Device for detection of the phase current asymmetry in the three-phase lines of non-traction consumers

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Abstract: electrified railway transport receives power from the power system and operates on a single-phase current, which leads to uneven loading of networks of the traction power supply system. There is a danger of overload and additional losses of active power and electrical energy of three-phase electric motors by reverse sequence currents, therefore, any information obtained about the values (phase currents and voltages) allows carrying out corrective actions for the level of asymmetry. In this paper, discuss the design of the device for detecting the asymmetry of phase currents in three-phase lines is proposed. It is shown that the device can convert the DC current difference and measure three linear currents in a three-wire three-phase circuit.

1. Introduction
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.

2. Main part
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:

- 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 [3];
- 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 [5, 6].

In the asymmetric mode of current consumption, amplitude, phase, amplitude-phase asymmetry of voltages and currents can occur. Therefore, any information obtained about the values of values (phase currents and voltages) allows carrying out corrective actions for the level of asymmetry, which in practice is relevant.

The authors have developed a device [7] designed to detect asymmetry of phase currents in three-phase lines of current load in parallel branches of conductors of various power equipment, the design scheme of which is shown in figure 1.a.

The device consists of the extreme rods 4 and 6, the central rod 5 with a cutout, three current-carrying buses 1, 2 and 3, of which 1 and 2 are covered by these rods, the modulating winding 7, fed from a modulating voltage source and the output windings 8, 9, and 10 covering the cutouts together with the modulating windings.

![Figure 1](image.png)

**Figure 1.** Design diagram of power equipment.

The principle of operation is based on the interaction of the two fields generated by modulating current flowing in the modulation coil 7 of an alternating magnetic field $H_0(t)$ with a strength and
created during the flow of DC buses 1 and 2 constant field strength \( \Delta H_0 \) (directions shown in figure 1, b), defined as the difference of tensions \( H_{0a} \) and \( H_{0b} \) (in figure 1, b they are not given), created by the corresponding currents of the buses 1 and 2 in the rod 5. Hence, in the case of equality of tensions \( H_{0a} \) and \( H_{0b} \) tension \( \Delta H_0 = H_{0a} - H_{0b} = 0 \). In this case, there is no signal at the output of the output winding 9. However, as soon as it appears \( \Delta H_0 \), different from zero in the rod, there will be an overlap of the direct \( \Delta H_0 \) and alternating \( H_u(t) \) modulating currents.

In general, the superposition of the intensities of these fields in rod 5 is given by the expression [8]:

\[
H_\Sigma(t) = \Delta H_0 + H_M(t). \tag{1}
\]

The EMF induced in the output winding can be found on the basis of the law of electromagnetic induction:

\[
e(t) = -w_2 \frac{d\Phi}{dt} = w_2 s \frac{dB}{dt}, \tag{2}
\]

where \( W_2 \) - the number of turns of the output winding; \( \Phi = BS \) - magnetic flux in the cores; \( S \) - the total cross-sectional area of the converter cores.

The modulus of the instantaneous value of the total field intensity is found from the expression (1):

\[
H_\Sigma = \sqrt{\Delta H_0^2 + 2\Delta H_0 H_u \cos \alpha + H_u^2}, \tag{3}
\]

where \( \alpha \) - is the angle between the vectors \( \Delta H_0 \) and \( H_u \).

Consider the operation of a device with mutually parallel fields, i.e.:

\[
\alpha = 0, \quad H_\Sigma = \Delta H_0 \pm H_u; \tag{4}
\]

For this purpose, we will use the most common in practice magnetic modulator (ferrosonde) with two core cores [9]. In this case, we assume that the vector is directed along the longitudinal axes of the cores, as well as the cores and the windings covering them are identical.

In the reference [4] it is shown that at \( \Delta H_0 = \text{const} \neq 0 \) (constantly transformed field) appearance of EMF \( e(t) \) in principle it is possible only in the presence of nonlinear dependence \( B(H) \).

Now we approximate the dependence \( B(H) \) by a shortened polynomial of the third degree [10, 11]:

\[
B = aH - bH^3, \tag{5}
\]

where \( a \) and \( b \) - are the positive coefficients of the approximation. Then, taking into account the expression (1, 2), we obtain EMF in the output winding of the converter:

\[
e(t) \big|_{\Delta H_0=\text{const} \neq 0} = 6bsw\Delta H_0 \frac{d}{dt} H_u^2(t) \neq 0. \tag{6}
\]

Hence it can be seen that the nonlinearity of the dependence \( B(H) \) is indeed a fundamental factor responsible for the appearance of an EMF carrying information about the converted direct current.

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

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 of the two phases. In the symmetric mode of the three-phase circuit, the output voltage will be zero.

If it is necessary to measure three linear currents in a three-wire three-phase circuit using a device, then the use of the output windings on the two extreme rods is sufficient to measure three currents. This directly follows from the property of the sum of linear currents, according to which the sum of three linear currents is zero:

\[ i_A + i_B + i_C = 0 \]

and, therefore, the sum of the two linear currents is equal to the third linear current taken with the inverse sign.

One of the possible inclusion schemes is given in figure 1.

As can be seen from the scheme, through the first ammeter current passes through the second - \( i_B \), therefore, the current in the third ammeter, equal to the sum of two linear currents \( i_A \) and \( i_B \) is equal to the third linear current - \( i_C \):

\[ i_C = i_A + i_B \]

**Conclusion**

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.

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