Universal Measuring Unit for High Voltage Measurements

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Abstract

Traditionally, high voltage (HV) laboratories have required different measuring instruments to measure alternating voltages 50/60 Hz (AC), using peak voltmeters, lightning impulses, through peak voltage meters or oscilloscopes and the apparent charge, by means of partial discharge (PD) measuring instruments. All of them with very different technical requirements stablished in applicable hardware and software standards (IEC 61083 series [1], IEC 60060 series [2, 3] and IEC 60270 [4]). However, the technological evolution of measuring instruments has allowed these measurements could be carried out through high-performance digital recorders. This article describes a new universal measuring instrument, developed by the LCOE for high voltage quantities, known as *UMU* (*Universal Measuring Unit*), for the five typical measurements to be carried out in any high voltage laboratory: AC 50/60 Hz, DC, Lightning impulse 1.2/50 µs (LI), Switching impulse 250/2500 µs (SI), partial discharge measurements, Radio Interference Voltage (RIV) measurements, transmitted overvoltage in secondary winding of voltage and current measuring transformers.
A new software package has been also developed in the framework of 19NRM07 *HV-com²* project [5].

1. Introduction

AC voltage measurements can be made with digital recorders with 1 MΩ input impedance, kilohertz (kHz) bandwidths and sampling rates of tens of kilosamples per second (kS/s). Lightning impulse measurements are also made with 1 MΩ input impedance but with bandwidths of tens of MHz and sampling rates of 100 to 200 kS/s. Furthermore, PD measuring instruments work with bandwidths and sampling rates similar to those required for lightning pulses, but with 50 Ω input impedance. Now, there are digital recorders that meet the technical requirements demanded by the indicated measurements, which makes it possible to have a universal measuring instrument for testing in HV laboratories. To this end, the R&D laboratory of LCOE has developed a new universal measurement instrument called *UMU*, shown in Figure 1.

Fig. 1 – *Universal Measuring Unit (UMU).*

2. Designing the *UMU* universal measuring instrument

The adaptation of the input voltage level and input impedance according to the needs of each measurement was one of the main problems to be solved. When the recorder is connected to the output of a high voltage divider, it is necessary to have a suitable attenuator depending on the low voltage branch of the divider, as well as when it is connected to a shunt for current measurements. Furthermore, when it is used for PD measurements, it must be adapted to the 50 Ω measurement impedance. The developed instrument has 4 channels, which allows simultaneous measurements of voltages and currents.

A digital recorder with adequate frequency response and bandwidth has been checked for suitability use in the different HV testing and measurements. A shielded enclosure has been designed to mitigate the electromagnetic interferences produced during tests, especially when disruptive discharges occur. *UMU* is connected to the different measuring systems to be used: AC, DC, LI, SI or PD through coaxial measurement cables. *UMU* is designed to be arranged in proximity to the divider limiting the length of the measurement cables, as shown in Figure 2. Figure 2 shows a high voltage test with a four-stage Marx type impulse generator (on the left) and an impulse measuring system consisting of a divider and the *UMU* connected to its low voltage branch (on the right).

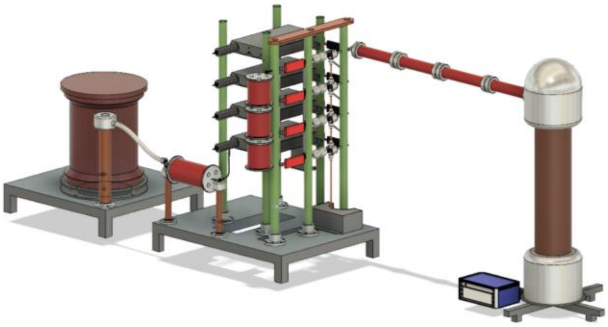


Fig. 2 – Conceptual layout of HV laboratory. *UMU* connected to the divider.

A fibre optic output is used for communication with the computer placed in the control room. Fibre optic ensures galvanic isolation between the testing facilities and the control room where the technicians operate the computers and monitors, as well as avoiding electromagnetic interference.

