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Performance of current-voltage converter with amorphous core

The paper presents and discusses investigated results of metrological characteristics of a new generation of current-voltage converters manufactured with the use of the innovative technology of soft magnetic components. Current and angle errors of the converters together with current and frequency ranges of their work have been identified.

Keywords: *amorphous material, current measurement, current-voltage converter, deformed current waveform.*

1. INTRODUCTION

Currents measured in primary circuits are the basic source of information on the status of electrical systems. Lack of these data prevents proper control of the operation of any electrical power object and its protection in the event of a failure. Primary current values usually exceed the capabilities of measuring devices therefore it is necessary to use appropriate auxiliary equipment for matching the signals of an acceptable level. Here the most commonly used are current transformers and/or Rogowski coil converters [7, 11, 12]

Power electronic devices are used more and more frequently to control various electrical apparatus and equipment (e.g. electrical machinery powered by frequency converters). Obviously, in such cases it is related to the deformation of current and voltage waveforms. These disturbances have a significant impact on the quality of measurements in electrical power networks. It is particularly important when power and/or energy as well as current and/or voltage are considered operation criteria in automated electrical power system protection measures [1, 4, 5].

The experience shows that errors involved by common current transformers or interference due to the use of Rogowski coils can be quite significant in the case of distorted waveforms [6, 10]. Therefore, it is necessary to look for a suitably designed technical solution or other current transducers (or current-voltage convectors) to be used where there are a lot of power electronic devices applied that can significantly distort current waveforms due to generated high harmonics. All such converters should be resistant to external interference of electromagnetic fields generated by adjacent current paths. An alternative to traditional current transformers and/or Rogowski coils can be newly developed current-voltage converters with a technologically modified core made of an amorphous material [3, 8].

2. AMORPHOUS MATERIALS

The requirements for current measuring converters refer mainly to the magnetic coil. The exact transformation of signals requires to use materials which have a minimum power loss and maximum magnetic permeability. The applied magnetic materials no longer meet the requirements of users and designers, particularly as far as a broader range of frequency and increased accuracy are concerned.

Now one can distinguish two directions of magnetic materials development. The first one is to improve the properties of commonly used materials, such as Ni-Fe alloys or electrical steel. The iron-nickel alloys can be also doped with other suitable metals. Whereas the second direction is the development of amorphous soft magnetic materials, which are fine-grained alloys consisting, in 80%, of metallic elements like Fe, Ni and/or Co. The remaining 20% are nonmetallic elements such as boron B, carbon C, germanium Ge, phosphorus P, or silicon Si. They belong to the group of the so called metallic glasses whose structure is similar to liquid metals. These materials characterized by a metallic bond and are obtained under the process of rapid cooling of a molten alloy which forms an amorphous structure. Due to their thin and brittle structure they are called glassy materials. Their structure does not contain arranged atoms. Therefore, the position and type of alloying elements in the environment of the atom, the number of chemical bonds as well as the distances and angles of the form are various for different positions of the atom [13]. The basic characteristics that determine the usefulness of amorphous materials (produced in the form of tape) in electric and/or electronic power devices are:

- narrow hysteresis loop,
- high resistivity,
- small thickness of the tape.

The narrow hysteresis loop results in small hysteresis losses while the plate thickness of around 0.1 mm produces low eddy current losses. However, the disadvantages of these materials are high hardness and brittleness.

3. INVESTIGATED RESULTS AND DISCUSSION

The objects of the study were current-voltage converters, with amorphous cores, at the turn ratio equal to 1mV/A (as in Fig. 1). Primary winding creates one turn passing through the current transformer (CT) window, whereas the secondary winding of a suitable number of turns wound on the core. The CT terminals S1, S2 are loaded with resistor which decides about the desired value of the turns ratio.. Magnetization characteristics of the applied amorphous material for the core are presented in Fig. 2.

