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STUDY OF FIRE HAZARDS IN ELECTRICAL CONNECTIONS OF VARIOUS TYPES

Research was conducted to determine the temperature of various types of electrical connections under emergency operating conditions of the power grid, specifically during overloads. The most common electrical connections were selected as the subjects of the study. Experimental measurements of connection temperatures were performed at various current values exceeding the conductor's rated values. Graphs were plotted showing the dependence of the temperature of electrical connections on time as different values of electric current passed through them. Mathematical models were obtained for the dependence of the temperature of various types of electrical connections on time during overload conditions. The adequacy of the models was verified, and their maximum relative errors were determined. It was established that the temperature of electrical connections increases with an increase in electric current and exhibits a nonlinear dependence. It was determined that certain types of electrical connections heat up significantly during overload, accompanied by deformation of their structural elements, smoke emission, and melting of conductor insulation. It was established that the heating of such connections does not cease during the study period, indicating their hazardous behavior under overload. It was determined that other types of electrical connections are characterized by a more stable temperature regime; their heating slows down over time and is not accompanied by visible signs of failure. It has been established that such connections are capable of withstanding short-term overloads without losing their operational properties. It has been established that during emergency operating conditions of electrical networks with faulty protective devices, certain types of electrical connections can be a source of ignition due to significant heating, deformation, and structural failure. The necessity of testing electrical connections under overload conditions to improve the fire safety of electrical networks has been substantiated.

Keywords: temperature, electrical connection, overload

1. Introduction

Harsh winter weather conditions and damage to the power infrastructure, along with widespread power outages and scheduled blackouts, created conditions conducive to overloading, which in turn led to electrical appliances, wiring, and lighting systems operating under emergency conditions. The unstable and emergency operating conditions of Ukraine's power system significantly increased the risk of fires in certain sections of electrical networks and in electrical equipment. According to an analysis of statistical data on fire incidents during the first two months of 2026 [1], a significant increase has been recorded, with the leading cause being violations of fire safety regulations during the installation and operation of electrical installations, accounting for 2.925 cases, compared to 1.693 cases during the same period in 2025. These data highlight the need to study the hazardous parameters of emergency operating modes in electrical systems in order to improve the safety of electrical equipment operation.

Given that conductor joints are among the areas where contact resistance can potentially form, this can create conditions conducive to the occurrence of abnormal operating conditions in electrical networks. The importance of researching the fire safety of conductor joints is growing even more, as damaged or unstable electrical networks can increase the risk of fires.

A review of the most common methods for connecting conductors reveals the widespread use of solderless terminal blocks, which are available in a wide variety on the market and must comply with current regulatory requirements. In particular, manufacturers of terminal blocks for copper conductors are required to ensure and verify the fire safety of their products in accordance with DSTU EN 60947-7-1:2017 [2]. In accordance with the requirements of this standard, the insulating parts of terminal devices that may be exposed to thermal stress, particularly under conditions of overheating of current-carrying elements, must not ignite or contribute to the spread of flames under abnormal operating conditions, which is a critical criterion for ensuring their operational and fire safety.

Research into the condition of terminal devices used to connect conductors remains a relevant topic of study, as it affects the overall fire safety of facilities. Consequently, the occurrence of fires resulting from abnormal operating conditions in electrical networks is a pressing issue.

2. Analysis of the literature and statement of the problem

The paper [3] investigates the problem of increasing contact resistance in spring-type contact connections due to mechanical wear and operational loads. The physical and mechanical processes of electrical current transmission and the deterioration of electrical contact quality, accompanied by local heating and a decrease in connection reliability, are considered. It has been established that the degradation of contact surfaces leads to an increase in contact resistance. At the same time, these processes are not considered for conductor connections using terminals.

The study [4] examines the reliability of spring-socket contact connections, taking into account degradation mechanisms, in particular the oxidation of contact surfaces and the loss of contact pressure. It is shown that these factors cause an increase in contact resistance and a decrease in the stability of the electrical contact, particularly under conditions of long-term storage. However, thermal loads on contact connections during the passage of fault currents during operation are not taken into account.

