| **ARTICLE TITLE**       | ESTIMATING THE PROBABILITY OF THE EMERGENCY OPERATION OF THE QUARRY ELECTRIC LOCOMOTIVE TRACTION ELECTRIC DRIVE |
|------------------------|----------------------------------------------------------------------------------------------------------|
| **AUTHOR(S)**          | Artem Artemenko, Oleksii Chornyi, Valeriy Sydorenko, Serhii Serhiienko, Yurii Zachepa, Vitaliy Kuznetsov, Alisa Kuznetsova |
| **ARTICLE INFO**       | Artem Artemenko, Oleksii Chornyi, Valeriy Sydorenko, Serhii Serhiienko, Yurii Zachepa, Vitaliy Kuznetsov, Alisa Kuznetsova. (2021) Estimating the Probability of the Emergency Operation of the Quarry Electric Locomotive Traction Electric Drive. World Science. 2(63). doi: 10.31435/rsglobal_ws/28022021/7448 |
| **DOI**                | https://doi.org/10.31435/rsglobal_ws/28022021/7448 |
| **RECEIVED**           | 24 December 2020 |
| **ACCEPTED**           | 15 February 2021 |
| **PUBLISHED**          | 20 February 2021 |
| **LICENSE**            | This work is licensed under a Creative Commons Attribution 4.0 International License. |
ESTIMATING THE PROBABILITY OF THE EMERGENCY OPERATION OF THE QUARRY ELECTRIC LOCOMOTIVE TRACTION ELECTRIC DRIVE

Artem Artemenko, Senior lecturer, Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine, ORCID ID: http://orcid.org/0000-0001-9191-493X
Oleksii Chornyi, Doctor of Technical Science, Professor, Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine, ORCID ID: http://orcid.org/0000-0001-8270-3284
Valeriy Sydorenko, Candidate of technical sciences, associate professor, Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine, ORCID ID: http://orcid.org/0000-0002-4449-073X
Serhii Serhiienko, Candidate of technical sciences, associate professor, Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine, ORCID ID: http://orcid.org/0000-0003-3977-5239
Yurii Zachepa, Candidate of technical sciences, associate professor, Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine, ORCID ID: http://orcid.org/0000-0003-4364-6904
Vitaliy Kuznetsov, Candidate of technical sciences, associate professor, National metallurgical academy of Ukraine, Dnipro, Ukraine, ORCID ID: http://orcid.org/0000-0002-8169-4598
Alisa Kuznetsova, Student, Oles Honchar Dnipro National University, Dnipro, Ukraine, ORCID ID: http://orcid.org/0000-0003-4772-683X

DOI: https://doi.org/10.31435/rsglobal_ws/28022021/7448

ARTICLE INFO
Received: 24 December 2020
Accepted: 15 February 2021
Published: 20 February 2021

KEYWORDS
quarry electric locomotive, distribution law, traction electric drive, parameters irregularity, distribution density.

ABSTRACT
The paper deals with the problem of the assessment of the functionality of the multi-motor direct current traction electric drive of the quarry electric locomotive. The problem of the failure of electric drive motors because of extremely unsatisfactory state of the rail tracks and the wear of wheel pairs is analyzed. Taking into account the number of the existing repaired electric motors the probability of fitting up the traction electric drive with the electric motors with the widest electrical parameters variety is determined.

Citation: Artem Artemenko, Oleksii Chornyi, Valeriy Sydorenko, Serhii Serhiienko, Yurii Zachepa, Vitaliy Kuznetsov, Alisa Kuznetsova. (2021) Estimating the Probability of the Emergency Operation of the Quarry Electric Locomotive Traction Electric Drive. World Science. 2(63). doi: 10.31435/rsglobal_ws/28022021/7448

