IMPROVEMENT AND UPGRADING OF THE PTB STANDARD MEASUREMENT SYSTEM FOR HIGH ALTERNATING VOLTAGES

M. Schmidt* and J. Meisner and W. Lucas
Physikalisch-Technische Bundesanstalt , Bundesallee 100 38116 Braunschweig, Germany
*Email: Matthias.Schmidt@PTB.de

Abstract: This publication describes the extension and modernization of the precision measuring device for the measurement of high ac voltages at the Physikalisch-Technische Bundesanstalt. In addition to the measurement of the peak value, the extension of the present PTB standard for measurement of high ac voltages based on the capacitor charging current procedure (Chubb-Fortescue method) MAZI [2] allows also the effective value and the positive and negative peak of an ac voltage up to 1 kHz to be exactly determined. A 24 bits A/D conversion with a maximum sampling rate of 15 MS/s was used. The thus obtained time-discrete values are evaluated, displayed and filed by means of a software, programmed at the Physikalisch-Technische Bundesanstalt. The digitalization of the measurement signal allows current mathematical functions to be used for the determination of relevant characteristics such as, for example, the harmonic distortion.

Comparison measurements with the existing PTB standard as well as mathematical uncertainty determinations provide (without taking the high-voltage capacitor into account) an overall uncertainty of less than 0.005 %. This uncertainty is valid for both the effective value measurement and the peak value measurement of high ac voltages.

1 INTRODUCTION

In high-voltage technology, the measurement of ac voltages plays a decisive role. Both the determination of the peak values of a sinusoidal high voltage - which is decisive for flashovers on insulation sections - and the determination of the effective value which is relevant in the supply networks are indispensable. [1]

In the past few decades, these questions have been successfully dealt within the scope of PTB's legal tasks by the development of new measurement techniques and the establishment of corresponding measuring instruments. Precision measuring devices for measuring the peak values and the effective values of high ac voltages have, in this connection, been developed already in the years 1990, 2003 and 2006. The increasing requirements for the measurement uncertainty as well as the development of new working equipment in energy supply engineering and the requirements thus resulting for metrology enforce, however, the further development of the existing precision and standard measuring devices.

In the course of the modernization of the existing PTB standard for high ac voltages, a modular precision measuring system, based on the charging current method, has been developed. [2],[3],[4],[5]

2 BASIC PRINCIPLE OF THE MEASUREMENT

The basic principle of the measuring devices developed at PTB for high ac voltages can be derived from the charging current procedure according to Chubb-Fortescue. The charging current of a high-voltage pressure-type capacitor in the high-voltage circuit is converted into a proportional ac voltage and measured with the aid of an I/U converter as follows:

$$i_m = \frac{1}{T}\int_{t}^{t+\frac{T}{2}} i(t)\,dt$$
$$= \frac{1}{T}\int_{t}^{t+\frac{T}{2}} C\frac{du}{dt}(t)\,dt = \frac{1}{T}\int_{\hat{u}_-}^{\hat{u}_+} C du = 2fC\hat{u}$$

This procedure allows the peak-to-peak voltages of a high ac voltage to be measured under laboratory conditions with an overall uncertainty of 0.005 %. This indication does not contain the uncertainty of the high-voltage capacitor. [1]

Due to the lacking possibilities of a sufficiently exact A/D conversion of this signal, a voltage-frequency conversion is carried out in the case of MAZI (named after the two developers Rainer Marx and Roland Zirpel) with the aid of which a frequency proportional to the high voltage can be determined. The sequence of pulses of the alternating frequency is used to calculate the peak-to-peak voltage. Figure 2a shows the principle of the set-up of the MAZI.

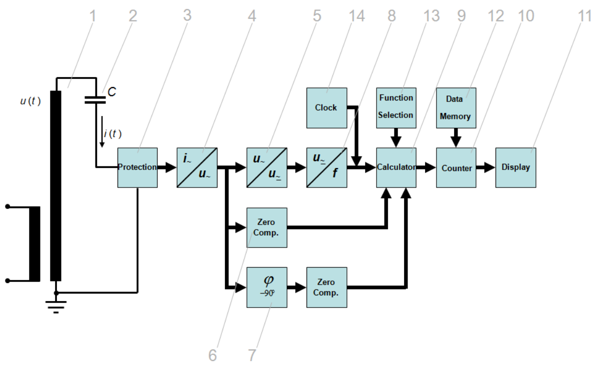

Figure 2a: Precision measuring device MAZI composed of: 1 HV generator, 2 HV capacitor, 3 protection circuit, 4 I/U converter, 5 rectifier, 6 zero-voltage comparator, 7 phase shifter 90°, 8 U/f converter, 9 computer, 10 impulse meter, 11 display, 12 measured data memory, 13 function control, 14 timer

UMAS 1 (Universal Marx System) is a further development of MAZI, established in the years 2002-2003. In this system, analog-to-digital conversion by means of a transducer card with a vertical resolution of 16 bits and a sampling frequency of 1 MHz is used. Figure 2b shows the construction of this measuring device. Processing and storage of the digital measurement data are completely realized by a computer. Sampling of the voltage proportional to the charging current allows both the shape of curve and the effective value of the voltage to be exactly determined. UMAS offers a measurement uncertainty of $2{\cdot}10^{-4}$.

