ENG61 FutureGrid

GOOD PRACTICE GUIDE

on the installation of non-conventional sensors in order to ensure high accuracy - recommendations for applying Rogowski coils in power grids

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1 Overview

Rogowski coil sensors are the most common type of non-conventional current sensors in power grids. Due to their operating principle, they have a wide working range, a linear transmission behaviour and are well suited for measuring harmonic currents. This guide presents some fundamental recommendations for the application of Rogowski coils in power grids.

Due to their structure principle, Rogowski coils are prone to external perturbations. For example, the accuracy of flexible Rogowski coils depends on the position of the primary conductor and the position of nearby conductors. These influences are quantified, using the behaviour of a commercially available flexible Rogowski coil. To prevent these negative influences, some recommendations on the installation of Rogowski coils are given, to ensure an appropriate accuracy of the measuring results.

In contrast to conventional current instrument transformers, the output signal of Rogowski coils are prone for electromagnetic disturbances. Hence, the transmission of the output signal has to be set-up to transfer the output signal of the Rogowski coil without significant disturbances. In Section 3, measuring setups are presented, which are suitable to ensure a robust transfer of the analogue output signal to the measuring device. Furthermore, a measuring setup is presented, which is very well suited for using Rogowski coils for measuring current harmonics. By exploiting the special operating principle of Rogowski coils, also high order harmonics with small magnitudes can be measured and transferred accurately.

2 Recommendations on Installation of Rogowski Coils

The following sections give recommendations for the installation of Rogowski coils in power grids. Flexible Rogowski coils are widely used for test measurements in power grids and particularly vulnerable for interferences caused by negligent installation. Therefore, the decisive effects are explained by regarding flexible Rogowski coils. Afterwards, some special features of rigid Rogowski coils are described.

2.1 Installation of Flexible Rogowski Coils

Flexible Rogowski coils allow to measure currents contactless, potential-free and without the necessity to open the electric circuit. Hence, they are often used for measurements in power grid. However, there are many parameter [1] [2], which influence the transmission behaviour of Rogowski coils, such as

- Position of the primary conductor and nearby conductors,
- Currents in nearby conductors,
- Frequency of the current,
- Manufacturing tolerances of the devices.

Due to their lock, flexible Rogowski coils often have a pronounced air gap. Hence, especially the position of the conductors related to the air gap have a high influence on the transmission error of flexibe Rogowski coils. Simulations in [2] [3] show deviations of several percent, if the primary conductor is close to the lock. Measurements in [4] and [2] confirm this behaviour.

Hence, the distance between the primary conductor of a Rogowski coil and its lock should be as large as possible to minimize the error due this influence.

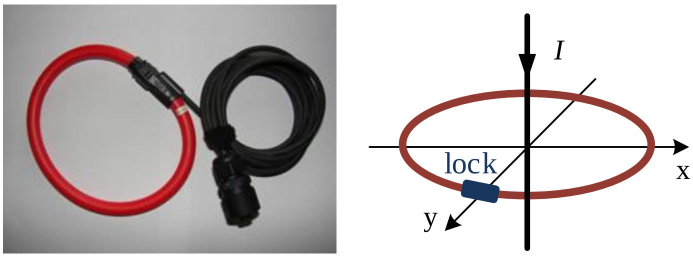

Fig. 1: Rogowski coil and regarded coordinate system [2].

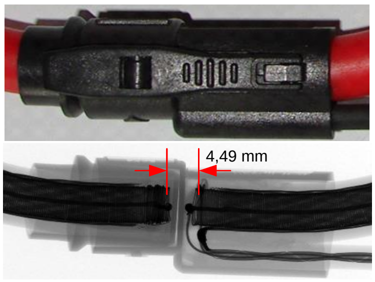

Fig. 2: Lock of a Rogowski coil (photo and X-ray photo) [2]

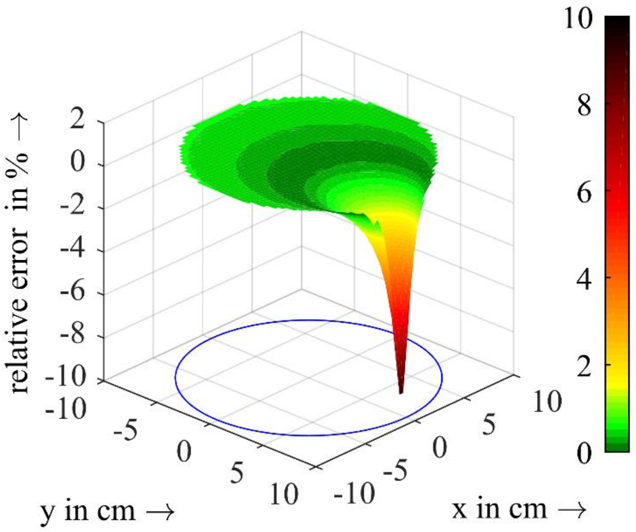

Fig. 3: Relative error dependent on the postion of the primary conductor [2].

