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DETERMINATION OF VARIOUS TYPES ELECTRIC LAMPS PARAMETERS IN EMERGENCY MODES OF OPERATION

Studies have been conducted to determine the temperature of electric lamps of various types in emergency modes of operation of power grids, namely overvoltage. Graphs of the dependence of the temperature of the bulb of incandescent lamps, arc mercury lamps and LED lamps on the voltage applied to them. Mathematical models of the value of the heating temperature of the bulb of the electric incandescent lamp, the arc mercury lamp and the LED lamp are obtained depending on the time. It is determined that the temperature of the bulb of the incandescent electric lamp increases exponentially and stabilizes after about 300 seconds. The temperature of an arc mercury lamp also varies exponentially, but, compared to an incandescent lamp, it is not so fast, but stabilizes after about 600 seconds. It is determined that in emergency modes of operation, the temperature of incandescent lamps and arc mercury lamps may exceed the normative values of temperature groups, as a result of which, when used in environments where explosive gases or vapors are present, they can become a source of ignition and lead to explosion or ignition of these substances. It is determined that the temperature of the LED lamp changes according to the linear law and after 300 seconds stops growing. Temperature dependencies of different elements of the LED lamp are built depending on the electric voltage applied to it. It was found that the driver, namely the power control chip, heats up most when the LED electric lamp is operating. It is determined that when the electric voltage decreases, the power control chip heats up more, but not significantly. It was found that the LED lamp is the best from the point of view of fire safety, since it has the lowest temperature, and also the change in the voltage of the electrical network reacts the least, which is explained by its design and principle of operation.

Keywords: lamp temperature, overvoltage, undervoltage, fire hazard

1. Introduction

In conditions of military aggression, accompanied by the destruction of the country's critical infrastructure and leading to frequent power outages, the risk of emergency modes of operation of electrical appliances, wiring and lighting systems increases. Unstable voltage, sudden de-energization and restoration of power supply can lead to overloads, short circuits, overheating of electrical network elements and failure of household and industrial equipment. Such phenomena threaten not only a decrease in energy efficiency, but also an increase in the risk of fires, electric shock, as well as prolonged interruptions in the operation of critical infrastructure. The study of these emergency modes is necessary to develop protective solutions, improve consumer safety and ensure the stable functioning of electrical systems in emergency situations.

Emergency and unstable modes of operation of the energy system of Ukraine significantly increase the risk of fires in certain areas of electrical networks. According to the State Emergency Service of Ukraine, in the 10 months of 2024 [1] there were more than 9500 fires caused by emergency modes of power grids and devices.

These data make it necessary to study the dangerous parameters of emergency modes of operation of electrical systems, in order to improve the level of safety of functioning of electrical appliances, which is an integral element of ensuring proper living conditions for people.

Under the conditions of emergency modes of operation of electric networks, the relevance of the study of fire safety of electric lighting increases even more, since damaged or unstable operating electric networks can increase the risk of fires.

Thus, the occurrence of fires due to emergency modes of operation of electrical networks is an urgent problem.

2. Analysis of literature data and problem statement

In [2] highlights the problems of fire safety of electric networks and preventive measures for their safe operation of electric cables. Based on the analysis of the main fire characteristics (time to use, peak heat release rate and time to peak heat release rate), new types of nanometer fire retardant coating and the method of intermediate protective cable box are proposed. However, the study does not indicate parameters of emergency modes close to critical parameters.

The large length and probability of failure of insulation coatings of electrical conductors provide a large number of studies of the state of fire safety of electrical conductors. Thus, in works [3–6], fire resistance indices of different insulation and cross-sections of electrical conductors are established. In the work [3], the extremely low values of the parameters of the electrical conductors of the «ВВГ» and «АВВГ» brands are set, in which, in the event of a short circuit in the network with a faulty protective device, their insulation can ignite, which can cause a fire. In the case of [4, 5], a copper conductor made of polyethylene insulation was investigated using conical calorimetry under overload conditions with the definition of: time to ignition (TTI), heat release rate (HRR), gas release and loss of mass PE wires. In [5, 6], copper conductors with polyethylene and polyvinyl chloride insulation (PVC) were tested for flame propagation. The obtained results indicate that the propagation by conductors of a larger flame diameter is wider, but its propagation speed is less and rises more slowly with current. The considered works provide information on the spread of fire through live wires under overload conditions, but do not consider other emergency modes.