The study [5] describes the mechanism underlying contact resistance and its components, and presents a model and calculation method for contact resistance for practical engineering applications. The study demonstrates the influence of structural and physical parameters on the resistance value. However, the fire hazard associated with contact connections is not addressed in the study.

Studies [6, 7] focus on evaluating the contact resistance of connections between copper and aluminum conductors, taking into account the influence of material, surface condition, and clamping conditions. It has been established that the presence of oxide films and the quality of mechanical contact significantly affect the increase in resistance, especially for aluminum conductors due to more intense oxidation. In this context, the main focus is on the design parameters of the connection, specifically the connection angle and clamping conditions, as well as the processes of contact spot welding. Terminal connections of conductors are not considered in these works.

The works [8, 9] present experimental studies of various types of conductor connections regarding heat generation at contact points when an electric current flows to levels that may pose a fire hazard. A relationship has been established between contact resistance parameters and heating temperature. At the same time, terminal connections are represented only to a limited extent in the studies – specifically, by only one product – which does not allow for an assessment of the reliability and fire hazard of such connections for different design configurations.

The study [10] proposes a model of a fire protection element for electrical networks at connection points, which makes it possible to prevent emergencies caused by overheating in “plug-socket” contact zones. The effectiveness of detecting excessive local heating has been demonstrated. However, the behavior of conductor connections made using terminals under emergency operating conditions has not been investigated.

The study [11] presents experimental investigations of the fire hazard characteristics of cable and wire products, including the determination of the flame spread class, the mass and volume of combustible material, and mass loss during combustion. The influence of design and materials on the fire characteristics of the products is demonstrated. However, the fire hazard of conductor contact connections is not addressed in this work.

Thus, an analysis of the literature has shown that existing studies focus primarily on determining contact resistance, the mechanisms underlying its increase, and general thermal processes in contact connections. At the same time, insufficient attention has been paid to investigating the fire hazard posed specifically by conductor terminal connections, particularly under emergency operating conditions in electrical networks.

Given the widespread use of electrical devices and connections in industrial, residential, and public buildings, as well as their operation under conditions of unstable power supply, the likelihood of fire hazards is increasing. In this regard, the study of electrical connections using terminals under emergency operating conditions is a pressing scientific challenge.

3. Purpose and Objectives of the Study

The purpose of this study is to determine the thermophysical characteristics of various types of electrical connections resulting from heating caused by an overload in the electrical network.

To achieve this goal, the following tasks must be completed:

1. Conduct experimental studies to determine the temperature of various types of electrical connections under overload conditions.
2. Develop mathematical models of the relationship between the temperature of various types of electrical connections and current under overload conditions.

4. Materials and Methods

The object of this study is the thermal processes that occur in electrical connections under overload conditions.

The subject of this study is electrical connections of various types.

The research hypothesis is based on the assumption that, under certain conditions, when an overload occurs in an electrical network, the temperature of the electrical connection may rise, as a result of which it may become a source of ignition for certain materials and/or substances.

The electrical connections presented in Tabl. 1 were selected for the experimental studies. The electrical connections were chosen based on the principle of those that are most common and those available on the open market.

The tests were conducted using a laboratory power supply, the appearance of which is shown in Fig. 1, and whose specifications are presented in Tabl. 2.

This BVP TFT 30V 50A laboratory unit allows for testing within a current range of 0–50 A. To test various types of electrical connections, a ВВГ-П (3×1.5) electrical cable with a rated current of 19 A was used.