Copyright: © 2021 Artem Artemenko, Oleksii Chornyi, Valeriy Sydorenko, Serhii Serhiienko, Yurii Zachepa, Vitaliy Kuznetsov, Alisa Kuznetsova. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) or licensor are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Introduction. The problem of improving the efficiency of quarry electric locomotives operation is being solved during several decades [1, 2, 3], but it has not been solved yet. Modern achievements and the latest developments of scientists in the field of the control of electromechanical systems (EMS), in particular, the electric drives of industrial electric locomotives [4, 5, 6], do not enable getting the required results as the condition of the rail tracks, mechanical equipment and traction electric motors is extremely unsatisfactory. It should be taken into account that the mentioned factors are directly interconnected and it is impossible to solve the problem of the high-quality repair of electric motors without the improvement of the condition of the tracks and wheel pairs. Fig. 1 contains fragments of rail tracks of quarry electric locomotives providing the transportation of the mining muck.
Such defects reflect on the state of the surface of the wheel pairs (Fig. 2). In some cases the wheel diameter decreases by 10-12 mm (Fig. 2, a), and new dents cause the appearance of the analogous damage of the rail surface (Fig. 2, b), and even variation of the geometry of the rail head.

Appearance of hollows, caverns, dents results in slippage, which additionally damages the rail track and the wheels at the point of their contact. When the diameter of a wheel decreases, the wheels in the wheel pair rotate at different speed, which results in continuous slippage of the wheel surface against the rail surface [7]. During the slippage the load is distributed irregularly between the traction motors. Motors with a higher load overheat and quickly fail also due to the presence of low-quality electricity in the contact network [8-14]. Motors are repaired at specialized repair enterprises allowing the following deviation of the output parameters according to the GOST state standard: the armature winding – 10% and the excitation winding – 2% [11-18]. The irregularity of the parameters results in irregular rigidity of mechanical characteristics and in irregular distribution of the load among the motors. That is why the research of the operation modes of quarry electric locomotives is a topical problem.

**Problem Statement.** Electric locomotive OPE-1A (OPE-1AM) is the main type of the quarry electric locomotive at Poltava Ore-Dressing and Processing Enterprise. It is designed for the operation on the strip mining railways electrified by alternating current with the voltage of 10000 V, the frequency of 50 Hz, ruling gradient of 60‰. The servicing part of the traction unit consists of six two-axle bogies, two in each section. The bogies are equipped with two wheel-motor blocks consisting of a wheel pair and a traction motor. Direct current series excitation motors DT9N (NB-511 for OPE-1AM) are used as traction motors; in continuous duty their rated power is 418 kW at the rated voltage and current respectively 1500 V and 300 A, maximal rotation frequency 160 s-1.

**Fig. 1.** Fragments of the rail track condition: a) – break, b) – hollow, c) – dent

**Fig. 2.** Fragments of the wheel pairs condition: a) – change of the wheel diameter, b) – dent

**Fig. 3.** A fragment of the basic power circuits of the electric locomotive TED: M1E, M3E – traction motors; PRE – reverser; PTE1 – brake switch; PBE – Locomotive wheelslip relay; C1-C2 – motors field winding; R18, R20 – shunt resistors of the motor field winding; VD1, VD3 – disconnectors of the motor; K1-K2 – motor armature; LM1E, LM3E – inductance of the motor field winding.
An electric locomotive is manufactured in a three-section variant and consists of a driving electric locomotive, a diesel section, a motor dump car. Sometimes a second motor dump car is installed instead of a diesel section. An electric locomotive is equipped with 12 traction motors. In the traction, autonomous and brake modes traction motors are connected in parallel in each traction unit (Fig. 3).

Admissible 10% deviation of the armature winding parameters in repaired traction motors is determined according to heat condition [7, 8, 9, 10, 13-15] and, if forced ventilation of the motors is available, allows long-term operation. However, it should be taken into consideration that an electric locomotive is equipped with 12 traction motors that are not especially selected for the operation in a multi-motor electric drive system as they are motors of the same type. In this case there is a possibility of such a situation when one electric locomotive unit will contain motors with parameter deviation within the tolerance but of opposite values. Let us consider a probability of such a situation.

Let there be N motors in the repair fund; they are characterized by a vector of a certain parameter deviation from the norm \( \Delta = \left[ \Delta_1, \Delta_2, \ldots, \Delta_N \right]^T \). Value \( \Delta_i \), that characterizes \( i \)-th motor may be both positive and negative and may repeat \( m \) times (\( 1 \leq m \leq N \)).