A new software package has been developed for this measuring instrument. The software also allows the measurement of combined and composite waveshapes, according to the criteria established in the IEC 60060 series [2, 3] and the EURAMET EMPIR *HV-com*[2] project [5].

3. Building the *UMU* universal measuring instrument

The *UMU* measuring instrument consists of three modules:

- Module shielded against electromagnetic fields.
- Measuring module.
- Rack.

The shielded module contains the digital recorder and it has the function of avoiding possible interferences due to electromagnetic fields in the measurement. This module has four BNC connections for the four channels of the recorder and an USB connection for the communication cable. The 50 Ω matching impedance for PD is also contained in this module.

The shielded module is inside of the measuring module. The attenuators required for high voltage and current measurements (capacitive and/or resistive) and the USB to fibre optic converter device are also contained in the measuring module.

Finally, the measuring module is installed into an industrial rack. This rack contains a rechargeable battery, the input connections for the coaxial measurement cables and the fibre optic communication. In addition, the rack has a power button for switching on / off.

3.1. Digital recorder

UMU measuring instrument has a four-channel digital recorder. LCOE Calibration Department has proved that this recorder has a suitable frequency response of up to 16 bits for power frequency measurements (50/60 Hz), up to 12 bits with a sampling rate of 250 MS/s for lightning impulse and partial discharge measurements and can work up to 1 GS/s with 8 bits. Its bandwidth of up to 200 MHz guarantees its suitability for use in any measurement to be carried out in a high voltage laboratory.

3.2. Attenuators

UMU incorporates attenuators with the technical characteristics of impedance and ratio required by the high voltage dividers to which they are connected (HVAC, HVDC, LI, SI) or by the shunts in the case of current measurements. The attenuators also incorporate overvoltage protections. Figure 3 shows the 3D design of an attenuator.

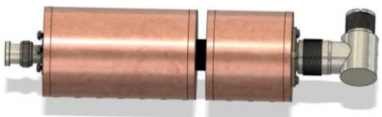


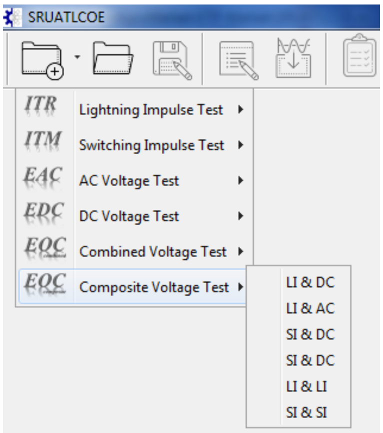
Fig. 3 – 3D design of an attenuator.

3.3 PD matching impedance

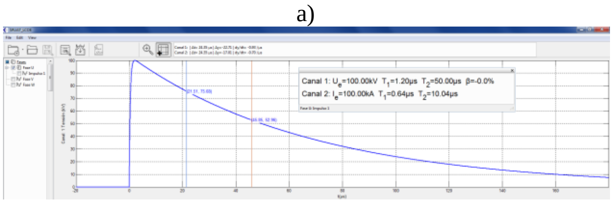
UMU incorporates a 50 Ω input impedance connected to the channel for PD measurements (instead of the 1 MΩ impedance used in the rest of the high voltage measurements).

4. Software

LCOE has developed an improved version of its own software, initially designed to evaluate different types of tests according to IEC 60060-1 [2], such as lightning or switching impulses, or AC and DC tests, including k-factor (determination of the test voltage according to IEC 60060-1 [2]). This new version has been developed to include combined and composite voltage waveforms analysis. A combined test voltage appears between the two energized terminals when energizing is provided by two different test voltages generated by two separate voltage sources (difference of waveshapes generated by two generators and measured with two different measuring systems). A composite test voltage is the superposition of two different test voltages generated by two separate sources sum of two waveshapes generated by different generators and measured with a single measuring system).
A view of the user interface is shown in Figure 4.



a)



