Model of power quality system using electric meter suppressor of fire and electric damage and hazards in the residential sector

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Abstract. The analysis, detailing, theoretical and technological justification of the concept of fire and electric damage. It is proposed to use the electric meter suppressor of fire and electric damage and fire hazards in the residential sector. The cognitive model taking into account possibilities of influence of the electric meter of the suppressor on decrease in damage for the electrical reasons and the functional model of electric power quality system are constructed. The cognitive model is considered as one of the components describing the external impact in the neurograph as a model to support control over the comprehensive objects safety for reducing fire risks in the residential sector associated with electrical causes of fires.

1. Introduction
Fires in the residential sector lead to numerous human losses, cause significant material damage. According to statistics, the residential sector accounts for up to 80% of the total number of fires, occurring annually in Russia. About 90% of dead in fires are also in the residential sector, the main causes of death are combustion products (up to 76% of deaths) and high temperature (up to 19%).

There is a correlation between the amount of fire damage in the residential sector with the corresponding quantity of electricity consumption. A significant number of fires in the residential sector are caused by various electrical reasons (Figure 1). Detailed statistical data detailing on sources and damage from fires in the residential sector allows to identify the main sources, among which the most common are various electrical devices and electrical networks equipment (Figure 2).

From the above it follows that in order to reduce the damage caused by fires in the residential sector, it is necessary to reduce the risk of fire break-out for the electrical reasons.

According to probabilistic-physical models of reliability, quality and safety [1-8], a significant risk reduction of fires for the electrical reasons requires the implementation of various measures related to two technological areas which ensure:

1. Reducing the fire hazard of electrical appliances.
2. Improving the quality of the consumed electricity.

Figure 1. The main causes of fires in the residential sector

Figure 2. Sources of fires for the electrical reasons

Nowadays, the development of risk-oriented methods and models of security management in sociotechnical systems are well-spread [8-10]. When applying the risk-oriented method to decrease the fire damage for the electrical reasons we should use the concept of fire and electric damage (FED) based on the complex factors study that affect the level of fire hazard while using electrical appliances [1].

2. Results and Discussion

In [1] FED is considered as a phenomenon, caused by a negative change in the quality of electrical appliances and wiring products at the facility for the conversion/transmission of high and low-quality electricity. As a result of the development of physical degradation processes in materials and components, the period of fireproof recourse of the electrical equipment is reduced that leads to the probability of fire for the electrical reasons occurrence.
Further development of ideas about the nature of the FED phenomenon led to the original interpretation change. In [1] investigated the connection of fire hazard of electric equipment with quality indicators of consumed electricity. As the electricity consumption with invalid quality indexes leads to a significant increase in the probability of fires for the electrical reasons. It is proposed to differentiate consumed electricity by quality indicators using electricity meters modified with additional functions.

Meanwhile, in terms of "low-quality electricity identification" [1] it is proposed to use a "statistical method" to determine the power consumption, in which for a specified time interval the deviations established by GOST 13109-97 values are defined (when measuring and digitizing alternating voltage curve). The consumed electricity is differentiated according to certain algorithms:

\[ W = W_a + W_u, \]

where \( W \) – the total amount of electricity distributed to a consumer during the time \( T \); \( W_a \) – the amount of consumed electricity with values within acceptable limits; \( W_u \) – the amount of consumed electricity with deviation parameters outside the acceptable limits.

According to [1], FED can be identified while measuring the amount of consumed electricity with its differentiation into acceptable and unacceptable components of quality assurance established by GOST 13109-97. Taking into account various probabilities of fires for the electrical reasons during the time \( T \), FED is represented by the sum of fractions of consumed electricity components:

\[ \text{FED} = P_a \times W_a + P_u \times W_u, \]

where \( P_a \) – a probability of fire for the electrical reasons with acceptable deviation parameters of electricity; \( P_u \) – a probability of fire for the electrical reasons with unacceptable deviation parameters of electricity.

According to [1], \( W_a \) and \( W_u \) are registered in the process of continuous monitoring of the consumed electricity quality, and the probabilities \( P_a \) and \( P_u \) can be identified based on the statistic data analysis of fires for the electrical reasons.

