Monitoring the technical condition of autonomous electrical systems with electric drive

Nikolay Korolev[1*] and *Sergey* Solovev[1]

[1] Saint-Petersburg Mining University, 2, 21 Line of Vasilyevsky Island, St. Petersburg, 199106, Russian Federation

Abstract. The article discusses the structure of autonomous electrical systems with an electric drive and an electric energy generation system. An approach is described for assessing the overall efficiency of technological cycle equipment with specification of parameters that must be considered when calculating it. The necessity of taking into account energy efficiency and operability indicators of autonomous electric complexes is substantiated. The effectiveness of the use of autonomous systems decreases throughout the entire life cycle due to wear and tear. As the operability of electromechanical equipment, an indicator of the residual resource is selected. The calculation of the residual resource, with the definition of its boundary values and recommendations for further use. Nominal energy efficiency parameters of autonomous electrotechnical complexes with electric drive deteriorate during operation, which also needs to be taken into account. To simplify the assessment of the operational state of electromechanical equipment, a state diagram is presented that allows you to track the dynamics of degradation of individual nodes. Taking into account the described indicators and means of control, it is possible to increase the efficiency of using autonomous complexes.

1 Introduction

At the enterprises of the oil and gas industry, technological complexes with multi-motor alternating current electric drives are being used, the electricity of which is supplied from autonomous sources of electricity. A typical example is the technological complexes of enterprises engaged in exploratory drilling, production and trunk transportation of oil and gas. The need for autonomous power supply may be due to various factors. First of all, it is suitable for objects located in remote areas. Recently, due to a decrease in the reliability of external power supply and a constant increase in electricity tariffs, the transfer to autonomous power supply has become a priority in the electric power industry of oil and gas and other industries [1-5].

Autonomous electrotechnical complexes with a multi-motor electric drive can be reflected in an enlarged circuit, which is shown in Fig. 1. The source of electrical energy is a set of N generators G_k $(k=1,N)$ with drive motors DM_k $(k=1,N)$, their implementation may be in the form of diesel generators, gas turbine units and, in some cases, wind generators. Using switches S_{1k} $(k = 1,N)$ to a common bus with voltage U_0 and frequency f_0 the required number of generators may be included. Consumers are divided into two groups, the main power of which is induction motors M_j $(j=1,S)$. Voltages U_j $(j=1,S)$ and frequencies f_j $(j=1,S)$ on the stator windings of these motors must be regulated during the process, so they receive power from static frequency converters FC_j $(j=1,S)$. For the second group of

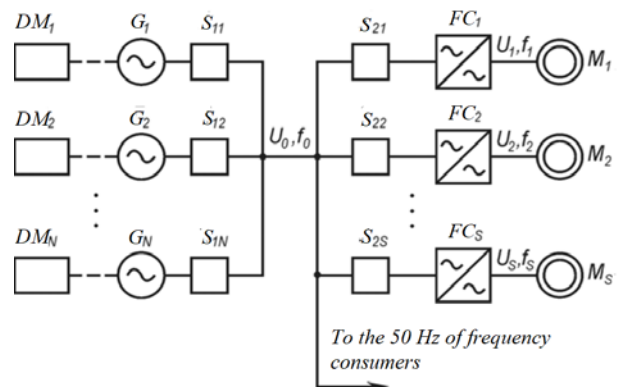consumers, industrial frequency electricity is needed, so they are connected directly to a common AC bus [1, 2, 6-8].

Fig. 1. A generalized scheme of an autonomous electrical complex with a group of electric drives.

The effectiveness of the use of such complexes will depend on many factors and, accordingly, to assess it, an integrated approach is needed that would take into account:

1. Energy efficiency of both generation and technological electric drives;

2. The performance of individual components and the entire autonomous electrical complex as a whole;

3 The degree and uniformity of loading of the electrical complex.

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* Corresponding author: korolev_na_spmi@mail.ru

2 Methods

It was used the world-famous OEE indicator – Overall Equipment Effectiveness, used to measure the overall effectiveness of equipment. The *OEE* indicator demonstrates that using a simple calculation and analysis algorithm, you can get an answer to the most important question for the head of the enterprise - how to quickly and significantly increase output without introducing additional capacities. *OEE* exposes the "black box" of losses and allows you to catch the problem areas of production.

According to the definition [9-12], the *OEE* indicator takes into account three factors:

1. *A* – Availability, takes into account losses associated with equipment downtime (Down Time Loss). Availability is the ratio of Actual hours worked to Planned Product Release Time;

2. *P* –Performance, takes into account losses associated with a decrease in production speed (Speed Loss). It is the ratio of the number of manufactured products to the time of work multiplied by the rate of production per hour;

3. *Q* –Quality, takes into account losses associated with poor product quality (Quality Loss). *Q* is the ratio of the quantity of quality products to all manufactured products.