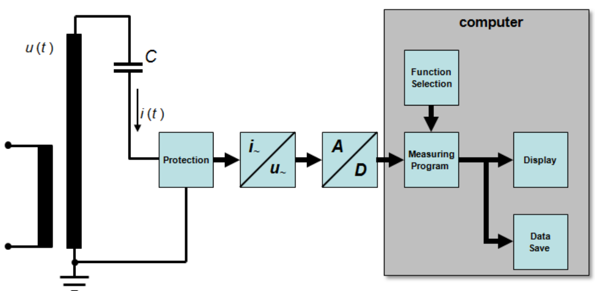

Figure 2b: Simplified block diagram of the UMAS measuring system

The extension of this set-up dates back to the years 2005-2006. At that time, standard components were used to achieve high mobility. The analog-to-digital conversion can be performed by means of a digital HP 3458A voltmeter. Digital measurement values are delivered to a measuring computer. Due to the low sampling rate of the HP 3458A (maximally 100 kHz) and a resolution of 16 bits, discrete Fourier transformation has to be carried out. This requires synchronization. [3]

Now, the system is to be further optimized with UMAS 3. This measuring system consists of two separate modules: the analog and the digital side. Figure 3a shows the block diagram of the UMAS 3. The analog side is composed of the measuring circuit and the signal processing unit. Here, a high-voltage pressure-type capacitor serves as generator of the charging currents to be measured, and an I/U converter converts the charging currents into a measurement voltage which is proportional to them in the range of ±5V. [4]

The interface between the analog and the digital side of the UMAS 3 is a 24 bit A/D transducer card. The digital side of the measuring system consists of the signal evaluation and signal display and of the filing of the data. Both processes are performed by means of a standard computer with specially programmed software. [2][5]

3 SYSTEM MODULES

Measuring circuit: The measuring circuit consists of an overvoltage protection circuit for voltages above 50 V and of a high-voltage pressure-type capacitor with a capacitance of approx. 100 pF. This capacitor has a minimum resistive fraction with a tan δ of less than 10^{-7}.

Signal processing: The signal is processed by converting the charging current of the HV capacitor into a proportional voltage. The I/U converter is realized by an inverting operation-amplifier circuit as shown in Figure 3a.

The virtual zero point A, by which the HV capacitor is connected to the zero potential at the low voltage side, proves to be an advantage. It allows the parasitic capacitances in the measurement cable and the deviations caused by them to be neglected.