In [7–10], studies are aimed at determining the fire hazard parameters of the connection of network contacts, characterized by large transitional supports and the release of a large amount of heat. In [7], the overheating conditions of the plug-socket connection are considered and an approach is proposed for fire protection of electrical networks by arranging an electric circuit opening element in the socket module. However, this method is effective for the case under consideration and was not investigated during the emergency operation of lighting devices. [8] presents studies of electrical connectors under the influence of current pulses when a short circuit occurs, which leads to softening of the conductor and instantaneous drop in contact resistance. The proposed technique for estimating the contact resistance drop, calculated using a transient electric-thermal model, is important for emergency operating modes, but it is only valid for impulse currents. The work [9] on the study of fire hazard parameters of contact connections of electrical conductors in conditions of overvoltage, overload, growth of transient resistances, which in the process causes strong heating, breakdown of insulation, sparking, appearance of an electric arc – gives a general significance and does not consider emergency modes for the lighting network. [10] discusses the fire safety problems of LED devices, including the flicker effect and other aspects that may affect the safety of operation, since they can lead to failure or fire. However, the given articles did not define the maximum permissible values of indicators of emergency modes of operation, and the obtained results of experiments were not included in the requirements of regulatory documents.

Given the analysis of sources, it was found that the study of emergency modes of operation of lighting networks was not sufficiently considered.

Since lighting devices have a wide range of applications in both industrial, residential and public buildings, and in unstable work can serve as causes of fire danger. That is why lighting networks require research in emergency modes with the proposal of safety measures.

Thus, an unsolved part of the problem under consideration is the study of the processes of occurrence of fire-hazardous parameters in lighting networks under emergency operating modes.

3. The purpose and tasks of the research

The purpose of the work is to determine the thermophysical characteristics of electric lamps of various types due to heating in the event of overvoltage or low voltage in the electrical network.

To achieve this goal, you need to solve the following problems:

– conduct experimental studies to determine the temperature of electric lamps of different types at different values of the electric voltage;

– build mathematical models of temperature dependencies of electric lamps of different types on voltage at overvoltage and in low voltage mode and check their adequacy.

4. Research materials and methods

The object of research is the thermal processes occurring in electric lamps in emergency modes of operation of electrical networks.

The subject of research are electric incandescent lamps, arc mercury lamps and LED lamps.

The hypothesis of the study was that under certain conditions, when an overvoltage occurs in the electrical network, the temperature of the electric lamp may increase, as a result of which it can become a source of ignition of certain materials and/or substances.

Measurements of the temperature of electric lamps were carried out on a laboratory stand, the appearance of which is given in Fig. 1.

Tabl. 1. Technical characteristics of laboratory autotransformer RUCELF LTC-300-16-D

Characteristic	Value
Load power, kVA/W	2.4
Rated input voltage, V	220
Output voltage control range, V	0–300
Mains frequency, Hz	50–60
Maximum load current, A	16
Protection Class	IP20

Three types of lamps were used for the study: a 100 W incandescent lamp, a 250 W mercury arc lamp and a 7 W LED lamp. Appearance of electric lamps used in the test is given in Fig. 2.

Fig. 1. Appearance of laboratory stand for fire hazard study of electric lamps

The laboratory stand consists of three main parts: a laboratory autotransformer, a stand for installing electric lamps and measuring instruments, and a laptop with software for processing results. The power supply of the stand comes from the laboratory autotransformer of the RUCELF brand LTC-300-16-D the technical characteristics of which are given in Tabl. 1.

Control over the values of electric current parameters was carried out by digital meters of voltage, current and power of the PeaceFair PZEM-008 brand. Thermocouples connected to the bulb of each of the lamps were used to measure the temperature, as shown in Fig. 3.

Fig. 2. Appearance of electric lamps of different types used for tests: 1 – incandescent lamp; 2 – LED lamp; 3 – arc mercury lamp

The thermocouple is necessary for measuring the temperature of the bulb of an electric lamp and transmitting its temperature values through a computing and measuring unit to a laptop, where the results were recorded using Thermopair software.

Fig. 3. Appearance of the thermocouple used to measure the temperature of the bulb of electric lamps

Additionally, to measure the temperature of the elements of the LED lamp, the WINTACT WT3160 thermal imager was used, the appearance of which is shown in Fig. 4, and its technical characteristics in Tabl. 2.

Fig. 4. Appearance of thermal imager WINTACT WT3160

Tabl. 2. Thermal imager characteristics WINTACT WT3160

Parameter, unit of measure	Value
Temperature measurement range, °C	-20–450
Display, inches	2,8 full-angle TFT
Temperature sensitivity, °C	0.07
Spectral range, µm	8–14
Measurement error, %	±2 (or ± 2% if more 300 °C ±5%)
Operating temperature, °C	0–45
Storage temperature, °C	-20–60
Humidity, %	< 85

To achieve this goal, analytical approximation methods and application of mathematical software in the Maple and Excel environments were applied.