In addition to the influence of the primary conductor, also nearby conductors affect the transmission behaviour of Rogowski coils [2]. Fig. 4 shows the compuation results of the transmission error dependent of the distance of the return conductor.

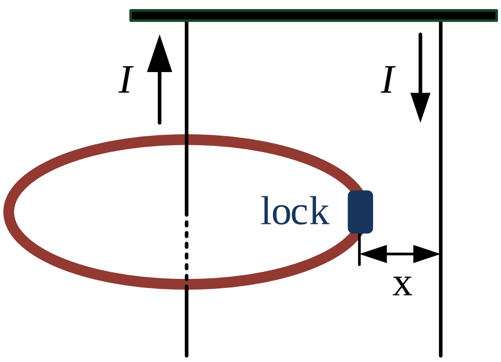

Fig. 5: Regarded geometry [2].

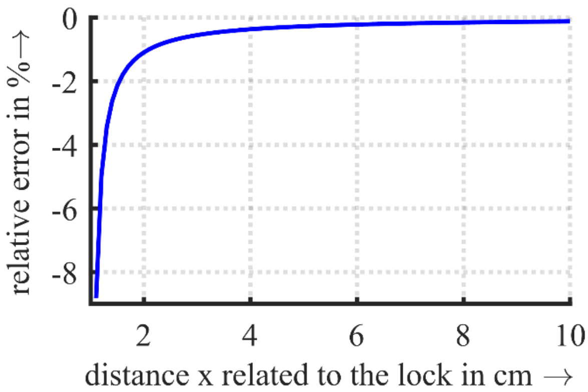

Fig. 4: Related error depended on the position of the return conductor [2].

The transmission error strongly increases with a decreasing distance between return conductor and the lock of the Rogowski coil. Hence, the distance between the lock of a Rogowski coil and nearby conductors should be as large as possible in order to minimize the error caused by the magnetic field caused by the currents in nearby conductors.

Investigations [4] show no apparent influence of electric stray fields on the transmission behaviour of typical Rogowski coils. Hence, no special shields to suppress electric fields have to be applied.

2.2 Installation of Rigid Rogowski Coils

Since rigid Rogowski coils do not have any lock, they are typically used for permanent measurement in power grids. Due to the manufacturing process, rigid Rogowski may have a small gap between the beginning and end of the winding as well. As with flexible Rogowski coils, this results in measuring errors depending on the position of the primary and nearby conductors. However, these influences are less pronounced than in flexible Rogowski coils, because of a much smaller gap.

The error due to the position of the primary conductor can be compensated, if the position of primary conductor and Rogowski coils is fixed, and the Rogowski coil is calibrated onsite. If the influences of nearby conductors on the accuracy of the applied Rogowski coil is to high, a magnetic shield may be applied to decrease this effect.

3 Transmitting and Processing the Output-Signals

3.1 Applying Rogowski coils with analogue integrator

Due to its operating principle, the output voltage of a Rogowski coil is propotional to the first derivative of the primary current. Hence, the output signal has to be integrated to determine the time resonse of the primary current.

Common flexible Rogowski coils are often connected to an analogue processing system which integrates and amplifies the voltage signal. This enables an easy realisation of real time measurements by using common voltage measuring devices, to show and record the current signal.

Transmitting the output signals of Rogowski coils is more complicated than transmitting the output (secondary) current of conventional current transformers. Because low voltage signals are prone for electromagnetic disturbances, which appear particularly strong in substations. Fig. 6 and Fig. 7 show setups which are commonly used at flexible Rogowski coils with integrated integrator.

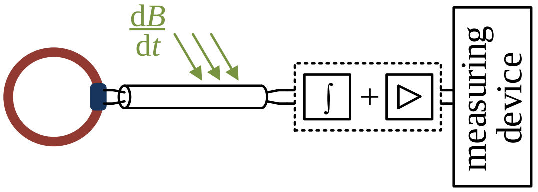

Fig. 6: Setup with signal intregration and conditioning close to the measuring device.

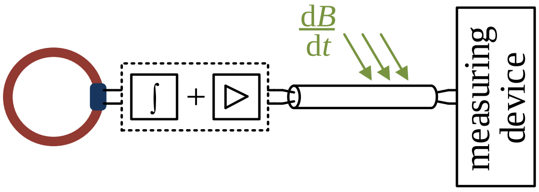

Fig. 7: Setup with signal integration and conditioning close to the Rogowski coil.