Tabl. 1. Electrical connections used in the test

ENEXT p0660204	
Country of origin	Germany
Manufacturer's part number	22-1482y-W
Rated voltage, V	450
Rated current, A	32
Operating temperature	from –40 °C to +105 °C
Protection rating	IP20
Material	Polyamide
WAGO transparent terminal block for 1 conductor (with lever)	
Country of origin	Germany
Manufacturer's part number	22-2611Y-W
Rated voltage, V	450
Rated current, A	32
Protection rating	IP20
EMT Electronics 22-4201y Service Terminal	
Country of origin	China
Manufacturer's part number	ZD-224-201
Rated voltage, V	220
Rated current, A	24
Material	Polyamide
Protection rating	IP20

Fig. 1. BVP TFT 30V 50A Laboratory Power Supply

Tabl. 2. Technical Specifications of the BVP TFT 30V 50A Laboratory Power Supply

Parameter	**Parameter value**
Supply voltage, V	198-242
Maximum output power, W	1500
Maximum input power, W	1800
Efficiency, %	85
Adjustable output voltage, V	1,0-15,0
Adjustable output current, A	1-100
Output current display resolution, A	0,1
Basic setting error, %	1,5
Operating temperature range, °C	+ 5..+40
Dimensions, mm	275x115x260

To measure the temperature of various types of electrical connections, a UNI-T UT133A digital multimeter with a thermocouple was used, as shown in Fig. 2; its specifications are listed in Tabl. 3.

Fig. 2. UNI-T UT133A A Digital Multimeter with Thermocouple

Tabl. 3. Specifications of the UNI-T UT133A Digital Multimeter with Thermocouple

Manufacturer	UNI-T
Device type	Multimeter
Measurement parameters:	Resistance, Voltage, Current, Capacitance, Frequency, Temperature
Temperature measurement range	–40°C – 1000°C
Temperature measurement accuracy	±4°C
Range selection:	Automatic

The test scenario considered a situation involving a faulty protective device. Overload was selected as the emergency operating mode. The tests were conducted for four current values—21; 28.5; 38 and 47.5 A—which correspond to 1.1; 1.5; 2.0 and 2.5 times the conductor’s rated current. In this test, the temperature of the electrical connections and their behavior under overload conditions were measured under the influence of various currents.

5. Experimental determination of the temperature of electrical connections at different current levels

A total of 10 tests were conducted for each electrical connection at various current levels. The electrical connections were tested for 300 seconds in most cases; in some instances, if their temperature rose, they were tested for a longer duration.

The test results for the E.NEXT p0660204 terminal block with a push-lever connector are presented in Tabl. 3.

Tabl. 4. Test results for the E.NEXT p0660204 terminal block

t,s	**ΔT,°C**			
	I=21 A	**I=28,5 A**	**I=38 A**	**I=47,5 A**
0	25	25	25	25
60	51	72	82	130
120	58	94	109	172
180	62	104	135	187
240	66	112	151	192
300	66	120	162	199

As can be seen from the test results in Tabl. 4, the E.NEXT terminal block heated up to 199 °C when a current of 47.5 A passed through it for 300 seconds, as shown in Fig. 3; however, its heating did not stop. At the 180-second mark, smoke appeared, and at the 240-second mark, deformation of the terminal block began. When a current of 38 A passed through it for 300 s, it heated up to 162 °C, as shown in Fig. 4. When currents of 38 A and 47.5 A passed through it, the terminal block began to deform under the influence of high temperatures. Fig. 5 clearly shows the melting of the electrical conductor's insulation at the connection point with the terminal block.

