Calculation of the relative deviation

$$\delta U = \frac{U - U_{Ref}}{U_{Ref}} x100\%$$

U_{Ref} voltage determined in the first performance check

U mean value of the 10 observations

Evaluation

The relative deviation should be within the range of ±1 %. If the condition is not fulfilled the reason has to be investigated.

6. Record of Performance

All documents of the MS (principal circuit, technical data, routine and type test reports, calibration certificates and the reports of the performance checks) are collected in the Record of Performance. It is in the responsibility of the operator of the measuring system to establish and maintain the record of performance. All new measuring systems delivered by HIGHVOLT are accompanied by a Record of Performance. It has the required structure and includes all existing documents.

7. Experiences of an accredited calibration laboratory (DKD-K-24501) /5/

New MS delivered by HIGHVOLT to HVT

Type of MS	Quantity	Uncertainty	Limit IEC 60060-2
300 kV-LI	$\hat{U}$ T_1, T_2	1.2 % 5.1 %	3 % 10 %
800 kV-LI	$\hat{U}$ T_1, T_2	1.4 % 6.0 %	3 % 10 %
1000 kV-LI	$\hat{U}$ T_1, T_2	1.0 % 7.6 %	3 % 10 %
100 kV-AC	$\hat{U} / \sqrt{2}$, $U_{r.m.s.}$	0.8 %	3 %
100 kV-AC	$\hat{U} / \sqrt{2}$, $U_{r.m.s.}$	1.5 %	3 %

Table 2: Uncertainties of MS calibrated by DKD-K-24501

The uncertainty of the measurements (Table 2) is well inside the limits.

Existing MS

If the existing MS is based on modern design there are no problems to meet the required limits of uncertainty.

For older MS the weak points are the instruments and impulse voltage dividers without damping resistors. In some cases a bad characteristic of an instrument can be compensated by corrections. But in cases of analog oscilloscopes and instruments there are no chances to fulfill the required uncertainty. An older MS might be improved by a upgrade with new low voltage arms and instruments.

8. Conclusions

- The calibration of MS must be considered as an element of the calibration system of the country under consideration. National regulations have to be taken into account.
- At HIGHVOLT MS of test equipment, RMS and service are available to fulfil the demands of IEC 60060-2.

References

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Information sheet 10.3/2e
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