The resulting expression for the calculation *OEE:*

$$OEE = A \cdot P \cdot Q \qquad (1)$$

In international practice, it is generally accepted that OEE is less than 65%, satisfactory - from 65% to 75%, good - more than 75% (world industrial leaders have values of 80–85%) [9].

OEE is a common indicator for the effective management of the technological cycle, but at the same time it does not allow a qualitative assessment of technical indicators. To supplement information on the overall efficiency of the autonomous complex, additional parameters are required.

Indicators for measuring energy generating device is a power factor K_{M1} and power factor of electric drives K_{M2}:

$$K_{Mi} = K_I \cdot K_U \cdot \cos\varphi \qquad (2)$$

Weighted average power factor $K_{M.av}$ possible to determine how:

$$K_{M.av} = \frac{\sqrt{\sum K_{Mi}^{2}}}{N} \qquad (3)$$

where K_I, K_U – current and voltage non-sinusoidality coefficient; $cos\varphi$ – cosine of phi; N – the number observed by the electric drive as part of an autonomous complex.

A comprehensive performance indicator for an electric drive will be its residual life δ.
Such indicator depends on values mentioned above and is complicated to determine, as the system can contain vast number of elements (generators, converters, etc.) In this case the

emergence of powerful analytical tools should be introduced. It allows operating the accumulated data in a mode close to real time, opens up new possibilities in the area of maintenance and repair systems, and also controlling the using of equipment. In this case, each unit of electromechanical equipment is endowed with "intelligence" without the need for a unified intelligent automation system.

The proposed approach to solving problems of increasing the accuracy and quality of the assessment of the state and residual life of electromechanical equipment is based on the analysis of data of systems for recording the quality of electrical energy, operating environment, vibration and electrical characteristics with using an artificial neural network [13-15].

The determination of the probability of no-failure operation of electric motor under the condition of the retrospective database is based on the algorithm for predicting the probability of trouble-free operation of electric motor and on the work of ANN (the multilayer perceptron), that was described in the articles [16-19]).

After determining the probability of failure and forming the matrix of the probabilities of defects by electric and vibration characteristics with a relative error of less than 5%, the estimate of the electromechanical equipment residual life, based on work of ANN, is made:

$$
\begin{aligned}
\delta &= K_1 \cdot P_{ih}^{pred.ANN}(h) + K_2 \cdot P_{im}^{pred.ANN}(m) + \\
&\quad K_3 \cdot P_{ih}^{pred.ANN}(h) + K_4 \cdot P_{im}^{pred.ANN}(m) = \\
&= K_1 \cdot F(\sum_{i=1}^{17}(\Delta w_{ij} \cdot x_{ij} - \Delta\theta_j) + \\
&\quad + K_2 \cdot F(\sum_{i=1}^{17}(\Delta w_{ij} \cdot x_{ij} - \Delta\theta_j) + \\
&\quad + K_3 \cdot F(\sum_{i=1}^{21}(\Delta w_{ij} \cdot x_{ij} - \Delta\theta_j) + \\
&\quad + K_4 \cdot F(\sum_{i=1}^{21}(\Delta w_{ij} \cdot x_{ij} - \Delta\theta_j)
\end{aligned}
\qquad (4)
$$

K_1 is a coefficient that takes into account the states of the boundaries of the estimation of vibration parameters taking into account the detected defects at time t and depending on the normal, pre-crisis and crisis states;

K_2 is a coefficient that takes into account the states of the boundaries of the estimation of electrical parameters taking into account the onset (detection) of defects at time t and depending on the normal, pre-crisis and crisis conditions;

K_3 is a coefficient that takes into account the boundaries of the assessment of vibration parameters, taking into account the measured parameters and factors affecting the compilation of the residual resource forecast, at time t and depending on the normal, pre-crisis and crisis conditions;

K_4 is a coefficient that takes into account the states of the boundaries of the estimation of electrical parameters, taking into account the measured parameters and factors influencing the compilation of the residual resource forecast, at time t and depending on the normal, pre-crisis and crisis conditions;

Table 1. Levels of an estimation of a residual life of the AC motor.