5. Experimental determination of the temperature of electric lamps at different voltage values

Studies to determine the temperature of electric lamps of different types were conducted for electric voltages of 195 V, 220 V and 245 V. In the first experiment, the temperature of the bulb of the incandescent electric lamp was measured. The total number of tests for each electric lamp at one given voltage value was 10 tests. Incandescent lamps were tested for 300 s, since when the tests continued for more than 300 s, their flask temperature did not change. Tabl. 3 shows the results of measurements of incandescent lamps temperature at different values of electric voltage applied to them.

Tabl. 3. Results of incandescent bulb temperature measurements at different voltage values

t,s	ΔT,°C		
	U=195 V	U=220 V	U=245 V
0	20.0	20.0	20.0
60	96.5	99.1	103.0
120	133.1	144.2	151.5
180	144.1	152.2	164.2
240	148.3	154.2	167.7
300	149.2	155.6	168.3

Tabl. 4. Temperature measurement results of the arc mercury bulb at different voltage values

t,s	ΔT,°C		
	U=195 V	U=220 V	U=245 V
0	29.0	29.0	29.0
60	35.6	35.2	34.5
120	45.3	60.5	64.1
180	80.3	120.6	137.2
240	126.3	169.7	183.2
300	155.5	188.5	212.5
360	167.7	195.6	227.2
420	174.4	199.1	232.1
480	181.3	205.1	232.6
540	183.1	207.8	233.7
600	184.9	209.4	234.3

Tests of arc mercury lamps were carried out for the same values of spectacular voltages as for incandescent lamps. Tabl. 4 shows the results of measuring the temperature of the arc mercury bulb at different voltages. The duration of the tests of arc mercury lamps was 600 s, since during this time it heats up to its working one, and the initial heating process is not as rapid as that of incandescent lamps.

The LED lamp is heated to the operating temperature in about 300 seconds, and the temperature change of its bulb changes almost linearly. Tabl. 5 shows the results of measuring the temperature of the bulb LED lamp at different voltages. The bulb temperature of the LED lamp compared to other types of electric lamps also increases with increasing voltage, but slightly.

Tabl. 5. Results of measurements of LDS lamp bulb temperature at different values of electric voltage

t,s	ΔT,°C		
	U=195 V	U=220 V	U=245 V
0	20.0	20.0	20.0
60	32.1	37.3	38.2
120	39.3	40.8	43.6
180	42.4	44.5	47.5
240	47.3	50.4	51.3
300	49.2	52.1	53.9

At the same time, during the research, it was found that the bulb of the LED lamp is not the hottest point of the LED lamp. As a result of this, additional studies were carried out to determine the temperature of the elements of the LED lamp when various electric voltages were applied to them.

