

Scientifically Grounded Analysis Of The Factors Causing Fire Hazards That May Occur In Electric Cables

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Abstract:

Secondary fires ignited by earthquakes, are common, which can aggravate human and
It is stated that a scientifically grounded analysis of the factors that may cause fire hazards in
electric cables has been comprehensively studied. Special attention is paid to the process of
conducting research aimed at ensuring the elimination of fires and, by identifying factors that
negatively affect the operational capability of facilities and taking into account preventive
measures, analyzing the consequences of fires at facilities, carrying out a comparative analysis
of fires in buildings and structures based on mathematical modeling, and developing the
theoretical foundations for continuously reducing the fire hazard of buildings and structures
under the influence of fire and its dangerous factors through fire detection. Scientifically
substantiated views are presented on preventing fires that may occur as a result of short
circuits in electric cable networks by reducing the scale through eliminating the formation of
a combustible environment, removing ignition sources, and blocking the possible paths
through which fire may spread.

Keywords: cable, network, load, nominal, metal, electric, aggressive environment

Introduction

Today, in order to improve the system for preventing and eliminating emergency
situations, a number of scientific studies are being conducted in this regard, aimed at
rapidly detecting and eliminating fires in public and residential buildings by using a
device for determining the coefficient of aspiration flows during the burning of electric

cable networks. In this regard, it has been shown that improving the system for preventing and eliminating emergency situations, including ensuring effective fire safety in sectors of the economy, can be achieved by adding flame resistant additives [1]. It has been shown that flame resistant additives can achieve this by influencing the combustion process, either by extinguishing the flame or by reducing the combustion rate.

In this regard, special attention is being paid to preventing fires that may occur as a result of short circuits in electric cable networks by reducing the scale through eliminating the formation of a combustible environment, removing ignition sources, and blocking the possible paths through which fire may spread. In order to increase the effectiveness of fire protection for polymer composite materials and easily flammable solid and liquid substances that are widely developing on the basis of modern technologies, certain results are being achieved in obtaining economically and environmentally efficient fire extinguishing compositions and preventing fires that may occur with their help. In Goal 92 of the Development Strategy of the New Uzbekistan for 2022–2026, the President of the Republic of Uzbekistan Sh.M. Mirziyoyev has set important tasks “to involve the private sector in the production of fire technical equipment.” In order to implement these important tasks, it is also of great importance to develop clear priority measures for improving the system for preventing and eliminating emergency situations [2].

According to statistical data, in the territory of the Republic of Uzbekistan, during the 12 months of 2023, the total number of fires that occurred was 10,204, and the total amount of damage amounted to 270,405,996,267 soums. It can be seen from this that nearly 40% of the fires that occurred were caused by malfunctions of electric cable networks and electrical equipment in buildings and structures.

Methodology

An Example of Pre-testing Leading to a Justification for Practical Precautions. This study combined both analytical and experimental approaches to determine the most significant risk factors associated with fire hazards in electric cable networks and argues for practical precautions to be supported. In the first place, to understand the share of cable and electrical equipment related fires and to isolate critical operating scenarios for further analysis, official fire statistics for the Republic of Uzbekistan for 2023 were systematized [3]. Finally, an analytic chemical evaluation of fire hazardous авария modes, in overload and short circuit (including metal and partial contacts) scenarios for single and bundle cable systems, from the transition resistance, insulation aging and aggressive environmental exposure perspectives was performed in a manner illustrative of ignition probability. In support of this, the empirical “eight degree” rule was then examined to determine the mechanism of how insulation degrades under thermal stress and determine the part moisture and chemically aggressive atmospheres play as a secondary factor that accelerates conductive path formation and leakage currents. Simultaneously a materials based assessment was carried out comparing polymer insulation systems widely used in cable manufacturing—PVC compounds,

polyethylene, cross linked polyethylene and modern thermoplastic elastomers—with respect to flame resistance, smoke formation, toxicity and operational reliability under conditions of fire extinguishing. Eventually, an element of practical verification was presented in the form of an experiment showing the risk of electrical failure when water comes into contact with mica tape protected fire resistant cables, which allowed a comparison of the benefits of ceramized silicone insulating material in ensuring continued integrity of the circuit during fire suppression.

