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Reference Measuring System for High Lightning and Switching Impulse Voltages.

Introduction

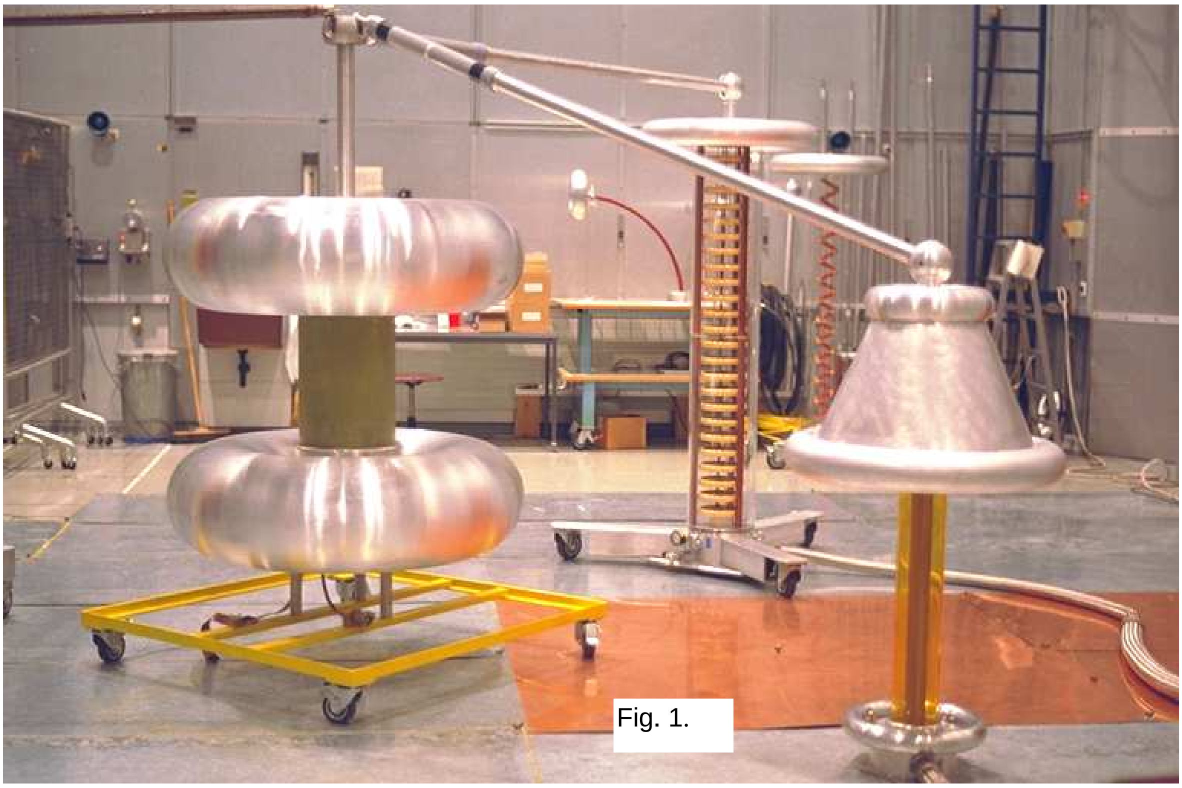

Fig. 1.

The measurement of voltages in the kV - and MV - range was always and still is a difficult task. This statement applies especially to high, transient impulse voltages for the following reasons:

- Any equipment used for electrical power transmission has to undergo a type or routine test before delivery to demonstrate its ability to withstand standard insulation levels. The peak values of rated lightning and switching impulse withstand voltages are always higher than those for the rated power - frequency (short duration) withstand voltage. The rated voltages are for example. standardized in IEC 71-1 (1993): "Insulation coordination, Part 1: Definitions, Principles and Rules." (As an example, the following rated levels, may be applied to 765 kV equipment: 2400 kV lightning impulse; 1550 kV switching impulse)
- The transient character of the impulses requires measuring systems which are able to fulfill the requirements for specific dynamic behavior, i.e. requirements for frequency dependent transfer characteristics (bandwidth) or step response parameters, which are difficult to achieve.

