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A device for detecting current asymmetry in a three-phase alternating current system

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Abstract. The article discusses the issues of identifying the asymmetry of currents in a three-phase alternating current system. The design of a current converter designed to detect the unevenness of the current load in parallel branches of the current lines of various power equipment is proposed. It is shown that a positive effect is achieved by making the magnetic circuit four-rod and the introduction of rectangular cutouts with modulating and output windings on two central rods of the magnetic circuit and it is possible to determine the unevenness of the current load of three parallel branches before (in three-phase AC circuits) or after rectifier-converter installations (in DC circuits), therefore, the functionality of the device for detecting current asymmetry is expanded.

1 Introduction

The operating conditions of traction power supply systems are characterized by current asymmetry and non-sinusoidal voltage, as a result of which current measuring converters (CMC) should be included in the composition of devices for automatic distribution of active and reactive loads between various power equipment (motor, generator, rectifier, etc.) switched on for parallel operation, as well as various current protection devices [1-4].

However, the power supply of power equipment from an asymmetric power supply system leads to a reduction in their service life and early failure. In this regard, the issues of identifying and reducing asymmetry in three-phase AC systems is relevant. The quality of the electric energy of the traction power supply system (TPSS) and its individual components largely depends on how correctly and fully taken into account the dangerous manifestations of the regimes arising in it, which can be caused both accidentally and intentionally. Knowledge of them is necessary, first of all, to prevent the emergence of dangerous regimes and to develop measures to combat their harmful effects. The deeper the penetration into the nature of these processes, the greater the possibility of conscious control of them [1, 2]. Electrified railway transport, receives power from the power system and operates on a single-phase current, which leads to uneven loading of TPSS networks.

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2 Methods

Currently, to identify the asymmetry of three-phase currents, CMC are used, having various designs based on various physical effects (on the magneto modulation effect, Hall effect, transformer effect, etc.) [5-10].

In [11], a three-phase load protection device against phase breakage is proposed, which consists of a load with the ends of the terminals connected to the primary windings of a current transformer. The windings are located on a common magnetic circuit and are connected in a triangle. The secondary winding of the transformer is connected to the relay. The current transformer contains relay contacts in the primary winding circuit. In addition, the relay contains a drive with a release mechanism. All nodes, together, form a so-called protective shutdown device (PShD).

The disadvantage of the device is that it is additionally equipped with two primary windings, and the core of the current transformer covers all three primary windings, which will reduce the accuracy of determining the asymmetry of currents in the windings, and also complicates the installation of the device.

3 Results and discussion

The authors have developed a device [12] designed to detect the unevenness of the current load in parallel branches of the current lines of various power equipment (motor, generator, rectifier, etc.), the design scheme of which is shown in Fig. 1.

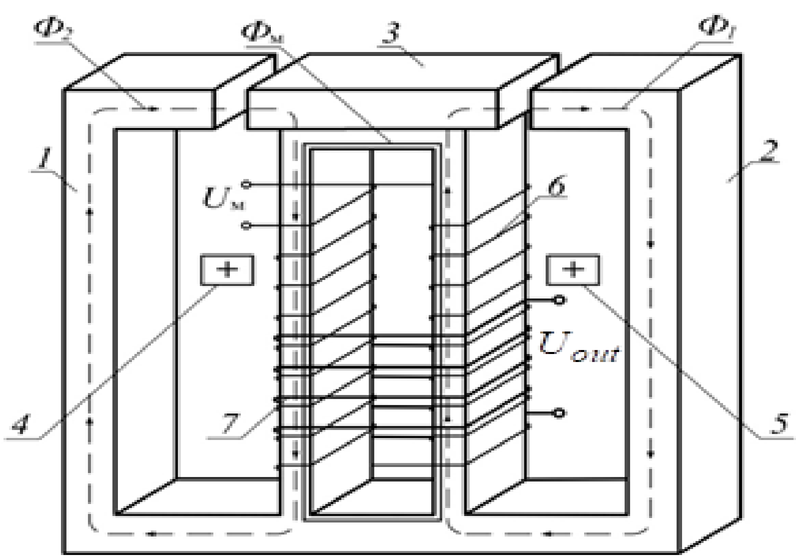

Fig. 1. A device designed to detect the unevenness of the current load [12].

