Improving maintenance system for controlled asynchronous electric drives of electric locomotives based on their diagnosis

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Abstract. The article assesses the reliability of improving the maintenance of the control system of an asynchronous traction electric drive of an electric rolling stock with a rectifier-inverter converter based on power IGBT transistors, increasing the power factor in traction mode and regenerative braking.

1 Introduction

Electrical equipment of electric rolling stock (EERS) of alternating current should be divided into a current collector, a controlled rectifier 4QS, a capacitive filter, an autonomous voltage inverter (AVI), and an autonomous current inverter (ACI), and a traction asynchronous motor (TAM). The maintenance and repair of the devices under consideration are primarily focused on the implementation of the relevant instructions and manuals for the maintenance and current repair (MCR) of AC electric locomotives following the instructions for scheduled preventive maintenance (SPM), i.e., production of checks and revisions of equipment. [1,2,9,10,13]. Plans for these works are established at predetermined intervals, taking into account the average statistical technical condition of electrical equipment. Plans for these works are established at predetermined intervals, taking into account the average statistical technical condition of electrical equipment. Such a service system does not correspond to the prevailing market relations on the one hand, as well as the achieved capabilities of modern methods and tools for diagnosing the electrical equipment of locomotives and the level of qualification of maintenance personnel, on the other hand [4,5]. Such a state dictates the transition to a new (MCR) execution system based on the actual technical condition of the object and its installed resource.

Objective. This study is devoted to the calculation of the reliability indicators of the AC electric drive system of EPS operated in electrified areas in "Uzbekistan temir yo'llari", based on which directions for improving their nodes will be determined based on modern existing functional and stationary methods and diagnostic tools. Separate functional links and units of electric traction rolling stock belong to units of relatively low reliability, so it is advisable to improve them, which is an important and urgent task. To achieve this goal, statistical data were collected on failures and damages of each link that converts the voltage of the contact network U_c and the type of current in it, characterized by the frequency of the contact network f_c into the voltage and type of current set for the TAM (U_d и f_d). Statistical data on damages and failures of electric drive elements over the past ten years

(2012-2022) according to the maintenance and repair logs of the "Uzbekistan" depot are shown in Table 1. The analyzed data were obtained with the same number of elements of the power part of the electric drive over a run of 1 .5 million km. for each EERS.

2 Main part

An analysis of the scatter of the resource values of each functional link of an asynchronous electric drive with a TIM allows us to state that by the time the maintenance work is carried out, the resource of the same type of functional parts of the electric drive will be underused. The other will experience the use of the established resource until the service life and, as a result, frequent unreasonable and unscheduled repairs leading to financial and material costs.

The development of perfect, reliable, and trouble-free complex technological processes for the movement of traction electric rolling stock depends on how much the problem of obtaining reliable and sufficient information from them is resolved [3,4]. The resulting diagnostic information can be divided into functional, i.e., when the locomotive is moving and stationary when not in operation.

An analysis of the existing diagnostic equipment shows that for the operating EERS fleet, diagnostics currently does not replace the installed system but is its addition. At the same time, there is a need for an individual approach to methods and means of diagnosing, adapting to each electric locomotive's technical and technological state separately, taking into account modern schemes for diagnosing complex radio hardware devices. The essential requirements for information about the failures of each functional link are reliability and sufficiency, determined by numerical values [4,7].

The MCR system under consideration for an asynchronous electric drive is primarily focused on the implementation of current MCR work, i.e., verification and revision of functional links following the periodicity schedule, taking into account the results of the diagnosis since the analysis of the existing instability of the preliminary state of each link leads to failures and, accordingly, failures, the costs of the electric locomotive schedule, and damage to expensive equipment.

The most dangerous in the organization of the movement of EERS are failures and damage to the elements of the control system of the asynchronous drive since it does not have a full reserve. As an example, in Fig.1. shows the diagram of failures of the power part of the electric drive serviced in the depot "Uzbekistan" of electric locomotives of the series "Uzbekistan", "Uz Y", "UzEL", "UzELR" for 2013-2022.

According to the results of a system analysis of failures of asynchronous electric drives of EERS, it is relatively acceptable; however, the material and general economic damage from traffic interruptions can be high. Therefore, it is necessary to determine the optimal maintenance period to minimize costs, taking into account the constructed diagrams shown in Fig. 1.

