GENERATION AND MEASURMENT OF AC RIPPLE AT HIGH DIRECT VOLTAGE

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Abstract: This paper describes the generation and measurement of precise, reproducible ripples on high-voltage potential. On the basis of the HVDC (high voltage direct current) transmission and the ac and impulse signals by which the dc voltage is superposed, a procedure for the implementation of ac voltages of different curve shapes, amplitude heights and frequencies on dc high voltage is shown. Proof of these ripples serves to determine the properties of dc high-voltage measuring devices and their calibration.
The generation of the reproducible sinusoidal signals is realized by means of a function generator which is operated on high-voltage potential. The output frequencies can be varied between 10 Hz and 1 MHz.
For the measurement of the signals generated on the high dc voltage, the charging current procedure is applied parallel to the high-voltage divider. With this procedure, varying voltages of a few volts can be exactly determined on a high voltage of up to 100 kV. For the measurement of the high dc voltage, the standards available at PTB are used. [1], [2], [3]

1 INTRODUCTION

The signal patterns on the dc voltage side of a high-voltage direct current transmission are in no case pure dc signals. In particular in the case of the IGBTs-based VSC (voltage source converter) technology, the output voltage of a converter contains - due to periodic switching transients - considerable harmonics fractions. These undesired effects are also referred to as "ripples" and represent a component of the loss energy in an HVDC system which cannot be neglected. To investigate and reduce these losses, both - measuring devices and a measuring set-up - are required for traceability. [2]

The measuring system described here, called SAMS 1 (Schmidt and Meisner Ripple Measuring System), allows periodic vibrations on high-voltage potential to be measured with high precision. In that process, the high dc voltage is determined separately from the oscillation effects.

To evaluate the uncertainty of this measuring system and to establish a test set-up for industrial dc wideband dividers, a method for the interference of high dc voltages with reproducible ripples was proved and implemented in addition.

2 GENERATION OF RIPPLES ON HIGH VOLTAGE

For the provision of the high dc voltage, the sources available at the Physikalisch-Technische Bundesanstalt are used. In laboratory 2.32 of PTB Division 2 "Electricity", dc voltages up to ±300 kV can be generated.

The implementation of reproducible ripples on high-voltage potential is performed by means of a function generator manufactured at PTB. This generator is operated with an input voltage of ± 12 V which is supplied by two batteries. Thus, the generation of different voltage forms can be realized in the low-volt range at a high potential. As a test signal for the determination of the measurement uncertainty, the sinusoidal form with variable frequencies is used.

3 BASIC PRINCIPLE OF THE RIPLE MEASUREMENT AT HIGH VOLTAGE

The capacitance charging current procedure (Chubb-Fortescue method) is well suited to measure low-voltage vibrations on high-voltage potential. As has already been explained in the PTB publications dealing with the subject "Measurement of high ac voltages" [3] [6], a high-voltage capacitance tuned to the desired frequency is implemented in the voltage circuit with a low resistive component. The charging current caused by the capacitor is converted into a proportional, well measurable voltage by means of an operational amplifier and determined by a sampling system. By integration of the current curve, which is represented by the converted voltage *u(t)*, the respective ac voltage is obtained in accordance with:

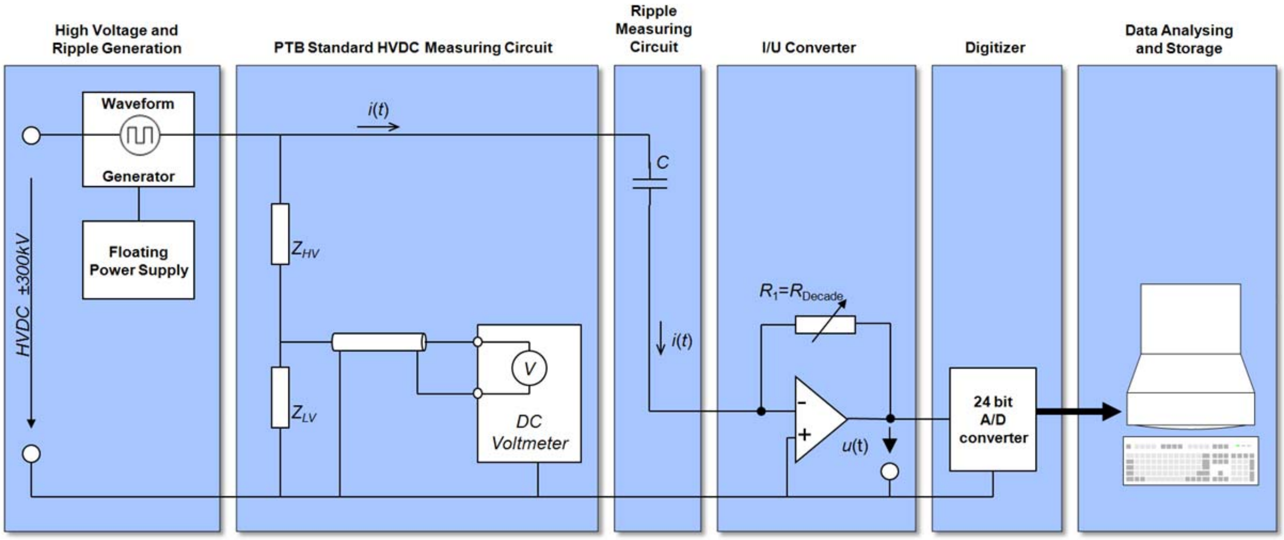

Figure 3a: Simplified block diagram of the SAMS 1

The dc component in the voltage is irrelevant as the charging current results from the voltage increase. The high dc voltage can be measured with a conventional resistive divider. To achieve a measurement uncertainty of the dc voltage of $2\cdot10^{-6}$, the national standard MT100 is used for the tests. [1], [3]

Figure 3a shows the simplified schematic view of the SAMS 1. In the range of the high voltage and ripple generation, an ac voltage with an amplitude of up to 10 V develops. The mean value of this function lies at the adjusted high voltage. In the dc high-voltage laboratory of PTB, the maximum value of this voltage amounts to ± 300 kV. The ac voltage results in charging currents *i(t)* in the high-voltage capacitance. The capacitance is connected to the zero potential via the virtual point of an operation amplifier. This way of proceeding offers the decisive advantage that any cable capacitances in the measuring line are minimized. The measuring resistance of the operation amplifier circuit includes a quadripole resistor. In this way, the detection of the internal resistance can be avoided. Furthermore, operation amplifiers are chosen which have smaller frequency ranges, but enhanced frequency properties. Two I/U converters with different analogue input filters are used in parallel. This allows the harmonics to be determined up to 100 kHz. By means of the operation amplifier circuit, the charging currents are converted into the voltage *u(t)* and digitized by a 24 bit A/D converter. The raw data of the measured ripples can now be determined and evaluated externally on a computer and investigated for the desired properties with the aid of well-established mathematical functions.

4 MEASURING SOFTWARE

The measuring software developed at the Physikalisch-Technische Bundesanstalt comprises the following sub-functions:

- Triggering and readout of the digitizer,
- signal correction by deposited correction factors and correction tables (e.g. offset correction, correction of the amplification, drift correction),
- different filter functions for the examination of adjustable frequency ranges,
- checking of the function of the evaluation software by an integrated simulation program,
- numerical integration of the measurement signal for reconstruction of the ac voltage applied to the high-voltage capacitor,
- signal analysis (e.g. U_{SS}, RMS, f, FFT),
- separate determination of the values for frequencies above and below 1000 Hz,
- linkage of the measured ripple with the high dc voltage,
- signal display in the form of numbers and diagrams,
- storage and export of data.