In about 1980 it was recognized that the former IEC publications related to high impulse voltage measuring devices (see IEC 60-3, Measuring devices, 1976, and IEC 60-4, Application guide for measuring devices, 1977) could not provide sufficient guidance to avoid unacceptable measurement errors. Based on extensive international cooperation and investigations therefore, the new International Standard, IEC 60 -2 (High voltage test techniques, Part 2: Measuring Systems [6]) was established and issued in 1994. This standard is based on a relatively new philosophy concerning the procedures, how the measuring system should be qualified and used, and how the quality of the systems can be maintained during the service life. To summarize, this new philosophy of IEC 60 - 2 may be characterized by the following topics:

- In order to achieve world-wide equivalence of test results and certificates, it is necessary to assess the test laboratories of the manufacturers of equipment for how competently they apply the testing and measuring methods. The procedure for assessment is carried out on the basis of essentially international agreement (see e.g. ISO/IEC Guide 58:1993, Calibration and Testing Laboratory Accreditation Systems - General requirements for operation and recognition). Testing laboratories should, therefore, undergo an accreditation procedure in order to acquire the status of an "Accredited Testing Laboratory", should possess "Approved Measuring Systems" and should have the expertise to perform measurements according to the requirements of IEC 60-2 (see Annex A of the standard).
- "Approved Measuring Systems" (as used daily for testing) are required to undergo not only an acceptance test (during purchase) but also periodic performance tests and checks to demonstrate that the quality of the devices can be maintained. (See IEC 60-2, clause 4)
- Although there are some alternative procedures which can be applied using the test facilities to perform the periodic test, there is one new method available which fulfills all the requirements of performance tests and performance checks. This method is based on the availability of "Reference Measuring Systems" which have "sufficient accuracy and stability for use in the approval of other systems by making simultaneous comparative measurements with specific types of waveform and ranges of voltage" (see sub-clause 3.1.4. of IEC 60-2). The procedure for performing these comparative tests is called "*Reference Method*".

To measure high impulse voltages, the requirements for *Approved Measuring Systems* are stated in sub- clauses 9.1 and 10.1 of IEC 60-2. These requirements call for overall uncertainties within ±3% for the measurement of peak values (full impulses) and within ±10% for time parameters (as e.g. front time T_1 or time to half value T_2 etc.). One major contribution to this overall uncertainty is made by the oscilloscopes, peak voltmeters and digital recorders, which should be less than ±1% (see IEC 790: 1984 and IEC 1083-1/2 1991/1995) for peak values. The requirements for a whole *Reference Measuring Systems*, however, are much more severe (see clause 12, IEC 60-2). For the overall uncertainties mentioned above, the quantities are ±1% and ±5% respectively. In addition, well defined quantities for the response parameters have to be fulfilled, not mentioned here (see sub-clause 12.2.2. of IEC 60-2). Taking again the considerable uncertainties of the scale factors for the indicating or recording instruments (oscilloscopes, etc.) into account, it can easily be recognized that the "converting device", i.e. the "*Reference Impulse Dividers*" should be as accurate as possible! They should actually comply with etalons, i.e. national primary standards, with uncertainties much of less than ±1%.

To maintain the quality of a Approved Measuring System, performance tests need to be repeated only annually but at least once away 5 years and after majors repairs of a measuring system. However performance checks should be made much more often. If no *Reference Measuring System* is available, the tests and checks based on the "*Reference Method*" can only be made by an *Accredited Calibration Laboratory* which owns *Certified Reference Systems*. To apply the first possibility, the measuring systems as used by the testing laboratory must then be transported to the *Accredited Calibration Laboratory*, which is nearly impossible to do as transportation is expensive and likely to damage the high voltage dividers which are often designed for nominal voltage in the million volt range. In addition, annual performance tests which are made by the staff of the *Accredited Calibration Laboratory* the user's laboratory are expensive, though the transportation of *Reference Measuring Systems* is easier due to the fact that the nominal voltage of *Reference Measuring Systems* can be as low as 20% of the system which has to be approved. Therefore, the most economical solution is to retain a *Reference Voltage Divider* in the your own (testing) laboratory.