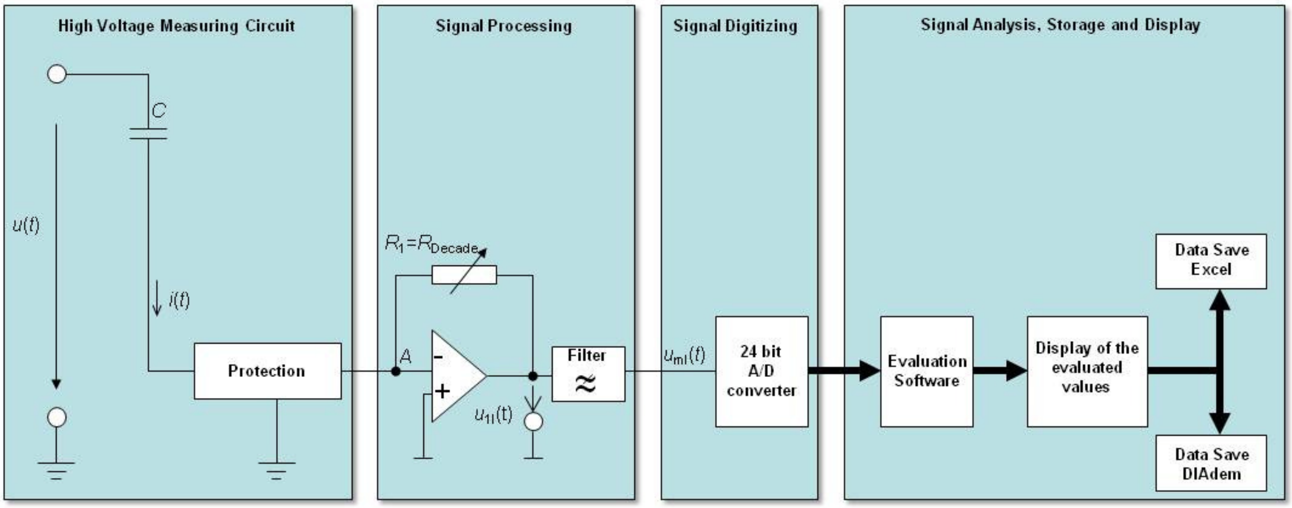

Figure 3a: Simplified block diagram of the UMAS 3

Digitalization: The intersection between the analog and the digital part of the measurement circuit is realized by means of a 24 bit digitizer card. Digitalization is performed with 22 bits and a sampling rate of 1 MS/s with the aid of which 400.000 values are recorded differentially in two channels.

The amplification of the measuring system was determined in a comparison measurement with the traced-back subsidiary system of the primary power sampling standard (PPSS), the national standard for electrical power measurements. By means of the software, this deviation is deduced - together with the offset - for each measurement. Here, the temperature dependence is taken into account and compensated during the measurements with the aid of the temperature determination on the A/D converter card.

Evaluation and display: The measurement software covers triggering of the hardware, signal correction, signal display and filing. Figure 3b shows the schematic view of the software construction. In the input, the settings of the digitizer, of the signal correction and of the signal processing are defined by the user. In addition, the function and the precision of the evaluation software can be checked by means of a signal simulator.

For signal correction, first of all, possible correction factors, which result from divider ratios and resistance properties, are applied. Here, the deviation of the system from the PPSS is included. In addition, the read-in temperature on the A/D transducer card serves to determine and compensate the temperature drift of the digitizer. A digital Butterworth low-pass filter of the 6th order with adjustable edge parameters limits the signal to relevant frequencies and delivers it - without high-frequency interferences - to the amplitude adaptation where the software converts the actual charging current values of the capacitor by means of the calculated scale factor from the high-voltage capacitance and the decade resistance of the I/U transducer. After compensation of the offset, the corrected data are passed to the signal processing unit.

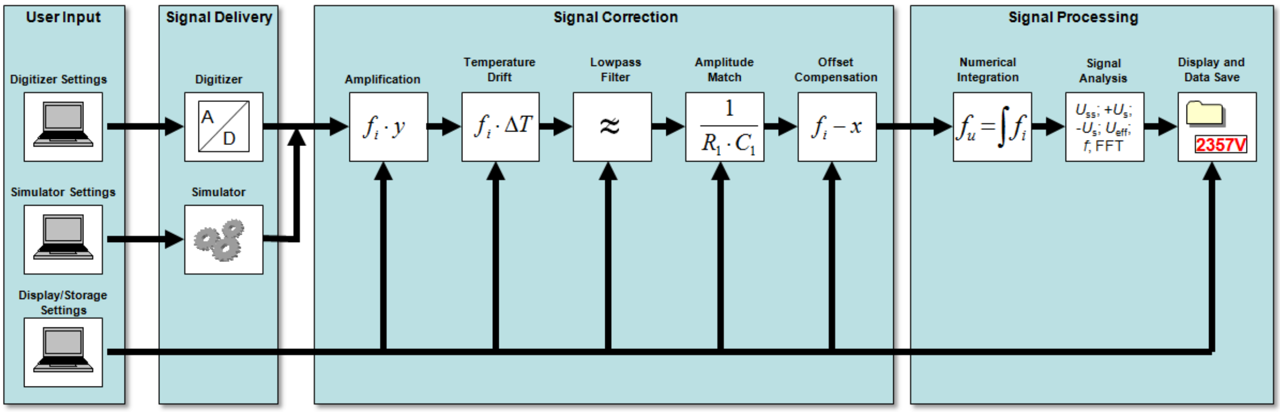

Figure 3b: Simplified software build up of the UMAS 3

For signal processing, the integration is carried out in accordance with the formula above. By this, the ac voltage on the high voltage capacitor is determined. These values can now be used to calculate the required voltage values of the ac voltage on the basis of known analysis procedures. Depending on the adjustment, the measurement values of the system and the measurement data of a test piece can be exported into well-established analysis and evaluation software. Storage of the raw data and of the evaluated results can also be performed in an automated way.

