The expert system for assessing fire risks of electrical installations in the agrarian industrial complex based on neural networks

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Abstract. The article is devoted to the analysis of fire risks of the operation of electrical installations in the agro-industrial complex of the region. According to statistics, the number of fires occurring for electrical reasons is steadily increasing, which makes the issue of fire risk management relevant. In order to identify and prevent these risks, a technogenic safety system has been developed, presented as a set of methods and tools, which are based on the generation of new data on the causes of threats to the operation of electrical installations based on the analysis of data on the current state of the system. Highlighted characteristics such as Human Parameters, Electrical Installation Parameters and Environmental Parameters. Mathematical models of the given components are considered, a fire risk assessment tree is compiled, in which the input parameters and intermediate vertices with the solution methods in them were determined. The developed model can be used to carry out experiments in order to study the behavior of an electrical installation under various conditions. The application of this method is especially important in cases where the removal of indicators and testing of the operation of an electrical installation is impossible due to the risk of injury or material damage.

1. Introduction

Nowadays, technical devices and electrical installations are actively used in all fields of the national economy. However, along with all their advantages, they are also sources of fire danger, so their technical condition control is the most important area of research.

According to the Russian Ministry of Emergencies data, in 2019 a significant number of fires were caused by the reasons related to the violations of installation and electrical equipment operation rules – 49638 units (10.5% of the total number of fires in the country, while 31.07% of all fires that occurred in buildings was the result of electrical equipment failure).

In the Altai Territory in 2020, 13728 fires were registered, 178 people died and 158 people were injured. One of the main causes of fires was an electrical engineering – 1021 accidents that is 7.4% of the total number. At the same time, in comparison with the same last year period, the number of fires in industrial buildings, warehouses, industrial structures and installations has increased.

The current situation is national security risk of the country, indicates the need to improve fire safety systems based on scientifically proved solutions. "One of the main reasons of the existing negative industrial technogenic situation is the insufficient study of the problem of electrical installations fire safety" [1]. In order to improve the current situation, it is necessary to carry out fire
prevention work based on the factors analysis that cause the fire hazards occurrence of electrical installations in the agrarian industrial complex.

According to statistics, the number of fires increased from 3259 in 2016 to 13728 in 2020. A special increase was noted in 2019 – 455%; however, it should be noted that this is due to a change in the Order of fires accounting and their consequences, approved by Order No. 714 of the EMERCOM of Russia since November 21, 2008.

In the fires location distribution in 2020, the largest number occurred in places of materials open storage, farmlands and other open areas – 9554 fires or 69.6% of the total number (2019 – 10069, -5.1%).

Analyzing the fires location distribution, it was found out that the fires increase was in industrial structures and installations – 81 (2019 – 60; +35%); in industrial buildings – 86 (2019 – 70; +22.9%); warehouse – 38 (2019 – 36; +5.6%). In commercial premises it is 42 (2019 – 60; -30%), in administrative – 22 (2019 – 31; -29%); in services – 16 (2019 – 19; -15.8%); in agriculture – 20 (2019 – 24; -16.7%); under construction and reconstructed facilities – 5 (2019 – 7; -28.6%); in education – 1 (2019 – 0). In culture and leisure – 2 (2019 – 2) we can note a decrease in the number of fires. This trend can be explained by the inspections tightening of fire safety systems, including at electrical installations.

One of the main fires causes was electrical causes – 1021 (7.4%), which was a direct result of rules violations of electrical equipment installation and operation, which caused fires 11.5% more often than in 2019.

In addition, according to statistics, there are more fires per capita in villages, people killed in them, and there is a higher average damage from fires than that in cities. This is due to electrical equipment deterioration, the installation and operation of electrical equipment rules violation as well as insufficient control by supervisory authorities (figure 1).

