Problems of methodological support in the verification of instrument current transformers

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Abstract. The article deals with the technical and methodological problems that arise during the verification of transformers at the site of operation. Devices of this type are included in the systems of commercial metering of electricity consumption; therefore, periodic verification of their characteristics is necessary, however, in most cases, verification is necessary to perform at the installation site for a number of reasons that exclude the dismantling and transportation of transformers. The article provides an analysis of the reasons that limit the possibility of using on-site verification of transformers due to the principle of their operation and design features. The possibility of solving the identified problems as a result of the use of improved equipment and measurement rules is shown. A significant dependence of the influence of the load on the secondary winding of transformers to the error of measurement results has been established, and for voltage transformers this dependence is stronger than for current transformers. It is also proposed to provide for unique measuring instruments, such as transformers, methods for determining metrological characteristics available for their implementation at the site of operation, the use of which will lead to significant savings in verification costs.

1. Introduction
Custody transfer of electricity uses systems that include instrument current transformers and instrument voltage transformers [1]. To date, for the purposes of commercial accounting, a large number of instrument transformers are used, the principle of which is based on the law of electromagnetic induction. Such instrument transformers have sufficient reliability characteristics, which allows them to be used for decades. Nevertheless, during the operation of transformers, it is necessary to periodically confirm the compliance of the metrological characteristics of the transformers with the established requirements, which is carried out in the process of their periodic verification [2;3]. Many instrument transformers have large overall dimensions and large weight; therefore, such transformers are most often verified without dismantling at the place of their operation. Also, a limiting condition for dismantling and delivery to verification organizations is the impossibility of disconnecting the power line for a long time, and there is no reserve for replacing instrument transformers during their calibration. All organizational and technical work on dismantling, installation and delivery of measuring transformers to verified organizations is many times higher than the cost of organizing their verification at the site of operation without dismantling.
However, on-site verification of instrument transformers has limitations due to technical and methodological problems.

2. Theoretical foundations of errors of transformers

The operation of a current transformer is assessed by the basic quantities, the relationships between which are established in accordance with its equivalent circuit (figure 1) and the corresponding vector diagram (figure 2) [4].

![Figure 1. Ratio of parameters in accordance with the equivalent circuit.](image1)

![Figure 2. Distribution of vector characteristics for current transformers.](image2)

The diagram in figure 1 shows the resistances of the secondary winding of the current transformer reactive $x$ and active $r$, which represent the sum of the resistances of the elements of the secondary circuit of the current transformers $Z_n$. This parameter called the secondary load resistance of the current transformer. For dissect the operation of current transformers when constructing vector diagrams, non-sinusoidal voltages and currents are replaced by equivalent sinusoidal ones, with the same effective values.

Figure 2 shows a vector diagram of the parameters of a current transformer. The electromotive force $E_2$ of the secondary winding is determined by the relation (1)

$$E_2 = U_2 + I_2 \sqrt{r_2 + x_2},$$

(1)

In accordance with expression (1) and the diagram in figure 1, the EMF of the primary winding $E_1$ is in antiphase with the EMF $E_2$. The magnetic flux vector $\Phi$ lags behind the vector by an angle $\gamma$ from the magnetizing current vector $I_0$ and is $90^\circ$ ahead of the EMF vector $E_1$. The angle $\gamma$ is obtained
experimentally from the relation $\gamma = f(B)$, where $B$ is the magnetic induction, taking into account the vectors of the primary current $I'_1$ and the magnetizing current $I_0$

$$I'_1 = I_2 + I_0$$

(2)

In accordance with this expression, the magnetic flux of the primary winding is balanced by the working magnetic flux generated by the current $I_0$ and the demagnetizing action of the current $I_2$.

Differences of the secondary current vector $I_2$ from the vector of the reduced primary current $I'_1$ in angle and in modulus are determined as errors of the current transformer, which are due to the magnetizing current $I_0$, which creates a magnetic flux in the transformer core.

The analysis of the equivalent circuit allows us to conclude that the error of the current transformer is determined by the ratio of the resistances of the branches of the secondary circuit and the magnetization and increases with an increase in the current branching into the magnetization resistance.

Taking into account the transformation ratio, the current error is defined as the relative difference between the modules of the current vectors in the secondary winding and the current in the primary winding [5].

$$\delta_f = \left( \frac{|I_2| - |I'_1|}{I'_1} \right) \times 100\%$$

(3)

The angular error (the angle $\delta$ between the vectors of the primary and secondary $I_2$, $I'_1$ currents, see figure 2) is taken positive if the current vector $I'_1$ lags behind the current vector $I_2$, and is determined through the angle $\gamma$ between the vectors $E_2$ and $I_2$ and the loss angle $\alpha$ (ratio 4).

$$\delta_f = \arcsin \left( \frac{I_0}{I'_1} \cdot \cos (\alpha + \gamma) \right)$$

(4)

From the presented theoretical foundations, it can be seen that the determining factor for the error of measuring current transformers is the load on the secondary winding. According to the requirements set forth in the regulatory documents [6], the secondary load of measuring current transformers should be in the range from 25 to 100% of the rated load value specified in the operating documentation for a specific current transformer. When checking current transformers, the operations of determining metrological characteristics are performed precisely at two values of the secondary load, connecting a resistance box, for example, MR 3027. When operating a current transformer, the measurement of a real secondary load is performed only when checking commercial metering systems that include this current transformer [7].