In this interpretation, the cause of the fire is electrical equipment, due to the electricity consumption with both: valid and invalid quality parameters. In this case, the components of FED have a dimension (kW) and are proportional to the corresponding amount of consumed electricity.

Accepting the undoubted usefulness of the proposed approach to the study of the fire hazard nature of electrical appliances operation and the significance of the concept of FED introduced in [1], it is necessary to emphasize, that the above interpretation of FED does not provide the possibility of its practical use for solving problems of fire risks for the electrical reasons. This is due to the fact, that authors [1] they did not offer a practical method for constants determination \( P_a \) and \( P_u \) from (2). Moreover, the dimension of the defined in accordance with (2) FED is in the logical contradiction with the original meaning of this rational concept that reflects the level of fire risk and is inextricably connected with the expected material losses from fires for the electrical reasons. It should be noted, that in the considered interpretation FED is a damage, directly related to electrical equipment, it isn’t determined as a damage to the facility where it is operated.

However, it follows from the above discussion that so far FED indicator has a contradictory and blurred character for practical use when controlling fire risks for the electrical reasons. For this purpose, the identification and numerical evaluation of FED require clarification, detalization, theoretical and technological justification.
Based on the meaning of the notion of harm as a synonym for damage to a facility, FED parameters must be related to the extent of the expected material damage from fires for the electrical reasons within a certain time interval. At the same time, the damage must be measured in monetary terms.

For FED’s representation in a monetary format it is necessary to move from the probabilistic characteristics of the fire for the electrical reasons within a certain time interval $P_a$ and $P_u$ to indexes, related to the specific amount of expected material damage. A specific damage expected from fires for the electrical reasons is assessed by the value of material damage expressed in a monetary term per unit of consumed energy; meanwhile, the consumed energy can be differentiated by quality characteristics. Two options can be specified for introducing such indicators.

The first option is: FED identification when setting the average fire damage indexes $\langle U \rangle$ and converting (2) to:

$$FED = W_a \times P_a^a + W_u \times P_u^s \times \langle U \rangle,$$

(3)

Where $P_a^s$ – the specific probability of fire in the electrical reasons with acceptable deviations of electric power parameters (1/kW); $P_u^s$ – the specific probability of fire in the electrical reasons with unacceptable deviations of electric power parameters (1/kW).

It is possible to offer more convenient interpretation (3), highlighting the works of medium damage from a fire at the specific probability and considering them as specific indicators $K_a$ and $K_u$, characterizing the corresponding values of expected damage per unit of consumed high-quality and low-quality energy:

$$K_a = P_a^s \times \langle U \rangle, \quad K_u = P_u^s \times \langle U \rangle,$$

(4)

We introduce these specific rates in (3), and then FED is represented as:

$$FED = W_a \times K_a + W_u \times K_u.$$

(5)

As can be seen in (5), FED represents the sum of fire and electrical damage components, connected with electrical appliances exploitation with acceptable and unacceptable characteristics of the consumed electricity quality:

$$FED_a = W_a \times K_a, \quad FED_u = W_u \times K_u.$$

(6)

The usability of (4) specific indicators is obvious, however, it is necessary to assess an average fire damage to set them, as well as determine the specific probabilities of (3) fire for the electrical reasons.

The second option is: direct determination of specific indicator quantity of FED $K_a$ and $K_u$, characterizing the extent of expected damage, accounted for one unit of consumed high and low-quality energy, based on the summary statistics of consumed electricity volume with differentiation by quality characteristics and statistics of fire damage for the electrical reasons.

Each of the specific indicators of FED is identified by the damage change $\Delta U$ from fires for the electrical reasons, caused by the corresponding increase in electricity consumed:

$$K_a = \frac{\Delta U}{\Delta W_a}, \quad K_u = \frac{\Delta U}{\Delta W_u},$$

(7)

by $\Delta W_a \to 0$ and $\Delta W_u \to 0$.