Result and Discussion

The term “fire hazard” of cables and electric cables describes three main fire dangerous manifestations of electric current:

- the ability of a cable network to become a source of fire in certain авария situations (short circuit, overload, etc.) (burning of its own insulation, and then burning of supporting structural elements);

- the ability of the insulation of electric cables to spread flame when a fire occurs from external sources;

- the ability to form molten parts of conductor metals during a short circuit [4].

If we consider the reasons for the most widespread occurrence of fires that may occur in electric cable networks, they are the result of overload and short circuits.

Overload is a type of авария operating mode in which, as a result of consumers being connected to electric cables, the nominal current value allowed for the cross sectional surface of a certain conductor (according to heating conditions) is exceeded. If the overload is large, the duration of the operating mode (until the protection operates or before the electric cable burns) can be equated to the duration of a short circuit.

A short circuit is the contact of current carrying parts that is not предусмотрено under normal operating conditions, connected to different phases or having different potentials (grounded, objects connected to ground, and neutral electric cables). Usually, at the point of contact, a certain transition resistance formed as a result of a loose contact, a large oxide film, burnt insulation, and others appear. This type of contact is called a partial contact. In some cases, transition resistances are so small that they can almost be ignored. Such contacts are called metal contacts. In a metal short circuit and in protection, the fire hazard is caused by the burning of insulation at any point of the electric cable due to the significantly large magnitude of the short circuit current.

Unlike metal short circuits, partial short circuits lead to fires even with properly selected protection, because the resistance of the damaged area limits the current and keeps it at a level insufficient for the protection to operate [5]. The occurrence of fires in electric cable networks mainly arises as a result of the formation of short circuits or excessive voltage.

Grounding may be carried out directly through the ground or through equipment, tools, and devices connected to the ground, for example, through water pipelines, heating systems, metal trestles, and others. These contacts can be especially fire hazardous if the length of the formed grounding circuit is large and it is located in zones

of rapidly flammable materials (warehouses, agricultural buildings, oil and gas storage facilities, and others). In such a case, the fire hazard increases because the current is limited due to the high resistance of the contact circuit and does not lead to the operation of protection. The main causes of the occurrence of short circuits are the aging of insulation materials under thermal effects, overvoltages of the electrical network, mechanical damage, and the destruction of the insulation of current carrying parts during installation and operation due to the aggressive influence of the environment.

Thermal aging of insulation most often occurs due to overloading of the electrical network, when the amount of current passing through the cross section of a certain conductor exceeds the permissible value for a long time. The relative service life of insulation is determined by an empirical (“eight degree”) rule, according to which an increase in conductor temperature by 8°C shortens the service life of insulation by two times. Aging of insulation is characterized by a decrease in its elasticity and mechanical strength. As a result, insulation may be punctured under electrical influence and electrical equipment may be damaged, and in the presence of combustible insulation and fire hazard, a fire or explosion may occur.

Overload phenomena occur when the permissible cross section of current carrying electric cables is incorrectly calculated, or due to additional connection of consumers not предусмотрено in the design, mechanical overload of the shaft, partial phase operating modes of motors, and a decrease in network voltage [6]. Mechanical damage to the insulation of electric cables most often occurs due to careless installation (pulling electric cables through walls, partitions, and others without observing the relevant rules) or improper use (lack of protection of electric cables from mechanical impacts in the operating zone of moving equipment, etc.).

Under certain conditions, the influence of moisture and an aggressive environment significantly worsens the condition of the insulation of electric cables. Under the influence of moisture, a conductive layer forms in the insulation and heating appears in the cable network under overvoltage. As a result, the polymer layer evaporates from the generated heat and salt traces remain in the insulation. When evaporation stops, the overvoltage heating disappears. When the moisture effect is restored, the process is repeated and conductivity increases due to an increase in salt concentration. As a result of constant repetition of the process, after evaporation the leakage current does not stop, but, on the contrary, the smallest sparks appear.