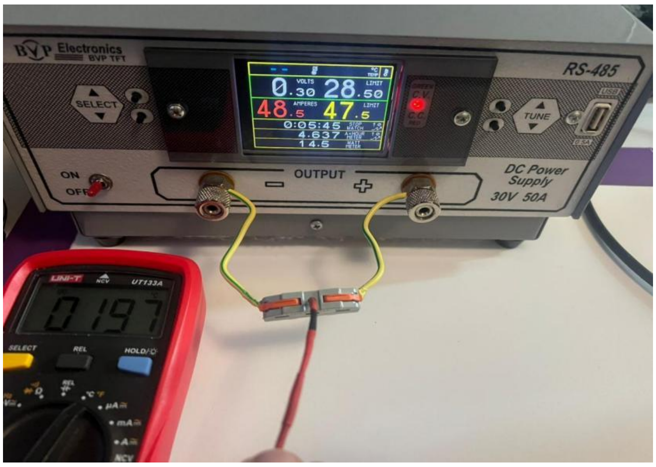

Fig. 3. Testing of the E.NEXT p0660204 terminal block

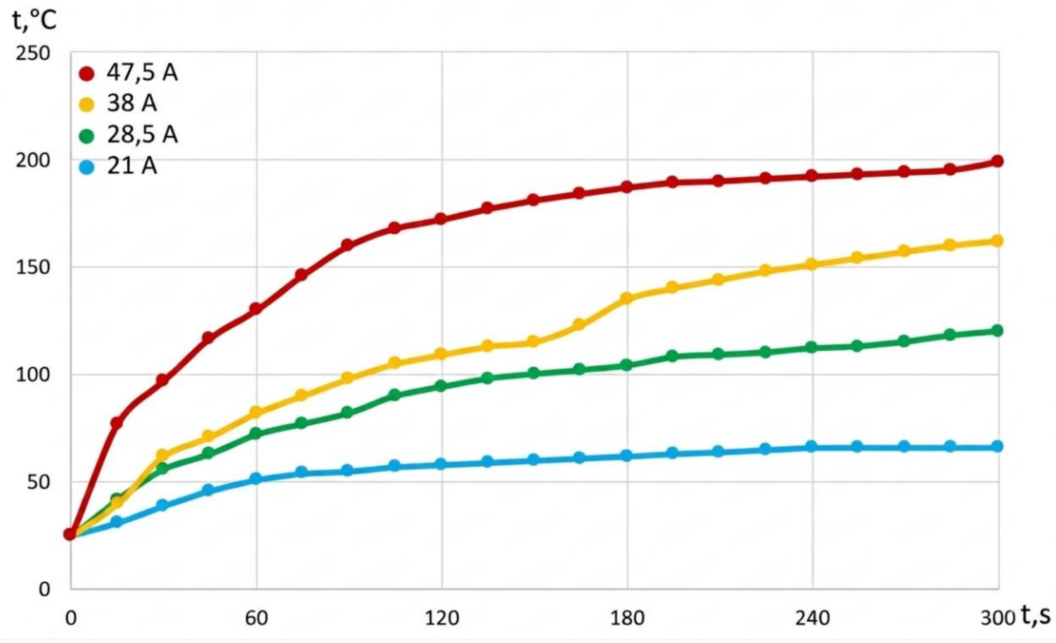

Fig. 4. Graph showing the relationship between the temperature of the E.NEXT p0660204 terminal block with a pressure lever and time as various electrical currents pass through it

Based on the above, it can be concluded that the E.NEXT p0660204 push-lever terminal block poses an electrical hazard under overload conditions and may create conditions conducive to a fire. The WAGO transparent 1-conductor terminal with lever 22-2611V-W heated up to only 76 °C in 300 seconds when a 38 A electric current passed through it, as shown in Fig. 6, and to 113 °C when a current of 47.5 A was applied, as shown in Tabl. 5. During the test, the WAGO terminal did not deform, and its temperature stopped rising after 300 seconds. Graphs showing the dependence of the terminal temperature on time at different current values are presented in Fig. 7. It follows that the terminal is capable of withstanding short-term overloads in the electrical network, and the melting of the conductor insulation will occur faster than the deformation and melting of the electrical terminal.