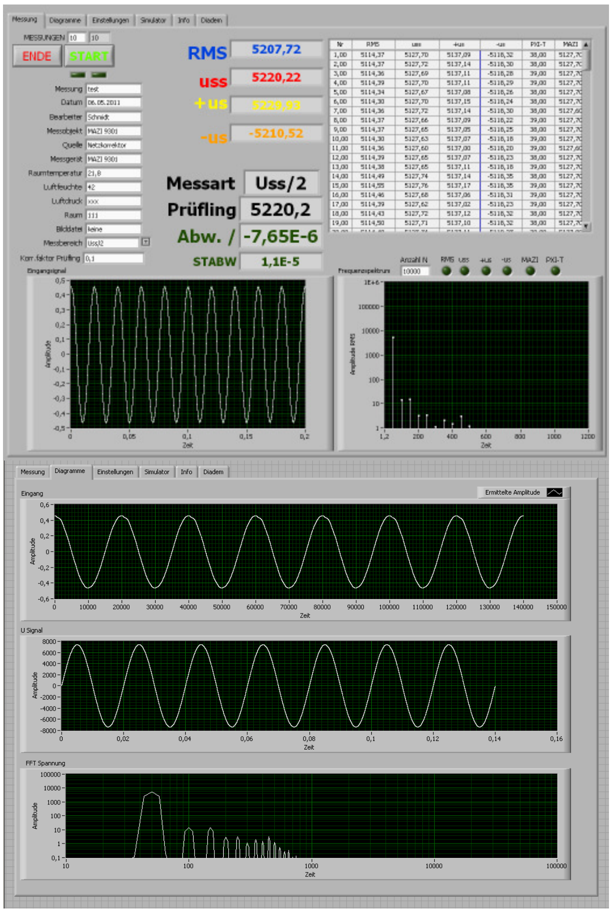

Figure 3c: Software display of UMAS 3

For different test pieces, the UMAS 3 offers the following interfaces: GPIB, USB, RS232, TCP/IP. The display can be adapted to the user. One possibility is shown in Figure 3c. The run of the voltage signal as well as a frequency analysis are shown in the upper window. The lower window shows the measured voltage, the calculated high voltage and the frequency spectrum. Furthermore, relevant signal parameters such as, e.g., the RMS-voltage, the deviation of the test piece and the standard deviation can be shown.

4 COMPARISON MEASUREMENTS AND RESULTS

To ensure the correctness of the calculated maximum measurement uncertainty, comparison measurements were carried out on two national standards at the Physikalisch-Technische Bundesanstalt. Furthermore, the internal resistance of the measuring system was detected by a comparison with a voltage standard.

4.1 Comparison of UMAS 3 and PPSS

To determine the deviation of the UMAS 3, a comparison with the traced-back PPSS (Primary Power Sampling Standard) at an rms-value of 3 V was made. The expanded uncertainty (k=2) of the PPSS at the power frequencies is less than 2 10^{-6}. At higher frequencies up to 333 Hz, the expanded uncertainty is less than 12 10^{-6}.

Figure 4a shows the results of this comparison, i.e. the deviation of the pre-calculated correction value of the UMAS 3 against the frequency. According to this figure the influence of the frequency on the uncertainty is less than $2.5\cdot10^{-6}$. This diagram represents also the difference between the UMAS 3 and the PPSS with a standard deviation of $2\cdot10^{-6}$. [6]

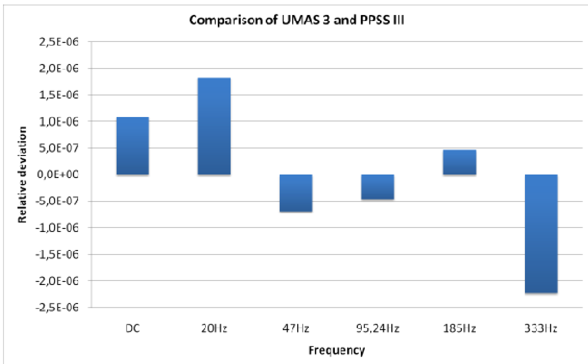

Figure 4a: Comparison of the UMAS 3 with the PPSS

4.2 Comparison of UMAS 3 and MAZI

A comparison of the UMAS 3 with the present PTB standard for high ac voltages, MAZI, has been made at several voltages up to 10 kV and frequencies of 50 Hz and 300 Hz. Both the MAZI and the UMAS 3 were operating in the 10 kV range. The deviation to be determined could only be detected in the range of the deviation of the MAZI. The accurate acquisition of measuring data was limited by the least significant bit (LSB) of the MAZI result display. The difference between the deviation due to the least significant bit of the MAZI and the measuring deviation of the UMAS 3 is shown in Figure 4b. The run of the curves indicates that the LSB of the MAZI affects the deviation of the UMAS 3. Therefore, a better uncertainty of the UMAS 3 is expectedly.