Design of Resistor/Capacitor Reference Divider Type ID-____-CD__

This family of *Reference Dividers* is designed for standardized full or (front and tail-) chopped lightning impulse (1.2/50 - impulse) and switching impulse voltages (250/2500 - impulse or any other waveshape) as specified an IEC 60 -1 (1989). In addition, this family is also applicable to power frequency AC voltages. Fig. 2. shows the simplified basic circuit of a complete system, again for relatively low output voltages. Without the second converting device (attenuator: R_3, R_4, C_3, C_4), the main "converting device" includes the resistors R_D, R_H, R_L, R_A, the capacitors C_H, C_L, the high voltage lead (designed for the nominal voltage) and the transmission system, a very well shielded and low-loss coaxial cable. As is well known, this basic design was proposed in 1965 by W.S. Zaengl (see e.g. [1] and [2]) and has since this time, also been applied to the measurement of extremely high impulse voltages (see [3]). The high voltage arm of the divider (R_H, C_H) is designed to provide an "optimally damped capacitor divider", i.e. the effective capacitance C_H is a result of more than 10 high voltage capacitor units (C_H'), which are series - connected by means of an equal amount of resistor units (R_H') the values of which are carefully selected. Hence, for the very high frequency components of any impulse voltage, the scale factor of the converting device is, controlled by the resistors R_D, R_H and R_L which form a low ohmic resistor divider, whereas the scale factor for all lower frequency components is governed by the capacitances C_H and C_L. The special attenuator (R_3, R_4, C_3, C_4) is used if scopes or digital recorders are used with low input voltages.

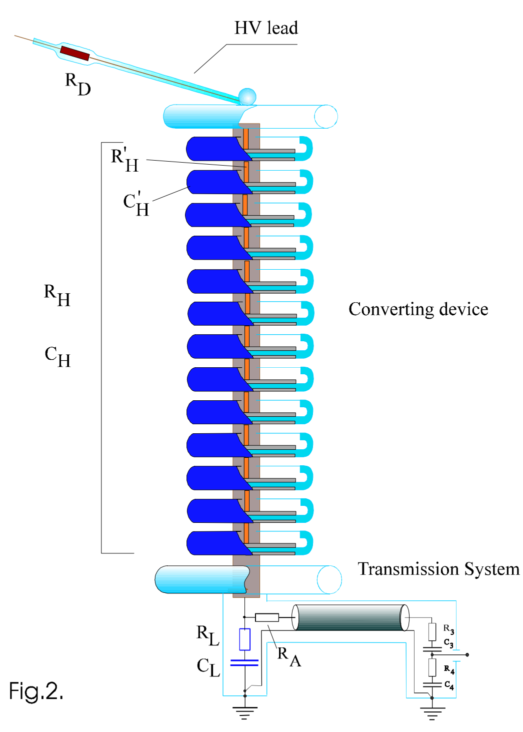

Fig.2.

The high precision of this family of *Reference Dividers* is reached by applying very stable ceramic-type capacitors, the moderate temperature-coefficient of which is compensated for by applying the same materials the high and low voltage arm. As the stray capacitance of the R_H -C_H column to ground potential (C_S) will influence the scale factor, if the ratio C_H/C_S becomes small, the nominal values of C_H are large enough for this influence to become negligible. The simple top electrode is not shaped to compensate for C_S, as this is not necessary; it is, however, discharge free up to the rated voltages in order to avoid any non - linearity.