During the test the RMS values (Root Mean Square values) as well as primary and secondary current waveforms were measured and recorded. The effect of the transformation accuracy of the current and angle error was investigated. Current waveforms of different distortions were simulated with various contents of higher harmonics. A simplified scheme of the system for testing the performance of current-voltage converters is presented in Fig. 3.

Fig. 1. View of the current-voltage converter with amorphous material

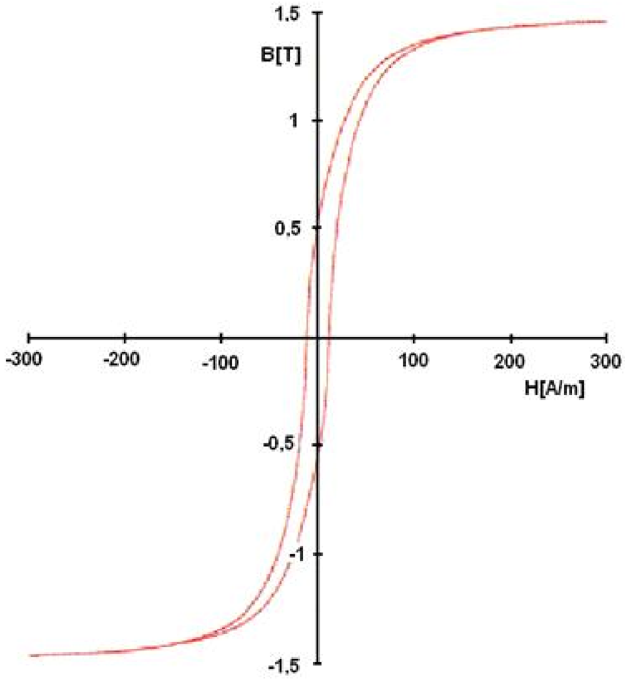

Fig. 2. Magnetization curve of the core of the current-voltage converter under test

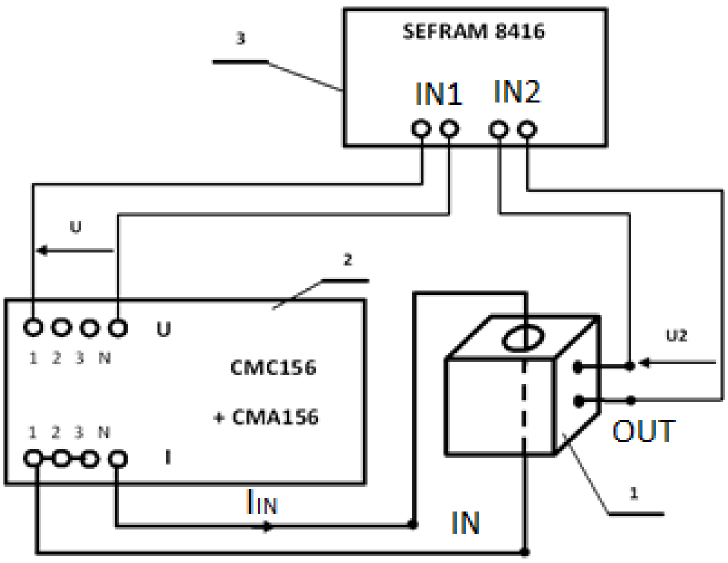

Fig. 3. Simplified electric scheme of system for testing current converters; 1 – examined current converter, 2 – microprocessor-based signal simulator, 3 – digital recorder

A primary current I_{IN} of a required amplitude and frequency was generated by an OMICRON current source . The secondary waveforms were next registered by means of the SEFRAM recorder. Based on the results of measurements, both current and angle errors were determined. The current errors DI were calculated by comparing the amplitude of the voltage (converted into current I_{OUT}) recorded on the secondary side with the reference amplitude of the generated current I_{IN}:

$$DI = \frac{I_{OUT} - I_{IN}}{I_{IN}} \cdot 100\% \quad (1)$$

where:

I_{OUT} – RMS current value of secondary side referred to primary winding [A];

I_{IN} – RMS value of the primary current set in the simulator [A].