![Figure 1. Fires dynamics and their consequences in 2016-2020.](image-url)
Electrical installations of inhabited, public and industrial buildings built in the 50-60 years of the XX century, which residual resource is almost exhausted, are of particular fire danger. The current situation is caused by a complex of economic, legislative and technological problems. In accordance with [1], the most significant ones of them are:

- a unified concept lack of fire risk management of electrical installations;
- methods imperfection of monitoring and diagnosing the technical condition of electrical installations and devices in the cities and settlements infrastructure;
- lack of an effective measure of electrical protection and perspective power supply systems in inhabited and public buildings;
- a low level of electrical installations maintenance, lack of qualified electrical personnel and population technical illiteracy involved in “household electrical equipment” handling;
- material and financial resources lack allocated for ensuring technogenic safety.

2. Methodology of Assessment and Management of Agricultural Objects Technogenic Safety

The fires causes are explained, first of all, by the appearance of leakage currents through the insulation of current-carrying parts of electrical installations, electrical equipment, electrical networks, accompanied by short circuits, the appearance of a large transient resistance, and, secondly, of the operating mode violations and structural malfunctions of electrical engineering. These fires causes during the electrical installations operation lead to the appearance of high temperature, electric arc, sparks, splashes of molten metal particles and, as a result, to the insulation ignition and the instantaneous fire spread.

Fire situations in electrical installations, analysis and forecasting of fire risk continue to be a significant social task [2]. Analyzing the fire risk of $R_f$, various interpretations can be used, the most acceptable among them from the point of view of efficiency is to consider it in the form of a two-parameter model consisting of the probability of fire-hazardous situation occurrence and the part of possible losses and damages (figure 1).

Figure 2. Classification of fire risks electrical installations.
The concept of fire risk management of electrical installations can be schematically presented as in Figure 3.

![Figure 3. Fire risk management of electrical installations.](image)

3. Methodology of Assessment and Management of Agricultural Objects Technogenic Safety Based on Human-Machine System "H-E-S" Analysis

Effective management of technogenic threats is a complex socio-economic problem connected with the search of new non-traditional approaches to solve the risks optimization problem, assuming here the prevention of dangerous technogenic situations themselves, and minimize their consequences (reducing moral losses associated with the death of people, material and environmental damage). All this determines the importance of the intelligent technologies roles that support decision-making.

For the analysis, the concept of a three-component human-machine system "H-E-S" was adopted as the basic one, which can be interpreted as a simulation model of the electrical installations operation of a real production object. This model component, interacting with each other, creates the conditions for a dangerous fire situation (DFS).

![Figure 4. A generalized model of the fire risks management system.](image)

In figure 4 the following notation is used:
- X – incoming environmental impact;
- Y – outgoing impact on the environment;
- Cx, Cy – methods for environmental parameters calculation.
Control system is the system that creates the impact $U$.

Execution of the control action is functions implementation of the control system (CS); $V$ – internal and external factors that affect the object state.

To obtain the calculations results, it is necessary to determine the control goals $T$ and calculation algorithms $A$. The calculation algorithm is the steps order that must be done to achieve the control goals $T$. The description of the processes state and control objects is presented in the form of a primary indicator set: $X_{ef} = \{x_i | i = 1,2,...,n_u\}$ – a set of indicators describing the fire risks level state of an electrical installation.

The calculation of the fire risks ($R_f$) indicators of the electrical installation fire risk is carried out in accordance with certain procedures $F_{Rf}$ that describe the calculating models of the indicators in the information system:

$$R_f(t) = F_{Rf}(X_{EF}(t))$$

where $R_f$ – fire risks, $F_{Rf}$ – function of $R_f$, $X_{EF}$ – criteria affecting the possibility of a fire.

Figure 5. Structural and functional diagram of HMS «H-EI-E».
The implementation of fire risks management of electrical installations is carried out by the management system. The management system is defined as all the necessary information processing algorithms and means of their implementation, combined to achieve the management goals [3].

A generalized model of the management system is shown in figure 5.

4. Assessment Mathematical Model of Electrical Installations Fire Risk

The task is to determine the risk class of electrical equipment based on the selected parameters.

As a research method, it was decided to use neural networks as they allow working effectively with noisy data.

The selection of evaluation criteria and baseline indicators is carried out in stages. To create an indicators list, similar assessment methods and the work of other authors were studied [4,5,6].