The described processes of insulation destruction are especially intensified in an aggressive environment, that is, when acids or ammonia vapors are present in the atmosphere (for example, in cattle sheds). In this regard, we will consider measures to reduce the fire hazard of cable networks and electric cables, where fire safety is ensured provided that the following basic requirements are observed [7]. It is required to correctly select the type of cable networks and electric cables and the method of their laying, the compliance of the type of electric cables and the electric cables, cables, and pipes used with the permissible methods of laying supporting bases and structures, and to correctly select electrical protection.

In addition, in the design and installation of electric cables, strict compliance with general fire prevention requirements is necessary, the cable and electric cables must meet all requirements of the surrounding conditions, the convenient laying of cables that helps to quickly limit the fire source is required, and when laying protected electric cables with a sheath consisting of combustible and unprotected electric cables in an open method, the air gap between the electric cable and the nearby bases, structures made of combustible materials, and spare parts must be at least 10 mm. It is allowed to separate the electric cable from the specified surface with a layer of non combustible material protruding at least 10 mm from each side of the electric cable.

If it is not possible to provide the specified gap, the electric cable must be protected on all sides by a continuous layer of non combustible material (for example, an asbestos board with a thickness of at least 3 mm; plaster, alabaster, or цемент mortar with a thickness of at least 10 mm). Of course, in this regard, it is required to conduct research to further improve this work.

How do polymer materials affect the quality of cable products? In the CIS countries, the main raw material for the production of flame resistant polymer materials is polyvinyl chloride (PVC) mixtures [8]. This is a polymer of vinyl chloride, which, in turn, is formed as a result of chlorination of ethylene obtained as a result of pyrolysis of petroleum distillates. In the cable industry, a PVC compound based on PVC resin is used, to which plasticizers, stabilizers, special fire resistant agents, other modifiers, and sealing substances are added. Naturally, traditional rubbers based on natural, isoprene, and styrene butadiene rubbers were widely used for insulation and sheath, and widely распространено electric cables and cables designed for voltages up to 25 kV.

Among the protective (cover) sheaths of cable products, it is necessary to note the use of a number of polar rubbers that are distinguished by high chemical resistance to the effects of petroleum products and other aggressive environments. Chloroprene, and later nitrile rubber, began to be widely used as a sheath from the середина of the 20th century (telephone, mine, oily underwater, and other electric cables). However, their consumption level has not increased over the last 10–15 years, because they are lower in heat resistance compared to relatively new sheath compounds based on chlorinated and chlorosulfonated polyolefins, as well as rubbers containing silicon and fluorine [9]. Today, the main polymer materials for the production of cable products in the world are polyolefins.

At the same time, in the cable industry of Russia and the CIS countries, PVC plastics remain the most widespread (more than 60% of the total volume of polymers consumed), followed by polyethylene compounds (only about 37%, including: low density polyethylene (LDPE or LDPE) 21%, high density polyethylene (HDPE or HDPE) 9%, and cross linked compositions 7%). In order to ensure the stability of the material properties achieved in the production of electric cable pipes, their networks, and in cable testing, the polymer material must have high quality and the production process must be stable.

Polyolefin insulation has a very valuable set of properties: very high dielectric characteristics over a wide temperature range, chemical resistance, significant heat

resistance, strength, low specific weight, and others. Among the polyolefins used in electrical engineering, polyethylene compositions have been successfully introduced (power and other cables, many traditional rubber and impregnated paper insulation). Approximately 10% (\approx 5 million tons) of the polyethylene produced in the world, including low and high density as well as linear grades, is used for the production of a wide range of cable compounds.

