System for ensuring the detection and elimination of fires in the building of the hydroelectric power station

Farrukh Shaazizov¹, Diyor Shukurov² and Elyor Shukurov¹

¹Tashkent institute of irrigation and agricultural mechanization engineers, Tashkent, Uzbekistan
²Saint Petersburg state electro technical university, Saint Petersburg, Russia

E-mail: shosfarruh@mail.ru

Abstract. The aim of the work is to develop theoretical and methodological foundations for predicting the likelihood of fires in the premises of hydroelectric power plants, as well as compiling algorithms for monitoring the fire safety system, the "Serviceability control" technological process and the "Fire" technological process.

In the course of the work, theoretical studies of methods for assessing the safety of power generating enterprises in the "man - machine - environment" system and ways of occurrence of emergency situations at power plants were carried out.

The analysis of methods for assessing the safety of power plants in the "man - machine - environment" system is considered and the analysis of the ways of occurrence of emergency situations at power plants, as well as the types of fires and the peculiarities of their detection in the premises of the hydroelectric power plant. And an attempt is made to solve the problem of super-early detection of fires and fires in the system under consideration.

The theoretical and methodological foundations for predicting the probability of fires depending on the operating modes of systems, devices and equipment and a compiled model of a fire hazard monitoring system are given.

1. Introduction

Every year, at industrial facilities, as well as at energy facilities, due to a large number of fires, people die and become injured, and state property is destroyed.

In this regard, the state suffers significant losses associated with fires. Therefore, fire safety systems must ensure the required level of safety for people and property. [1]–[16].

The most fire hazardous facilities are power generating enterprises (power plants). Currently, in the conditions of Uzbekistan, there are mainly two types of power plants - thermal power plants and hydroelectric power plants, which are constituent elements of the country's unified energy complex.

Most of the energy generating enterprises (power plants) have been built and have been in operation for over 60 years. Therefore, the systems of fire protection means and fire detection systems at the facilities under consideration leave much to be desired, in view of the imperfection of their designs, deterioration and obsolescence of the equipment of fire safety systems[17]–[22].

2. Research methods

In the process of performing the work, theoretical studies of methods for assessing the safety of power generating enterprises in the "man - machine - environment" system and ways of occurrence of emergency situations at power plants were carried out.
The analysis of methods for assessing the safety of power plants in the "man - machine - environment" system is considered and the analysis of the ways of occurrence of emergency situations at power plants, as well as the types of fires and the peculiarities of their detection in the premises of the hydroelectric power plant.

The theoretical and methodological foundations for predicting the probability of fires, depending on the operating modes of systems, devices and equipment, are given.

2.1. Quantitative assessment of the fire hazard of HPP

Considering that the fire hazard of any substance is formulated as “the possibility of the occurrence or development of a fire in it or from it,” the fire hazard of a room can be estimated by the formula:

\[ K_{fh} = P_{fp} P_{pfs} P_{ffp} \]  

(1)

Where: \( K_{fh} \) is indicator characterizing the fire hazard of the premises; \( P_{fp} \) is fire probability; \( P_{pfs} \) is conditional probability, taking into account the scale and consequences of a fire; \( P_{ffp} \) is probability of failure of the fire protection system.

The probability of a fire in the premises of a hydroelectric power station, taking into account potential ignition sources, is determined as the sum of joint events [23], [24]:

\[ P_{fp} = P_{fp}^{ee} + P_{fp}^{os} - P_{fp}^{ee} P_{fp}^{os} \]  

(2)

Where: \( P_{fp}^{ee} \) and \( P_{fp}^{os} \) are probabilities, respectively, of a fire from electrical equipment or other source. According to statistical data probabilities: \( P_{fp}^{ee} \approx 0.0487 - 0.0676; \ P_{fp}^{os} \approx 0.01 - 0.015. \)

The probability, taking into account the scale and consequences of the fire, \( P_{pfs} \), is expedient to determine in the form of a product of dependent events [23], [24]:

\[ P_{pfs} = P_{df} P_{fb} \]  

(3)

Where: \( P_{df} \) is conditional probability of development of a fire that has arisen to a size that is dangerous; \( P_{fb} \) is the probability of loss of fire resistance by the building envelope under the influence of temperature.