The next stage was the compilation, refinement and development of the model. In this regard, a group of experts consisting of 6 people, Doctors and Candidates of science, specialists in the field of electrical safety was formed. The competence of the experts is confirmed by multi-year experience in the energy and agro-industries.

The research of the expert group allowed identifying a number of factors that characterize the fire risk of electrical installations, on the basis of which an array of input data X was formed. This problem is structured in the form of a hierarchical model (graph-links), in the upper level of which, in accordance with the concept of the human-machine system, 3 indicators are allocated "Human" \((R_H)\), "Electrical Installation" \((R_{EI})\) and "Environment" \((R_E)\), which, in turn, are divided into 17 intermediate nodes.

The assessment consists of three main factors, each of which affects the level of fire safety from its own point of view. Thus, the fire risks analysis of electrical installations can show the weaknesses and strengths of the fire safety system and carry out work on its optimization.

The fire safety analysis of electrical installations are to be carried out within a separate field (in our case, this is the agro-industrial complex), because in different industries and even specializations, the same factors have different values, respectively, different weights, rules and interpretations.

The resulting factor can be described as a function of several variables:

\[
R_f = F(R_H, R_{EI}, R_E)
\]

where the indicator Human is \(R_H\), \(R_{EI}\) is the Electrical Installation indicator, \(R_E\) is the Environment indicator.

\(R_H\) – for "Human" component assessment (electrical personnel) is characterized by the following groups of risk factors:
- suitability by physical indicators;
- suitability by physiological indicators;
- technological discipline;
- professionalism.

Each risk-forming factor \(X_{EI}\) is a cluster that unites a subgroup of fire risk indicators, united by a semantic criterion and is assessed by a set of its components. For example, \(X_4\) includes:
- availability of specialized education \((X_{4.1})\);
- experience and seniority \((X_{4.2})\);
- skills development \((X_{4.3})\).

\(R_{EI}\) – assessment for the Electrical Installation Component:
- equipment wear rate;
- fault tolerance;
- possibility of a fire hazardous situation;
- effectiveness of electrical protection;
Of these, parameter $X_6$ includes:
- functional (partial) failure ($X_{6.1}$);
- electrical network, wiring ($X_{6.1.1}$);
- technological equipment ($X_{6.1.2}$);
- control panels, instrumentation, switching equipment ($X_{6.1.3}$);
- structural (complete) failure ($X_{6.2}$);
- electrical network, wiring ($X_{6.2.1}$);
- technological equipment ($X_{6.2.2}$);
- control panels, instrumentation, switching equipment ($X_{6.2.3}$);

**Figure 6.** Hierarchical metric tree.
$R_E$ – the assessment for the component "Environment" is divided into two sets, such as Internal
$(X_9)$ and $(X_{10})$ External environments, which, in turn, have a number of indicators, such as:
- fire hazard $(X_9.1)$;
- danger of climatic factors $(X_{9.2})$;
- legislative base $(X_{10.1})$;
- economic indicators $(X_{10.2})$;
- innovative indicators $(X_{10.3})$.

The range of criteria values was determined by experts according to the concept of acceptable risk
[7, 8], according to which the individual fire risk $R_f$ should be no more than $10^{-6} - 10^{-4}$. Three risk
groups were identified (figure 4), acceptable risk $<1 \times 10^{-6}$, valid $1 \times 10^{-4} - 10^{-3}$, unacceptable $1 \times (10^{-2} - 10^{-3})$. Each of them was assigned the value 1 – unacceptable risk, 2 – acceptable, 3 – unacceptable.

After that, the expert had to put down a generalized assessment of the fire safety of each electrical
installation.

Based on these data, a training sample was formed, consisting of 42 input parameters that
characterize 31 electrical installations of the agro-industrial complex enterprise of the Altai Territory.