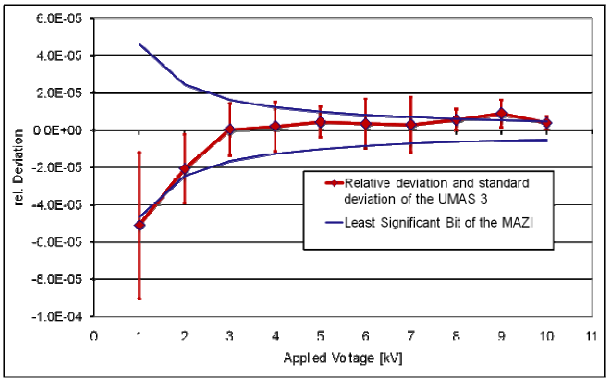

Figure 4b: Comparison of the UMAS 3 with the MAZI and declaration of the LSB

Figure 4c shows the comparison of the MAZI with the UMAS 3. To determine the uncertainties in lower areas of the whole range, the measurement was made in 10% steps of the range ±10 kV. The deviation between the MAZI and the UMAS 3 is more precisely than the declaration of the uncertainty of the MAZI. This indicates a measurement uncertainty lower than $2{\cdot}10^{-5}$ of both the UMAS 3 and the MAZI.

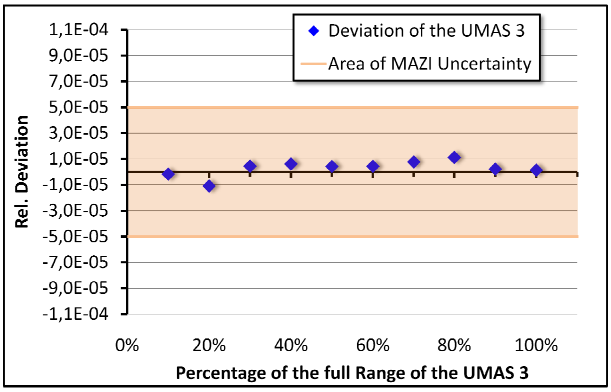

Figure 4c: Comparison of the UMAS 3 and the MAZI with indication of the percentage of the full Range of the UMAS 3

5 CONCLUSION

A transportable measuring system for high ac voltages consisting of modular components was developed. To verify the uncertainty of the UMAS 3 system comparison measurements were carried out with two PTB standards and the analogue components determined. The results indicate an uncertainty which is comparable to the present standard for high ac voltages MAZI. Therefore, further research on this measuring system and the evaluation of the actual uncertainty will be done in the next period.

A decisive advantage of the extended measuring system is its modularity. The measuring equipment consists of commercially available components and thus offers fast maintenance and modernization possibilities. In addition, the frequency analysis offers the view on the harmonics of the measured high ac voltage. A development of a stationary UMAS 3 is in process at the Physikalisch-Technische Bundesanstalt.

6 REFERENCES

[1] D. Kind: “Einführung in die Hochspannungs-Versuchstechnik“, Friedr. Vieweg & Sohn, Braunschweig/Wiesbaden 1978.

[2] Rainer Marx, Roland Zirpel: “Präzisions-Messeinrichtung zur Messung hoher Wechsel- und Gleichspannungen“, PTB-Mitteilungen 100 2/90, PTB Braunschweig 1990.

[3] Matthias Schmidt, Diplomarbeit: “Weiter-entwicklung und Optimierung eines digitalen Präzisions-Hochspannungsmesssystems mit PXI-Komponenten“, PTB Braunschweig and FH Braunschweig / Wolfenbüttel 2008.

[4] Martin Meyer, Diplomarbeit: “Untersuchung eines digitalen Meßsystems für hohe Wechselspannungen“, PTB Braunschweig and FH Braunschweig / Wolfenbüttel 2003.

[5] Markus Meier, Diplomarbeit: “Entwicklung und Erprobung eines digitalen Hochspannungs-messsystems für Wechselspannung mit einem Abtast-Voltmeter unter Verwendung einer objektorientierten grafischen Software“, PTB Braunschweig and FH Braunschweig / Wolfenbüttel 2006.

[6] Günther Ramm, Harald Moser, Andreas Braun: “A New Scheme for Generating and Measuring Active, Reactive, and Apparent Power at Power Frequencies with Uncertainties of $2.5{\cdot}10^{-6}$“, IEEE Transactions on Instrumentation and Measurement, Vol. 48, No. 2, April 1999