Automated fire risk evaluation of electrical installations in the man-machine system

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Abstract. The article considers approaches to the formation of a system of criteria for assessing the electrical installations fire condition of the agricultural and industrial complex. Based on the analysis of the literature, the conclusion is made about the appropriateness of the use of expert assessments. To implement the decision, a group of experts was assembled, on the basis of whose knowledge a list of 42 parameters characterizing the fire condition of the electrical installation was determined. To identify the relationships and form a method for calculating the estimated value of fire risk, experts assessed the fire condition of 70 electrical installations of the agricultural and industrial complex of the region. A knowledge base was formed from the resulting values. As a method of data analysis, it was decided to use neural networks, but the available sample is not sufficient for high-quality training of a neural network. Therefore, the correlation method and the principal component method were considered, and based on the calculations, it was decided to use a training sample consisting of 6 principal components for training a neural network. A neural network was trained on these data and the values of the average error were obtained sufficiently low, which may indicate sufficient accuracy of the generated model. The article also presents a conceptual scheme of a software package for automating calculations in accordance with the developed model.

1. Introduction

The operational safety state of electrical installations in various sectors of the economy (agriculture, electric power, communal services) has reached a critical level, which, of course, poses a threat to national economy.

The most dangerous is the fire situation, 30% of the causes of fires occur for electrical reasons. Moreover, the number of fires, losses (deaths and injuries of people) and material damage, as well as significant deterioration of the environmental situation tend to increase significantly both in the short and long term.

Governments regulation mechanisms of electrical installations fire safety in buildings have shortcomings. Insufficient enforcement of regulations and laws leads to fires [1].

According to the Ministry of the Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters about 1/3 of all fires occur for electrical reasons [1].

The current situation poses a threat to the national security of the country, and also indicates the need to improve fire safety systems based on scientifically sound solutions.

One of the main reasons for the existing negative technogenic situation in the fire sector is the insufficient elaboration of the problem of electrical installations ensuring fire safety.

In order to improve the current situation, it is necessary to develop practical recommendations based on the analysis of factors that are the causes of fire hazard risks of electrical installations in the agro-industrial complex.
To reduce the number of accidents leading to fires at electrical installations and electrical injuries, large amounts of data are collected and processed, which entails the need for automation of these processes.

Work in this direction was carried out in [2,3], but, these works leave open questions about the use of intelligent technologies to manage the fire risks of electrical installations and create simulation models based on them to form recommendations for preventive measures, that reduce the fire risks of electrical installations.

Reducing the number of fires and damage from fires is possible only by carrying out preventive measures to inspect the current state of electrical installations and implementing measures to prevent fire-hazardous situations.

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

Many Russian and foreign scientists have been dealing with the risks of operating electrical networks with a voltage of up to 1000 V, the results of their work have been the creation of theoretical foundations of electrical and electrical installations fire safety, the formation of methodological and regulatory frameworks on its basis for the creation and operation of safe exploitation electrical installations.

To determine the risk level of various factors, many authors use mathematical modeling based on probabilistic analysis the risks of operating electrical installations and the development of practical calculation methods [4]. In order to test the developed models, it is necessary to collect data on the condition of real objects, which begins with technical diagnostics of the fire condition, consisting of three elements: control, measurement and testing.

Subsequent presentation of the data obtained should be carried out in accordance with the concept of the human-machine system "Human - Electrical Installation - Environment" [5].

The issues related to the analysis and synthesis of a weakly structured dynamic human-machine system "Human-Electrical Installation-Environment" (H-E-S), which allows identifying risk factors, are sufficiently studied [6, 7], however, the question of choosing the most optimal calculation method remains open.

Fire risk management is based on decision-making in conditions of uncertainty associated with such features as:

a) lack of a clear structure, uncertainty and physical heterogeneity of the system components;
b) difficulty in identifying events leading to the emergence of dangerous man-made situations;
c) the complexity of obtaining and interpreting data describing the state of the electrical installation.

These factors, as well as the lack of an accurate and complete description of the relationships between the values of indicators, the occurrence and development of emergency situations, complicate the decision-making procedure.

To solve the problem of increasing the diagnostics efficiency of the electrical installations technical condition, it is necessary to create a new methodology based on algorithmization of technogenic risk management throughout the entire life cycle of an electrical installation of a production facility.

The aim of the work is to reduce fire risks of electrical installations, based on mathematical models and automate calculations with the use of intelligent components for analyzing diagnostic data on the condition of electrical installations.

The objectives of the work are:
- identification of parameters that have the greatest impact on the level of fire risk of electrical installations;
- conducting experiments to select the most optimal calculation methods;
- development of a software package that automates calculations.

The quantitative indicator that most fully characterizes the technical condition and residual life of electrical installations is the fire risk $R_f$ [8]. It is known that the basis for an objective assessment of the risks of an electrical installation can be field experiments, the conduct of which in some cases is unacceptable for humane or economic reasons [9]. The determination of quantitative and qualitative indicators of the state of an electrical installation is fraught with difficulties both in obtaining and interpreting them. That’s why to solve the problem was used the expert evaluation method.
3. Methodology of assessment of agricultural objects fire safety based on human-machine system "H-EI-E".