To determine the significance level of the input parameters, the correlation coefficients between
the input and output parameters were calculated. The highest value of the correlation coefficient
modulo is in such inputs as $x_{18}$, $x_9$, $x_7$:

| Indicator | Correlation coefficient | Parameter name |
|-----------|-------------------------|----------------|
| $x_{13}$  | - 0.217315              | 4.2. Experience and seniority |
| $x_{23}$  | - 0.107833              | 6.2.3. «Structural (complete) failure» «Control panels, instrumentation, switching equipment» |
| $x_{14}$  | - 0.026958              | 4.3. «Skills development» |
| $x_{40}$  | 0.008924                | 10.2.3. «Planning and control system» |
| $x_{28}$  | 0.062631                | 8.2. «The effectiveness of electrical protection» «Passive remedies» |
| $x_1$     | 0.090059                | 1.1. «Endurance» |
| $x_{36}$  | 0.107833                | 10.1.2. «Compliance level with regulatory and technical and sanitary standards» |
| $x_{22}$  | 0.113795                | 6.2.2. «Structural (complete) failure» «Technological equipment» |
| $x_{39}$  | 0.113795                | 10.2.2. «Adequacy of funding» |
| $x_{31}$  | 0.135896                | 9.1.3. «Preventive measures level» |
| $x_{32}$  | 0.161749                | 9.2.1. «Temperature variation» |
| $x_{30}$  | 0.215258                | 9.1.2. «The degree of danger of consequences» |
| $x_{16}$  | 0.243199                | 5.2. «Insulating elements» |
| $x_{20}$  | 0.250000                | 6.1.3. «Functional (partial) failure» «Control panels, instrumentation, switching equipment» |
| $x_{29}$  | 0.263451                | 9.1.1. «Frequency of occurrence» |
| $x_4$     | 0.287686                | 2.1. «Psycho-emotional state» |
| $x_{34}$  | 0.296540                | 9.2.3. «Biological organisms» |
| $x_{27}$  | 0.300739                | 8.1. «Active funds» |
| $x_{12}$  | 0.315617                | 4.1. «Availability of specialized education» |
| $x_{24}$  | 0.332623                | 7.1. «Number of potentially dangerous areas for personnel» |
| $x_2$     | 0.345834                | 1.2. «Health status» |
| $x_{17}$  | 0.356581                | 5.3. «Equipment wear rate» «Structural elements» |
| $x_{10}$  | 0.359561                | 3.3. «Performance of official duties» |
| $x_{15}$  | 0.373215                | 5.1. «Equipment wear rate» «Conductive elements» |
| $x_{41}$  | 0.374192                | 10.3.1. «Introduction of new equipment» |
| $x_5$     | 0.390988                | 2.2. «Self-control in extreme situations» |
| $x_{19}$  | 0.391636                | 6.1.2. «Functional (partial) failure» «Technological equipment» |
| $x_6$     | 0.395349                | 2.3. «Ability to make independent decisions» |
| $x_{11}$  | 0.424178                | 3.4. «Quality and frequency of instruction» |
| $x_{25}$  | 0.428391                | 7.2. «Possibility of forced or accidental stay in the danger zone» |
| $x_3$     | 0.442536                | 1.3. «Age» |
Table 1. Continuation Correlation coefficients of input parameters and resulting value.

| Indicator | Correlation coefficient | Parameter name |
|----------|-------------------------|----------------|
| x₈       | 0.445285                | 3.1. «Knowledge and implementation of job descriptions» |
| x₂₆      | 0.447674                | 7.3. «Duration of forced stay in hazardous areas» |
| x₃₃      | 0.479564                | 9.2.2. «Humidity level» |
| x₂₁      | 0.482243                | 6.2.1 «Structural (complete) failure» «Electrical network, wiring» |
| x₇       | 0.484178                | 2.4. «Workplace vigilance» |
| x₉       | 0.487510                | 3.2. «Fixing technological violations» |
| x₁₈      | 0.574705                | 6.1.1. «Functional (partial) failure» «Electrical network, wiring» |
| x₃₅      | NaN                     | 10.1.1. «Compliance with GOSTs, IEC requirements» |
| x₃₇      | NaN                     | 10.1.3. «Compliance with the law» |
| x₃₈      | NaN                     | 10.2.1 «The economic condition of the enterprise» |
| x₄₂      | NaN                     | 10.3.2. «R&D» |

Five most significant parameters with the highest correlation out of 42 indicators were selected.