Fig. 5. Deformation of the E.NEXT p0660204 terminal block with a pressure lever following testing

Tabl. 5. Test results for the WAGO 22-2611V-W terminal

t,s	ΔT,°C			
	I=21 A	I=28,5 A	I=38 A	I=47,5 A
0	25	25	25	25
60	36	43	54	70
120	40	50	67	92
180	40	53	72	102
240	41	55	75	108
300	41	55	76	113

Fig. 6. Testing of the WAGO transparent 1-conductor terminal with lever 22-2611V-W

The test results for the EMT electronics 22-4201y terminal are presented in Tabl. 6. Testing for this terminal took longer than for the other terminals because its heating did not stop at the 300-second mark; therefore, the test was extended to obtain more accurate results.

Tabl. 6. Test results for the EMT electronics 22-4201y terminal block

t,s	ΔT,°C			
	I=21 A	I=28,5 A	I=38 A	I=47,5 A
0	25	25	25	25
60	66	70	86	94
120	76	97	106	134
180	79	102	116	163
240	81	105	122	170
300	85	106	126	179
360	86	107	130	180
420	86	107	131	182
480	86	107	132	186

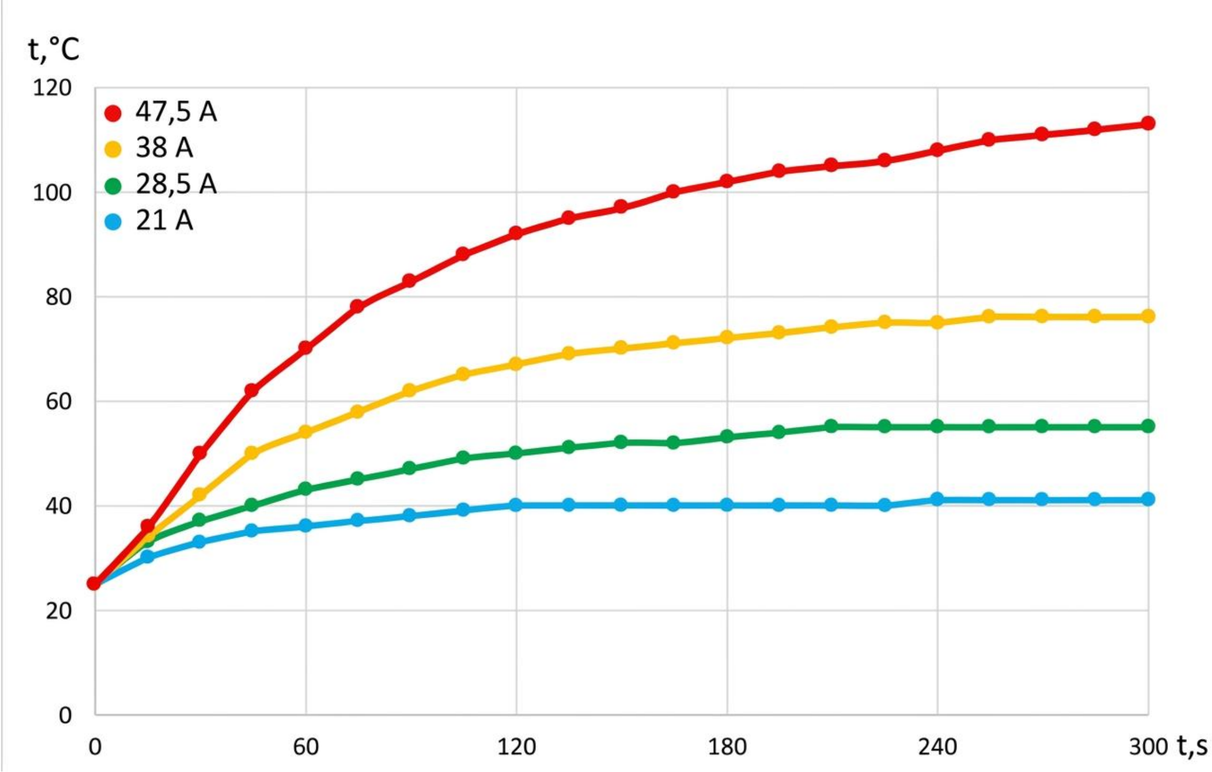

Fig. 7. Graph showing the temperature of the WAGO 22-2611V-W terminal as a function of time when various electrical currents pass through it