Further development of the above approach involves such measures as monitoring of consumed electricity quality, also, statistics data accumulation of fire damage for the electrical reasons.
When implementing these measures, from the analysis of fire statistics and electricity quality, it is possible to directly assess local fire and electric damage. While operating a certain set of electrical equipment, if electricity consumption data is available at various points in time as well as damages from fires for the electrical reasons from the system:

\[
FED = W_a \times K_a + W_u \times K_u
\]

(8)

it is easy to determine specific indicators of FED:

\[
K_a = \frac{FE \{D \times W_a - FED \times W_a\}}{W_a \times W_a - W_a \times W_u}
\]

(9)

Monitoring the quality of consumed electricity through the use of electric meters of a special type with the functions of suppressing fire electric damage and fire hazards (ESSFED and FH) creates a technological and organizational base for the electric power quality management system formation (EPQMS) in the residential sector.

This article proposes the definition of local EPQMS as sets of organizational structure, responsibility, procedures, processes, and resources ensuring the implementation of general quality management of the consumed electricity in a certain area.

The interaction of factors affecting the occurrence and the change of FED can be analyzed using the cognitive modeling tools (Figure 3).
Figure 3. A cognitive model, that includes the possibility of influence of ESSFED and FH on decrease of fire damage for electrical reasons: (a) if there is no accounting for the amount of consumed electricity with valid and invalid quality indicators; (b) when monitoring the consumed electricity quality through the application of ESSFED and FH

If there is no accounting for the amount of consumed electricity with valid $W_v$ and invalid quality indicators $W_u$, FED it can only be connected with the total electricity consumption and the probability of fires for the electrical reasons (Figure 3a).

When monitoring the consumed electricity quality based on the use of ESSFED and FH there is a number of possibilities for influencing FED, that's shown by cognitive modeling (Figure 3b).

The most significant possibility is a differentiation of the total amount of consumed energy $W$ by quality characteristics, that is the basis for a number of measures aimed at improving the quality of supplied electricity to consumers.

As shown by the corresponding arcs of the cognitive graph (Figure 3b), ESSFED and FH, in addition to monitoring the consumed electricity quality that is mentioned above (function 1) can fulfill the additional function of suppressing FED [1] using the built-in adjustment mechanisms in the device. There can be some improvement in the quality of consumed electricity as a result of the function 2 ESSFED and FH compensation of deviations from acceptable values of power quality. If fire hazard conditions occur and the compensation is not possible, ESSFED and FH fulfill the function 3 of emergency disconnection of electrical equipment and de-energizing the power supply network.

For the power quality management system formation (PQMS), along with technical tools introduction, it is necessary to integrate them into a single information system for electric power quality monitoring (ISEPQM). Further development of appropriate legal, economic, and organizational mechanisms based on local PQMS forms a united state-wide Electric Power Quality System (EPQS), which includes (Figure 4) functional subsystems:

1. Power quality standardization system (PQSS).
2. Power quality monitoring system (PQMS).
3. Fire and electric damage suppression system (FEDSS) and local automated microsystem diagnostics and protection of the residential sector (LAMDP) and information diagnostics, suppression and notification (IDSN).

4. Energy quality management system (EQMS).

5. Legal and regulatory system for ensuring electric quality (LRSEEQ).

As can be seen from the proposed model EPQS, its main functions are related to the impact on management, power supply and energy inspection companies with the help of appropriate economic and legal mechanisms. As a result of this influence, energy retail and energy inspection companies will be interested in ensuring the proper quality of electricity supplied to consumers.

3. Conclusion

ESSFED and FH integration in the residential sector with the further development of EPQS, representing the total sets of organizational structure, responsibilities, procedures, processes, and resources, ensuring the implementation of general management of the consumed electricity quality, will allow to create effective technological, economic and legal mechanisms to reduce one of the main components of fire risks for the electrical reasons in the residential sector. For further scientific research, the proposed cognitive model is considered as one of the components describing the external impact in the neurograph as a model to support control over the comprehensive objects safety [8] to reduce fire risks in the residential sector associated with electrical causes of fires.

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