**Results of the Research.** We introduce an upper-triangle matrix of the modules of the first final pairwise differences \( \nabla \) characterizing the difference between the motors in the pair according to the preset parameter:

\[
\nabla = \begin{bmatrix}
0 & \nabla_{12} & \cdots & \nabla_{ij} & \cdots & \nabla_{1N} \\
0 & 0 & \cdots & \nabla_{2j} & \cdots & \nabla_{2N} \\
0 & 0 & 0 & \cdots & \cdots & \cdots \\
0 & 0 & 0 & 0 & \cdots & \cdots \\
0 & 0 & 0 & 0 & 0 & \cdots \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]  

(1)

With the dimension of \( N \times N \) (the number of the elements \( N^2-N \)/2), its elements are calculated by the following rule:

\[
\nabla_{ij} = \begin{cases} 
\Delta_{ij} = |\Delta_i - \Delta_j|, & \forall i < j \\
0, & \forall i \geq j 
\end{cases}
\]  

(2)

If \( \nabla_{ij} \approx 0 \) or \( \nabla_{ij} = 0 \), it means that the difference between the \( i \)-th and the \( j \)-th motor by preset parameter \( \Delta_i \) is respectively minimal or absent.

We are interested in the maximal value \( \max(\nabla_{ij}) = \nabla_{max} \). Naturally, \( \nabla_{max} \) may repeat \( k_{max} \) times (in theory \( 1 \leq k_{max} \leq N-1 \)).

Let us estimate the probability of the situation when during the selection of 12 motors for a locomotive there will be a pair corresponding to \( \nabla_{max} \): a) once; b) at least once.

On the basis of the hypergeometric distribution of probabilities it is possible to write down a probability that during the selection of 12 motors out of \( N \) the number of the chosen ones will include exactly \( k \) (\( 1 \leq k \leq k_{max} \)), corresponding to \( \nabla_{max} \):

\[
p(\nabla_{max}, k) = \frac{C_{k_{max}}^k \cdot C_{N-k_{max}}^{12-k}}{C_{12}^{12}}.
\]  

(3)

Then for the probability of the extraction of one such pair it is possible to write down (one pair – \( k=2 \)):

\[
p(\nabla_{max}, 2) = \frac{C_{k_{max}}^2 \cdot C_{N-k_{max}}^{10}}{C_{12}^{12}}.
\]

In practice \( N=100..400 \). Let us consider the “worst” case when the repair park is minimal, i.e., \( N=100 \) and, e.g. there is a chance to select \( k_{max}=12 \) (6 pairs) of motors with the maximal difference by the parameter. Then

\[
p(\nabla_{max}, 2) = \frac{C_{12}^2 \cdot C_{88}^{10}}{C_{12}^{12}}.
\]

Taking into account that \( C_n^k = n!/(k!(n-k)!)) \) and \( n \) is big, Stirling’s formula will be used for the calculation of factorials:

\[
n! \approx \sqrt{2\pi n} \left( \frac{n}{e} \right)^n.
\]

RS Global
Then

\[ p(V_{\text{max}}, 2) = \frac{C_{12}^2 \cdot C_{10}^{12-m}}{C_{100}^{12}} = 0.284, \text{ i.e. 28.4\%}. \]  

\[ \text{...............(4)} \]

The probability of the situation when during the selection of 12 motors at least one pair will be with the maximal difference of the conditions is:

\[ p(V_{\text{max}}, (k = 2) \lor (k = 4) \lor (k = 6) \lor (k = 8) \lor (k = 10) \lor (k = 12)) = \sum_{m=2,4,..,12} \frac{C_{12}^m \cdot C_{12-m}^{12}}{C_{100}^{12}} = 0.314, \]  

\[ \text{i.e. 31.4\%}. \]

\[ \text{...............(5)} \]

**Fig. 4.** The probability of the situation when during the selection of 12 motors out of \( n \) motors of the repair park one pair will be with the maximal difference of the parameters

**Fig. 5.** The probability of the situation when during the selection of 12 motors out of \( n \) motors of the repair park at least one pair will be with the maximal difference of the parameters

The obtained results reveal that in every third case there may be a situation that will be unfavorable from the point of view of the reliability characteristics of the wheel pair of the electric locomotive after repair.

