On the Issue of the Probabilistic Safety Analysis for Large Pumps of Machine Irrigation Systems Using a Neural Network and the Definition of Their Reliability Indicators

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Abstract: In the existing method of safety analysis, a failure development model represented by a right-handed dichotomous "event tree" is used for correct input of complex risk indicators characterizing safety during operation. In the considered method of risk calculation, realization of probabilistic safety analysis in many cases can be complicated, especially in the absence of information about certain processes. The risk calculation is accompanied by a high degree of uncertainty, which requires a significant investment of time. From this point of view for realization of the probabilistic safety analysis of pumps it is proposed in the article to apply systems based on neural networks, genetic algorithms, expert and odd logic systems. Also, the article presents the results of research on determining the reliability index of a large synchronous motor, i.e. the failure-free probability of synchronous motor operation taking into account the increased excess winding temperature in the overload mode.

1 INTRODUCTION

The study of normal operation failure (NOF) causes in large machine irrigation pumps demonstrates the need to develop a methodology for accident risk management and safety assessment, which will allow assessment of the balance between the scale of possible damage from potential accidents of this system and its technical and economic advantages (Aljwary, Yusupov, Toirov and Shokirov, 2021, Abdi Yonis, Yusupov, Habbal and Toirov, 2023, Andreikov, 1966, Allaev, Toshov and Toirov, 2023, Borisov, 2005).

The paper proposes application of artificial intelligence systems based on neural networks, genetic algorithms, expert and odd logic systems for probabilistic analysis of pump safety.

The basis of each artificial neural network consists of elements (cells) simulating the work of brain neurons (hereinafter by neuron we mean an artificial neuron, an artificial neuron cell, an artificial neural network cell). Each neuron represents a pump element and events occurring as a result of NOF and is characterized by its current state similar to nerve cells of the brain, which can be excited or inhibited. It possesses a group of synapses - unidirectional input connections connected to the outputs of other neurons, and also has an axon - the output connection of a given neuron, from which (excitation or inhibition) flows to the synapses of the following neurons. Each synapse is characterized by the synaptic coupling value or weight W_{ij}, which is physically equivalent to electrical conductivity (Litvinenko, Auhadeev, Khusnutdinov, Antipanova and Kisneeva, 2021).

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2 RESEARCH METHODOLOGY

The current state of a neuron is defined as the weighted sum of its inputs:

$$S_{ij} = \sum_{\substack{i=1 \\ j=1}}^{n} X_{ij} \cdot W_{ij} \quad (1)$$

The output of a neuron is a function of its state:

$$y = f(s) \quad (2)$$

The nonlinear function f is called the activation function and can be of the following types: single jump function; linear threshold (hysteresis); sigmoid.

In this case, the chosen type of function is sigmoid - hyperbolic tangent, where the input of the function is the operating time t, the parameter of the function is the failure rate - λ, and the output is the probability of failure-free operation - *P (t)*. The fuzzy set theory (Jumaeva, Raximov, Toirov, Ergashev, and Abdyrakhimov, 2023, Jumaeva, Toirov, Numonov, Raxmatullaeva,and Shamuratova, 2023, Kamalov, Isakov, Shavazov, Elmuratova, and Tukhtamishev, 2021) is used to estimate the criticality indicators.

Normal operation of pump elements is disturbed due to abnormal operating mode of the pump and mechanical malfunctions of its elements (Jumaeva, Raximov, Toirov, Ergashev, and Abdyrakhimov, 2023, Kamalov, 2014).

Figure 1 shows the existing 9 types of pump failures.

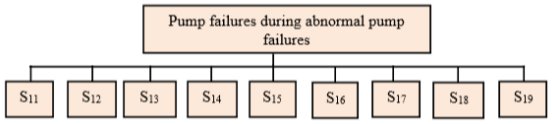

Figure 1: Pump failures during abnormal pump failures.