The device consists of extreme rods 1 and 2, a magnetic core, a central rod 3 with a cutout, two current-carrying buses 4 and 5 covered by these rods, a modulating winding 6 powered from a modulating voltage source and an output winding 7 covering the cutout together with the modulating winding.

The principle of operation of the device is as follows.

When direct current flows through buses 4 and 5, magnetic fluxes proportional to the corresponding currents arise in rods 1 and 2.

With the same direction of currents in the tires, the magnetic fluxes Φ_1 and $\Phi_2$are closed along the extreme rods 1 and 2 and through the central rod 3 in opposite directions. The output winding 7 is penetrated by magnetic fluxes Φ_1 and $\Phi_2$of the opposite direction. These flows are modulated by a modulating winding, w_M, powered by a modulating voltage source. If the busbar currents are zero, then the total flow $\Phi_2$penetrating the output winding is zero. If the current in one of the buses is greater, then the total flow $\Phi_2$is the difference between the flows Φ_1 and Φ_2, and the corresponding voltage at the output of the output winding is determined by the derivative of the difference between the flows Φ_1 and $\Phi_2$in time.

The value of the output voltage U_{out}does not depend on the value of the modulating flow Φ_M. This is explained by the fact that the modulating flow $\Phi_{\text{м}}$from each point, at each moment of time, in one part of the cutout is summed with a constant current Φ_1, and in the other part is subtracted from the constant flow $\Phi_2$as a result, the total flow Φ_2 is determined only by the difference between the flows Φ_1 and Φ_2.

The sign of the output voltage indicates in which bus the current is greater. The use of magneto modulation windings as a sensing element allows to increase the reliability of the device in comparison with similar devices on the Hall elements.

Thus, the proposed device allows you to convert the difference of direct currents into alternating voltage with high accuracy and reliability.

The device can be used as a primary sensor for controlling and regulating the uniformity of the current load of parallel branches of power equipment (motor, generator, rectifier, etc.) in both DC and AC circuits.

As a result of studying the issues of identifying the asymmetry of three-phase currents in the traction power supply system, it was found that the most complete information about the degree of asymmetry of parallel currents with high accuracy can be obtained when all three phases participate in the process of conversion (measurement) by the device.

In this regard, the authors propose a different design of a device with advanced functionality designed to detect the asymmetry of three-phase currents [6].

A general view of the design of the proposed device for detecting current asymmetry in a three-phase alternating current system is shown in Fig. 2.

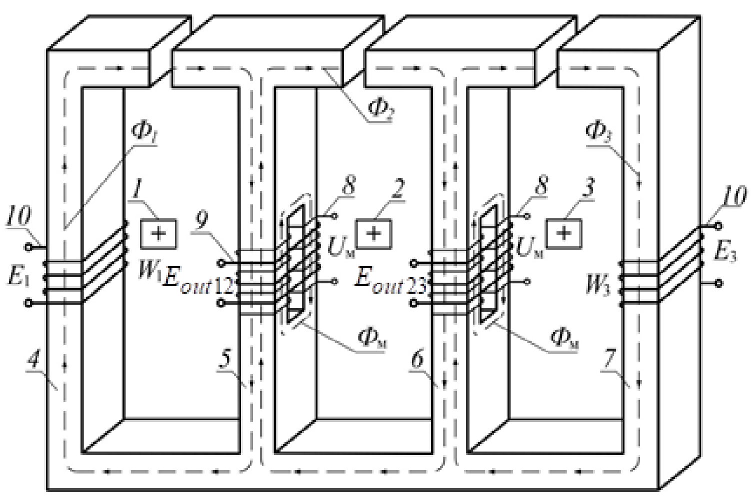

Fig. 2. Device for detecting current asymmetry in a three-phase alternating current system [6].