As mentioned above, to get real assessment of the said probabilities it is necessary to know the law of distribution of value \( \Delta_i \) of the preset parameters as it would allow the assessment of the share of the motor pairs with maximal deviations from the preset parameter.

Let \( \Delta^k \) be a casual deviation of the \( k \)-th parameter of the electric motor after repair. For the convenience of further reasoning let us pass to relative deviations

\[ \delta^k = \frac{\Delta^k}{\delta_{\text{nom}}^k} \cdot 100\%, \]

where \( \delta_{\text{nom}}^k \) – rated (published) value of the required parameter. As transform (6) is of linear character, the form of the law of distribution of probabilities of \( \Delta^k \) and \( \delta^k \) coincide. Let the law of distribution \( \delta^k \) be preset by the density of probability \( f_{\delta^k}(x, \Theta^k) \), i.e. \( \delta^k \sim f_{\delta^k}(x, \Theta^k) \), where \( \Theta^k = \{\Theta_1^k, \Theta_2^k, ..., \Theta^k\}^T \) – vector of the distribution parameters. It is necessary to:

1) assess \( f_{\delta^k}(x, \Theta^k) \);

2) assess the probability of the situation when two motors of size \( N \), randomly chosen out of the repair fund, will have critical deviations by the \( k \)-th parameter;

3) assess the probability of the situation when two motors of size \( N \), randomly chosen out of the repair fund, will have critical deviations by at least one of \( k \) \( (k = 1, K) \) parameters.

The assessment of the law of distribution \( f_{\delta^k}(x, \Theta^k) \) requires structural and parametrical identification of the model. Taking into account the complexity of obtaining the sufficient amount of empiric data, which would provide the opportunity to suggest and verify a definite statistical hypothesis as to the model, we will consider the assessment of the law of distribution based on a number of a priori assertions and suppositions.

By virtue of the central limit theorem we can suppose, that the law of distribution \( \delta^k \) should have a normal or at least an asymptotically normal law of distribution with zero mathematical expectation (\( \mu = 0 \)):
However, according to the standard requirements, the absolute value of the post-repair deviation of the preset parameter $k$ cannot exceed a certain admissible value. Otherwise the electric motor is considered unfit for operation and does not replenish the repair fund. In other words, in practice, it is necessary to have not a normal but a truncate normal law of distribution with symmetrical boundaries and it should be preset by the following expression with four parameters:

$$f_{\delta^k}(x, \mu, \sigma, x_1, x_2) = \begin{cases} 0 & x \leq x_1 \\ \phi \left( \frac{x - a}{\sigma} \right) & x_1 < x < x_2 \\ 0 & x > x_2 \end{cases},$$

(8)

Where $\phi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{8}}$ – Laplace’s function, $\Phi(x) = \frac{1}{\sqrt{2\pi}} \int e^{-\frac{x^2}{8}} dx$ – Laplace’s integral function. In this case three out of four components of the distribution parameter vectors can be considered exactly preset:

$$\Theta^k = \begin{bmatrix} \mu \\ \sigma \\ x_1 \\ x_k \\ x_{1k} \\ x_{2k} \end{bmatrix},$$

where $x_{1k}, x_{2k}$ – particular tolerances for the $k$-th parameter, $\sigma_k = \frac{1}{(n-1)} \sum_{i=1}^{n} (\delta_i^k - \text{mean}(\delta_i^k))^2$ – sample point unbiased and consistent assessment of parameter $\sigma$, $\text{mean}(\delta_i^k) = \frac{1}{n} \sum_{i=1}^{n} \delta_i^k$, $n$ – sample size.