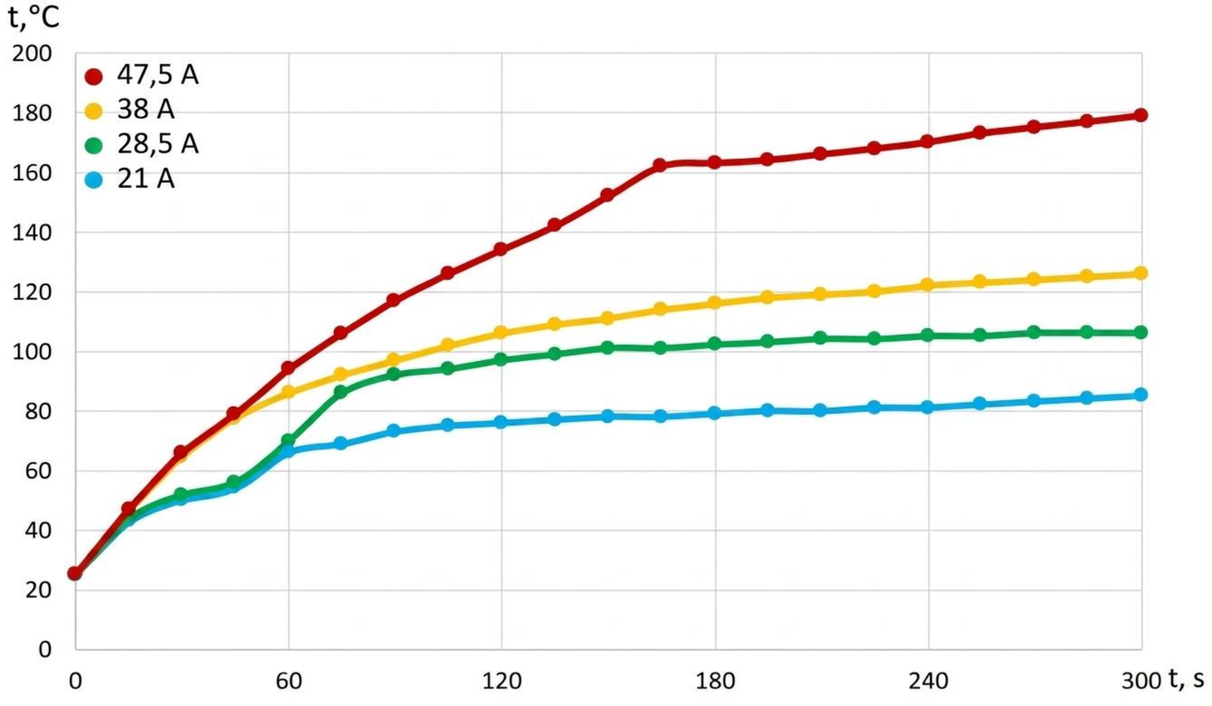

Fig. 8. Graph showing the relationship between the terminal temperature of the EMT electronics 22-4201 and time as various electric currents pass through it

As shown by the test results, the EMT electronics 22-4201y terminal heated up to 186 °C when a current of 47.5 A passed through it over 480 seconds. Smoke began to appear at 180 seconds, and deformation of the terminal began at 300 seconds. When a current of 38 A passed through it for 300 seconds, it heated up to 126 °C, as shown in Fig. 8.

6. Development of mathematical models describing the temperature dependence of various types of electrical connections under overload conditions

The obtained data were approximated, and mathematical models of the temperature dependencies for the E.NEXT p0660204, WAGO 22-2611V-W, and EMT electronics 22-4201y electrical connectors were derived, as shown in Tabl. 7. The adequacy of the mathematical models was verified, and their maximum relative errors were determined, which are also shown in Tabl. 7.