Then, several experiments were conducted to train neural networks and determine the risk class of electrical equipment by sequentially adding input parameters to the training sample, starting with the most significant ones and ending with the least significant ones was decisive for the training and test samples - the estimate of fire risks of electrical installation given by experts when assessing.

Table 2 shows the values of errors in the training and test samples, based on the values, it can be concluded that the most optimal is the use of three input parameters, \((x₁₈, x₉, x₇, y)\) when using them, the error values are minimal.

Table 2. Values of neural network learning errors.

| Set of input parameters | Training Average | Maximal | Testing Average | Maximal | Error simple average on the training and test sets |
|-------------------------|-----------------|---------|----------------|---------|-----------------------------------------------|
| \((x₁₈, y)\)            | 0.05            | 0.30    | 0.34           | 0.56    | 0.19                                          |
| \((x₁₈, x₉, y)\)        | 0.02            | 0.08    | 0.02           | 0.04    | 0.02                                          |
| \((x₁₈, x₉, x₇, y)\)    | 0.01            | 0.07    | 0.01           | 0.01    | 0.01                                          |
| \((x₁₈, x₉, x₇, x₂₁, y)\) | 0.01             | 0.07    | 0.10           | 0.17    | 0.05                                          |
| \((x₁₈, x₉, x₇, x₂₁, x₃₃, y)\) | 0.01              | 0.07    | 0.08           | 0.16    | 0.05                                          |

![Figure 7. Graphical representation of the neural network training error.](image-url)
The graphical representation of the results is shown in Figure 7. Sets of input parameters are placed horizontally. The presented graphs show that the lowest value of all types of errors is achieved using a set of input parameters \((x_{18}, x_9, x_7, y)\).

5. Conclusion

As a result, we can say that the most significant factors are:

\(x_{18} - 6.1.1.\) "Functional (partial) failure" "Electrical network, electrical wiring";
\(x_9 - 3.2.\) "Technological violations recording";
\(x_7 - 2.4.\) "Workplace vigilance".

The average error of 0.01 indicates that the model for risk class assessing of electrical equipment is sufficiently adequate.

As part of further work on the model, it is planned to refine it by increasing the number of examples in the training sample.

References

[1] Nikolsky O K 2003 Reader for an electrical engineer: a textbook. (Krasnoyarsk: Publisher “Krasnoyarsk State Agrarian University”) p 654 (in Russian).

[2] Nikolsky O K, Vorobiev N P, Eremina T V, Kostyukov A F, Kalinin A F and Tushev A N 2015 Theory and practice of man-made risk management: textbook. Manual for students of higher educational institutions (Barnaul: AltGTU Publishing House) p 126 (in Russian).

[3] Uskov A A and Kuzmin A V 2004 Intelligent control technology. Artificial neural networks and fuzzy logic (Moscow: Publisher “Hot Line – Telecom) p 143 (in Russian).

[4] Shanygin I A 2020 Man-made risk management and optimization of the security system for electrical installations of the infrastructure of the agro-industrial complex: dis. ... Ph.D. Ulan-Ude.

[5] Nikolsky O K, Kachesova L Yu and Shanygin I A 2018 Mathematical model for assessing and managing the risks of accidents in power supply systems Electrical equipment: operation and repair 11 72-77 (in Russian).

[6] Nikolsky O K, Mozol V I and Shlionskaya Yu D 2020 Management and optimization of hazard risks of electrical installations in man-machine systems: monograph (under the general editorship of Honored Worker of Science and Technology of the Russian Federation, Professor OK Nikolsky) (Barnaul: Publishing house “AltSTU”) p 159 (in Russian).

[7] On fire safety: Federal Law of December 21, 1994 No. 69 (as amended on December 22, 2020).

[8] Ostroukh E N and Chegodar M Yu 2008 Teaching a neural network using genetic algorithms. Izv. South Feder. un-t. Technical science 11 86–87 (in Russian).

[9] Hopfield J J 1982 Neural networks and physical systems with emergent collective computational abilities Proceedings of the national academy of sciences. vol. 79. No. 8. pp. 2554–2558.