The angle errors were determined by comparing the time of the current zero at both sides of the converter.

Basic research was carried out for the fundamental frequency equal to 50 Hz by changing the RMS value of the primary current up to 1000 A. In addition, the author examined the impact of frequency changes on the accuracy of the transformed current waveform on the secondary side. Selected results of investigations are shown in Fig. 4 ÷ Fig. 9.

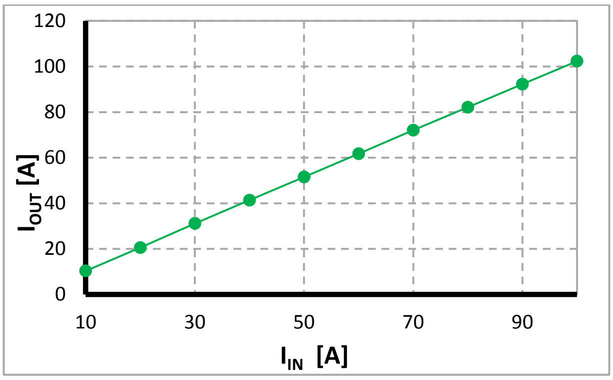

Fig. 4. RMS value of IOUT output current (on secondary side) as a function of RMS primary value IIN for frequency equal to 40 Hz and IIN in the range (from 10A to 100 A)

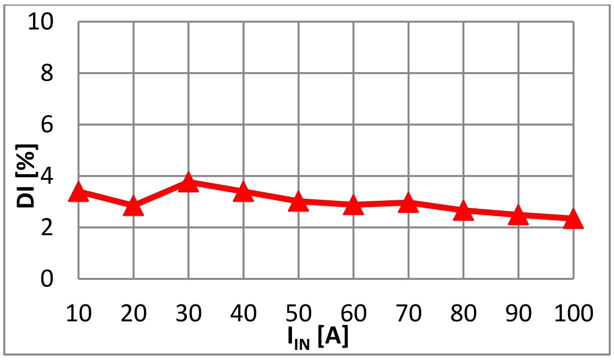

Fig. 5. Current error DI versus IIN (RMS value) in the range from 10 A to 100 A, for 50 Hz frequency

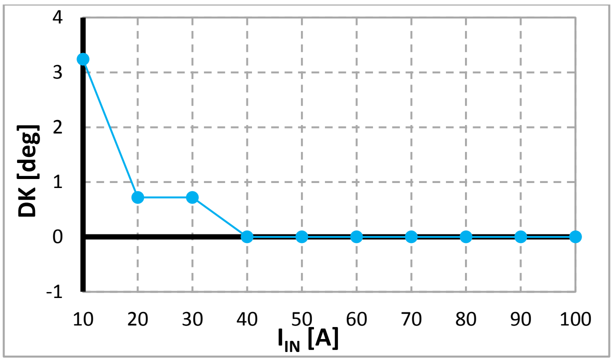

Fig. 6. Angle error DK versus IIN (RMS value) in the range from 10 A to 100 A, for 50 Hz frequency

For the frequency equal to 50Hz and the primary current value (RMS) changed from 10 A to 100 A, all the tested converters preserve linear transformation (see Fig. 4). The registered current waveforms are hardly disturbed which is reflected by low current (≤3%) and angle errors (up to 3 degrees), indicated in Fig. 5 and Fig. 6. For higher currents (up to 1000A RMS) both errors are insignificant (DI<2%, DK<0.2°). The study shows that at low frequency of the input signal (from 10 Hz to 50 Hz), the current and angle errors are also low (see Fig. 7÷9).