S_{11}- appearance of vibration and increased run-out of the pump shaft, accompanied by bumps, knocks in the impeller; S_{12} - pump pressure and flow pulsate and do not correspond to the operating mode; S_{13} - vibration with prevailing cavitation frequencies 800-20000 Hz; S_{14} - pressure is pulsating and above the permissible head, the flow rate is significantly less than the rated value; S_{15} - the unit vibrates intensely with cavitation frequencies; S_{16} - the pump does not deliver water at motor overload, permissible pipe resistance and underpressure; S_{17} - increased vibration at multiples of blade and rotational frequencies; S_{18} - pump does not supply the required pressure, vibration at blade frequencies; S_{19} - the pump does not supply the required flow.

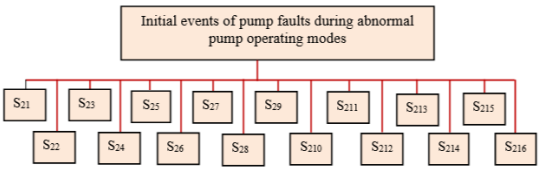

Figure 2: Initial events of pump faults during abnormal pump operating modes.

S_{21}- grating blockage; S_{22} - ingress of air into the suction pipe; S_{23} - formation of air sacs in pipelines; S_{24} - suction pipe blockage; S_{25}- critical cavitation mode with typical clattering sounds of stones hitting iron; S_{26} - sharp level drop curve in the forechamber with sinkholes at a low level of the lower floor; S_{27} - increased flow swirl in the forechamber in plan view; S_{28} - pumping events; S_{29} - hydraulic resistance exceeds the permissible resistance; S_{210} - pump running braking or reversing mode in reverse rotation; S_{211}- blade breakage and misalignment of the pump rotor; S_{212} - significant wear of impeller and chamber blade ends; S_{213} - wear of the front wheel disc O-rings; S_{214} - axial pump blade swing angle set out of order; S_{215} - the valve on the pipeline is covered or fully open; S_{216} - vacuum breaker valve is leaking (Abdi Yonis, Yusupov, Habbal and Toirov, 2023, Litvinenko, Auhadeev, Khusnutdinov, Antipanova and Kisneeva, 2021, Filina, Khusnutdinov, Vakhitov, Abdyllina, and Salnikova, 2023, Kiselev, German, Lebedev, 1977).

3 RESEARCH RESULTS

The value of the function will be the probability of failure-free operation $P_{11}(t)$ of the pump at abnormal modes of its operation. From the outputs of neurons S_{12} - S_{19} we obtain the probability of failure-free operation $P_{12}(t)$ - P_{19} (t). Here the sets of neurons S_{12} - S_{19} characterise failures, the set of signals X_{12} … X_{19} are the output of these neurons. These output signals correspond to the signals arriving at the synapses of a biological neuron and each of them is multiplied by the corresponding weight W_{12} … W_{19} and arrives at the input of the failure neuron. Each weight corresponds to the "weight" of one biological synaptic connection SN_1. The neuron SN_1,

corresponding to the body of the biological element, sums the weighted inputs algebraically, producing an output, which we will call NET. In vector notation, this can be written as follows

$$NET_{N1} = X_{N1} \cdot W_{N1} \quad (3)$$

The paper presents the results of research on determining the reliability index of a large synchronous motor (SM), i.e. the probability of failure-free operation of the SM taking into account the increase in the excess winding temperature in the overload mode.

In the machine irrigation system, the reliability of large synchronous motors and their component parts of pumping units determines the uninterrupted water supply to consumers (Kamalov, Isakov, Shavazov, Elmuratova, and Tukhtamishev, 2021, Kamalov, 2014, Filina, Khusnutdinov, Vakhitov, Abdyllina, and Salnikova, 2023, Kiselev, German, Lebedev, 1977, Khujaev, Toirov, Jumayev, and Hamdamov, 2023).