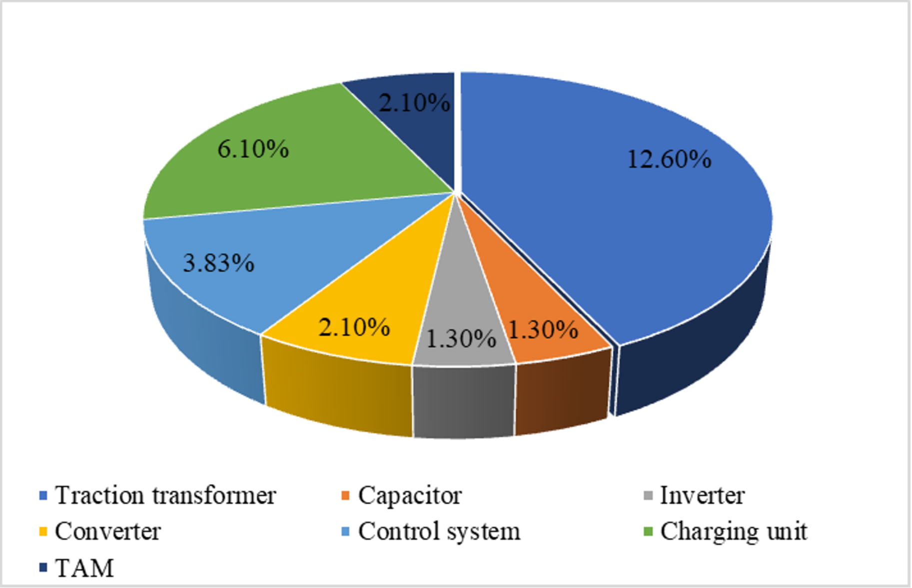

Fig. 1. Diagram Specific failure rate of functional duties of links of electric locomotives of Uzbekistan, O'z Y, O'zEL, O'zELR series with asynchronous drives

To separate the factors and the impact on the occurrence of failures with the division into important and non-essential, we will use the Pareto diagram, which is a kind of curve chart along which the factors are distributed in decreasing order of values. The Pareto chart allows you to identify the causes for their subsequent elimination.

According to the results of the research, it was found that one of the important but unreliable installations of electrical equipment of the EERS is a controlled asynchronous electric drive, which requires consideration of it as a whole due to the electrical-galvanic and information-structural relationship of the processed control signal. Accordingly, methods for diagnosing and evaluating reliability indicators should be developed, considering these relationships.

Consider and analyze some issues of reliability and diagnostics of AC electric drives with TAM. Quantitative indicators of reliability are the probability of failure-free operation P, defined as:

$$P = \frac{N - N_0}{N} \quad (1)$$

where N is the total number of drive links during the observation, pcs; N_0 is the number of failed links of the same type, pcs.

It is known that the probability of failure q, which characterizes the rate of occurrence of failures over time, is defined as [4]:

$$q = \frac{N_0}{N} = 1 - P \quad (2)$$

One of the most important indicators of reliability is the failure rate λ(t) - the conditional density of the probability of a failure by a given point in time, provided that there was no failure before this moment:

$$\lambda(t) = \frac{N_0(\Delta t_i)}{N_{cp}(\Delta t)} \quad (3)$$

where $N_0(\Delta t_i)$ is the number of failures i.e., functional links (FL) of elements in i that time interval; $N_{cp}(\Delta t)$ is the total number of elements in the same time interval. The FL failure rate in the first approximation is also defined as the ratio of the number of failed FLs over a certain period to the number of operable FLs at the beginning of this interval [2-4]:

$$\lambda(t) \approx \frac{\Delta n(t)}{N(t)\Delta t} \quad (4)$$

where Δn(t) is the number of FLs that failed during the time Δt, (year); N(t) is the number of links that are working properly by the beginning of the interval Δt.
Average time to failure:

$$T_{cp} = \frac{L_n}{N_0} \quad (5)$$

where L_n is the mileage of the electric locomotive between failures; N_0 is the number of failures of each type.

Failure flow parameter:

$$\omega = \frac{N_0}{L_n} \quad (6)$$

where L_n is the total mileage of electric locomotives during the observation period.
The mean time of failure-free operation T_c with probability is related by the relation [3,4]:

$$T = \int_0^\infty P(t)dt \quad (7)$$

The intensity curve of the FL of radio-electronic equipment and the dependence of the number of failures on time are shown in Figs. 2 and 3.