At the same time, polyethylene insulation of manufactured cables has some disadvantages, the main ones being degradation and a sharp deterioration of mechanical properties up to the loss of dimensional stability at temperatures close to the melting point (125–130°C). These properties are explained by the linear structure of polyethylene macromolecules [10]. Therefore, creating a three dimensional structure by forming cross links between polymer macrochains (that is, cross linking) makes it possible to improve the individual properties of the material. The main advantage of cables insulated with cross linked polyethylene is an increase in current carrying capacity due to an increase in the permissible core temperature. Depending on installation conditions, the permissible current load is 15–30% higher than that of a cable with oil impregnated paper insulation. The use of cross linked materials makes it possible to obtain insulation with improved operating characteristics: the long term permissible heating temperature of conductive cores (TCC) with thermoplastic insulation increases by 20°C and reaches 90°C. In addition, in emergency mode the heating temperature of cable networks increases from 80°C to 130°C, and during short circuit currents the permissible maximum electric cable temperature increases from 130°C to 250°C.

According to the cross linking method, three types of cross linked polyethylene are known: radiation, peroxide, and silanol cross linked [11]. For insulation intended for voltages up to 400 kV, peroxide and radiation cross linked polyethylenes are considered the most widespread. However, at present, in global cable technology, priority is given to the so called “silanol process,” that is, cross linking based on a chemical reaction between organofunctional groups containing silane grafted onto polyethylene macromolecules. It is important that the bonding between polymer macrochains through the Si O Si cross bridge is more stable than the bonding formed during peroxide and radiation cross linking, since the energy (strength) of the Si O bond is relatively 780 J/mol, compared with the energy of the bond in C C substances (630 J/mol). The above determines the high heat resistant properties of silanol cross linked polyethylene insulation.

Increasing the heat resistance of cable networks, as well as improving the physical and mechanical properties of cable insulation, is due to its thermal stability and resistance to the external environment, and it is also considered an environmentally clean method requiring less capital investment compared with peroxide and radiation methods [12]. Polyethylene compositions are considered to have long term prospects in the production of electric cables and cables for various purposes.

In 1998, at a congress of the International Cable Manufacturers Federation held in Istanbul, which united more than one hundred major cable companies from 51

countries of the world, it was emphasized that the cable industry must protect the environment. The main attention was focused on significantly reducing the use of PVC materials, as well as on the use of cadmium and lead. The European Union has already adopted a number of laws imposing restrictions on the production of such cables, in particular, the European Union Directive No. 2002/95 prohibiting the use of hazardous substances in PVC plastics. New generation electric cables meet modern requirements by maintaining flame resistance, with reduced smoke formation in insulation and reduced emission of hydrogen chloride toxic gases, in the forms of cable insulation (“ng LS” and “ng FRLS”). In addition, in order to improve the quality of cable products and adapt them to modern requirements of international standards, work is being carried out in Russia to create and develop plastic compounds with non toxic stabilizers (based on Ca Zn compounds).

World experience in the production and operation of electric cables and cables using thermoplastic elastomers is very limited, since foreign manufacturers began using this class of polymer materials approximately 30 years ago. The first example of using TPE was the replacement of the sheath material of geophysical cables, namely chloroprene based rubber, with thermoplastic polyurethane [13]. Since the 1990s, thermoplastic elastomers based on polyurethanes, polyolefins, and copolyesters have begun to be used for commercial purposes in certain types of cable products. Relatively inexpensive types of TPE, based on dynamically vulcanized (Santoprenes) and styrene block copolymers (Tefablocks), are currently very widely used in the production of automotive electric cables and telecommunication cables, as well as power and other types (listed below), instead of thermosets, namely rubbers (chloroprene, chlorosulfopolyethylene, ethylene propylene diene, and others) and PVC plastics (Table 1).

Table 1.