In a device for detecting current asymmetry in a three-phase alternating current system containing current-carrying buses, a magnetic circuit with air gaps and a rectangular cutout on which the modulating and output windings are wound, the magnetic circuit is made of four rods, the corresponding current-carrying buses pass through the windows of each pair of rods, a rectangular cutout with modulating and output windings is made on two central rods of the magnetic circuit, and the output windings cover the cutout together with the modulating winding.

A positive effect is achieved by making the magnetic circuit four-rod and the introduction of rectangular cutouts with modulating and output windings on two central rods of the magnetic circuit, as a result of which it is possible to determine the unevenness of the current load of three parallel branches before (in three-phase AC circuits) or after rectifier-converter installations (in DC circuits), therefore, the functionality of the device for converting current into voltage is expanded [13,14].

A device for detecting current asymmetry in a three-phase alternating current system contains three current-carrying buses 1, 2, 3 passing through the corresponding windows of a four-rod magnetic circuit consisting of non-adjacent rods 4, 7 with corresponding air gaps and adjacent rods 5, 6 made rectangular cutouts, on parallel branches of which there are modulating windings 8 and output windings 9 covering each rod together with a cutout.

The device for detecting current asymmetry in a three-phase alternating current system works as follows.

When determining the unevenness of the current load of parallel branches of three-phase circuits of installations, direct currents I_1, I_2, and I_3 pass through buses 1, 2, 3 in the same direction. These currents in non-adjacent rods 4 and 7 of the four-stranded magnetic circuit create permanent magnetic fluxes Φ_1, Φ_2, and $\Phi_3$in adjacent rods 5 and 6 - the difference of magnetic fluxes $\Delta\Phi_{12} = \Phi_1 - -\Phi_2$and $\Delta\Phi_{23} = \Phi_2 - \Phi_3$. When the modulating windings 8 are connected to an alternating voltage source $U_м$, a modulating alternating magnetic flux $\Phi_м$is closed along the branches of each rectangular cutout. There is no EMF from the magnetic flux $\Phi_м$in the corresponding output windings 9. This is due to the fact that the magnetic flux lines $\Phi_м$do not cover the turns of the output windings. When the currents I_1, I_2, and $I_3$3 are equal to each other, then their magnetic fluxes Φ_1, Φ_2, and $\Phi_3$are equal, and the difference magnetic fluxes are zero, i.e.$\Delta\Phi_{12} = 0$ and$\Delta\Phi_{23} = 0$. Therefore, the EMF of E_{out12} and E_{out23}at the ends of the output windings 9 are also zero[15,16].

If the currents in the current-carrying buses 1, 2, 3 (or at least in one of the buses) If they differ in magnitude, then the corresponding difference magnetic fluxes are not equal to zero and, according to the law of electromagnetic induction, EMF appears at the ends of the corresponding output windings, proportional to the magnitude of the corresponding difference magnetic flux and, consequently, the difference current in adjacent buses [17,18].

Asymmetric modes are characterized by the appearance of components of the reverse and zero sequences of currents and voltages, which lead to the following adverse consequences [19,20]:

• There is a danger of overload of three-phase electric motors with reverse sequence currents. Synchronous and asynchronous motors have low reverse sequence resistance. Even small reverse sequence voltages in the TPSS can cause significant reverse sequence currents in engines, which, superimposed on the direct sequence currents, cause current overload of individual phases of the engine and, consequently, additional heating of the stator and rotor which leads to accelerated aging of the insulation and a decrease in the available power of the engine [21,22];

• There are additional losses of active power and electrical energy due to the flow of reverse and zero sequence currents in the elements of the TPSS up to 1 kV [4]; • Due to voltage losses from the reverse and zero sequence currents, additional voltage deviations in individual phases of the TPSS up to 1 kV appear, which are not eliminated by conventional (three-phase) voltage regulation means [23,24].

4 Conclusion

When installing the proposed device in three-phase AC circuits, the modulating windings are disconnected from the source. In this case, the voltage on the output windings will be proportional to the asymmetry of the currents in the three-phase circuits. In the symmetrical mode of a three-phase circuit, the output voltage will be zero.

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