3. Technical problems when checking transformers

From the experience of checking current transformers at the place of operation, the following problems have been identified:

1. Connection to the primary windings of current transformers is difficult due to the design features of 6-10 kV cells. Often there is no access for connection to the primary winding of the current transformers under test or to the high-voltage buses before and after the place of the transformer installation (for example, when the transformer is installed in the floor between the floors of the switchgear). Current transformers installed in electrical installations of 35-220 kV must be connected to the primary windings located at a height of 3-10 meters. This requires special copper long and thick power wires.

2. Absence of a 220 V power supply network for reference devices and auxiliary equipment, and even if the power supply network is available, its characteristics do not meet the conditions for carrying out verification in terms of harmonic distortion.
3. The current transformers built into the oil circuit breaker cannot be dismantled during on-site verification, therefore, it is impossible to perform an external inspection of the built-in current transformers without draining the oil and disassembling the oil breaker tank.

4. The marking of secondary circuits in the cabinets of high-voltage current transformers is missing or violated, and access to the secondary windings of the transformer under test is difficult. As a result, it is difficult to determine the parameters of the secondary winding of the transformer under test.

5. For verification of current transformers with a primary current of more than 1000 A, it is rather difficult to pass 120% current through the primary winding due to the lack of power of the current source or the high resistance of the primary current loop.

6. Climatic conditions for verification impose serious restrictions on verification in spring and autumn. In winter, verification can only be carried out in heated rooms, not outdoors.

Employees of the West Siberian branch managed to solve all the above technical problems by improving the equipment used for verification and raising the qualifications of the verifiers.

As a result of carrying out a number of experiments when checking current transformers at the place of operation, the following was revealed:

- the error of current transformers with a significant excess of the load on the secondary winding leads to a sharp underestimation of the readings and a decrease in the error in the negative region of the less than the permissible lower limit, and this decrease appears at currents close to the nominal;
- when the load on the secondary winding of the current transformer decreases, the error does not go beyond the permissible limits for current transformers of accuracy class 0.5S and less accurate.
- the error of voltage transformers has a stronger dependence on the secondary load than for current transformers. A load on the secondary winding higher than the rated one leads to a shift of the error to the negative area, and when the load drops to zero, the error shifts to the positive area and the limits of the permissible error are exceeded.

It is proposed during operation to pay special attention to meeting the requirements for the load on the secondary windings and current transformers and voltage transformers. And also to carry out periodic control of the load power according to the certified measurement methods [8], for example, during the verification of the transformers themselves at the place of operation.

4. Methodological problems in the verification of transformers
Verification of current transformers is carried out according to a normative document approved as a verification procedure during type approval tests. This document is GOST 8.217 [6]. In previous versions of this normative document, requirements for an ambient temperature of 15 to 35° C were laid down. But in the latest edition with additions from 2008, a note was added that, in justified cases, a deviation from the specified climatic conditions is allowed. Unfortunately, it is not said on what principles such a justification should be based. Since all types of non-laboratory current transformers do not have a standardized additional error depending on the ambient temperature, it means that for the entire range of operating conditions of use, the metrological characteristics should not exceed the established limits. Thus, (according to GOST 8.009 [9]), provided that the additional error does not exceed 0.17 of the maximum error in operating conditions, such an additional error may not be standardized. As a conclusion, the following can be indicated: the verification of current transformers can be performed under the operating conditions of the use of the current transformer under test, while it is imperative that the requirements for the conditions of use of standards are met.

5. Conclusion
There are methods for determining the metrological characteristics of current transformers that differ from the methods described in GOST 8.217, for example, one point of the measurement range and the
current-voltage characteristic [10, 11]. Such techniques have a number of advantages, because they do not require a strict solution to the above technical problems No. 1, 5, 6. But such techniques cannot be used when checking current transformers, since they are not established as a verification method when approving specific types of transformers. The existence of methods for checking measuring instruments that differ from standardized ones does not mean that they cannot be used. Therefore, it is recommended for unique measuring instruments, which are current transformers installed on generators of power plants with primary currents up to 30 kA, to provide methods for determining metrological characteristics that are available for their implementation at the site of operation. The presence of such techniques will lead to savings in calibration costs, and to the timely detection of metrological failure of metering devices for commercial metering of electrical energy.

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