The reliability of large synchronous motors in pumping units is affected by such factors as excess temperature of active parts in synchronous motors, temperature of cooling and ambient environment, shocks and vibrations of installations, etc. These factors arise in the system "SM - pump" during start-up processes, during operation in overload mode, increase and decrease of mains voltage, as well as during non-stationary processes in the pipeline (in case of hydraulic shock) (Toirov, Jumaeva, Mirkhonov, Urokov and Ergashev, 2022, Toirov, Alimkhodjaev, and Pardaboev, 2021, Toirov, Khalikov, 2023, Toirov, Urokov, Mirkhonov, Afrisal, and Jumaeva, 2021, Pavlov, Fandeev, Aukhadeev, Litvinenko, and Butakov, 2019, Aleksandrovskai, Aronov, Elizarov, 1966, Toirov, Ivanova, Tsypkina, Jumaeva, and Abdullaeva, 2023, Toirov, Khalikov, 2023, Toirov, Khalikov, 2023, Toirov, Khalikov, Khalikov, and Sharopov, 2023).

The authors have derived mathematical relations linking the stator winding temperature exceedance and reliability indices. The methods of probability theory and mathematical statistics are used in constructing the mathematical model. During operation of SM, as a result of periodic heating and cooling of windings there are thermomechanical loads, which, affecting the insulation, significantly reduce their service life. As a result of wear of winding electrical insulating materials during operation the breakdown voltage decreases and accordingly the SM probability of failure-free operation decreases.

The influence of the winding temperature excess increase in the overload mode on the reliability of SMs is determined in the following sequence. The dependence of SM service life on the excess temperature of its windings is revealed. Insulation service life of electric machine windings is determined by American and German scientists, in particular, they established the so-called "eight degrees' rule", which is suitable only for insulation class A (Toirov, Urokov, Mirkhonov, Afrisal, and Jumaeva, 2021), and also derived a formula for determining the insulation service life for class A, E, B, F, H, C, taking into account the law of chemical reaction kinetics, the combined effect of temperature, humidity and aggressive environments (Toirov, Khalikov, 2023). However, due to the lack of specific values of these factors and the law of their variation, additional research is required. In (Toirov, Khalikov, 2023, Toirov, Khalikov, Khalikov, and Sharopov, 2023) a more simplified method of determining the influence of overloads on the reduction of winding insulation service life for insulation class B is given and this method was adopted by the authors to determine the relative reduction of SM winding insulation service life.

In case there are operational or experimental data of the overload mode, the time amount of stator winding overheated state is determined: $\Delta(\Delta V) = f(t)$, where $\Delta(\Delta V)$ - increase of stator winding temperature exceeding its nominal value.

Using expressions of heating Z_{heat} and cooling Z_{cool} wear in overheated mode, the following is determined: total insulation wear in overload mode Z_1; wear for the rest of the year Z_2; after that, total wear for the year Z; wear in the absence of overheating Z_{nom}.

Insulation service life including overheating is equal to

$$\xi_1 = \frac{1}{z_1 + z_2} \quad (4)$$

and insulation service life in the absence of overheating –

$$\xi_n = \frac{1}{z_{nom}} \quad (5)$$

The reliability research was carried out using the statistical method (Toirov, Pirmatov, Khalbutaeva, Jumaeva, and Khamzaev, 2023, Toirov, Sadullaev,

Abdullaev, Jumaeva, Ergashev, and Sapaev, 2023, Toirov, and Khalikov, 2023).

To determine the quantitative change in the reliability criterion of the SM from the operational data, a statistical series is calculated, e.g., the average operating time of a synchronous motor on failure for a year:

$$T_o = \frac{\sum_{i=1}^{n} t_i}{n} \quad (6)$$

where t_i is the operating time of SM between (*i-1*) and *i* failures (*h*); n is the number of occurred failures.

