Monitoring of the thermal state of induction motors with low quality power supply

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ABSTRACT. An innovative technological system that provides the control process of the induction motors thermal state, when exposed to unbalanced supply voltage or power supply which can have the presence of higher harmonics frequencies and with the presence of technological defects in the rotor winding. The monitoring system calculates the temperature of the stator and the rotor on the basis of transfer functions, which take into account the impact of individual factors of low quality power supply. The calculation of the thermal state can occur in real-time.

Introduction. The system providing control of an overheat of asynchronous engines at influence of asymmetrical feeding pressure with presence of the higher time harmonics and in the presence of technological defects of a winding of a rotor is developed.

Topicality. Recently, upon failure of the auxiliary electrical machines (AEM) on electric because of the influence of various unfavorable factors [1]. These factors include:

1) unbalance power supply;

2) the presence of higher harmonics frequencies;

3) poor quality of manufacturing rotor.

This is particularly a problem for auxiliary motors, working on locomotives. This is confirmed by statistics of failures caused by auxiliary machines.

Solution. In this paper we consider a universal monitoring system, which allows to control the overheating of induction motor based on measurements of phase voltages and currents. Unbalanced power usually causes additional losses in the stator and rotor induction motor. These losses lead to overheating and reduce the life of stator winding insulation.

Already, there are ways to control the state of induction motors, using information about the consumed currents. For example a way to monitor the condition of the rotor and stator currents [2], [3], [4]. Existing methods do not give a complete picture is the thermal state of the engine, based on current consumption. Especially if it is necessary to take into account factors such as unbalanced and sinusoidal voltage, as well as the presence of defects in the rotor shaft.

This system allows to take into account such factors.

Figure 1 shows a block diagram of a monitoring system consisting of the measurement circuit and the microprocessor unit (MPU) with appropriate software (SW). The circuit comprises sensor measurements of phase voltages Dn1, Dn2, Dn3 and current sensor analog-digital converter ADC. LPA Software, created by the system software NI LabVIEW [5]. The algorithm of the system is as follows. With sensors Dn1, Dn2, Dn3 removed and the values of phase voltages. In the ADC, they are converted into digital form and transmitted to the MPU. Here, these voltages are processed in order to isolate the input from the following harmonics: main (first), third, fifth and seventh. For the first harmonic it is also determined and the initial phase angles for all three phases. According to

Theorem Fortescue [6], any asymmetric system can be decomposed into three symmetrical - a system of positive sequence, negative and zero. With this in mind, for the first harmonic is the definition of each of these sequences. To top the third, fifth and seventh, these sequences are not determined, since they usually make up a relatively small part of the fundamental and significant impact on the non-uniformity of thermal heating of stator. These harmonics are more strongly affect the thermal state of the rotor due to the guidance in it more of EMF with increased frequency.

