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Types of Current Sensors and their Efficiency Analysis

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Abstract: The article analyzes the operating principles, advantages, and disadvantages of various current sensors. The importance of sensors in improving electricity consumption and energy savings is emphasized. Information is provided on Hall effect, resistive and magneto-optic sensors, ferromagnetic systems, Rogowski coils, and optical fiber sensors.

The impact of each technology on accuracy and reliability has beyen considered, and conclusions regarding the improvement of current measurement are presented. The article serves as an important guide for research and practice on modern sensors.

Keywords: Current sensors, Hall effect, resistive sensors, magneto-optic sensors, Rogowski coils, optical fiber sensors, drift compensation, ferromagnetic current sensors, Allegro Microsystems.

INTRODUCTION

Nowadays, the constant growth in electricity consumption in industry and daily life is increasing the relevance of energy-saving technologies. In support of the state's energy-saving policy, reducing commercial losses in electrical networks is of great importance. Issues such as electricity theft significantly impact this process.

Current sensors play an important role in the reliable and efficient management of electrical energy. Modern current sensors are required not only to provide accurate measurements but also to have high technical and economic performance. This article analyzes the operating principles of various current sensors, their advantages and disadvantages, and examines their role in the effective monitoring of electrical energy.

METHODS

In this study, scientific and technical literature on various technologies of current sensors was analyzed. Specifically, information on current transformers, Hall effect-based sensors, resistive sensors, ferromagnetic, and magneto-optic current sensors was examined. The literature provides a detailed explanation of the operating principles, technical characteristics, and application areas of current sensors.

As a methodology, the comparison of existing current sensors based on their operating parameters, analysis of their advantages and disadvantages, and the proposal of new solutions for modern electrical measurement systems were employed. The following main steps were carried out during the analytical research process:

- Identifying factors affecting the accuracy, sensitivity, and reliability of current sensors in operation;
- Evaluating the applicability of technologies;
- Developing effective solutions to reduce commercial losses in electricity measurement.

The analysis of literature and the comprehensive approach of the methodology enable the study of advanced technologies in current sensors and the conduct of research aimed at improving their efficiency in electrical networks.

RESULTS

In recent years, electricity theft has become a significant contributor to commercial losses. This issue is facilitated by the unique characteristics of electricity, which involve its production, transmission, distribution, and consumption occurring simultaneously. Due to the inability to store electricity, the highest instances of theft and the largest amounts of stolen electricity occur in the utility sector, particularly within distribution networks.

The reasons for this include, on one hand, the simultaneous increase in consumption volumes and the constant rise in electricity tariffs amid a decline in the population's payment capacity. On the other hand, factors such as the relative accessibility and ease of implementing various methods of electricity theft, the imperfections of measuring devices, changes in primary and secondary circuits, the unsatisfactory technical condition of current transformers (CTs) and voltage transformers (VTs), and the lack of a legal basis for holding electricity thieves accountable, among others, contribute to the problem.

Currently, current sensors are required to provide maximum accuracy and improve energy consumption efficiency during measurements. Therefore, the most commonly used sensors today are current transformers and Hall effect-based current sensors. Their main disadvantages include: the large measurement error, the presence of saturation effects, the limited measurement range, and the mass-dimensional characteristics of the measurement systems.

Eliminating these disadvantages is currently a key requirement for achieving accurate measurements and improving technical and economic indicators to a high level in production.

1. The Hall sensor generates an output voltage depending on the magnetic field. The value of the output voltage is directly proportional to the magnetic field. During the measurement process, the current value is determined by measuring the magnetic field. The output voltage of such a sensor is very small and needs to be amplified to the required value for measurement. Therefore, an amplifier with a high gain coefficient and low noise level is necessary. Additionally, because the Hall sensor is a linear transducer, it requires an additional circuit. Its main disadvantage is as follows [1]:

1) The sensor requires compensation due to drift.
2) An additional circuit is necessary for the reliability of the output signal.
3) The cost is higher compared to the shunt measurement method.

2. The operating principle of resistive current measurement sensors is based on the change in their active resistance due to variations in the length of the conductor, its cross-sectional area, and the relative resistivity [1-6].

Its main disadvantages are as follows:

1) Such sensors are directly connected to the measurement circuit, leading to significant energy loss;
2) The service life of the contact system is limited;

3) The measurement accuracy decreases due to the temperature dependence of the resistance value when measuring large currents;

4) If the current exceeds 10 kA, the error ranges from 0.02 to 0.5, and the weight of the magnetic conductor increases [6,1];

5) There is no possibility of galvanic isolation.