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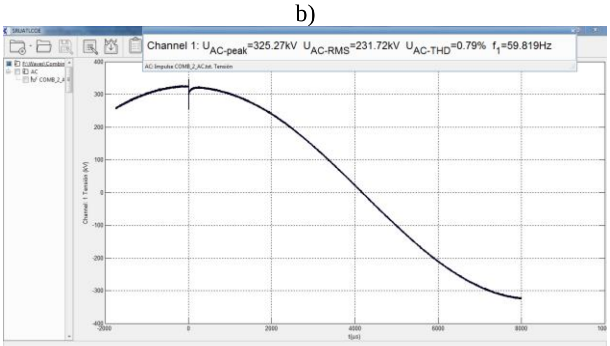

c)

Fig. 4 – New software interface: a) Test selection; b) Lightning impulse record; c) LI + AC combined record.

As an example, this software allows the simultaneous measurement of a lightning impulse applied on the operating voltage (AC or DC), that must be supported by the object under test.
The flowchart corresponding to the software analysis for composite and combined waveshapes is shown in Figure 5.

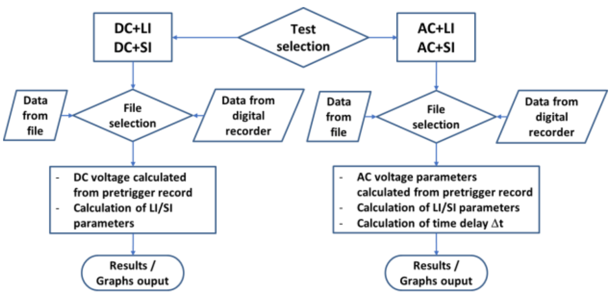

Fig. 5 – Software flowchart for composite and combined waveshapes analysis.

A complementary software is used for PD measurements.

5. Characterization of *UMU*

LCOE has carried out the tests and calibrations to check the correct operation of the *UMU* measuring instrument and its elements, in accordance with the current standards:

- Frequency calibration of the digital recorder (PS6.51 internal procedure of LCOE, accredited to ISO/IEC 17025 standard [6]).
- Frequency response of the attenuators (internal method of LCOE, as described in clause 7.1.3 of IEC 60060-2 [3]).
- Step impulse calibration (clause 5.3 of IEC 61083-1 [1]).
- Impulse calibration (clause 5.2 of IEC 61083-1 [1]).
- Electric field immunity test (clause 5.8 of IEC 61083-1 [1]).
- Magnetic field immunity test (clause 5.8 of IEC 61083-1 [1]).
- Electromagnetic compatibility test (EN 61326-1 standard, CE marking [7]).

5.1. Digital recorder

The frequency calibration of the digital recorder as a voltage meter and the calibration of its base time have been carried out by LCOE according to its internal procedure PS6.51. Figure 6 shows the correction factor obtained as a function of frequency in all ranges from 0.4 V/div to 4 V/div for one channel.

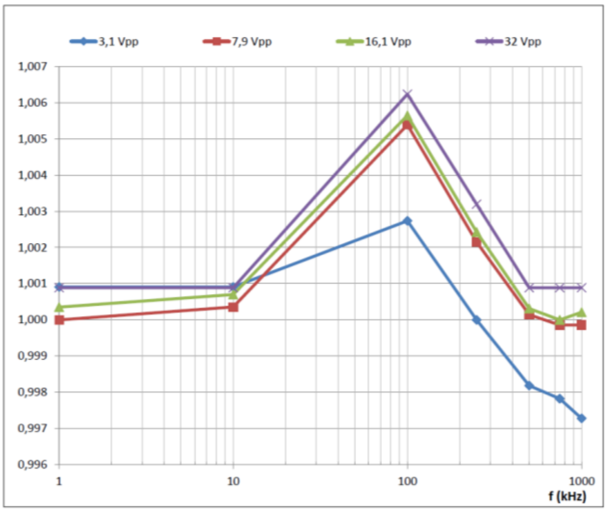

Fig. 6 – Correction factor obtained as a function of frequency.