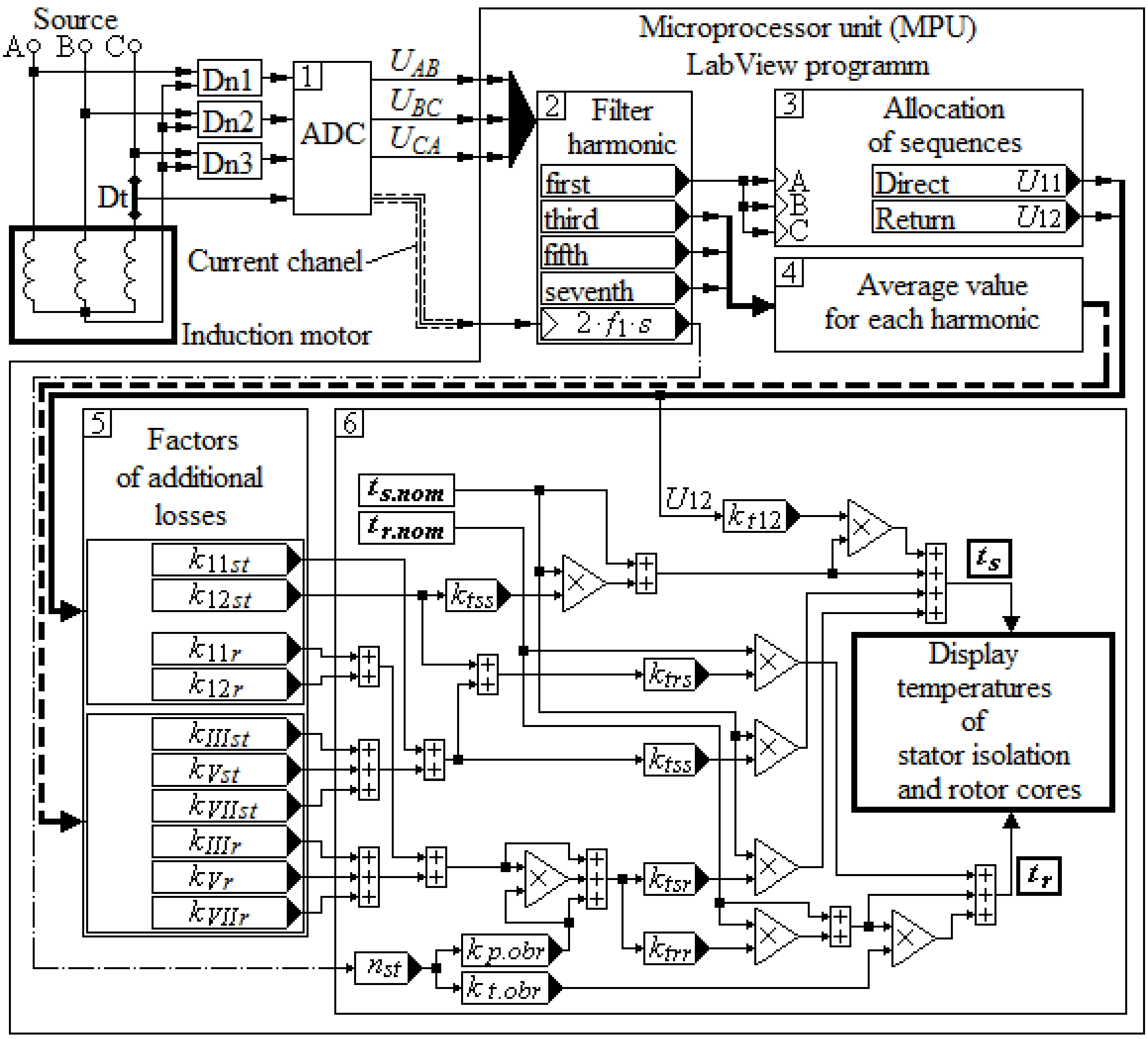


Fig. 1. The block diagram of the monitoring system of the induction motor

However, the asymmetry of these harmonics is practically no effect on the uneven heating of the rotor. For the higher harmonics in the phase voltages are determined by the average value of their units. The frequency of the induced EMF of these harmonics can be expressed by the formula $f_v = f_1 \cdot (s-1 \pm v)$, where f_1 - frequency of the basic harmonic (50 Hz), s - sliding, v - number of the higher harmonic. The sign «+» at a symbol «v» testifies that the field from the higher harmonic of feeding pressure rotates in the same party, as the basic field, a sign «-» - in return.

According to studies, it was found that each sequence of three-phase voltage system in its own influence on the occurrence of additional losses in the motor. Thus:

• The level of positive sequence voltage affects the uniform change in the phases of the stator and rotor currents.

• The increase in pressure of return sequence leads to a warp of currents in stator and on increase total stator losses. Besides, this pressure leads to occurrence electromotive power and a current in a rotor with the doubled frequency (the second harmonic) in relation to frequency of feeding pressure, and, hence, to additional losses of a rotor.

On this basis following factors of additional losses in stator and rotor are calculated:

k_{11st} и k_{11r} – coefficients of the additional losses in the stator and the rotor under the influence of positive sequence voltage;

k_{12st} и k_{12r} – coefficients of the additional losses in the stator and the rotor under the influence of negative sequence voltage;

k_{10st} – coefficient of the additional losses in the stator under the influence of zero-sequence voltage;

k_{IIIst} and k_{IIIr} – Coefficients of the additional losses in the stator and the rotor under the influence of the third harmonic voltage;

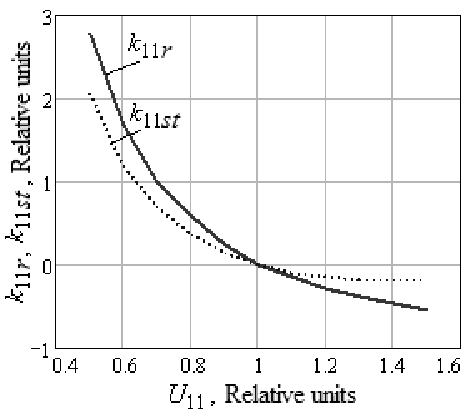
k_{Vst} and k_{Vr} - coefficient of the additional losses in the stator and the rotor under the influence of the fifth harmonic voltage;

k_{VIIst} and k_{VIIr} – coefficient of the additional losses in the stator and the rotor under the influence of the seventh harmonic voltage.