Residual life indicator δ	Description of technical state	Release to service
1<δ≤0.9	"Reference" state, there is no effect on performance	Allow
0.9<δ≤0.8	"Normal" state, the impact on performance is not significant	Allow
0.8<δ≤0.6	"Pre-crisis" state, the periodical comprehensive diagnosis and the reducing the load on the unit are recomended	Allow after comprehensive diagnosis
0.6<δ≤0	"Crisis" state, it is the high probability of failure equipment, the maintenance and repair work are required	Prohibit

$P_{ih}^{pred.ANN}(h)$, $P_{im}^{pred.ANN}(h)$ are predicted values of the probability estimate based on vibration and electrical parameters and ANN.

$$\Delta w_{ij} = \varepsilon(d_j^s - y_j^s) \cdot x_{ij}, \ \Delta\theta_j = -\varepsilon(d_j^s - y_j^s) \quad (5)$$

Δw_{ij}, $\Delta\theta_j$ – correction for weight coefficients and threshold levels, taking into account the calculated yield and comparison of the obtained output vector y_j^s with the reference d_j^s;
ε – rate of training ANN.

3 Results

The results of the system work for diagnosing the technical condition and estimating the residual life of the electromechanical equipment are diagnostic graphs of the technical state probabilities (Fig. 2-4).

Based on the results of processing parameters on the laboratory bench, the normal state of the unit was determined for all characteristics (Fig. 2). The calculated value of the residual life, obtained by ANN and electrical, vibration and indirect parameters, and also the detected defects, was estimated in accordance with the limits, presented in Table 1.

The artificial weakening of the mechanical fastening of the equipment led to the appearance of static and dynamic eccentricity and the emergence of these parameters in the pre-crisis zone, as a result, the estimation of the remaining resource corresponds to the level of the pre-crisis state (Table 1). A number of other parameters also went out the boundary of the normal probabilistic technical state.

In addition to the weakening of the mechanical fastening, an interturn closure, an asymmetry of the supply voltage and a bearing damage were artificially created. The presence of both electrical and mechanical inherent damage of the unit led to a violation of electromagnetic symmetry, as a result static and dynamic eccentricities began to rapidly move to the critical state zone, and as a result of significant vibrations, mechanical attenuation increased. Estimation of the residual resource after a long operation of the machine with artificially created defects corresponds to the level of the crisis state. The equipment is subject to withdrawal of the electric motor for repair. In this case, this method gives

an accurate knowledge of what part of the machine we need to pay attention to in maintenance and repair work.
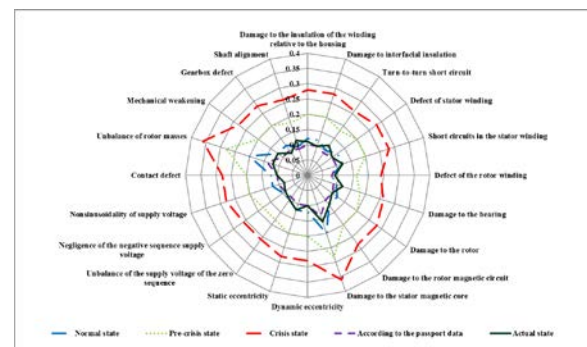

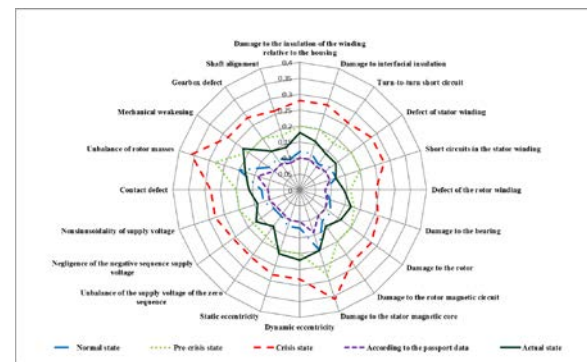**Fig. 2.** The diagram of the probabilistic technical state: the normal state.

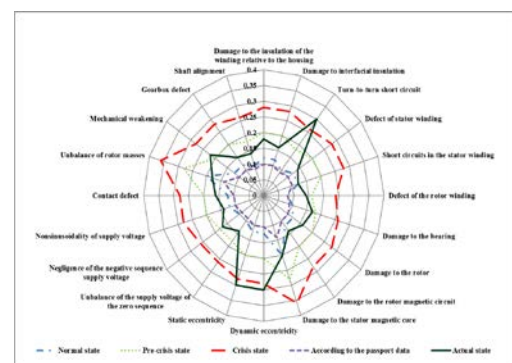**Fig. 3.** The diagram of the probabilistic technical state: the pre-crisis state.

Fig. 4. The diagram of the probabilistic technical state: the crisis state.

4 Conclusions

The result of an analysis of the operation of an autonomous electrical complex with an electric drive is an assessment of its effectiveness, taking into account the predicted value of the residual life:

1. Assess not only the actual OEE efficiency ratio, but also evaluate its change in the projected area;

2. Draw up an effective plan for technical inspections and repairs;

3. To exclude modes of operation with a reduced power factor, both the generator and the electric drive with a frequency converter;

4. Perform proactive control to ensure the required speed and torque in accordance with the technological mode.

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