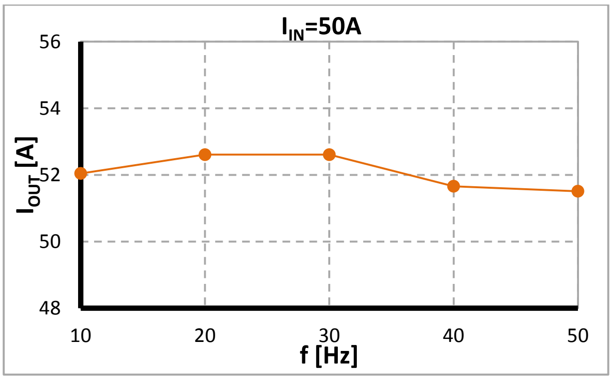

Fig. 7. Variation of RMS output current IOUT (on the secondary side) versus frequency of the input IIN (primary current) of RMS equal to 50 A

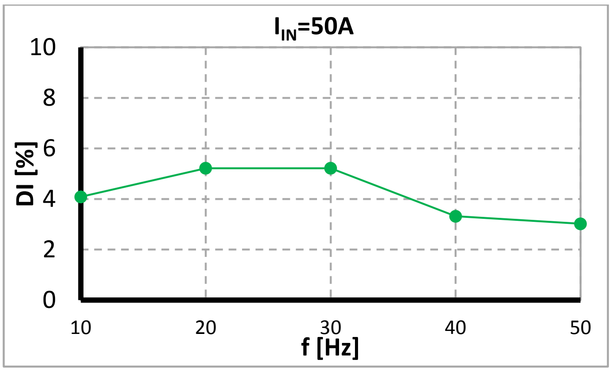

Fig. 8. Current error DI as a function of frequency of sine waveform IIN=50 A

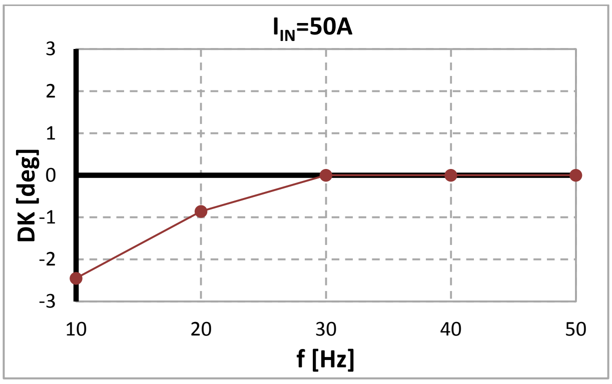

Fig. 9. Angle error DK versus frequency of a primary current (IIN=50 A RMS)

After increasing the frequencies up to 650 Hz it was found out that the transformation linearity of the current-voltage converter with an amorphous core is still maintained. Metrological characteristics of the newly developed current-voltage converters are much better than those of the most commonly used CTs and/or Rogowski coils [2, 9]. This is evident from the comparison of waveforms shown in Fig. 10.