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

Tabl. 7. Mathematical models of the temperature rise in electrical connections as a function of time

The value of electric current I, A	Mathematical model	Maximum relative error, %
E.NEXT p0660204		
21.0	$T(t)=4E\text{-}06t - 0.0023t^2 + 0.5027t + 25.805$	3.01
28.5	$T(t)=6E\text{-}06t - 0.0038t^2 + 0.9222t + 28.02$	2.15
38.0	$T(t)=4E\text{-}06t - 0.0031t^2 + 0.9921t + 29.154$	3.73
47.5	$T(t)=2E\text{-}05t^3 - 0.01t^2 + 2.1186t + 37.121$	3.36
WAGO 22-2611V-W		
21.0	$T(t)=2E\text{-}06t^3 - 0.0011t^2 + 0.2215t + 26.359$	3.14
28.5	$T(t)=2E\text{-}06t^3 - 0.0014t^2 + 0.3321t + 27.097$	4.31
38.0	$T(t)=4E\text{-}06t^3 - 0.0025t^2 + 0.5966t + 26.023$	1.73
47.5	$T(t)=-2E\text{-}08t_4 + 2E\text{-}05t^3 - 0.0058t^2 + 1.0682t + 23.448$	1.95
EMT electronics 22-4201y		
21.0	$T(t)=2E\text{-}06t^3 - 0.0018t^2 + 0.5212t + 34.398$	2.78
28.5	$T(t)=3E\text{-}06t^3 - 0.0029t^2 + 0.8313t + 30.202$	2.56
38.0	$T(t)=3E\text{-}06t^3 - 0.0027t^2 + 0.8473t + 37.52$	3.55
47.5	$T(t)=4E\text{-}06t^3 - 0.0037t^2 + 1.2827t + 28.307$	4.03

Based on the data obtained, it can be concluded that during emergency operating conditions in electrical networks with faulty protective devices, certain types of electrical connections can cause a fire. Test results showed that the EMT electronics 22-4201y terminal and the E.NEXT p0660204 terminal block deformed under overload, emitted smoke, and experienced melting and destruction of the housing, which could have become a source of ignition if they were subsequently used in such a mode. The WAGO 22-2611V-W terminal briefly withstood an electrical current of up to 47.5 A in overload mode without deformation or smoke emission.

7. Discussion of the results of measuring the temperature of various types of electrical connections under overload conditions

The study yielded temperature-current relationships for various types of electrical connections in the range from 21 A to 47.5 A, as well as mathematical models of these relationships.

Based on the analysis of the graphs, it can be concluded that the temperature of electrical connections increases with an increase in the current supplied to them. Based on the experiments conducted, it can be concluded that the relationship between temperature and applied current for electrical connections is not linear.

An analysis of the data in Fig. 1 shows that the temperature of the E.NEXT p0660204 electrical connection exceeded the permissible temperature for this connection by 54 % when a current of 38 A passed through it, and by 89 % when a current of 47.5 A passed through it. At the same time, the terminal began to deform and emit smoke. The insulation also melted at the point where the electrical conductor connected to the terminal. Based on this, it can be concluded that high contact resistance occurs at the points where the terminal contacts the conductor, which can cause the insulation to melt and, as a result, create a source of ignition.

An analysis of the data in Fig. 5 shows that the temperature of the EMT electronics 22-4201y electrical connection exceeded the permissible temperature for this connection by 25 % when a current of 38 A passed through it, and by 77 % when a current of 47.5 A passed through it. At the same time, the terminal began to deform and emit smoke.

Based on this, it can be concluded that when electrical circuits are overloaded, the temperature of the EMT electronics 22-4201y and E.NEXT p066020 electrical connectors may exceed regulatory limits, causing their housings to melt; consequently, their use – even during brief overloads – can pose electrical and fire hazards. This is due to the release of hazardous fire-causing factors and the potential for an ignition source to arise as a result of the melting of the electrical connection.