Consequently, the probability of the situation when during the selection of two motors for one wheel pair one will choose two specimens with deviations by the preset parameter $k$ that will be

$$p\left(\delta^k \leq \frac{x_1}{2}\right) = p\left(\delta^k \geq \frac{x_2}{2}\right) = \int_{x_1}^{x_2} f_{\delta^k}(x, \mu, \sigma, x_1, x_2) dx.$$

(9)
diametrically opposite and of the type that $|\delta_1 - \delta_2| \geq x_1$, will be equal to the following, according to the theorem of multiplication of dependent events

$$p\left(|\delta_1^k - \delta_2^k| \geq x_1\right) = p\left(|\delta^k \leq \frac{x_1}{2}\right) \cap \left(p\left(|\delta^k \geq \frac{x_2}{2}\right) = 2 \cdot p\left(|\delta^k \leq \frac{x_1}{2}\right) p\left(|\delta^k \leq \frac{x_2}{2}\right). \quad (10)$$

Finally, the probability of the situation when two motors of size $N$, randomly selected out of the repair fund, will have critical deviation by at least one of $k$ parameters can be calculated by formula:

$$p\left(|\delta_1^k - \delta_2^k| \geq x_1\right) \cup \left(|\delta_1^k - \delta_2^k| \geq x_2\right) \cup \cdots \cup \left(|\delta_1^k - \delta_2^k| \geq x_{1K}\right) = 1 - \prod_{k=1}^{K} p\left(|\delta_1^k - \delta_2^k| < x_{1k}\right). \quad (11)$$

As an example, let us consider a case with two parameters: armature winding resistance ($R_a$) and excitation winding resistance ($R_e$). The distribution parameter vector for the armature

$$\Theta^1 = \left[\begin{array}{c}
\mu \\
\sigma_1 \\
\mu \\
\sigma_2 \\
\mu \\
\sigma_2 \\
\mu \\
\sigma_2
\end{array}\right] = \left[\begin{array}{c}
0 \\
5.077 \\
-10 \\
1.106 \\
0 \\
-2 \\
10 \\
2
\end{array}\right].$$

For the excitation winding $- \Theta^2 = \left[\begin{array}{c}
\mu \\
\sigma_1 \\
\mu \\
\sigma_2 \\
\mu \\
\sigma_2 \\
\mu \\
\sigma_2
\end{array}\right] = \left[\begin{array}{c}
0 \\
1.106 \\
0 \\
-2 \\
10 \\
2
\end{array}\right].$$

The assessment of parameter $\sigma$ is obtained on the basis of the selective data Then, according to formula (6), the following is true for the armature:

$$p\left(|\delta^1 \leq \frac{\text{max}}{2}\right) = p\left(|\delta^1 \leq \frac{\text{min}}{2}\right) = p\left(|\delta^1 \geq 5\right) = \frac{10}{5} \int_{f_{\delta}} (x, 0.5.077,-10.10) dx = 0.145.$$

It means that $\approx 15$ motors at $N=100$ have the value of resistance exceeding half of the admissible one on the right, i.e. 5%, and the same number of motors with deviation on the left.

Analogously, for the excitation winding:

$$p\left(|\delta^2 \leq \frac{\text{max}}{2}\right) = p\left(|\delta^2 \leq \frac{\text{min}}{2}\right) = p\left(|\delta^2 \geq 1\right) = \frac{2}{1} \int_{f_{\delta}} (x, 0.1.106,-2.2) dx = 0.15889.$$

Then the probability of the situation when during the selection of two motors for one wheel pair one will choose two specimens in which the deviations of the armature winding will be diametrically opposite and of such type that $|\delta_1 - \delta_2| \geq 10$ by formula (10) will equal:

$$p\left(|\delta_1 - \delta_2| \geq 10\right) = p\left(|\delta^1 \leq -5\right) \cap \left(p\left(|\delta^1 \geq 5\right) = 2 \cdot p\left(|\delta^1 \leq -5\right) p\left(|\delta^1 \geq 5\right) = \frac{15}{100} \cdot \frac{15}{100} = 0.04545.$$