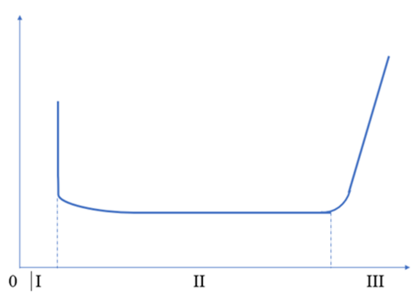

Fig. 2. Intensity curve λ(t)
I – area of hidden defects
II – area of normal operation

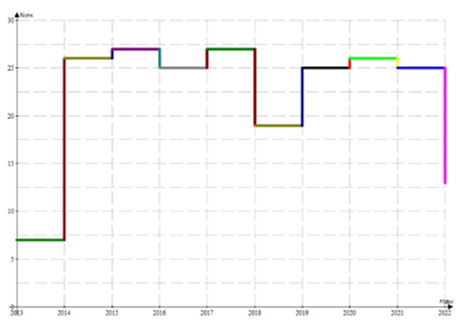

Fig. 3. Dependence of number of failures on time

The experiments were carried out on single-section electric locomotives with an asynchronous electric drive of 49 pieces. The technical condition of traction transformers (TT) of electric locomotives is characterized primarily by the temperature of the most heated point of the winding described by the regression of the form:

$$\nu_{nitmk} = 17.7 \cdot k^2 + 5.3 \quad (8)$$

where k is the relative load of the TT; V_{nitmk} is excess of the temperature of the most heated point over the oil temperature.

Oil temperature rise above ambient temperature $-20^0 \div +40^0$ is defined as [2]:

$$\nu_m(t) = \nu_{mk} - (\nu_{mk} - \nu_{mn}) \exp\left(\frac{-t}{\tau_m}\right) \tag{9}$$

where ν_{mk} is the steady-state value of the excess of the oil temperature over the ambient temperature for the new load value, ⁰C; ν_{mn} is excess of oil temperature over ambient temperature before load change, ⁰C; $\tau_m$is oil time constant, from 0.5 to 3.5 h. It is known that the average oil temperature during mode K is defined as:

$$\mu\theta_{inti} = \frac{\theta_{intn} + \theta_{intk}}{2} \tag{10}$$

where θ_{intn} is the temperature of the most heated point before the beginning of the K mode, Δ; θ_{intk} is the temperature at the end of the K mode, ⁰C.
Relative insulation wear for the i-th interval of the load curve:

$$S_i = \frac{t_i}{T} 2\left(\frac{\mu\theta_{inti} - \theta_{int}\delta}{\Delta}\right) \tag{11}$$

where t_i is the duration of the mode, T = 24 hours; $\theta_{int}\delta$ is base temperature value hottest point winding; θ_{int}=28^0C.
It is known that a change in the temperature of the winding by $\Delta = 6^0\text{C}$ reduces the service life of the insulation by half.

3 Degradation processes of capacitor filters (CF)

In devices of traction asynchronous electric drive, KF operate in heavy electrical and mechanical modes: increased currents I≈1000A and voltage U≥1500V, the existence of electromechanical resonance phenomena, high values of currents 2,3,4 and 5 harmonics, reaching 0.5 ÷ 0.80 vibrations, heating of the capacitor from active leakage currents as a result of an increase in the tangent of the dielectric loss angle tgδ. With an increase in the temperature of the dielectric, thermal stability is violated up to the onset of thermal breakdown.

The steady temperature value of the KF dielectric in the form of paper insulation impregnated with trichlorodiphenyl impregnation above the ambient temperature is defined as [6]:

$$\nu = R_T \cdot I^2 \cdot x_c \cdot tg\delta \tag{12}$$

where R_T is the thermal resistance of the capacitor equal to 0.2÷0.5⁰C/W; I is the current through the capacitor, A; x_c is capacitance of the capacitor, Ohm; $x_c = \frac{1}{\omega c}$; tgδ is dielectric loss tangent, tgδ≤0.003.

The temperature of the most heated point of the KF dielectric as a function of time t is defined as [4]:

$$\theta(t) = \theta_{охл} + \nu_k - (\nu_n - \nu_k) \cdot \exp\left(-\frac{t}{\tau}\right) \tag{13}$$

where $\theta_{охл}$is the ambient temperature, ⁰C; ν_k is the steady-state value of the excess of the dielectric temperature over the ambient temperature, ⁰C;

ν_n is exceeding the temperature of the dielectric above the ambient temperature before changing the load; τ is the thermal constant of the condenser (τ_k = 2.5…3.5 h). The relative degree of wear of the capacitor dielectric is defined as [6, 8]:

$$S_i = \frac{t_i}{T}\left(\frac{I_i \mu \theta_i}{I_{nom} \cdot \theta_{nom}}\right)^c \quad (14)$$

where $I_i \, \mu \, \theta_i$ is respectively, so through the capacitor and the average temperature of the dielectric in the i-load interval; $I_{nom} \cdot \theta_{nom}$ is respectively the nominal value of the current through the capacitor and the temperature of the dielectric ($\theta_{nom} = 95^0 C$; C - even 7.7 is chosen).