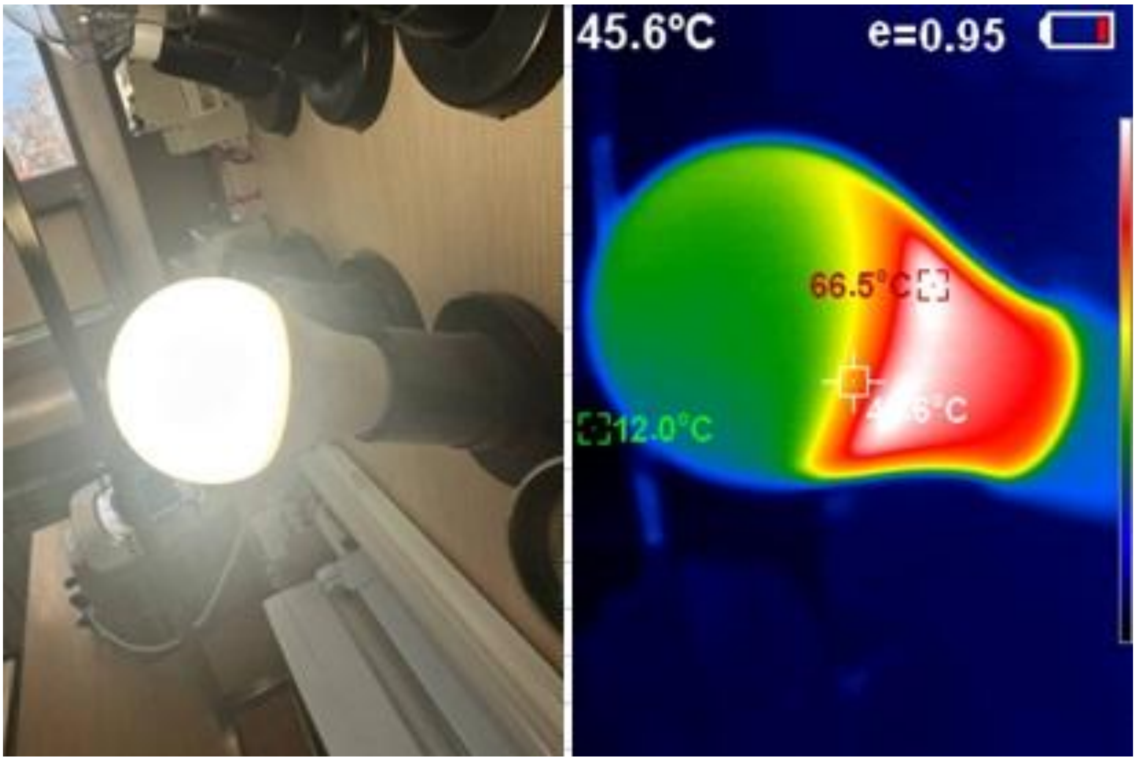

Fig. 5. Principle of heat distribution over the LED lamp body

As a result of experiments, it was determined that the hottest element of the LED lamp is not its bulb, but the body, as shown in Fig. 5. This is due to the fact that when the LED lamp is operating, its driver is most heated, namely the power control chip, which is installed in the lamp body.

Fig. 6 shows the temperature of the power control chip at different voltages, and Fig. 7 shows the temperature relationships of different elements of the LED lamp when they are supplied with an electric voltage of different values.

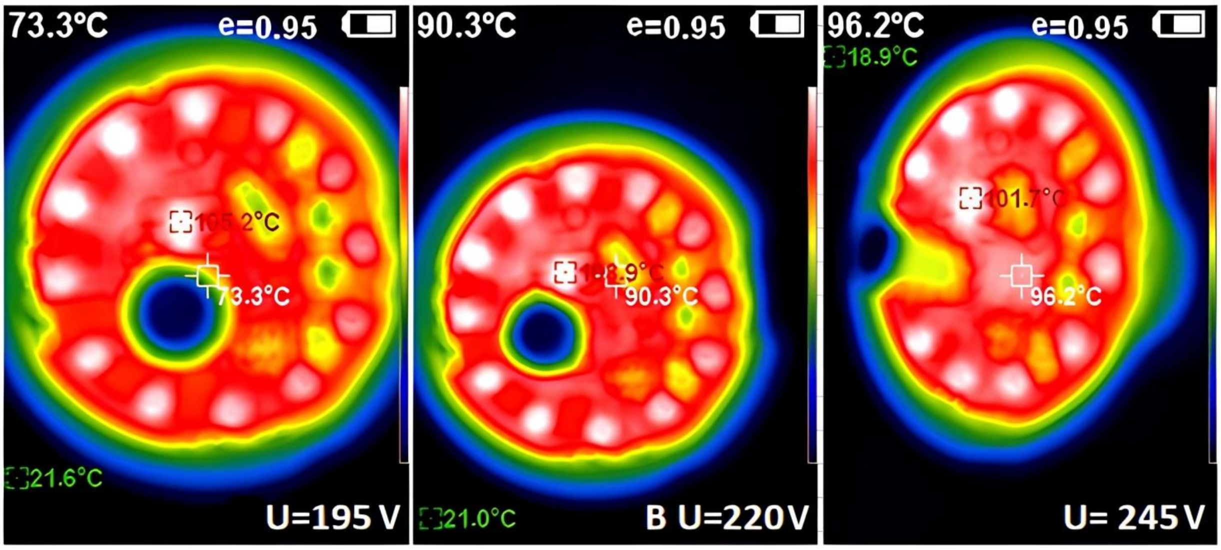

Fig. 6. LED lamp driver temperature at different voltages

From the analysis of Fig. 6. it can be seen that when the electric voltage decreases, the power control chip heats up more, but not significantly.

Fig. 7. Dependence of the temperature of the LED lamp elements on the supplied electric voltage.

Fig. 8 dependence of temperature of bulb of electric lamps of different types on electric voltage in stationary operation mode is presented. From the analysis of the graphs presented in Fig. 8, it can be argued that LED electric lamps are the safest lamps from the point of view of fire safety, since they have a lower heating temperature and work more stably under voltage drops.

6. Construction of mathematical models of dependence of temperature of electric lamps depending on voltage

The obtained data were approximated and mathematical models of temperature dependencies of incandescent bulbs, arc mercury lamps and LED lamps were obtained, which are presented in Tabl. 6. The adequacy of these mathematical models was checked and their maximum relative errors were determined, which are also given in Tabl. 6.