Figure 7 shows the bandwidth graph for 12-bits resolution. The frequency-dependent characterisation of the recorder shows a 12-bit maximum error of less than 0.5 % for the frequency of 200 kHz (corresponding to full impulses) and an error of less than 1 % up to 10 MHz.

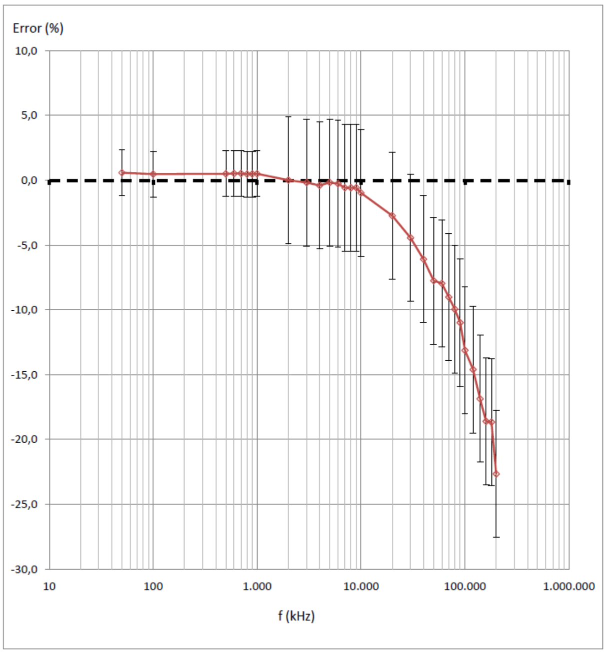

Fig. 7 – Bandwidth for 12-bits resolution.

5.2. Attenuators

Frequency response has been performed on the attenuators to characterise their performances to different frequency for input voltage signals. A flat frequency response is required depending on the test voltage to be measured for each attenuator, which implies that the scale factor remains constant over this frequency range.

Figure 8 shows an example of the frequency response obtained for two capacitive attenuators (flat frequency response up to frequencies of the order of megahertzs).

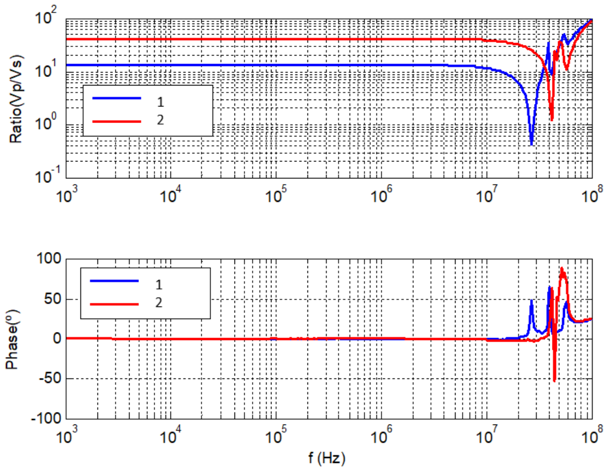

Fig. 8 – Frequency response for two capacitive attenuators.

5.3. *UMU* measuring instrument

The complete *UMU* instrument has been certified as high voltage measuring equipment: step impulse calibration, lightning impulse calibration and immunity to electric and magnetic fields, in accordance with standard EN 61083-1 [1].

In addition, the required tests have been carried out to obtain the CE marking (EN 61326-1 [7]).

5.3.1. Step impulse calibration

Different step impulse voltage levels were applied to calibrate its time response, according to clause 5.3 of IEC 61083-1 [1]. The voltage levels applied were the following ones: 50, 100, 200 and 300 V. Figure 9 shows one of the records as an example.

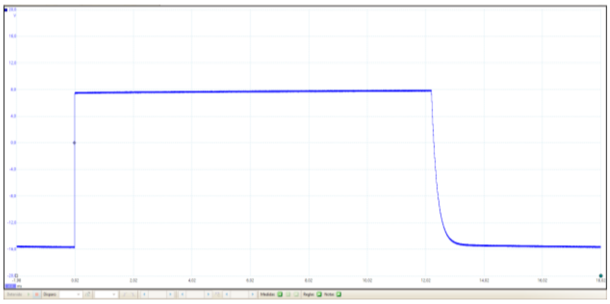

Fig. 9 – Step impulse voltage recorded by *UMU*.