A histogram is drawn and the statistical distribution density function *f(t)* of SM uptime is determined.

The closest of these theoretical distributions is determined by the type of statistical density of the uptime distribution (Toirov, Khalikov, 2023, Toirov, Urokov, Mirkhonov, Afrisal, and Jumaeva, 2021, Pavlov, Fandeev, Aukhadeev, Litvinenko, and Butakov, 2019, Toirov, and Khalikov, 2022, Toirov, Khalikov, and Sharapov, 2023). To confirm whether the uptime of SMs is really distributed according to a certain law, the consistency of theoretical and statistical distributions is assessed using Pearson's chi-square and academician A.N. Kolmogorov's criteria.

The research results have shown that the uptime of failure-free operation of SMs in pump units of the pumping station (PS) of the Karshi main canal (KMC) is distributed according to the exponential law (Toirov, Sadullaev, Abdullaev, Jumaeva, Ergashev, and Sapaev, 2023, Toirov, and Khalikov, 2023, Toirov, and Khalikov, 2022, Toirov, Khalikov, and Sharapov, 2023, Kamalov, and Halikov, 2019)

For the case of the exponential law, the probability of SM failure-free operation without taking into account the influence of stator winding temperature exceeding is calculated by the formula:

$$P_o(t) = e^{-\frac{t}{T_o}} \quad (7)$$

To determine the SM probability of failure-free operation taking into account the influence of winding temperature exceeding, the load factor is introduced

$$K_l = \frac{\xi_1}{\xi_l} \quad (8)$$

Here ξ_1 is found by expression (4) taking into account superheats, and ξ_l - from (5) without taking them into account.

Thus, the probability of SM failure-free operation taking into account the increase of winding temperature excess in the overload mode is equal to

$$P_0'(t) = e^{-\frac{t}{\kappa_l T_0}} \quad (9)$$

4 DISCUSSION OF RESULTS

The developed mathematical model is implemented for synchronous motors in pump units of pumping station No. 7 of the Karshi main canal.

Figure 3 shows the graph of winding temperature exceedance on the example of pump unit No.3 SM, and the change in the graph of temperature exceedance for a particular period has a stepped character, the alternation of stator winding heating ($\Delta(\Delta V)^H$) and cooling ($\Delta(\Delta V)^C$) graphs does not have a certain sequence. Therefore, heating and cooling schedules are taken into account in determining the total insulation wear.

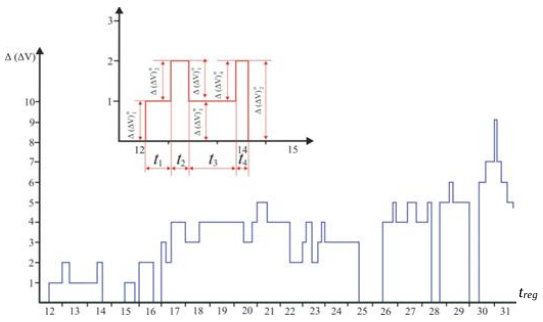

Figure 3: Dependence $\Delta(\Delta V) = f(t_{reg})$ of SM-3 PS-7 KMC.

Taking this into account, based on the results of the calculations carried out on the expressions (7) - (9), the curves of probability of failure-free operation $P_o(t)$ and $P'_o(t)$ (Figure 4) are constructed.

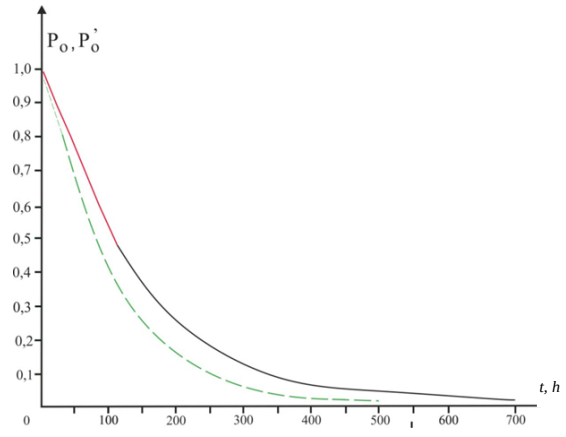

Figure 4: Probability of failure curves $P_o(t)$ and $P'_o(t)$ of SM-3 PS-7 KMC where: P_o - without into account temperature exceedance; P'_o - with taking into account temperature exceedance.