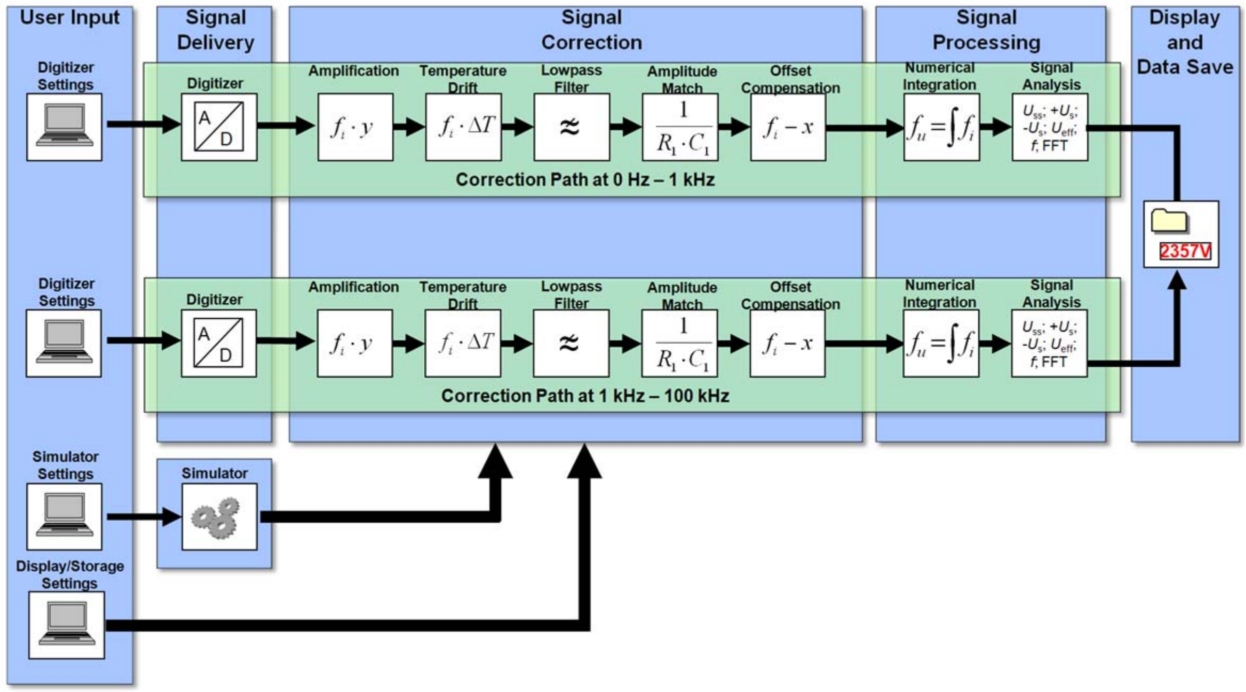

Figure 4a: Simplified block diagram of the ac measuring software of the SAMS 1

In addition, the software can be used to determine the RMS values of all frequencies simultaneously to make a statement about the height of the determined frequency components. For frequencies above and below 1000 Hz, the values are determined separately as shown in figure 4a. Each of the correction paths has a digital Butterworth-Filter of the 6th order to limit the signal to relevant frequencies. Figure 4b shows the relative deviation of the filtered signal. It the area below 1 kHz the filter of channel one is enable. Above 1 kHz up to 100 kHz the filter of channel two is enable. Thus, the maximum deviation based on the digitals filter is in the range of $1{\cdot}10^{-4}$.

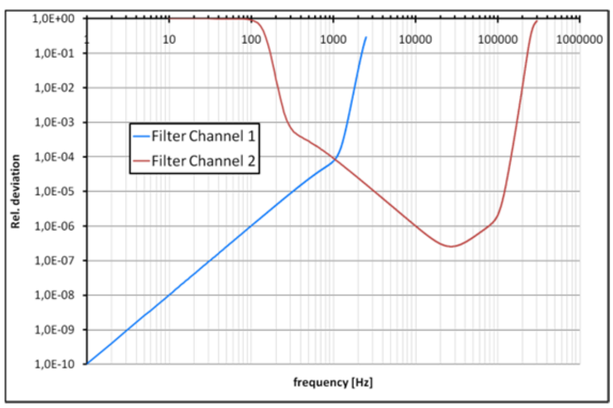

Figure 4b: Frequency ranges of the digital Butterworth filters of the 6th order

5 LOW-VOLTAGE MEASUREMENT AND THE DETERMINATION OF THE ACCURACY

To determine the accuracy of the measuring system, the characteristics of the I/U converter were determined with the aid of low ac voltages. For this purpose, a traced-back calibrator was used to carry out measurements with 1 V, 2 V and 3 V at frequencies between 10 Hz and 100 kHz. At the same time, a comparison measurement was carried out with the digital voltmeter Agilent 3458A to confirm the determined values.

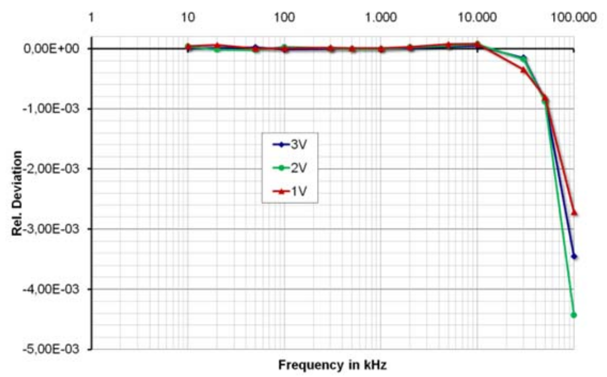

Figure 5a: Frequency response of the I/U converter

These investigations serve to assess the frequency response of the I/U converter. Figure 5a shows the determined values. The uncertainty at frequencies of up to 10 kHz is less than $1{\cdot}10^{-4}$. At frequencies between 10 kHz and 100 kHz the uncertainty is less than $5{\cdot}10^{-3}$.