Flame Resistant Cable Classes

Type of Cable Products	Insulation Grades	Insulation Indicators	Additional Markings for Insulation
Flexible, spiral electric cables and cables	San 261-87 and 451-87	San 251-87 and 251-80	UL 62 flexible wire, SEO, SEOW
Test electric cables and cables	San 453-45	San 453-45	UL 1277, CSA jacket approval, ICEA 82-552
Submersible cables	San 261-87	San 101-80	UL submersible pumps
AWM cables	San 451-87 and 453-45	San 451-87 and 453-45	UL AWMmisc
Automotive industry	San 251-92 and 453-45	—	SAE J1128, types GPT, PVE; SAE J1127, type SGE

Notes: In the designation of Santoprenes, the 1st digit indicates the color (1 = black, 2 = natural); the 2nd digit indicates the application areas (0 = general purpose, 1–9 = special grades, including 5 = non flammable; the 3rd digit indicates Shore hardness: on the A scale (1) and on the D scale (3)).

Thus, using this method, the TPE production process consists of two stages: 1) mixing the elastomer and the thermoplastic in a high speed mixer at a temperature 20–30°C higher than the melting point of the plastic until a melt is formed; 2) subsequent introduction of the vulcanizing agent and mixing until the electric cables reach tackiness.

Today, a wide range of thermoplastic elastomer materials with various important performance properties is being produced. Despite the growing interest in this type of polymer materials worldwide in recent years, the industrial scale production of various types of TPE and the production technology at Russian enterprises have not developed to the level we would like [14]. This is due to a number of reasons. First, due to the specific features of the synthesis technology itself and the need for special equipment, and second, due to the low level of development of the domestic market for the consumption of these materials.

Polyvinyl chloride plastic has been used for insulating electric cables, and polyethylene has been used for insulating telephone cables. Fire statistics show that to this day more than 50% of fires are malfunctions related to electric cables and cables. Thus, in 2008, 64.2% of the total number of fires caused by malfunctions in electrical equipment were related to cables and electric cables.

The study of a polyvinyl chloride plastic compound for flame resistance showed that, compared with polyethylene, polyvinyl chloride is a self extinguishing material. The reason is that half of the polyvinyl chloride molecule is chlorine, and chlorine not only does not support combustion, but also does not spread flame.

Based on this, low voltage electric cables and power supply circuits, as well as electric cables for internal wiring, began to be produced primarily with insulation and sheath made of polyvinyl chloride plastic, and GOST 12176-76 was introduced, which standardizes the requirement to test cables for flame propagation during single installation. At approximately the same time, in various countries of the world, several major fires occurred in places with large numbers of people, such as concert halls, dance halls, supermarkets, as well as in industrial enterprises with automated control systems connecting remote network facilities by channels [15]. This was due to the fact that electric cables widely used at large hazardous industrial facilities, aerodromes, and thermal power stations were not sufficiently covered with flame resistant sheaths.

Analysis of the causes of fires showed that the requirement for non propagation of fire during single installation does not ensure safety if a large amount of combustible mass is accumulated in a cable bundle. The method of protecting cable bundles with special mastic layers was unsuccessful: the mastic application technology worked with very low reliability and was extremely labor intensive (over time, the mastic cracked and crumbled, which led to the need to apply a new layer of mastic after several years).

In order to solve this problem, in a number of countries a polyvinyl chloride plastic compound was developed, which ensures that the cables do not burn out when laid in a bundle with a combustible mass of electric cable amounting to 7 liters per meter. A characteristic parameter for such materials is the oxygen index. The oxygen index was determined in accordance with GOST 12.1.044-18. “The oxygen index is

the minimum oxygen content in an oxygen nitrogen mixture at which, under special test conditions, a material can burn with a candle like flame.” In the CIS, compositions of high quality polyvinyl chloride plastic compounds were also developed, which obtained the classes NGP 30-32 and NGP 40-32 with an oxygen index of 32.