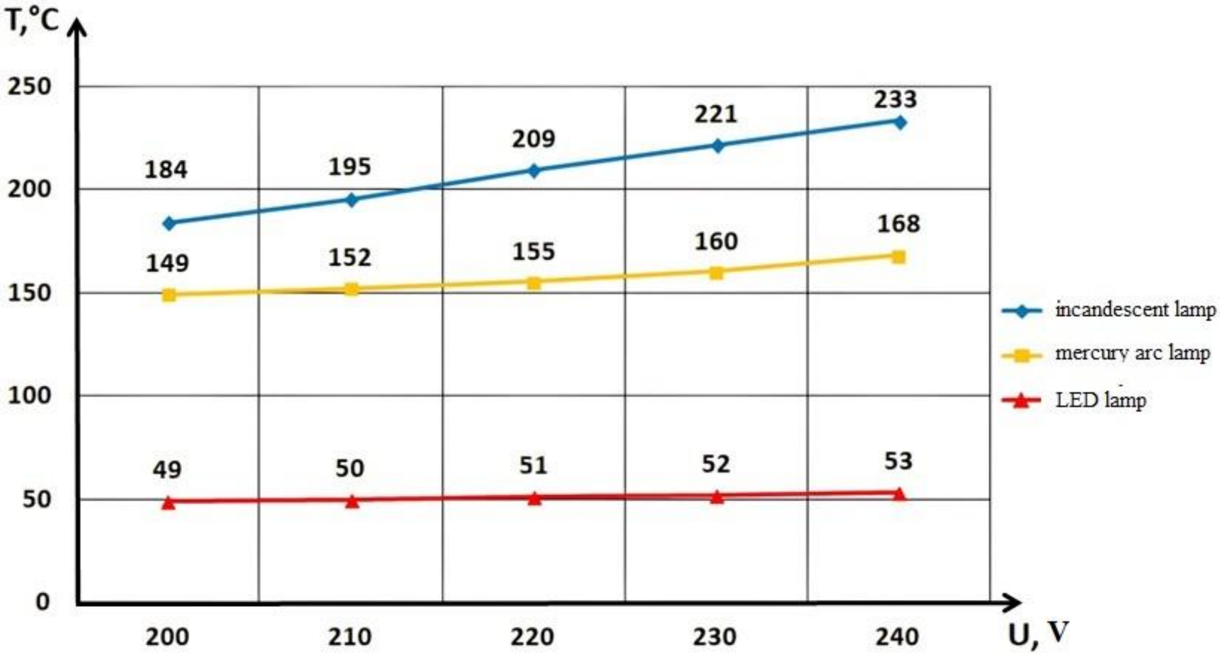

Fig. 8. Dependence of the heating temperature of the lamp bulb of different types on the electric voltage at steady operation mode

In this voltage range, the temperature dependence of an incandescent bulb on time is best described by polynomial models of the third degree, for arc mercury lamps by polynomial models of the fourth degree, and LED lamps by polynomial models of the second degree. Based on the measurement results, graphs of the heating temperature of the incandescent bulb and the arc mercury lamp versus time at different electrical voltages were plotted, which are shown in Fig. 9, Fig. 10, respectively.

From the analysis of these graphs, it can be argued that the filament bulb temperature varies exponentially. From the first to the hundredth second it grows rapidly, from the hundredth to the two hundredth second it grows, but not so sharply, and after 200 s it almost does not change.

From the analysis of the graphs in Fig. 10, it can be argued that the dependence of the temperature of the bulb of arc mercury lamps on the applied voltage in the stationary mode of operation is almost linear.

Fig. 11 shows graphs of the LED bulb heating temperature versus time at different electrical voltages. It follows from the graphs that the temperature change of the flask is almost linear, and its difference when applying a voltage of 195 V and 245 V is only 4.7 °C. In this voltage range, the temperature dependence of the bulb of the LED lamp on time is best described by polynomial functions of the second degree, since the dependence is almost linear.

Tabl. 6. Mathematical models of the value of the heating temperature of the electric incandescent bulb depending on the time

Voltage values U, V	Mathematical model	Maximum relative error, %
Incandescent lamps		
195	$T(t) = 0{,}0965t^3 – 3{,}7532t^2 + 48{,}154t – 36{,}429$	4.02
220	$T(t) = 0{,}0945t^3 – 3{,}6364t^2 + 45{,}764t – 33{,}080$	1.93
245	$T(t) = 0{,}0914t^3 – 3{,}3933t^2 + 41{,}832t – 24{,}863$	5.35
Arc mercury lamps		
195	$T(t) = 0{,}0029t^4 – 0{,}1941t^3 + 3{,}9079t^2 – 13{,}626t + 37{,}740$	3.22
220	$T(t) = 0{,}0028t^4 – 0{,}1901t^3 + 4{,}0222t^2 – 18{,}897t + 50{,}338$	3.46
245	$T(t) = 0{,}0018t^4 – 0{,}1318t^3 + 2{,}9315t^2 – 14{,}280t + 47{,}545$	2.13
LED Lamps		
195	$T(t) = – 0{,}1418t^2 + 4{,}1813t + 20{,}968$	3.74
220	$T(t) = – 0{,}1012t^2 + 3{,}4320t + 21{,}789$	4.35
245	$T(t) = – 0{,}0758t^2 + 2{,}8960t + 21{,}534$	4.02