4 Failures of power semiconductor devices

Diodes, thyristors, and IGBT bipolar transistors are widely used in systems of controlled asynchronous AC electric drives. A characteristic feature of these devices is the presence of two failures - open and short circuit, as the analysis of their failures in the «Uzbekistan» depot shows, as well as experiments on failures on MATLAB Simulink conducted at the Department of Electric Rolling Stock. The failure rate of an electric drive containing IGBTs can be approximated by a Weibull distribution. The probability density function for the Weibull distribution is described by the expression [7, 12]:

$$f(t) = \beta \frac{t^{\beta-1}}{\eta^{\beta}} e^{-\left(\frac{t}{n}\right)^{\beta}} \quad (15)$$

where t is the current operating time; η is the scale parameter of the Weibull distribution; β is the Weibull distribution shape parameter. The shape parameter indicates the failure rate change rate over time. The probability density function of the Weibull distributions is shown in Fig.4.

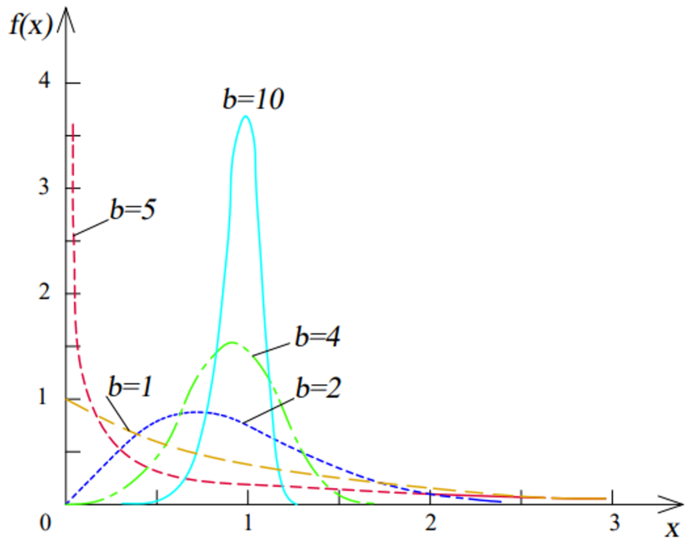

Fig. 4. Probability density function of Weibull distributions of failures

It is known [7] that with a long operating time of IGBT transistors (≈30 thousand hours), the number of valve damage increases: the failure is the crystallization of the solder to the tungsten disks. Crystallization occurs due to IGBT temperature cycling due to the current increase. When the temperature is heated up to 140 ºC, there is a risk of damage to the device.

Large values of the rise in current surges are accompanied by the release of a relatively large amount of heat in a small volume of the crystal, which leads to the melting of silicon, leading to a short circuit of the device. One of the spectacular operations of IGBT is temperature control within $t^o \approx 100$ ºC.

The organization of maintenance of the technical condition of electric locomotives based on an integrated maintenance system for electric drive devices with TAM in the depot "Uzbekistan" is the creation of a center for diagnostics and monitoring of electric locomotives (CDMEL). The activities of the created center should include [2,3,4,6]: detection of pre-failure conditions and control over the timely elimination of the causes of damage to electrical equipment to prevent failures and violations of the train schedule; accounting and analysis of pre-failure states to develop corrective measures and increase the service life of electrical equipment; quality control of maintenance work.

It is CDMEL, based on the use of diagnostic systems, that should become a structure that provides the organization of an integrated model for the operation of all electric locomotive devices according to their technical condition, taking into account the reduction in the scope of SPM.

Among the main tasks for the implementation of an integrated approach to the organization of maintenance of the electrical equipment system, the following should be highlighted: identifying the scope of work to be excluded from the PPR schedule by the new maintenance system; determination of the principle and amount of information to create an effective tool for organizing the operation of electrical equipment according to the actual technical condition; determination of the effectiveness assessment, a monitoring and diagnostics system was applied.

5 Conclusions

The existing system of planned preventive repair and maintenance of electrical equipment of electric locomotives in market conditions does not meet the modern requirements of reliability and quality of work.

The operating costs for the maintenance of electrical equipment require a significant, which is impossible without a structural change; maintenance of electric power devices at the current stage and an integrated organization of maintenance of the most vulnerable functional units of electrical equipment is promising. Maintenance should be based on statistical and mathematical analysis methods, modern methods, and diagnostic tools.

The article indicates the main distribution patterns in an asynchronous electric drive of an electric locomotive. It identifies possible methods for improving the reliability of the corresponding nodes. The lists and priority of inclusion in the equipment monitoring system for the transition according to the actual state are determined.

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