To establish the parameters, characterizing the fire condition of the electrical installation, was formed a group of experts from 6 people, specialists in electrical engineering and fire safety. They determined the parameters, that influence greatest impact on the electrical installation fire risk. The results obtained in accordance with the concept of the human-machine system "Human-Electrical Installation-Environment" were divided into 3 clusters and presented in the form of a hierarchical structure (Figure 1).

![Hierarchical diagram of fire risk-forming factors of human-machine system "H-EI-E"](image)

- **Human**
  - Physique (x)
  - Health status (x)
  - Age (x)
  - Psycho-emotional state (x)
  - Self-control in extreme situations (x)
  - Ability to make independent decisions (x)
  - Workplace vigilance (x)
  - Knowledge and implementation of job descriptions (x)
  - Fixing technological violations (x)
  - Implementation of job descriptions (x)
  - Quality and frequency of instruction (x)
  - Availability of specialized education (x)
  - Experience and seniority (x)
  - Training (x)

- **Electrical installation**
  - Wear rate of current conductors (x)
  - Wear rate of insulating elements (x)
  - Wear rate of structural elements (x)
  - Functional (partial) failure
  - EL network, wiring (x)
  - Technological equipment (x)
  - Control panels, instrumentation, switching equipment (x)
  - Number of potentially dangerous areas for personnel (x)
  - Possibility of forced or accidental stay in the danger zone (x)
  - Duration of forced stay in hazardous areas (x)
  - Active means of electrical protection (x)
  - Passive means of electrical protection (x)

- **Environment**
  - Internal environment
    - Fire frequency (x)
    - Amount of fire damage (x)
    - Preventive measures level (x)
    - Microclimate in the working space
    - Temperature differences (x)
    - Humidity level (x)
    - Biological organisms (x)

  - External environment
    - Compliance with GOSTs, IEC requirements (x)
    - Compliance level with technical and sanitary standards (x)
    - Compliance laws in work and industrial safety (x)
    - The economic condition of the enterprise (x)
    - Adequacy of funding (x)
    - Planning and control system (x)
    - Introduction of new equipment (x)
    - R&D (x)

**Figure 1. Hierarchical diagram of fire risk-forming factors of human-machine system "H-EI-E"**

Experts identified 42 parameters, which were divided into three clusters:

"Human" is the content of data on the physical, psychoemotional state of the facility's personnel, their professional knowledge and work experience. "Electrical installation" - assessment of the technical condition of the electrical installation itself, its structural and functional elements, applied protective equipment and fire-hazardous areas on or near the object.
"Environment" is divided into two subsections:

"Internal environment" - characterizing the frequency of fires, the level of preventive measures and the microclimate in the work space, where the electrical installation is operated.

"External environment" - the level of compliance with laws, GOST standards, technical and sanitary standards, as well as a number of economic indicators characterizing the general condition of the enterprise, updating outdated equipment and conducting research and development.

Each of the parameters takes a value in the range 1-3. Which corresponds to the fire risk level defined in GOST 12.1.004-91, where the permissible level of fire danger for people should be no more than $10^{-6}$ exposure to fire hazards exceeding the maximum permissible values per year per person.

3 – acceptable risk ($[1*(10^{-6})]$);
2 – tolerable risk ($[1*(10^{-4}-10^{-5})]$);
3 – unacceptable risk ($[1*(10^{-2}-10^{-3})]$).

In accordance with a certain structure, a questionnaire was developed, on the basis of which a group of experts examined the technical condition of 70 electrical installations of an enterprise engaged in processing agricultural products. Based on these data, a knowledge base was formed, consisting of 42 input parameters characterizing 70 electrical installations of the agro-industrial complex of the Altai region.

4. Implementation of calculations

Based on the analysis of works in this field [6, 7], neural networks were chosen as a method for calculating the final value of fire risk, as a tool that allows finding solutions with implicit patterns and is resistant to inaccuracies in input data, which are possible due to the human factor when using a system of expert assessments. [10]

Using a neural network requires a training sample, which was formed from the knowledge base and amounted to 70 examples with 42 estimated parameters. With such characteristics, high-quality training of a neural network is difficult, and collecting additional examples involves significant time and cost costs. In this regard, it was decided to use mathematical methods to reduce the training sample without reducing the data.