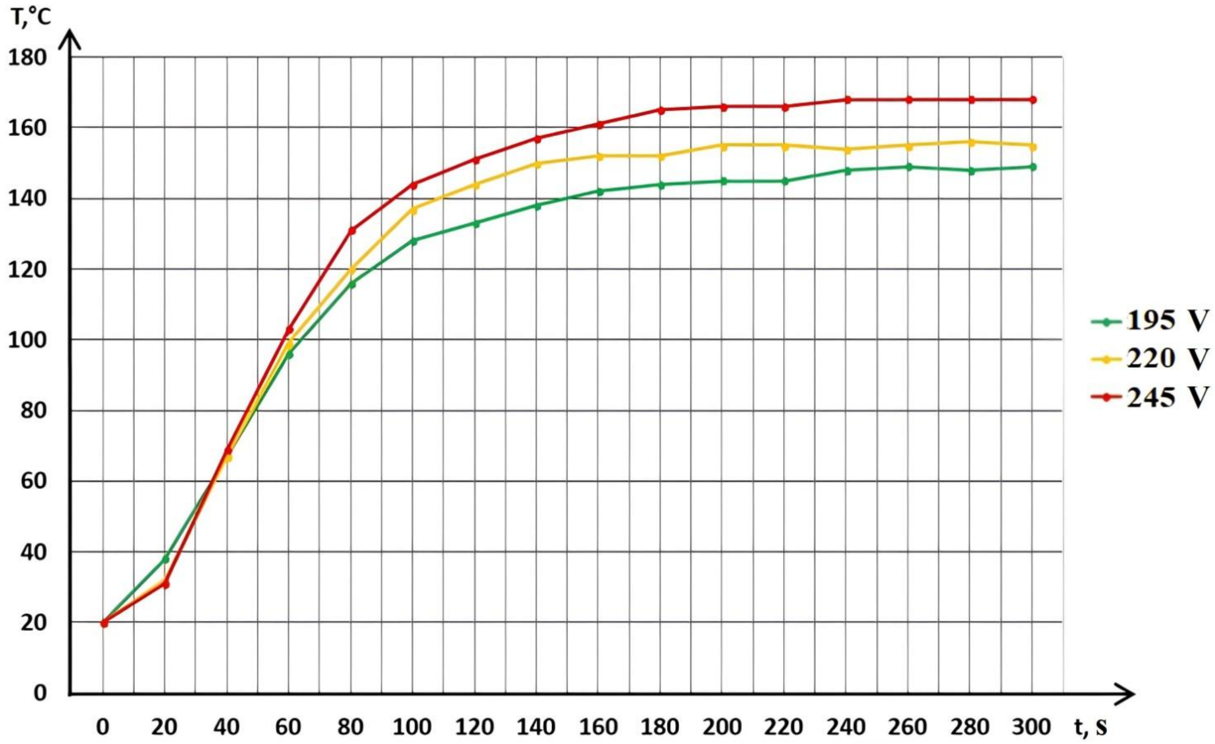

Fig. 9. Dependence of incandescent bulb heating temperature on time at different electric voltages

7. Discussion of the results of determining the temperature of electric lamps at overvoltage

As a result of the study, the temperature of electric lamps of various types was obtained from the supplied electric voltage, in the range from 195 V to 245 V, and mathematical models of these dependencies were obtained.

From the analysis of the graphs in Fig.5, it can be argued that the temperature of the bulb of the incandescent lamp increases with the voltage applied to it. At a voltage of 220 V, the temperature of the flask was 155.6 °C and at a voltage of 245 V – 168.3 °C, which is 8.1% more than the standard operating mode. At the same time, reducing the applied voltage to 195 V reduced the temperature of the bulb of the incandescent electric lamp by only 4.2%. From the experiments conducted, it can be argued that the dependence of temperature on the applied voltage for electric incandescent lamps is not linear.