The solved problem addressed only part of the problems that arise when cables burn during a fire. Another problem was the release of smoke during the burning of polymer elements of electric cable networks and the toxicity and release of halogens during flame exposure. The reason is that, according to fire statistical data, in many cases people’s deaths were caused not by burns, but by poisoning with combustion products inhaled through the respiratory tract. To solve this problem, halogen free polymer materials were developed in a number of leading European countries. On the basis of such materials, the absence of halogens sharply reduced the share of halogen containing acids in combustion products, but at the same time made it more difficult to achieve the required non propagation of flame, smoke release during flame exposure, and its toxicity.

In the Russian Federation, based on the traditional use of polyvinyl chloride plastic compounds in a number of cable networks (for example, cables for use in hazardous areas must have insulation and sheath made of a polyvinyl chloride plastic compound or rubber, according to Clause 102 of the Electrical Installation Rules (PUE)), they proceeded along the path of improving the polyvinyl chloride plastic compound. The obtained materials turned out to be close in fire safety level to halogen free polymer compositions, except for the requirements for the release of halogen containing acids during flame exposure, which limits their use in premises containing electronic equipment.

GOST R 53315-2009 developed technical requirements for cables with core insulation and sheath in cable networks. Cables made of halogen free polymer compositions, and cables made of a polyvinyl chloride plastic compound with reduced smoke and gas emissions, having insulation, sealing compound, and sheath, were recognized as a polyvinyl chloride plastic compound that reduces fire hazard. One of the most widely used fire extinguishing agents is water. At the same time, in explosive zones, water is often used during a fire to cool technological equipment and containers for storing explosive liquids and gaseous substances.

The stable operation of facilities is hindered by the wear of almost most of the electrical networks (60%), which is often the cause of fires. All of this leads to an increase in fire hazard and to the occurrence of fires in buildings and structures. Therefore, the issue of protecting electric cable networks from fire is considered a relevant direction for further research.

The paired insulated section was immersed in water. The measured resistance between the cores approached zero. This experiment shows that if, during the fire extinguishing process, water gets onto a fire resistant cable, where fire resistance is ensured by wrapping with glass mica tapes, then, in the most general case, a short circuit of the conductors occurs through the water and the operational requirement is violated. From this point of view, fire resistance ensured by silicone ceramized

insulation will be useful. In order to ensure the elimination of fires and, by identifying factors that negatively affect the operational capability of facilities and taking into account preventive measures, it is necessary to analyze the consequences of fires at facilities, carry out a comparative analysis of fires in buildings and structures based on mathematical modeling, and develop the theoretical foundations for continuously reducing the fire hazard of buildings and structures under the influence of fire and its dangerous factors through fire detection.

Conclusion.

The analysis carried out in this mode proves that electric cable networks have at the moment remained one of the most important causes of fire hazard in multiple stores and items of estate, and what is most significant, for overload modes and short circuits (both on metal and partial contacts), transition resistance which does not hold back the act of protective devices in time, prevails. The results demonstrate that thermal aging, moisture and strident conditions noticeably accelerate insulation damage and decrease mechanical strength, increase leakages currents, and generate sparking settings that can promote sparking, even under normal exploitation. The polymer composition of insulation and sheath materials is shown to strongly influence the fire performance of cable products, with the more typical polyvinyl chloride compounds being self extinguishing but restricted under fire condition due to halogen acid content, whilst halogen free and low smoke formulations offer superior environmental performance under exposure to fire. Additionally, experimental observation of the fact that when opposed to inter core resistance of mica tape protected fire resistant cables, water contact can reduce to near zero, it indicates a potential extreme operational hazard during firefighting situations, suggesting that an insulation system capable of withstanding water based suppression whilst maintaining electrical integrity is required (e.g. silicone ceramized materials). Such findings are of importance to practice to develop and to seek improved cable selection and installation requirements and fire prevention strategies in high risk facilities, especially in facilities with an increased incidence of aging electrical infrastructure. Additional efforts are needed for establishing harmonized formulations of fire resistant polymer minimizing toxicity, studying the behavior of cable bundles in real fire events, and enhancing mathematical modeling of fire propagation in cable systems for evidence based regulatory and engineering decision making.

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