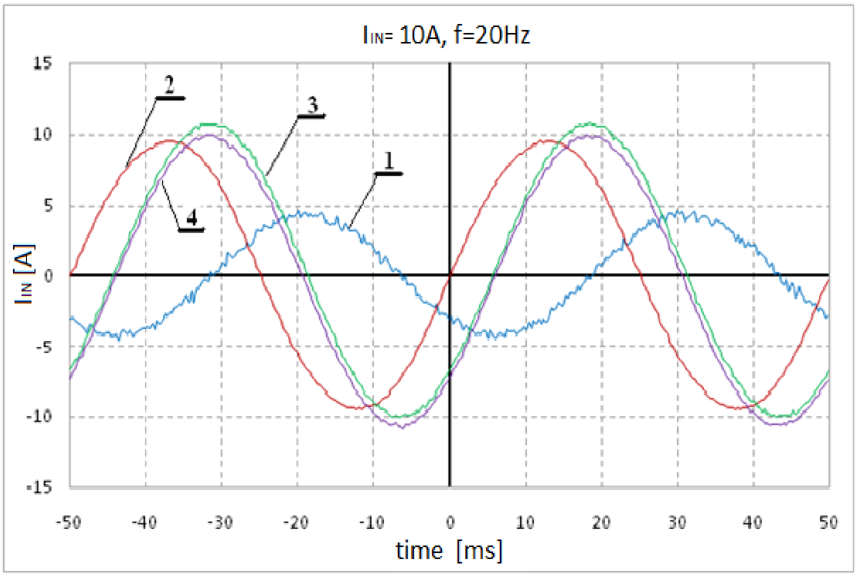

Fig. 10. Output current waveforms at sine input current of (IIN) 10A RMS and 20 Hz; 1 – Rogowski coil, 2 – common current transformer, 3 – current-voltage converter with amorphous core, 4 – input current

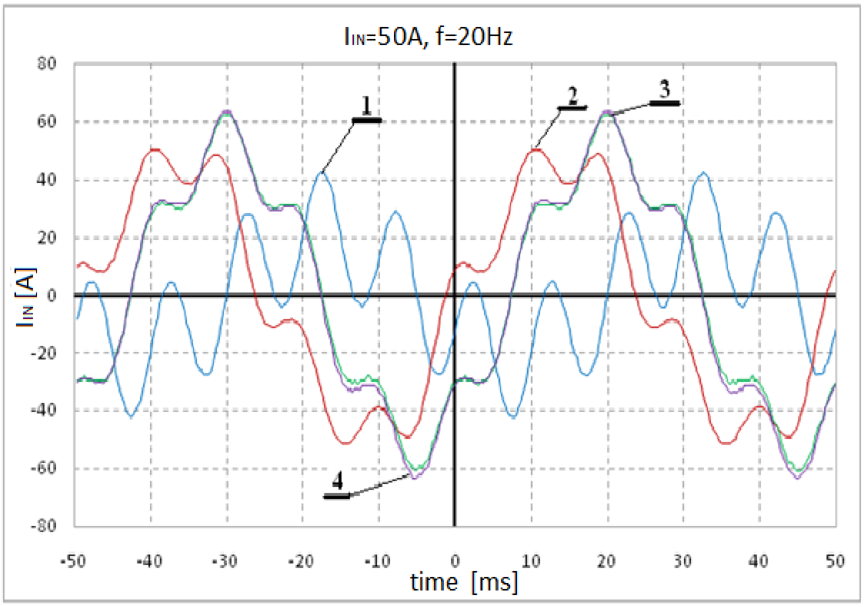

Fig. 11. Output current waveforms for input current value equal to 50 A of frequency 20 Hz with imposed 5-th harmonics of magnitude equal to 2A (20%); 1 – Rogowski coil, 2 – common current transformer, 3 – current-voltage converter with amorphous core, 4 – input (primary) current

Analyzing test output waveforms of different transmitters it can be concluded that only an amorphous core converter accurately reproduces the input signal. Both its current and angle errors are the smallest.

Figure 11 shows output current I_{OUT} waveforms for the tested transducers in the case when primary current (I_{IN}) is distorted. As it can be seen, the output signal for the amorphous converter is practically identical with the input current waveform, while for the other investigated transmitters the shape deviates significantly.

4. CONCLUSIONS

Based on the obtained results it can be concluded that:

- the current-voltage converter with an amorphous core is linear over the range of studied primary current values (from 1 A to 1000 A),
- the newly developed current-voltage converter performs very well (metrological properties) in a broad range of RMS values of the primary current (from 1 A up to 1000 A) and its frequency (from 10 Hz up to 650 Hz). Current errors are at the level of a few percent, while angle errors do not exceed 6 degrees,
- the demand for this type of amorphous current-voltage converters is particularly high in measurement and protection systems with significantly deformed current waveforms.

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