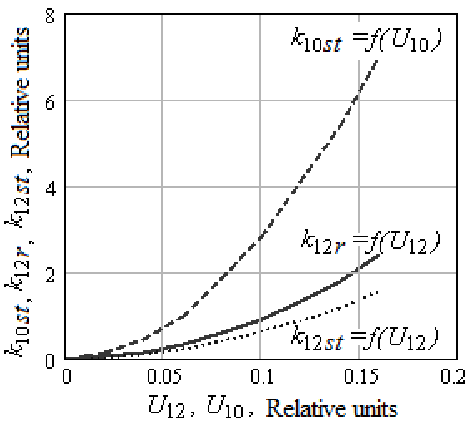
These coefficients are calculated by dividing the loss of electric heating the engine with the appropriate power factor influencing the loss obtained in the nominal mode of the machine. Heating is the loss of the engine to find the sum of products of the electric resistance of a particular section of the square of the current flowing through it. Accordingly, the currents are calculated using a mathematical model of an induction motor in phase coordinates. The model was constructed based on the basic relations [7] and implemented in a software package MATLAB 7.

Below are the results of calculations of the coefficients for the auxiliary motor NVA-55, has the following options: synchronous speed 1500 rev/min, the active resistance of stator and rotor phase R_1=0.045Ω and R'_2=0.064Ω; inductance of the field scattering phase stator and rotor $L_{\sigma1}$=0.00038H and $L'_{\sigma2}$=0.0005H; mutual inductance of phases stator and rotor L_m=0.01H; number of phases of a rotor m_2=38; number of pairs poles p=2; the moment of inertia of a rotor together with the inertia moment moving mechanism J=1 Kg·m^2; nominal 3-phase supply voltage 380/220V, 50Hz. Scheme winding connection - "Star". These parameters were determined using the method [8].

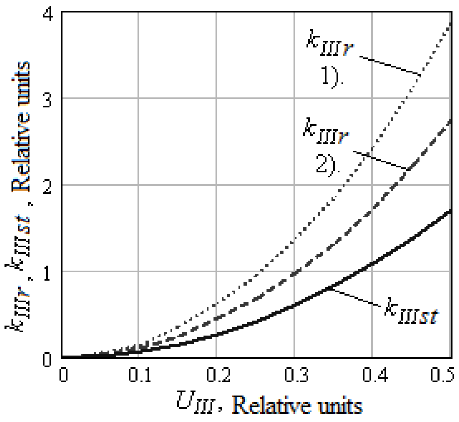
Figure 2 shows the dependence of the coefficients of the additional losses from the line voltage levels, negative and zero sequences, as well as the level of the higher harmonic frequencies.



(a)



(b)



(c)

Fig. 2. The coefficients of the additional losses in relative units, 1 - *the field of higher temporal harmonic rotates in the opposite direction with respect to the main field*, 2 - *time the field of higher harmonic rotates in the same direction as the main.*

Further, based on the coefficients of the additional losses are calculated coefficients of the additional temperature in relative units. The auxiliary motor NVA-55 [9] to isolate the stator temperature at rated speed is 140 ˚ C for the rotor shaft 145 ˚ C. These coefficients depend on the additional losses in the stator kps and rotor kpr designated as:

k_{tss} – additional temperature coefficient of the stator insulation under the influence of additional losses in the stator. It uses the transfer function, shown as in fig. 1;

k_{trs} – additional temperature coefficient of the rotor shaft under the influence of additional losses in the stator. Transfer function on fig. 1;

k_{trr} – additional temperature coefficient of the rotor shaft under the influence of additional losses in the rotor. Transfer function on fig. 1;

k_{tsr} – additional temperature coefficient of the stator insulation under the influence of additional losses in the rotor. Transfer function on fig. 1.

Values of factors of additional temperature in relative units are resulted on fig. 3.

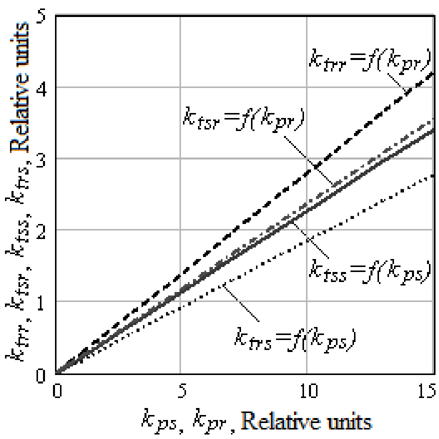


Fig. 3. The coefficients of the additional temperature in relative units.

These values were obtained using a software package ELCUT [10] as follows:

• k_{tss} obtained from the experiments of change of the additional losses in the stator at a constant losses in the rotor;

• k_{trs} as well as ktss, the temperature calculated for the rotor;

• k_{trr} obtained from the experiments changing the ditional losses in the rotor at a constant loss in the stator;

• k_{tsr} as well as ktrr, the temperature calculated for the stator.

ELCUT software product designed to simulate the thermal fields of electromechanical transducer finite element method. The necessary input data for calculation of specific losses were attributable to the unit volume of an area, the properties of the surfaces of heat and thermal conductivity of the materials motor parts.

