Using the new configuration of the current transformer as a safe current meter

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Abstract. The normal functioning of energy systems cannot be achieved without solving the most important issue, which can be formulated as a reliable and safe measurement of electric current. For this purpose, an industrial current transformer is most often used, which has a number of significant disadvantages during operation. These deficiencies can be corrected using an improvement in the design of the current transformer. The device of a similar current transformer, the results of studies of the electromagnetic field of an industrial current transformer and a current transformer with an improved configuration are presented in this article. In addition, the results of the experiments of the samples under study are set out, suggesting the possibility and preference of using a similar design of current transformers for measuring single-phase current of industrial frequency.

1. Introduction

In the electric power industry, current transformers are most often used as an industrial current meter; this is due to the simplicity of the design and the physical processes taking place in this electrical measuring device. The current transformer is a static electromagnetic device designed to measure alternating current and transmit measurement information to measuring devices [1]. A distinctive feature of the current transformer is a short-circuited secondary winding or closed at a low resistance of the measuring instruments secondary winding. Since the operating mode of the current transformer is characterized by the fact that the total magnetic flux in the magnetic circuit is determined by the difference in the fluxes of the primary and secondary currents, it is necessary that the magnetic flux generated by the primary current (and this can be tens or hundreds of kiloamperes) is always compensated by the magnetic flux generated by the secondary current. Otherwise, core heating and high voltage on the secondary winding occur, which is extremely dangerous for maintenance personnel.

2. Materials and methods

Since it is impossible to completely exclude the possibility of accidental opening of the secondary winding, it is necessary to improve the design of the current transformer and make it impossible to open the secondary winding. This can be achieved by using a non-separable conductive ring made of aluminum or copper as a secondary winding, and the measuring winding can be wound on top or under a short-circuited ring. Due to the similar design of the current transformer with a short-circuited ring, the measuring winding can be in the open state without causing an emergency at the factory.

To confirm the possibility of using a current transformer with a short-circuited ring instead of an industrial current transformer, it is necessary to study their electromagnetic fields in the operating mode and prove experimentally that the voltage signal obtained from the measuring winding of the current...
transformer with a short-circuited ring coincides with the secondary voltage signal of the industrial current transformer.

For the research, samples that have the same magnetic core sizes, matching the bus bar configuration with the measured current and the circuit diagram of the experimental setup were selected. A sample of an industrial current transformer, indicating the geometric dimensions is shown in Figure 1, where 1 is a ferromagnetic magnetic circuit, 2 is a bus bar with primary current, 3 is the secondary winding of the current transformer, 4 is a section of the magnetic circuit for which the magnetic flux was calculated (figure 1). Figure 2 presents a picture of the distribution of the electromagnetic field when studying the model of this sample in the ELCUT software package, which allows modeling electrical machines and transformers to obtain a picture of the electromagnetic processes that occur in them (figure 2).

Figure 3 shows a sample of a current transformer with a short-circuited ring, where 5 is the signal winding of the transformer current sensor; 6 is a short-circuited electrically conductive ring, 7 is a section of the magnetic circuit, for which the magnetic flux was calculated (figure 3). The geometric dimensions of the magnetic circuit and the current bus bar for the current transformer with a short-circuited ring have the same values as for the current transformer (figure 1). Figure 4 shows the result of modeling the electromagnetic field in the ELCUT software package [2]. The calculation results of the electromagnetic field of the current transformer and squirrel-cage current transformer are presented in table 1.

**Figure 1.** Test sample of current transformation.

**Figure 2.** Distribution pattern of the lines of induction of the magnetic field of the current transformer.

**Table 1.** Results of numerical calculation of the electromagnetic field of the samples.

|                      | $I_1$, A | $\Psi_{I_1}$ | $I_2$, A | $\Psi_{I_2}$ | $\Phi_1$ | $\Psi_{\Phi_1}$ |
|----------------------|---------|--------------|---------|--------------|---------|----------------|
| Current transformer  | 60      | 0            | 59.891  | 0.995        | 1.2833  | 89.03          |
| A squirrel-cage current transformer | 60 | 0 | 59.895 | 0.484 | 1.0069 | 89.99 |

$\Phi_1 \times 10^{-5}$ Wb
In the research, it was assumed that the magnetic cores of two samples were made of electrical steel grade 3413, the properties of the material of the magnetic circuit [3] in the ELCUT software package were set by the main magnetization curve, which was possible because the working induction in the magnetic circuit would take values much smaller than the saturation induction [4]. The secondary winding of the current transformer is made of copper, the wire diameter is 1 mm, the number of turns was taken to be 60, the measuring winding of the current transformer with a short-circuited ring is made of copper, with the number of turns 50, and the wire diameter is 0.1 mm. The bus bar with the primary current is connected to a sinusoidal current source, the effective value of the measured current is assumed to be 60 A, the initial phase of the current is 0 °, and the frequency of the mains is 50 Hz. The short-circuited ring is made of aluminum, the dimensions of which are shown in figure 3.

3. Results
An analysis of the results of the study, presented in table 1, allows concluding that the phase error of the current measurement for two samples does not exceed a value of 1 °, which corresponds to an accuracy class of current transformer of 0.5. According to the standards [5], [6] for current transformers, an acceptable angular (phase) error is considered to be a value in the range from 0.5° to 1.5°.

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**Figure 3.** Test sample of a squirrel-cage current transformer.

**Figure 4.** Distribution pattern of the lines of induction of the magnetic field of a squirrel-cage current transformer.

**Figure 5.** Experimental setup
The results of the researches allow confirming the possibility of using the proposed version of the current transformer configuration as a current meter on the industrial scale. The issue of experimental confirmation of the possibility of using different AC and voltage meters in industry [7] has always been given special attention. Therefore, in addition to studying the electromagnetic field in ELCUT software package of two samples, experimental studies were conducted on the installation shown in figure 5, where 1 is an industrial current transformer, 2 is a current transformer with a short-circuited ring (Figure 5). The geometric dimensions and materials of the magnetic circuit, bus bars with current, and squirrel-cage ring correspond to the previously considered models in ELCUT. To increase the value of the signal received from the secondary winding of the current transformer and the measuring winding of the current transformer with a short-circuited ring, the current in the experiment was taken 300 A.

Figure 6 shows the result of an experimental study, where 1 is a signal from a current transformer with a short-circuited ring, 2 is a signal from an industrial current transformer. Analysis of the obtained waveforms allows drawing the following conclusions:

1. The phase shifts between the signals from the secondary winding of the current transformer and the signal from the measuring winding of the current transformer with a short-circuited ring have minimum values that appear due to the permissible error with which the USB oscilloscope registers signals.
2. The waveform of the squirrel-cage current transformer is the same as that of an industrial current transformer.

4. Conclusion

Analyzing the results of the research of the electromagnetic field of the samples under study in ELCUT software package and the experiment, it can be concluded that the use of a short-circuited current transformer, instead of an industrial transformer, will make the process of measuring alternating current completely safe, without reducing the accuracy of the measurement result. Similar designs of squirrel-cage current transformers can find wide application in industry both as an independent current meter and as an integral part of intelligent measuring systems [8].

References
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