As shown in Fig. 7, the temperature of the WAGO 22-2611V-W electrical connection did not exceed the permissible temperature for this connection when a current of 38 A passed through it, and when a current of 47.5 A passed through it, it exceeded the permissible temperature by only 7.6 %. Based on the experiments conducted, it can be concluded that this terminal is safe from a fire safety perspective during short-term electrical network overloads, but requires more detailed investigation under conditions of prolonged overloads.

A limitation of the studies conducted is that mathematical models for predicting the temperature of various types of electrical connections can only be applied to those specific models of electrical connections, and the temperature trends of different models of the same type of electrical connection under overload conditions may vary. This is precisely why it is necessary to test all types of electrical connections under overload conditions before they are released for sale and to verify the relevant documentation during market surveillance by State Emergency Service personnel.

8. Conclusions

1. Experimental studies were conducted to determine the temperature of various types of electrical connections when an overload occurs in an electrical network. It was determined that the temperature of the WAGO 22-2611V-W terminal when subjected to a current of 47.5 A was 113 °C, with no deformation or smoke emission observed. The E.NEXT p0660204 and EMT electronics 22-4201y terminals heated up to 162 °C and 126 °C, respectively, when an electric current of 38.0 A passed through them, resulting in deformation of the terminals, indicating that these terminals can cause a fire even under short-term overloads.

2. Mathematical models of the temperature dependence of electrical connections on the applied current and during overload were constructed, and their adequacy was

verified. The maximum relative errors of the obtained mathematical models were determined. For the mathematical models of the E.NEXT p0660204 electrical terminal, the maximum relative error is –3.73 %, for the EMT electronics 22-4201y – 4.03 %, and for the WAGO 22-2611V-W – 4.35 %.

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ДОСЛІДЖЕННЯ ПОЖЕЖНОЇ НЕБЕЗПЕКИ ЕЛЕКТРИЧНИХ З'ЄДНАНЬ РІЗНИХ ТИПІВ ПРИ ПЕРЕВАНТАЖЕННІ

Проведені дослідження з визначення температури електричних з'єднань різних типів при аварійних режимах роботи електричної мережі, а саме при перевантаженні. В якості об'єктів дослідження обрано найбільш поширені електричні з'єднання. Проведено експериментальні вимірювання температури з'єднань при різних значеннях електричного струму, що перевищують номінальні значення провідника. Побудовані графіки залежностей температури електричних з'єднань від часу при проходженні через них різних значень електричного струму. Отримані математичні моделі залежностей температури електричних з'єднань різних типів від часу при перевантаженні. Проведено перевірку адекватності моделей та визначено їх максимальні відносні похибки. Встановлено, що температура електричних з'єднань зростає зі збільшенням електричного струму та має нелінійний характер залежності. Визначено, що окремі типи електричних з'єднань при перевантаженні значно нагріваються, при цьому відбувається деформація їх конструктивних елементів, виділення диму та плавлення ізоляції провідників. Встановлено, що нагрівання таких з'єднань не припиняється протягом досліджуваного часу, що свідчить про їх небезпечну поведінку при перевантаженні. Визначено, що інші типи електричних з'єднань характеризуються більш стабільним температурним режимом, їх нагрівання з часом сповільнюється та не супроводжується видимими ознаками руйнування. Встановлено, що такі з'єднання здатні короткочасно витримувати перевантаження без втрати експлуатаційних властивостей. Встановлено, що при аварійних режимах роботи електричних мереж з несправним апаратом захисту окремі типи електричних з'єднань можуть бути джерелом запалювання, що зумовлено значним нагріванням, деформацією та руйнуванням їх конструкції. Обґрунтовано необхідність проведення випробувань електричних з'єднань у режимах перевантаження з метою підвищення рівня пожежної безпеки електричних мереж.

Ключові слова: температура, електричне з'єднання, перевантаження

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