It should be noted that the above factors added temperature calculated taking into account the fact that the total losses, they have caused, are uniformly distributed on the stator and rotor. This was achieved using the data in the calculation of equivalent current losses in all three phases, as a result of which, the total losses are losses in the non-uniform current load. And finally to more accurately determine the actual temperature of the stator insulation, using special coefficients, called the bias temperature coefficients (see figure 4). These coefficients were derived from the calculated data using the program ELCUT.

In addition to the above listed, for the calculation of the possible change in temperature of the rotor bars under the influence of their workmanship, is the display of the stator current frequency harmonics $2 \cdot f_1 \cdot s$ using a current sensor Dt is made. This current Is.д.с increases with the number of defective rods (figure 5b). On the schedule value of this current in relative units in relation to actual value of a current of the first harmonic in a phase means.

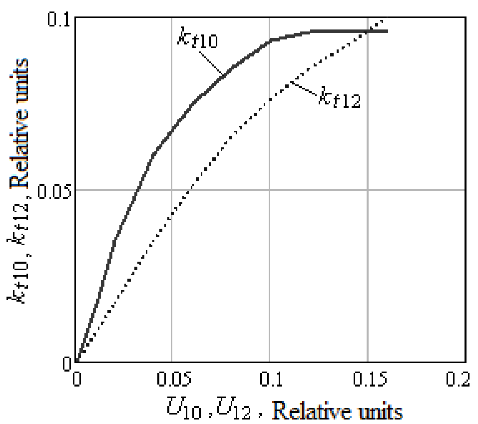
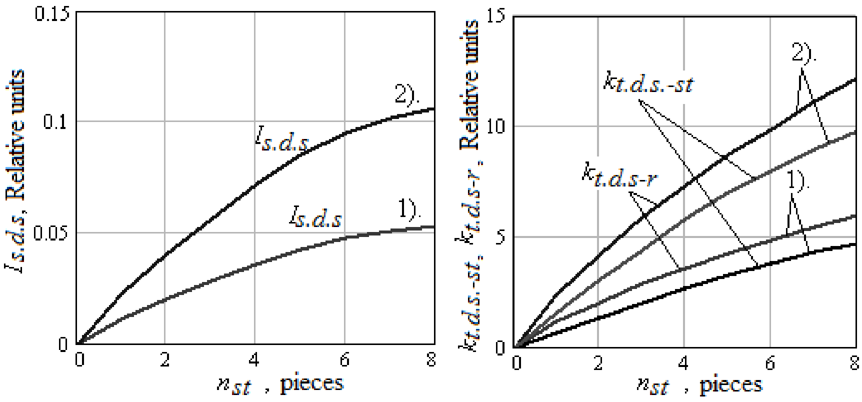


Fig. 4. The coefficients of the conditional bias temperature uniform in relative units from the actual to the stator losses caused by the zero voltage U_{10} and U_{12} reverse sequences.

The principle indication is based on the fact that the rotor bars with defective system of currents become unbalanced and there will be negative sequence current, which induces in the stator winding additional EMF, which leads to the pulsation of the stator current with a frequency $2 \cdot f_1 \cdot s$. The magnitude of this current can be judged on the degree of damage to the engine from overheating, defective areas of the rotor bars.



(a) *(b)*

Fig. 5. Depending on the presence of faulty rotor bars: a - coefficients of the additional stator temperature kt.d.s-st and a rotor kt.d.s-r; - a current stator frequency $2\cdot f_1\cdot s$*;* 1 *- a case when the section of transition of a defective site of a core is reduced in 9 times;* 2 *- too at the reduced section of transition in* 16 *times.*

It should be noted that the decrease in area under different sections of the transition of the defective part of the bar, the additional temperature increase by approximately the same time, how much current is increased frequency of $2\cdot f_1\cdot s$ (figure 5). This proportion is very easy to harp on this current one could judge the overheated motor. The resulting coefficients allow calculating the temperature of the stator insulation of the rotor shaft *ts* and *tr* using their nominal temperature and rotor $t_{s.nom}$ and $t_{r.nom}$. The values obtained are compared with the maximum allowable temperature, above which the operation of the motor is an emergency.

Summary. The developed system of monitoring of induction motors with low quality power supply allows you to quickly calculate the heating of the stator and rotor windings during operation and the signal reaches the limit temperature. Calculations were carried out by the example of an asynchronous auxiliary engine NVA-55 is installed on the locomotive 2ЭС5К "Ermak" [11]. Feature of the proposed monitoring system is not necessary to install temperature sensors in the motor. By determining the temperature produced by indirect means of system. For implementation of this algorithm is sufficient to calculate a single sample pre-factors for the particular motor and enter them into the memory of the microprocessor unit. After this, the monitoring system can operate in real time for optimum performance of motor.

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