3. Ferrozond current sensor for measuring large currents. Nuclear magnetic resonance is used to measure a constant magnetic field with high accuracy [7-15]. However, nuclear magnetic resonance is not suitable for measuring oscillating magnetic fields. In geomagnetic navigation systems, the magnetic field is very small, and ferrozonds are used to measure it.

4. Magneto-optical current sensors. The operating principle of magneto-optical sensors is based on the Faraday effect, where the rotation of the plane of polarization in optically active, non-magnetic materials is induced by a strong magnetic field.

The main disadvantages of these sensors are as follows:

1) They have relatively low sensitivity;

2) They are structurally complex;

3) There is a disproportionate relationship between the change in the polarization angle and the current [15-20].

5. Rogowski coil. This sensor is manufactured in a spiral coil shape and is designed for measuring large currents. The main disadvantages of these sensors are as follows [21-27]:

1) It only measures alternating current;

2) Its sensitivity is much lower compared to current transformers;

3) The uneven distribution of EMF induction and the high reverse effect when measuring current in the spiral section.

6. Optical fiber current sensors. These sensors are primarily used for measuring impulse currents and the intensity of magnetic fields. The main disadvantages of these sensors are as follows [28-32]:

1) Limited functional capabilities;

2) There are limits to the measured current values;

3) The polarization plane depends on the rotation angle;

4) Loss of linearity due to changes in light intensity;

5) Increase in measurement error due to all of the above effect.

7. Current sensors from Allegro Microsystems. Allegro Microsystems specializes in producing current sensors based on analog and digital Hall effect technology. They manufacture intelligent integrated circuits in the range of 5-200 A and remote-controlled current sensors for ranges of 1000 A and higher.

These sensors have the following disadvantages:

1) High cost;

2) Complexity of the electrical circuit [1, 33-38].

8. Current Sensor with a Multi-Coil Steel Core (CSMCSC). These sensors are primarily designed for measuring large and extremely high currents. To theoretically study the main characteristics of the CSMCSC, they must have analytical expressions for the magnetic flux and magnetic voltage (magnetic induction) as a function of the coordinates of the placement of the magnetic-sensitive elements [22,39-48].

However, the magnetic circuits of the KTD (current transformer) designed to work with MCSC have specific characteristics:

First, in the case of many well-known designs of magnetic systems with certain parameters, the redistribution of magnetic flux along the electronic length occurs through an air gap between one pole piece (ferromagnetic core) and another. In the developed KTD, however, the magnetic field lines pass through the air gap from the first coil of the core to the second coil of the same core.

Secondly, the magnetized coil or the modified current and measurement coil simultaneously covers several coils of MCSC.

Thirdly, while in conventional KTDs, the coil carrying the current passes through the MCSC, in the distance TDs, MCSC is located outside the current-carrying coil [23,50-61].

However, when measuring large currents with such sensors, their overall dimensions increase, and their weight exceeds the standard indicators by several times.

DISCUSSION

The research results show that the working principles and technical characteristics of different current sensors define their application areas and efficiency. For example, while Hall-effect-based current sensors have high accuracy, they require additional circuits and compensation mechanisms, which increases their cost. Resistive sensors, on the other hand, are considered inexpensive but are evaluated as components with limited lifespan and increased energy consumption.

Magneto-optical current sensors, although capable of measuring high currents, are limited in practice due to their low sensitivity and complex construction. Additionally, the Rogowski coil, which is mainly designed for alternating currents, has been found to have low sensitivity when measuring high currents.

Ferrozond and optical fiber sensors are considered modern solutions for measuring high currents. However, their high cost and functional limitations hinder their widespread application. While current sensors from Allegro Microsystems improve accuracy through the use of intelligent microcircuits, their complexity and cost may present challenges in their practical use.

During the discussions, directions for addressing the main shortcomings of current sensors were identified. According to the research, approaches focused on high accuracy, sensitivity, and energy efficiency are preferred in the development of modern current sensors. These solutions are crucial for improving the efficiency of electrical energy measurement systems and reducing commercial losses.

CONCLUSION

This research is dedicated to the analysis of various technologies of current sensors and their technical and economic indicators. It has been determined that current sensors play a crucial role in ensuring accurate and efficient measurement of electrical energy.

According to the research results:

1. In the development of modern current sensors, ensuring high accuracy and sensitivity, as well as simplifying the design, is of paramount importance.

2. Technologies such as the Hall effect, magneto-optic, and optical fiber sensors offer advantages that allow for their widespread application in electrical networks, but their cost and complex design limit their use.
3. The development and implementation of modern current sensors is a critical task to reduce commercial losses in electricity consumption.

The results identified during the research can be applied in developing new solutions for improving electrical measurement systems. Enhancing the efficiency of modern current sensors will play a crucial role in energy conservation and ensuring safety in electrical networks.

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