The duration of the development of a fire is an important indicator characterizing the fire hazard of any room at a hydroelectric power station. Analysis of the results of experimental studies carried out in residential premises made it possible to obtain the following empirical dependence for assessing the time of fire development.

\[ \tau_p = 40,2 \ q_0 + 120 \]  

(4)

Where: \( q_0 \) is specific fire load of the room [kg/m^2];

120 is the average burning time of the lining and equipment of the room at the local site until the temperature rises rapidly.

For sealed (sealed) rooms, the time of fire development does not depend on the specific load, but is determined only by the oxygen concentration in the free volume. Therefore, the time of development of a fire in a sealed room with a volume of \( V_f \) can be estimated with sufficient accuracy for a liquid spilled in the room (the estimated combustion area of which \( F_f \) can be set in advance):

\[ \tau_p = K_i \ V_f / F_f \]  

(5)

For the case of combustion of solid materials (facing, heat and sound insulation, etc.) with a circular form of flame propagation over the surface, i.e. when \( F_f = \pi v^2 r^2 \), where \( v \) is the linear velocity of flame propagation:

\[ \tau_p = [K_i \ V_f / \pi v^2]^{1/3} \]  

(6)
Where: $K_i$ is parameter characterizing the intensity of fire development [m / s]. $K_i$ depends on the initial values of the gas environment of the room, the type and properties of the combustible substance, as well as on a number of other factors. Thus, the $K_i$ values for diesel fuel are 2.6; for "T-1" - 2.8; for alcohol -5.2.

Thus, the presence of numerical values of the actual fire hazard of premises, obtained by the above method, makes it possible to create systems for their indexing according to the degree of danger, as well as rationally determine the ratio of factors affecting the occurrence, development, detection and extinguishing of fires.

3. Research results and discussion

3.1. Development of theoretical and methodological foundations for predicting probability of fires

Initial data.

There is an initial set a priori set of real emergency conditions of the object $P(S_1/H_0), P(S_1/H_{1}); \ldots ; P(S_n/H_0), P(S_n/H_{n})$.

The mapping of each element from the set $S$ to $H$ is carried out using a certain set of processing methods $P_q$.

Formulation of the problem.

It is necessary to develop a method for automatic monitoring of a fire hazardous state (which implements a dynamic model of a fire hazardous state) of hydroelectric power plant premises for assignment to one (or several) elements of the set $H$ based on examinations that check the presence or absence of signs of states $S_{4j_0}$. The criterion for referring to a certain class of states is the numerical value of the fire-forming unit (FFU).

The algorithm and software built on the basis of the method should allow:

1. Store information about possible states of an object in the form of formalized descriptions.
2. Display the incoming signals using the set of methods $P_q$ in the form of sets of elements of the set $S$.
3. Comparison of the obtained feature descriptions using adequate proximity measures for elements of the set $H$.
4. Correlate the input signals with one (or more) elements of the set $H$ according to the chosen decision rule (likelihood criterion).
5. When referring the current state to one of the elements of the set $H$, the rate of change of the controlled parameter with the highest rank should be estimated.

The method and software developed on its basis must meet the following requirements:

- work in real time;
- have the ease of modifying the knowledge base;
- have ease of interfacing with other subsystems information support.

3.2. The architecture of the probabilistic-heuristic method for monitoring the fire hazardous state of hydroelectric power plant rooms and its purpose

1. Channel of receipt of input information. Input information can come either automatically from a centralized control system or from an operator. A telecommunication interface unit is designed for automatic information flow. The operator has the ability to enter both parametric information and non-parametric information using the interaction interface. In this case, the input uncertainty is taken into account, which manifests itself both in the possible uncertainty of the operator's response, delivered by the dispatcher, and in the fuzzy manifestation of individual signs $S_{4j_0}$. The last task is solved by the dispatcher.
2. The dispatcher is designed to optimize the examination sample and form the operator's question.
3. Block of preliminary processing of input information. Designed for recognizing the class to which the incoming information belongs and forming the numerical value of the intensity of manifestation of the sign $R$. 
4. The block for conducting the exam by interacting with the knowledge base ensures the recalculation of the current posterior probabilities of hypotheses in accordance with the information received from the block.