5.3.2. Lightning impulse calibration

Ten lightning impulses of different voltage levels were applied for calibration, according to clause 5.2 of IEC 61083-1 [1]. The voltage levels applied were the following ones: 400, 700 and 1400 V (negative polarity).

The maximum deviation of the output peak values was less than 1% of the mean value and that the maximum deviation of each time parameter (Front time, T_1 and Time to half value, T_2) was less than 2% of the mean value. This calibration complies the requirement indicated in IEC 61083-1 [1].

5.3.3. Electromagnetic field immunity test

This test was carried out according to clause A.3 of Annex A of IEC 61083-1 [1]. It checks the sensitivity of the instrument to each type of electromagnetic disturbance (electric and magnetic fields).

UMU instrument (without measurement cables) has been tested against to a rapid variation of electric and magnetic field, representative of those produced in high voltage laboratories. The testing circuit is shown in Figure 10.

Figure 11 shows the magnetic field testing set-up in the laboratory.

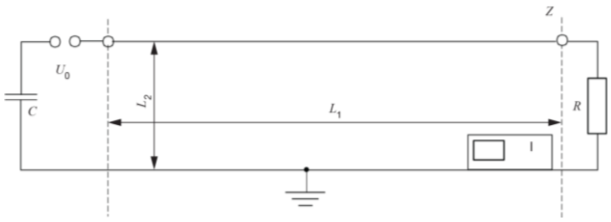

Fig. 10 – Circuit for electromagnetic field immunity test [1].

I: *UMU* instrument under test, placed at the end of the line.
Z: Characteristic impedance. C = 30 nF, L_1 = 5 m, L_2 = 1 m.
Electric field test: U_0 = 40 kV (R = Z).
Magnetic field test: U_0 = 100 kV (R = 0).

Fig. 11 – Magnetic field testing set-up.

Electric field immunity test:
Several discharges of the capacitor were applied at 40 kV and *UMU* always communicated correctly through the optical fibre. It means *UMU* did not lose the communication signal due to the electric field and it recorded the electrical disturbances caused by the capacitor discharges.

Magnetic field immunity test:
Several discharges of the capacitor were applied at 100 kV and *UMU* always communicated correctly through the optical fibre. *UMU* did not lose the communication signal due to the magnetic disturbances caused by the capacitor discharges.

6. Conclusions

LCOE has designed and developed a new universal measuring instrument, called *UMU*, consisting of a digital recorder, attenuators matched to the measuring devices (dividers and shunts) and measuring cables, capable of recording the different types of measurements carried out in a high voltage laboratory: AC 50/60 Hz, DC, Lightning impulse, Switching impulse, partial discharge measurements, RIV measurements, transmitted overvoltage and current impulse.

LCOE has certified the correct operation of the *UMU* according to the standards for this type of voltage measuring instruments and software.

Acknowledgement

This project 19NRM07 *HV-com*[2] has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

7. References

[1] IEC 61083-1 *"Instruments and software used for measurement in high-voltage impulse tests – Part 1: Requirements for instruments"*, 2001.
[2] IEC 60060-1 *"High-Voltage Test Techniques – Part 1: General definitions and test requirements"*, 2010.
[3] IEC 60060-2 *"High-Voltage Test Techniques – Part 2: Measuring systems"*, 2010.
[4] IEC 60270 *"High-voltage test techniques - Partial discharge measurements"*, 2000.
[5] H2020 EURAMET Project: EMPIR 19NRM07 HV-com[2] *"Support for standardisation of high voltage testing with composite and combined wave shapes"*, 2020-2024.
[6] ISO/IEC 17025 *"General requirements for the competence of testing and calibration laboratories"*, 2017.
[7] EN 61326-1 *"Electrical equipment for measurement, control, and laboratory use – EMC requirements – Part 1: General requirements"*, 2020.