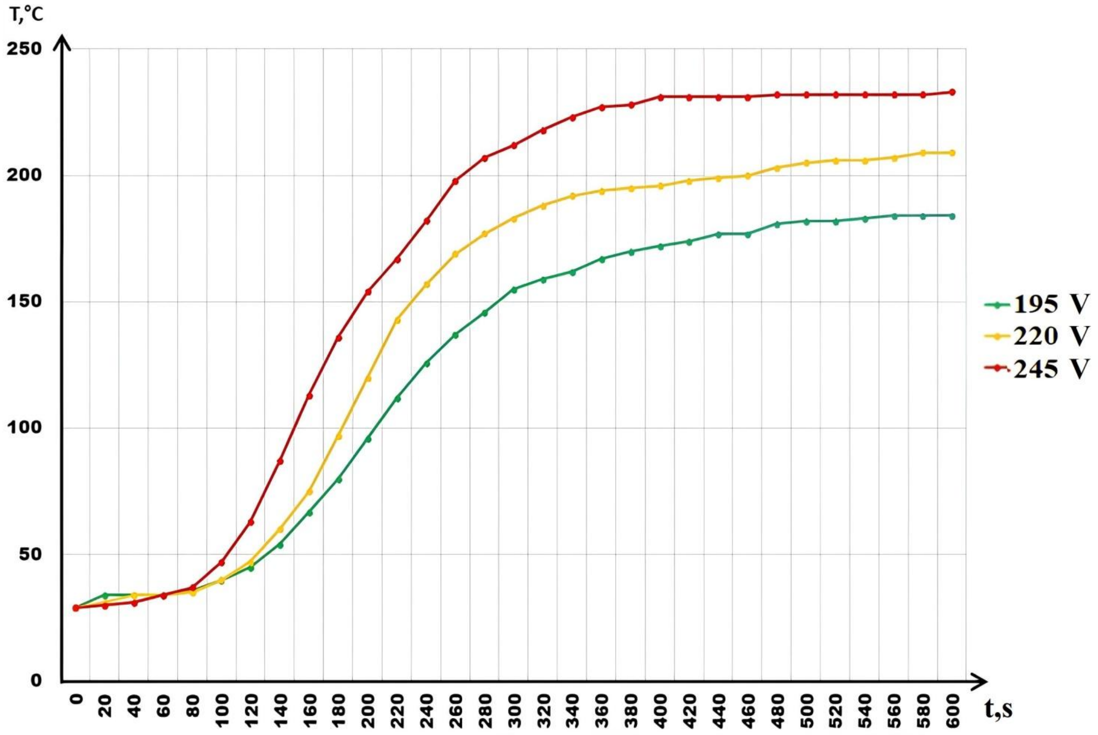

Fig. 10. Arc mercury bulb heating temperature vs time at different electrical voltages

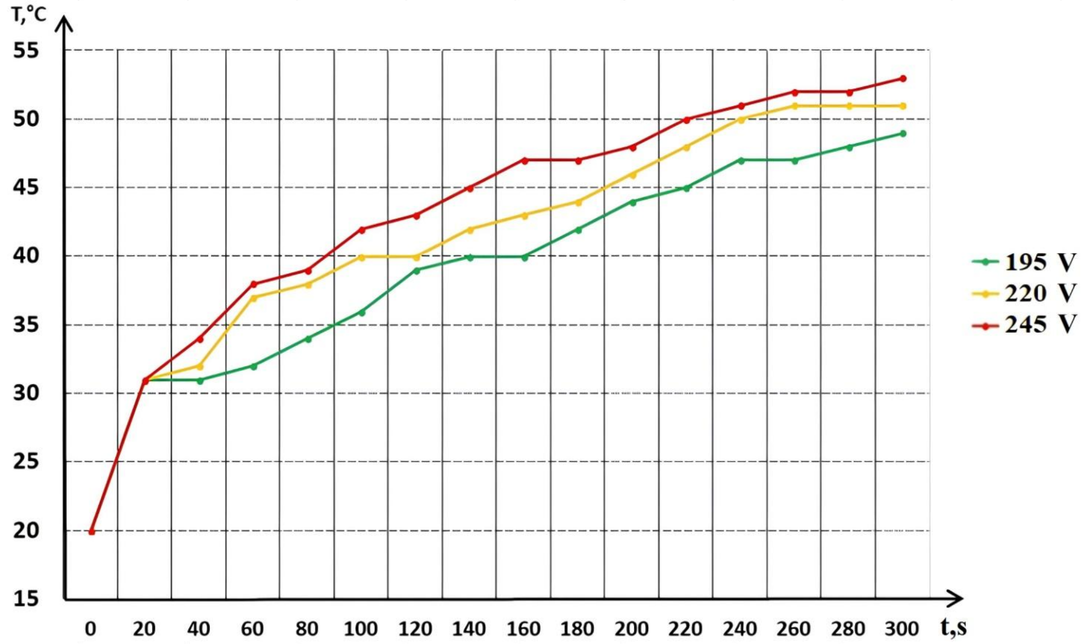

Fig. 11. Dependence of LED lamp bulb heating temperature on time at different electric voltag

The dependency analysis in Figure 6 shows that the temperature of the arc mercury bulb also increases with the voltage applied to it. At a voltage of 220 V, the temperature of the bulb was 209.4 °C and at a voltage of 245 V – 234.3 °C, which is 11.8 % more than the standard operating mode, and a decrease in the applied voltage to 195 V reduced the temperature of the bulb of the incandescent lamp by 13.2 %.

Based on this, it can be argued that in emergency modes of operation, the temperature of incandescent lamps and arc mercury lamps may exceed the normative values of temperature groups, as a result of which, when used in environments where explosive gases or vapors are present, they can become a source of ignition and lead to explosion or ignition of these substances.