Analogously, for the excitation winding:

$$p\left(|\delta_2^k - \delta_2^k| \geq 1\right) = p\left(|\delta^1 \leq -1\right) \cap \left(|\delta^1 \geq 1\right) = 2 \cdot p\left(|\delta^2 \leq -1\right) p\left(|\delta^2 \geq 1\right) = \frac{16}{100} \cdot \frac{16}{100} = 0.05172.$$

Finally, the probability of the situation when two motors of size $N$, randomly selected out of the repair fund, will have critical deviation by at least one of the parameters analyzed by formula (11) will be:

$$p\left(|\delta_1^k - \delta_2^k| \geq x_1\right) \cup \left(|\delta^k \geq 5\right) \cup \left(|\delta^1 \leq -1\right) = 1 - \prod_{k=1}^{K} p\left(|\delta_1^k - \delta_2^k| < x_{1k}\right) = 1 - p\left(|\delta_1^k - \delta_2^k| < x_{1k}\right) =$$

$$= 1 - (1 - 0.04545) (1 - 0.05172) = 0.095 \approx 0.10,$$

i.e. in every tenth case during the repair the selected pair may be of such a type that, at least by one parameter, there will be a deviation exceeding the admissible norms.

**Conclusions.** The performed analysis of the condition of the mechanical, electromechanical equipment of the quarry electric locomotives and rail tracks reveals that, due to deviation of the parameters of traction motors after repair in the electric locomotive multi-motor electric drive there occurs irregular distribution of load among the motors, the overheat of more loaded motors and their failure. Irregular distribution of load causes slippage resulting in the damage of the rail tracks and the
The calculated probability of fitting up the electric drive with motors with the widest variation of parameters reaches 30% in the existing repair park of traction motors. An analysis of mechanical characteristics of the two-motor electric drive has been carried out. It takes into account the slippage caused by the condition of the rail track. The growth of losses of the overloaded motor results in the decrease of its insulation durability by 25%. Taking into consideration the fact that there is no possibility of control of a separate track motor on the electric locomotive, high accident rate will remain in the future. The equalization of the irregular load among the motors caused by the irregular parameters and the deterioration of the coefficient of traction is only possible by means of additional control of the motor magnetic flux. Besides, the synthesis of a SMART-system of control of traction electric drive with the functions of self-control and analysis will provide the improvement of the efficiency of the operation of traction electric drives of quarry electric locomotives. It is also possible to solve the above problem by using additional power sources for electric motors, as alternative sources.