Figure 1. The main algorithm for monitoring the fire safety system of the HPP building (MTP – main technological process)

5. The set of decision rules is designed to assign the state of the object by the current value of the SFP to one of the elements of the set H and form a solution. If it is impossible to make a decision at this stage, then the dispatcher generates the next request for information through the block.

6. The decision formation block issues it to the operator and launches the forecast block and the parameter ranking.

| Step | Description                              |
|------|------------------------------------------|
| 0    | begin                                    |
| 1    | Has the fire alarm been triggered?       |
| 2    | Camera CCTV (if there is)                |
| 3    | Worked smoke detector, D1                |
| 4    | Worked temperature sensor, T2            |
| 5    | Worked temperature sensor, T1            |
| 6    | Physical fire alarm button               |
| 7    | MTP «Serviceability monitoring»          |
| 8    | MTP «Sensor malfunction»                 |
| 9    | MTP «Fire»                                |
| 10   | MTP «Emergency»                          |
| 11   | End                                      |
Figure 2. Graphs of temperature sensors above the fire
7. The parameter ranger determines the technological parameter having the highest rank for the given state of the object and issues a signal to start the prediction block by the parameter.
8. The forecast block determines the possibility and makes a forecast of changes in the numerical value of the FFU determined by the block. The decision (forecast result) is formed by the block.
9. The probabilistic knowledge base contains the knowledge of experts about the state of the object and, by interacting with the exam unit through the dispatcher), provides monitoring of the PIC.
10. The corresponding blocks are intended for modification and transformation of knowledge base.

Thus, the input to the method is:
- information about the current state of the object: parametric and non-parametric, coming automatically or through an operator;
- knowledge about the state of the object, including anomalous.

The output information is:
- message of the FFU numerical value and methods of its normalization;
- forecast of FFU development in time.

The probabilistic-heuristic method for monitoring the fire hazardous state of the HPP premises is intended for:
- monitoring the fire hazardous state of premises at an early stage of disturbances, under conditions of input uncertainty, inconsistency of signs, superposition of several factors by processing the formalized knowledge of experts stored in the knowledge base;
- predicting the development of the FFU numerical value in time by a set of defining parameters;
- formation of recommendations for the operator to normalize the situation in the premises.

In the course of the research, a system for automatic monitoring of the fire hazardous state in the building of the hydroelectric power station was developed, based on the theoretical developments considered.

On the PyroSim software platform, a 3D model of the buildings of the hydroelectric power station was developed and a mnemonic diagram of equipment control was drawn up for the dispatching control panel (Figure 2.).

On the basis of the above methods, the main algorithms for monitoring the fire safety system, the "Serviceability control" technological process and the "Fire" technological process were compiled.

The application of the above methods and algorithms, based on the considered theoretical materials, makes it possible to ensure the localization and timely elimination of fire centers in the building of the hydroelectric power station.

The use of this system allows to reduce the influence of the human factor in an emergency and to minimize the number of false alarms of the sensors of the fire extinguishing system.

4. Conclusion

1. In the course of the research, a system for automatic monitoring of the fire hazardous state in the building of the hydroelectric power station was developed.
2. A 3D model of the premises of the HPP buildings has been developed in the PyroSim program (Figure 2.).
3. A mnemonic diagram of equipment control for dispatching control panel.
4. The main algorithm for monitoring the fire safety system, the Algorithm of the technological process "Serviceability control" and the Algorithm of the Technological process "Fire" have been compiled.
5. The application of the above methods and algorithms, based on the considered theoretical materials, make it possible to ensure the localization and timely elimination of fires in the building of the hydroelectric power station.
6. The use of this system makes it possible to reduce the influence of the human factor in an emergency and minimize the number of false alarms of the fire extinguishing system sensors.
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