Both setups have disadvantages concerning the sensitivity against electromagnetic disturbances. The output voltages of Rogowski coils are typically very small. Hence, induce voltages caused by electromagnetic emissions may couple into the signal line and distore the measuring signal. Integrating and amplifying the output signal of the Rogowski coil, as shown in Fig. 7, therefore is a good approach. However this setup does not exploit the beneficial behaviour of the integrator, explained in the next section.

If the output signal is amplified to a sufficient high voltage level close to the Rogowski coil (see Fig. 8), the integration of the signal can be applied close to the measuring device. In contrast to the setup in Fig. 7, the integrator operates as an additional signal filter and attenuates the high frequency disturbances, which couple into the signal line.

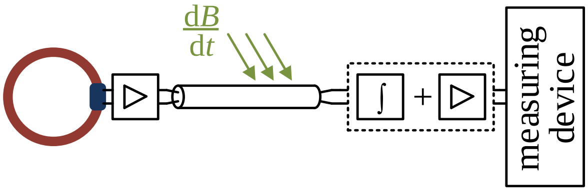

Fig. 8: Setup with using a preamplifier close to the Rogowski coil.

Converting the voltage signal of the Rogowski coil into a current signal (see Fig. 9) is the most robust method to transmit the measuring signals over long distances and prevents any disturbances. In this case, it is not necessary to exploit the integrator as addional filter at the end of the transmittion line.

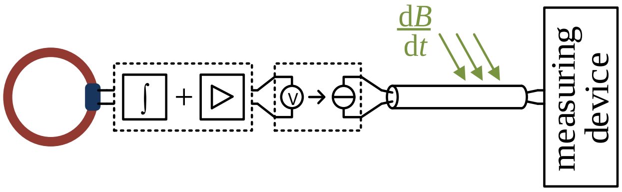

Fig. 9: Setup with using a voltage to current transducer.

3.2 Applying Rogowski coils without an analogue integrator

Alternatively to an analogue integrator, the output voltage of the Rogowski coil can also be sampled directy and integrated by using numerical integration algorithms (see Fig. 10). In this case, the output voltage should be amplified to a sufficient voltage level to realise an appropriate signal-to-noise ratio of the measuring signal.

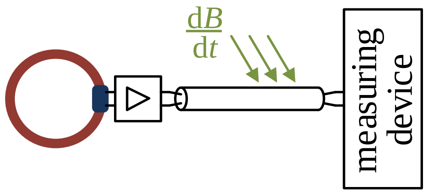

Fig. 10: Setup without using an analogue integrator.

Especially when measuring current harmonics, it is beneficial to measure the output voltage of a Rogowski coil directly. In this case, the integration of the signal does not have to be performed. Since the harmonics in power quality measuring devices are computed by discret fourier transform, the output voltage of the Rogowski coil can be integrated easily in the frequency domain. The current harmonics $\underline{I}^{(h)}$ can be determined by evaluating the regarded harmonic voltage $\underline{U}^{(h)}$ and considering the inductance of the Rogowski coil:

$$\underline{I}^{(h)} = \frac{1}{\mathrm{j}\omega\, L_\mathrm{R}} \cdot \frac{\underline{U}^{(h)}}{h} \tag{1}$$

Transmitting the output signal of a Rogowski coil directly yields excellent signal-to-noise ratios for all harmonics which have to be measured. The current levels of the harmonics often decrease with increasing harmonic order. Therefore, the low signal levels of high order harmonics are typically prone to high frequency disturbances. Due to their operating principle, the output signal of Rogowski coils is proportional to the derivative to the measured current. Hence, the influence of current harmonics increase linear with an increasing harmonic order. Therefore, high order harmonics with small magnitudes result in high voltage harmonics at the output of Rogowski coils. Compared to the integrated signal, the signal-to-noise ratio of the harmonics is significantly higher, if the not integrated signal is transmitted. Furthermore, the influence of the quantisation noise of the analoque-to-digital converter in the measuring device on the determined harmonics is significantly lower, if the not integrated signal will be sampled.

Compared to measuring setups with analogue integrators, the requirements for the inputs of the measuring devices are higher, if the output voltage of Rogowski coils is sampled directly. Similar to the harmonics in the primary current, also high frequency components in the primary current are amplified. Hence, the anti-aliasing filter has to have a much higher attenuation to ensure a signal which meets the needs of the sampling theorem. Furthermore, the inputs of the amplifier (see Fig. 10) have to resist the high input voltages, which may be caused by fast transients in the primary current. Hence, the application of an overvoltage protection device to protect the inputs of the amplifier is strongly recommended.

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