From Figure 4 it is determined that at exceeding the temperature of the SM windings the probability of failure-free operation of SM decreases up to 10 %.

According to the obtained results, as well as it is possible to determine the influence of winding temperature increase on the confidence limits of the average MTBF and average repair time.

5 CONCLUSIONS

1.Determination of failure-free operation probability with the help of neural network, allows to diagnose the technical condition of pumps, calculate the risk, determine the severity of each violation and assess the safety of each element of the pump, addressing each of them, display their states on the computer screen and effectively identify emergency factors, take the necessary emergency corrective measures aimed at improving the safety of pump operation.

2.From the analysis of probability change graphs, it can be concluded that the probability of failure-free operation decreases by 10 % when the temperature of the SM windings is exceeded.

REFERENCES

Aljwary, A., Yusupov, Z., Toirov, O., Shokirov, R., 2020. Mitigation of load side harmonic distortion in standalone photovoltaic based microgrid. *In E3S Web of Conferences*, 304, 01010.

Abdi Yonis, S., Yusupov, Z., Habbal, A., Toirov, O., 2017. Control Approach of a Grid Connected Dfig Based Wind Turbine Using Mppt and Pi Controller. *Advances in Electrical and Electronic Engineering*, 21(3), 157-170.

Andreikov, V., 1966. *The book*, The publishing company. Moscow.

Allaev, K., Toshov, J., Toirov, O., 2019. Modern state of the energy sector of Uzbekistan and issues of their development. *In E3S Web of Conferences*, 401, 05090.

Borisov, E., 2005. The book, The publishing company. Moscow.

Litvinenko, R., Auhadeev, A., Khusnutdinov, A., Antipanova, I., Kisneeva, L., 2021. An Approach to Determining the Integrated Reliability of Technical Systems at the Development Stage. In *International Symposium on Sustainable Energy and Power Engineering* (pp. 83-94). Singapore: Springer Nature Singapore.

Jumaeva, D., Raximov, U., Toirov, O., Ergashev, O., Abdyrakhimov, A., 2023. Basic thermodynamic description of adsorption of polar and nonpolar molecules on AOGW. In *E3S Web of Conferences*, 425, 04003.

Jumaeva, D., Toirov, O., Numonov, B., Raxmatullaeva, N., Shamuratova, M., 2023. Obtaining of highly energy-efficient activated carbons based on wood. In *E3S Web of Conferences*, 410, 01018.

Kamalov, T., Isakov, A., Shavazov, A., Elmuratova, A., Tukhtamishev, B., 2021, December. Calculation of specific rates of the electric energy consumption at frequency regulation of electric drives: A case study of pumping stations. In *IOP Conference Series: Earth and Environmental Science*, 939, 012001.

Kamalov, T., 2014. *The book*, The publishing company. Tashkent.

Filina, O., Khusnutdinov, A., Vakhitov, K., Abdyllina, A., Salnikova, O., 2023, March. Classification of vibration diagnostic systems Brush-collector assembly. In *2023 5th International Youth Conference on Radio Electronics, Electrical and Power Engineering*, 5, 1-6).

Kiselev, I., German, A., Lebedev, L., 1977. *The book*, The publishing company. Moscow.

Khujaev, I., Toirov, O., Jumayev, J., Hamdamov, M. 2023. Modeling of vertical axis wind turbine using Ansys Fluent package program. In *E3S Web of Conferences*, 401, 04040.