Again, for higher rated voltages (500 kV), the components of the high voltage arm (R_H,C_H) are built into a gas - tight and transparent tube filled with SF6 of low overpressure. A simple, visual control of these components is thus possible.

Further design topics are:

- Mobile base (for 500 kV - systems)
- Complete additional shield for transmission system
- Precise attenuator (R_3, C_3, R_4, C_4) (optional)

Advantage of the Reference Divider of Presco AG.

- Application of highly stable components
- Same resistive and dielectric materials used in high- and low-voltage-arms for effective compensation of temperature-, frequency and aging effects to provide constant scale factor of the divider.
- Scale factors can be calculated according to component calibrations, which can be performed with a precision of 100 ppm and less (see ISH'95, [4]).
- Electric components of the high voltage arms are visible and can be observed during tests.
- No oil is used for insulation (no leakage problems)
- Output voltages of either some 100 volts or in the 10 V range for the application of any kind of recording instruments.
- No interference problems resulting from the effective shielding of low voltage arm and the "transmission system" (double shielded coaxial cables).
- Small size of the dividers to optimal high voltage design
- Discharge free systems up to the nominal voltages to avoid uncontrollable non-linearity.

How to approve an impulse measuring system?

As already mentioned in the introduction, all measuring systems as used daily in the periodic testing of HV equipment are required to undergo periodic performance test and checks in order to retain approval. The main goal of these tests is to determine the "*Assigned Scale Factor*" and the "*Dynamic Behavior*" of the measuring system which has to be ascertained. Although some alternative methods are permitted to perform such tests and checks (see clauses 9.3/9.4 and 10.3/10.4 of IEC 60-2), the application of the *Reference Method* is the most economical and reliable. This method is demonstrated in Fig. 3:

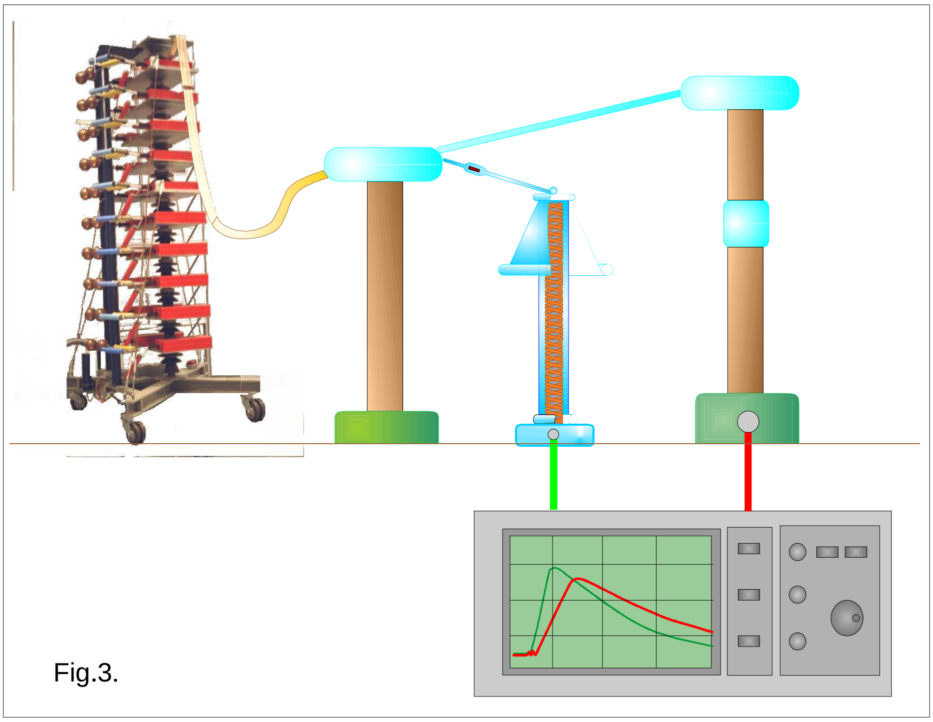

Fig.3.