REFERENCES
1. Ayzenshtok L.I., Ivanov Yu.A., Chernov E. A. The choice of traction characteristics of locomotives. Shakhntnyy karernyy transport - Mining quarry transport, 1990, no.11, pp. 205-208. (Rus).
2. Ziborov K.A., Tverdokhleb A.M., Voskoboynik S.A. Principles for the construction of a traction control system for drive wheel sets of a mine locomotive. Gornyach elektromehanika ta avtomatyka - Mining electromechanics and automatics, 2012, no.88, pp. 115-120. (Rus).
3. Ververg M.F., Kogan A.Ja. Vzaimodeystviye puti i podvzihnogo sostava [Interaction of the track and rolling stock]. Moscow, Transport Publ., 1986. 559 p. (Rus).
4. Sinchuk O.N., Shokarev D.A., Vypasanenko, S.I. Structure and method of controlling the traction asynchronous electric drive of a mine contact-battery electric locomotive. Elektrotekhnika i energetyka. Naukovi pratsi Donetskogo natsionalnogo tekhnichnogo universyteta – Electrical engineering and power engineering. Scientific works of Donetsk National Technical University, 2013, no.2(15), pp. 223-226. (Rus).
5. Sinchuk, O. N., Guzov, E. S., Sinchuk, I. O. et al. Mine hybrid electric locomotive with asynchronous drive and automated control. Elektromekhanichni ta energozberiyachyi systemy. Shchokvartalny nauko-vyrobnychyy zhurnal - Electromechanical and energy saving systems. Quarterly research and production journal, 2012, no.2(18), pp. 95-100. (Rus).
6. Kuznetsov B.I., Nikitina T.B., Tatarchenko M.O., Khomenko V.V. Multicriterion anisotropic regulators synthesis by multiaxis electromechanical systems // Tekhnichna elektrodynamika. – 2014. – №4. – P. 105-107.
7. Available at: http://ir.nmu.org.ua/handle/123456789/1176 (accessed 15 September 2017).
8. Nosach E.V., Chornyi O.P., Vorobcheych O.S. The issues of winding heating at the start of electric machines // Electromechanical and energy saving systems. – Kremenchuk: KSPU, 2011. – Is.1/2011 (13), P.75-79.
9. Chornyi O. P., Bohatyrev К. N., Berdai A. An analytical solution to the equation of heating the rods of synchronous motors for the system of controlled cooling // Electromechanical and energy saving systems. – Kremenchuk: KrNU, 2013. – Is. 2/2013 (22). Part 2 – P. 205-209.
10. Tytituk, V., Chornyi, O., Pozhizun, A., Baranovskyaya, M., Romanov, A. 2018, "Analytical study of starting current of the induction motor stator", EasternEuropean Journal of Enterprise Technologies, vol. 2, no. 2-92, pp. 75-81. DOI: https://doi.org/10.15587/1729-4061.2018.125801
11. Kotelnets N.F., Akimova N.A., Antonov M.V. Ispytaniya, ekspluatatsiya i remont elektricheskikh mashin [Testing, operation and repair of electrical machines]. Moscow, Publishing Center "Akademija", 2003, 384 p. (Rus).
12. Kopylov I. P., Klotkov B.K. Spravochnik po elektricheskim mashinam. V 2-kh tomakh [Directory of Electrical Machines. In 2 volumes]. Moscow, Energoatomizdat Publ., 1988, vol.5, 456 p. (Rus).
13. Kuzenkov, O., Kuznetsov, V., Tryputen, N. Analysis of phase trajectories of the third - Order dynamic objects (2019) 2019 IEEE 2nd Ukraine Conference on Electrical and Computer Engineering, UKRCON 2019 - Proceedings, pp. 1235-1243. DOI: 10.1109/UKRCON.2019.8879819
14. Kuznetsov V., Tryputen N., Kuznetsova Y. Evaluating the effect of electric power quality upon the efficiency of electric power consumption (2019) 2019 IEEE 2nd Ukraine Conference on Electrical and Computer Engineering, UKRCON 2019 - Proceedings, pp. 556-561. DOI: 10.1109/UKRCON.2019.8879841
15. Kuznetsova Yevheniia; Kuznetsov Vitalyi; Tryputen Mykola; Kuznetsova Alisa; Tryputen Maksym; Babjak Mykola Development and Verification of Dynamic Electromagnetic Model of Asynchronous Motor Operating in Terms of Poor-Quality Electric Power. 2019 IEEE International Conference on Modern Electrical and Energy Systems (MEES). Year: 2019 | Conference Paper Publisher: IEEE. DOI: 10.1109/MEES.2019.8896598
16. Romashykhin, I., Rudenko, N., Kuznetsov, V. The possibilities of the energy method for identifying the parameters of induction motor (2017) Proceedings of the International Conference on Modern Electrical and Energy Systems, MEES 2017, 2018-January, pp. 128-131. DOI: 10.1109/MEES.2017.8248869
17. Zagirnyak, M., Chornyi, O., Zachepa, I., Chencheyovi, V. The autonomous sources of energy supply for the liquidation of technogenic accidents [Autonomicne zhidlo zasilania w energuie przy likwidacij wypadkow technogenicnych] (2019) Przegląd Elektrotechniczny, 95 (5), pp. 47-50. DOI: 10.15199/48.2019.05.12
18. Zagirnyak, M., Chornyi, O., Nykyforov, V., Sakun, O., Panchenko, K. Experimental research of electromechanical and biological systems compatibility [Badania eksperymentalne kompatybilnosci systemow elektromechanicznych i biologicznych] (2016) Przegląd Elektrotechniczny, 92 (1), pp. 128-131. DOI: 10.15199/48.2016.01.31