Toirov, O.Z., Jumaeva, D., Mirkhonov, U.K., Urokov, S., Ergashev, S., 2022. Frequency-controlled asynchronous electric drives and their energy parameters, *AIP Conference Proceedings* 2552, 040021.

Toirov, O., Alimkhodjaev, K., & Pardaboev, A., 2021. Analysis and ways of reducing electricity losses in the electric power systems of industrial enterprises. In E3S *Web of Conferences*, 288, 01085.

Toirov, O., Khalikov, S., 2023. Algorithm and Software Implementation of the Diagnostic System for the

Technical Condition of Powerful Units, *E3S Web of Conferences* 377, 01004.

Toirov, O., Urokov, S., Mirkhonov, U., Afrisal, H., Jumaeva, D., 2021. Experimental study of the control of operating modes of a plate feeder based on the frequency-controlled electric drive. In *E3S Web of Conferences*, 288, 01086.

Pavlov, P., Fandeev, V., Aukhadeev, A., Litvinenko, R., Butakov, V., 2019. November. Technique for optimization of diagnostic parameters composition for power systems objects. In *IOP Conference Series: Materials Science and Engineering*, 643, 012013).

Aleksandrovskai, L., Aronov, I., Elizarov, A., 1966. *The book*, The publishing company. Moscow.

Toirov, O., Ivanova, V., Tsypkina, V., Jumaeva, D., Abdullaeva, D., 2023. Improvement of the multifilament wire lager for cable production. In *E3S Web of Conferences*, 411, 01041.

Toirov, O., Khalikov, S., 2023. Analysis of the safety of pumping units of pumping stations of machine water lifting in the function of reliability indicators, *E3S Web of Conferences* 365, 04010.

Toirov, O., Khalikov, S.S., 2023. Diagnostics of pumping units of pumping station of machine water lifting, *E3S Web of Conferences* 365, 04013.

Toirov, O., Khalikov, S., Khalikov, S., Sharopov, F., 2023. Studies of reliability indicators of pumping units of machine irrigation on the example of the “Namangan” pumping station. In *E3S Web of Conferences*, 410, 05015.

Toirov, O., Pirmatov, N.B., Khalbutaeva, A., Jumaeva, D., Khamzaev, A., 2023. Method of calculation of the magnetic induction of the stator winding of a spiritual synchronous motor, *E3S Web of Conferences* 401, 04033.

Toirov, O., Sadullaev, T., Abdullaev, D., Jumaeva, D., Ergashev, Sh., Sapaev, I.B., 2023 Development of contactless switching devices for asynchronous machines in order to save energy and resources, *E3S Web of Conferences* 383, 01029.

Toirov, O., Khalikov, S., 2023. Research and evaluation of reliability indicators of pumping units of machine irrigation pumping station “Kyzyl-Tepa". *Hydraulic Engineering*, (7), 50-57.

Toirov, O., Khalikov, S., 2022. Reliability study of large synchronous motors of irrigation pumping units. *Problems of informatics and energy*, 1.

Toirov, O., Khalikov, S., Sharapov, F., 2023. Experimental determination of quantitative characteristics of reliability of pumping units of machine irrigation. *Energy saving and Water Treatment*, 3(143), 42-50.

Kamalov, T., Halikov, S., 2019. Assessment of reliability and safety of work large pumps of machine irrigation systems. In *E3S Web of Conferences*, 139, 01014.

Kamalov, T., Khalikov, S., 2020. Operational safety management of the pumping installations of the pumping station of the machine irrigation system. In *E3S Web of Conferences*, 216, 01157.

Pavlov, P., Butakov, V., Khusnutdinov, A., Abdullina, A., Snezhinskay, E., CHerepenkin, I., 2021, December. Fault Isolation in Digital Instruments and Devices Used in Power-Engineering Systems. In *International Symposium on Sustainable Energy and Power Engineering*, 169-177.