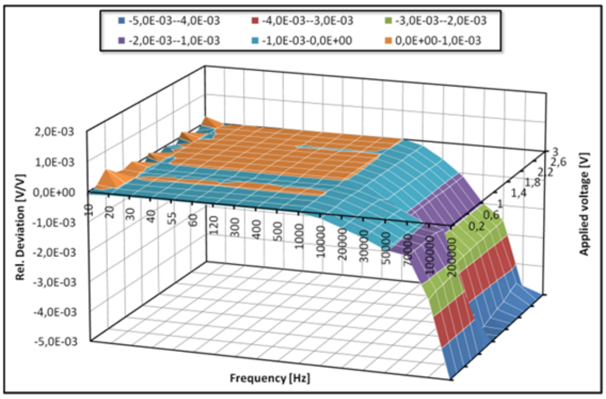

Figure 5b: Comparison of the UMAS 3 and the Fluke 8506 A

To determine the deviation of the SAMS 1, a comparison with a traced-back, thermic ac/dc measuring devise Fluke 8506 A was made. The results, which are shown in figure 5b, verify the results of the comparison with the Agilent 3458A shown in Figure. As the ac measuring circuit of the SAMS 1 used in the low-voltage comparison does not have to be changed for the measurements at high dc voltages, the measured deviation can be used in both cases.

6 MEASURING AT HIGH VOLTAGE AND DETERMINATION OF THE ACCURACY

In order to detect any possible influences of the high voltage during the precise measurement of the low ac voltage, the described waveform generator was used on high voltage. An rms-value of approximately 1 V and a frequency of 1.3 kHz were applied. In figure 6a, the discharging behavior of the battery is to be seen. An influence of the rising and falling high voltage on the rms-value of the low ac voltage is, however, scarcely noticeable. Thus, the uncertainty results of the comparison measurements carried out with the Agilent 3458 A at low voltages can be transferred to the measurements at high voltage. To eliminate the influences of the HVDC which are a result of the earth capacities, the I/U converter build-up has to be shielded.

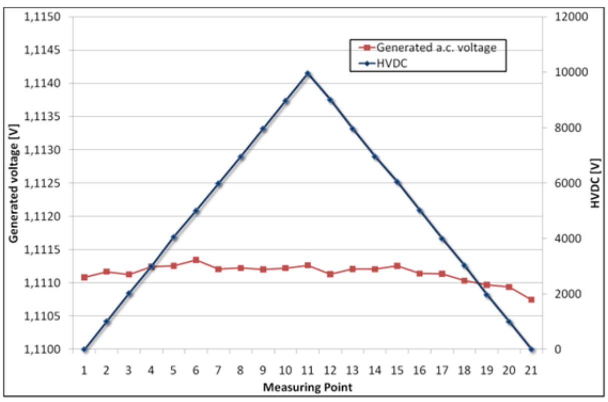

Figure 6a: Influence of the high dc voltage on the rms-value of the low ac voltage

To combine the measuring results of the high dc voltage with the superposed ac ripples, the software joins the measuring systems for dc and ac as described above. To merge the two signals with the time-discrete measuring points all measuring devices have to be synchronized.

7 SUMMERY AND OUTLOOK

This paper describes a system for measuring reproducible ripples on high-voltage potential and the generation of those ripples on HVDC. The first results indicate a ripple measurement uncertainty of less than $5{\cdot}10^{-3}$ at frequencies between 10 kHz and 100 kHz and $1{\cdot}10^{-4}$ at frequencies below 10 kHz. Thus, a precision system for specifying the dc uncertainty and the frequency characteristics of HVDC wideband dividers is available.

In the next research periods, the properties of the described generation of ac ripples will be upgraded. An input voltage stabilization with be realized with the aid of a buck converter and matched smoothing filters. This will prevent the distortion of the generated ac ripples caused by the discharging processes of the battery. Furthermore, first comparison measurements with dc-capable wideband dividers will be carried out.

8 REFERENCES

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