The first one used was the classical correlation method. As part of its use, the correlation coefficients between the input values and the output parameter were calculated to determine the significance level of the input parameters. The results are presented in table 1.

| №  | Name of the parameter                                      | Value of the correlation coefficient |
|----|-----------------------------------------------------------|-------------------------------------|
| x13| Experience and seniority of the staff                     | 0.202481                            |
| x14| Training of the staff                                     | 0.084985                            |
| x6 | Ability to make independent decisions                     | 0.225298                            |
| x28| Passive means of electrical protection                    | 0.254212                            |
| x23| Structural (complete) failure of control panels, instrumentation, switching equipment | 0.260194 |
| x2 | Health status of the staff                                | 0.295438                            |
| x4 | Psycho-emotional state of the staff                       | 0.303684                            |
| x30| Amount of fire damage                                     | 0.305517                            |
| x12| Availability of specialized education                     | 0.338251                            |
| x31| Preventive measures level                                 | 0.347354                            |
| x1 | Physique                                                 | 0.368032                            |
| x9 | Fixing technological violations                           | 0.378906                            |
| x24| Number of potentially dangerous areas for personnel      | 0.383887                            |
| x16| Wear rate of insulating elements                          | 0.385668                            |
| x29| Fire frequency                                           | 0.395843                            |
| x42| R&D                                                      | 0.414495                            |
Based on the data obtained, training samples were formed for the neural network, each sample was formed by sequentially adding input parameters, starting with the most significant and ending with the less significant ones. The decisive value for the training and test samples was the assessment made by experts when assessing the fire risk of an electrical installation. The results of the training are shown in Table 2.

**Table 2. Values of neural network training errors for the parameters that have the greatest correlation with the decisive value**

| Input parameter set | Training | Testing |
|---------------------|----------|---------|
| X18                 | 0.0912   | 0.0912  |
| x18 x21             | 0.0658   | 0.0658  |
| x18 x21 x8          | 0.0509   | 0.0509  |
| x18 x21 x8 x11      | 0.0330   | 0.0330  |
| x20                 | 0.0351   | 0.0351  |
| x20 x34             | 0.0255   | 0.0255  |

The analysis of errors on the training and test samples showed that the smallest error value when using 6 parameters, such as "Biological organisms in the space", "Functional (partial) failure of control panels, instrumentation, switching equipment", "Quality and frequency of instruction", "Knowledge and execution of job descriptions", "Structural (complete) failure of the electrical network, wiring", "Functional (partial) failure of the electrical network, wiring", 0.0202

With a further increase in the number of parameters, the error tends to increase, as can be seen from the graph shown in Figure 2.
However, despite the rather small error value, using this method, it must be recognized that its application is not optimal. The number of parameters on which the calculation is based is reduced to 6, and does not take into account other parameters that are also recognized by experts as important when calculating integral risk. In this regard, it was decided to use the principal component method, which allows you to take into account all the parameters.

A number of experiments were conducted to determine the optimal number of calculated principal components.

Based on the sample was calculated the values of the main components, then a neural network was trained on the resulting data.

The calculation results are presented in Table 3.

| Number of input main components | Training Average | Max | Testing Average | Max | Average error on training and test sets |
|--------------------------------|------------------|-----|-----------------|-----|----------------------------------------|
| 2                              | 0.008            | 0.083 | 0.076          | 0.118 | 0.042                                  |
| 3                              | 0.006            | 0.099 | 0.059          | 0.115 | 0.032                                  |
| 4                              | 0.005            | 0.096 | 0.052          | 0.101 | 0.028                                  |
| 5                              | 0.002            | 0.039 | 0.065          | 0.092 | 0.033                                  |
| 6                              | 0.003            | 0.047 | 0.036          | 0.039 | 0.019                                  |
| 7                              | 0.003            | 0.066 | 0.084          | 0.105 | 0.044                                  |

Leaving the resulting function unchanged, the neural network was trained for each of the newly generated sets of components.

Comparison of the smallest values of the training and test errors of the correlation methods and the main components shows a slight difference.

However, the main component method allows taking into account all the initial parameters in the calculations, making it more preferable for application. Since, given the uncertainty under which the settlement are carried out, a possible false-positive triggering of the system is more preferable than skipping an event that may lead to a fire-hazardous situation.

In accordance with the tasks set in this paper, a conceptual model of the software implementation of the developed methodology has been developed (Figure 3).
The software package consists of two modules: “Knowledge base formation module” and “Calculation module”.

“Knowledge base formation module” contains block of maintaining the catalog of evaluation objects, which combines data about organizations and electrical installations operated on them, and the form of editing this data. The entered data about the objects are recorded in the database. This module also contains a block for configuring the solution model.

“Calculation module” consists “Solution Function Launch Module” where is List of assessment objects and methods transmitted from the database. Based on the configured solution system, the calculation is performed using the principal component method and subsequent calculation based on a trained neural network.

The result obtained is given in numerical value, on its basis it is possible to make management decisions on carrying out preventive measures.

As part of further development, a software implementation of a simulation model is planned, which would carry out calculations with changing input parameters and generate recommendations on carrying out work to reduce the level of fire hazard risk.

5. Conclusion

The developed methodology makes it possible to calculate the fire risks of the operation of electrical installations of the agricultural and industrial complex based on the concept of the man-machine system "Man-Electrical installation-Environment".

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