The temperature of the bulb of the LED lamp also increases with increasing voltage, but slightly, as can be seen from the graphs in Fig. 7. At a voltage of 220 V, the temperature of the flask was 52.1 °C and at a voltage of 245 V – 53.9 °C, which is 3.4 % more than the standard operating mode, and reducing the applied voltage to 195 V reduced the temperature of the LED bulb by 5.8 %.

It was found that the driver, namely the power control chip, heats up most when the LED electric lamp is operating. From the analysis of Fig. 10. it can be seen that when the electric voltage decreases, the power control chip heats up more, but not significantly. At 195 V, its temperature is 105.2 °C, at 220 V – 103.9 °C, and at 245 V – 101.7 °C. At the same time, the temperature of its body also drops by about 1 °C with an increase in voltage by 25 V. And the temperature of the flask, on the contrary, increases by 2 °C with an increase in voltage by 25 V. This may be due to the fact that that the temperature of the flask depends not only on the heating temperature of the power control chip, but also on the temperature of the LEDs, inductor and capacitor, but for the reliability of this hypothesis, additional research is necessary.

Based on this, it can be argued that the LED lamp is the best from the point of view of fire safety, since it has the lowest temperature, as well as the least responsive change in the voltage of the electrical network, which is explained by its design and principle of operation.

The disadvantages of the studies are that mathematical models for predicting the temperature of electric lamps of different types can be applied only to electric lamps of the corresponding capacities, although the tendency to change their temperature under emergency operating modes will be the same for all lamps of this type.

With regard to LED lamps, the question remains open regarding their reliability and durability of operation in emergency modes of operation, which requires additional research.

8. Conclusions

1. Experimental studies were conducted to determine the temperature of electric lamps of different types at different values of the electric voltage. It was determined that the highest heating temperature of the bulb is observed in arc mercury lamps – 234.3 °C, which is 24.9 °C more than its temperature under standard operating conditions. The 100 W incandescent bulbs warmed up to 168.3 °C, which is 12.7 °C more than its temperature in standard operation, and the LEDs only up to 53.9 ° C, which is only 1.8 ° C more than the temperature in standard operation. LED lamps at work have a significantly lower temperature, which makes them safer to use in different conditions.

2. Mathematical models of dependence of temperature of electric incandescent lamps, arc mercury lamps and LED lamps on voltage at overvoltage and in low voltage mode are constructed and their adequacy is checked. The maximum relative errors of the obtained mathematical models were determined. For mathematical models of electric incandescent lamps, the maximum relative error is 5.35 %, for arc mercury lamps – 3.46 %, and for LED lamps – 4.35 %.

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ВИЗНАЧЕННЯ ПАРАМЕТРІВ ЕЛЕКТРИЧНИХ ЛАМП РІЗНИХ ТИПІВ ПРИ АВАРІЙНИХ РЕЖИМАХ РОБОТИ

Проведені дослідження з визначення температури електричних ламп різних типів при аварійних режимах роботи електромереж, а саме при перенапрузі. Побудовані графіки залежностей температури колби ламп розжарювання, дугових ртутних ламп та світлодіодних ламп від напруги, що подається на них. Отримані математичні моделі величини температури нагрівання колби електричної лампи розжарювання, дугової ртутної лампи та світлодіодної лампи в залежності від часу. Визначено, що температура колби електричної лампи розжарювання зростає за експоненціальним законом і приблизно через 300 секунд стабілізується. Температура дугової ртутної лампи також змінюється за експоненціальним законом, але, у порівнянні з лампою розжарювання, не так стрімко, а стабілізується приблизно через 600 секунд. Визначено, що при аварійних режимах роботи температура ламп розжарювання та дугових ртутних ламп може перевищувати нормативні значення температурних груп, внаслідок чого при використанні їх в середовищах, де присутні вибухонебезпечні гази або пари вони може стати джерелом запалювання і призвести до вибуху або загоряння цих речовин. Визначено, що температура світлодіодної лампи змінюється за лінійним законом і через 300 секунд перестає зростати. Побудовані залежності температури різних елементів світлодіодної лампи в залежності від поданої на неї електричної напруги. Встановлено, що найбільше при роботі світлодіодної електричної лампи нагрівається драйвер, а саме чіп керування живленням. Визначено, що при зменшенні електричної напруги чіп керування живленням нагрівається більше, але незначно. Встановлено, що світлодіодна лампа є найкращою з точки зору пожежної безпеки, оскільки має найнижчу температуру, а також найменше реагує зміну напруг електричної мережі, що пояснюється її конструкцією та принципом дії.

Ключові слова: температура лампи, перенапруга, знижена напруга, пожежна небезпека

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