The *Reference Measuring System* and the measuring system to be calibrated are connected parallel at the test object or at the front capacitor of an impulse generator. If a two-channel (digital) oscillographe is available, simultaneous readings may be taken on both systems for only one HV pulse applied. The value of the input (HV) quantity can the be obtained for each measuring system by multiplying the individual reading of records waveshape by the individual scale factors. As the scale factor of the Reference Divider is well known, the scale factor of system to be calibrated can be accurately checked and ascertained. When applying this method, the uncertainty is governed by the two-channel oscillographes, as the electronic systems of the channels are not very accurate. A higher accuracy for such a comparison is achieved if only one measuring instrument (the same channel of an oscillograph is used. Then, with the same connection between test object and dividers, at least ten voltage applications to each of the dividers are recorded and statistically evaluated. An alternate connection for each of the ten (or more) impulse voltages to the instrument is necessary as well as a stable ignition of the impulse generator in order to provide nearly equal voltage pulses. Specific investigations into the application of alternative method confirmed excellent results (see [4]).

References.

[1] W. Zaengl: "Ein neuer Teiler für steile Stoss-Spannungen (A new type of divider for steep-fronted high impulse voltages). Bulletin SEV 56 (1965) pp. 232-240

[2] Th. Blalock, D. Bullock, W. Zaengl, Tseng-Wu Liao: " A Capacitive Voltage Divider for UHV Outdoor Testing". IEEE Trans. on Power, App. and Systems, PAS-89 (1970), pp. 1404-1412.

[3] IRR-IMS Group:" Facing UHV Measuring Problems". ELECTRA No. 35 (1974), pp. 157-254

[4] S. Yimvutikul, W. Zaengl: "Reference measuring systems for lightning and switching impulse voltages." 9. International Symposium on HV Engineering (ISH'95), Graz/Austria, Aug.28 - Sept. 1, 1995, Report 4552.

[5] IEC 60-1. International Standard. 1: "General definitions and test requirements". Second edition 1989-11.

[6] IEC 60-2. International Standard. Part 2. "High voltage test techniques". Second edition. ?

Technical Data
Capacitor/Resistor Divider

	ID-0500-CD00 *
Rated voltages	
Lightning impulse voltage	500 kV
Front- chopped Lightning imp. voltage	500 kV
AC voltage	200 kV rms
DC voltage	250 kV
Measurement uncertainty	
Lightning impulse voltage	± 0.5%
Front- chopped Lightning imp. voltage	± 0.5%
Switching Impulse Voltage	± 0.5%
AC voltage	± 0.5% and 5 mrad
DC voltage	± 0.5%
Time parameters	± 2 %
Response data	
Experimental response time T_N	< 15 ns
Partial response time T_α	< 15 ns
Settling time t_s	< 100 ns
Overshoot β	< 10%
Impedances and ratios (1)	
High Voltage capacitor C_H	~ 200 pF
High voltage resistor R_H	~ 600 Ω
Scale factor without attenuator	~ 1000
Scale factor with standard attenuator (2)	
Reference conditions	
Temperature	10...30 °C
Relative humidity non-condensing	5...95%
Barometric pressure	70...106 kPa
Rated range of use (3)	
Temperature	0...40 °C
Miscellaneous	
Divider height	2 m
Length of HV lead including R_D	3 m
Net weight without connection cable	70 kg

Notes: * Including:

ID - 0xxx-XX35	Damping resistor and connection on high voltage side 350 Ω
ID - 0xxx-XXHV	High voltage divider
ID - 0xxx-XXCA	Coaxial cable screened 20 m 50 Ω
ID - 0xxx-XX04	Standard attenuator

(1) Approximated values, the actual values are certified
(2) The standard attenuator has app. 37 dB attenuation, producing 20 V for a scope. Other ratios are optional.
(3) With reduced specification