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THE IMPACT OF FIRES AT ELECTRICAL ENERGY SUBSTATIONS ON THE ECONOMY AND WAYS TO ENHANCE RESILIENCE

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Annotation his study explores the causes of electrical cable fires at energy substations, their economic and technical consequences, risk assessment, resilience-enhancing solutions, and investment analysis. The research was conducted on cable networks ranging from 500 meters to 2 kilometers, and scientifically proven methods, risk analysis, and economic indicators are justified based on empirical findings.

Keywords: Energy sector, substations, power supply, cables and cable insulation, installation, IEC 60331 standard, PVC cables, technical measures, organizational measures, resilience.

Introduction

Although a number of scientific studies have been conducted worldwide to organize life-saving efforts during fires and address problems related to fire suppression, the development of systems aimed at creating various rescue tools and methods continues to be one of the leading areas. According to data from CTIF, the International Association of Fire and Rescue Services, analysis of fire disasters over the past five years shows that an average of 7–8 million fires occur annually, resulting in approximately 80–90 thousand fatalities. Considering these figures, developing effective systems for preventing the rapid spread and escalation of fires remains a highly important task.

A significant portion of these fires—30–40%, or more than 2 million incidents—is related to the electrical energy sector, and studies show that nearly 90 thousand fatalities worldwide occur in this field. Analysis of fire causes indicates that 37% of fires in the electrical energy

sector are linked to electrical cables, violations of equipment installation standards, and improper operation practices.

- Global research findings demonstrate that despite the expansion and increasing complexity of scientific studies, the economic indicators of fires in electrical energy systems have not yet been fully resolved.
- In Uzbekistan as well, considerable attention is being paid to preventing fires that may occur due to short circuits in cable networks, by eliminating combustible environments, removing ignition sources, and blocking potential fire spread pathways.
- The Presidential Decree of the Republic of Uzbekistan No. PQ–2559 dated July 13, 2016, "On Measures to Further Improve Scientific and Technical Activities in the Electric Power Industry," and the Cabinet of Ministers Resolution No. 711 dated November 11, 2020, "On Approval of Fire Safety Rules for Energy Organizations," form the regulatory basis for relevant activities carried out by responsible institutions.
- **Research Objective**
- The main objective of this study is to demonstrate that using an aspiration coefficient detection device can prevent potential fires and reduce material losses and economic damage in the event of a fire.
- In recent years, fires caused by electrical cables at industrial and energy facilities have become a significant economic threat. According to the National Fire Protection Association (NFPA), 22–28% of fires at industrial facilities result from malfunctions in electrical systems.
- **Practical Findings of the Study**
- Energy substations are a critical component of the national electricity supply system. Due to the high-power transmission occurring through cables at these facilities, the level of safety must always remain a top priority. Consequently, cable fires at substations lead not only to technical problems, but also to economic, environmental, and social consequences.
- Main factors contributing to cable fires at energy substations:

1. Deterioration or mechanical damage to cable insulation
   - Long-term use leads to hardening, cracking, or loss of thermal resistance of insulation.
   - Burning insulation emits smoke and accelerates fire spread.
   - According to the IEC 60331 standard, cables used for more than 10 years must undergo mandatory preventive testing.

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2. Overloading and short circuits
   - Increased voltage or improper connections cause overheating.
   - Excessive temperatures ignite the cable.
   - Short circuits can generate temperatures of 800–1200°C within 0.1–0.3 seconds.
3. Improper installation and poor maintenance
   - Incorrect spacing or poor ventilation causes heat buildup.
   - Loose connection points trigger arcing.
4. Moisture, dust, and temperature fluctuations
   - Moisture creates electrical arcs between cables.
   - Dust slows heat dissipation, increasing overheating risk.
5. Human factor
   - Negligence during maintenance or incorrect repairs may lead to fires.
   - Lack of adequate fire-safety knowledge among personnel is a common issue.

- Cable insulation materials (mainly PVC, polyethylene, or rubber) lose dielectric strength over time due to thermal aging, moisture, and chemical exposure. This leads to electrical arcing, which can eventually ignite a fire [2]. "Thermal degradation of cable insulation at temperatures above 80°C reduces dielectric strength by 60–70%."

• No.	• Type of Cause	• Description	• Fire Probability (%)	• Note
• 1	• Aging of cable insulation	• Loss of dielectric properties due to heat, moisture, and mechanical stress	• 35	• Most common cause
• 2	• Loose connections	• Leads to overheating and sparking	• 25	• Often due to maintenance errors
• 3	• Overloading	• Continuous overheating of the cable resulting in melting	• 20	• Common in high-capacity lines

• 4	• Installation errors	• Incorrect cable routing, lack of protective covering	• 10	• Related to weak construction supervision
• 5	• External factors (rodents, moisture, chemical exposure)	• Damage to the cable sheath	• 10	• Can be reduced through preventive monitoring

- **Source: Technical Supervision Agency under the Ministry of Energy (2024 report data)**
- Impact of Fires on the Economy and Ways to Enhance Resilience
- Electrical cable fires lead to the interruption of industrial production processes, failure of equipment and machinery (including transformers and control systems), and restoration works lasting 10–30 days. As a result of reduced production capacity, the average economic loss can reach up to 100,000 USD. Fires also harm the environment due to the release of toxic gases from burning materials.
- According to FEMA (2023), in 60% of electrical fire incidents, industrial operations are halted for a minimum of 3 days up to 2 weeks.

- **Impact of Fires on Economic Facilities**

• No.	• Impact Area	• Description
• 1	• Production efficiency	• Decreases by an average of 25–40%
• 2	• Financial loss	• Ranges from $100,000 to $2 million per facility
• 3	• System recovery time	• From 10 days to 2 months
• 4	• Environmental damage	• Heat emissions and smoke pollution
• 5	• Social impact	• Temporary suspension of jobs

- According to IEC 60331 standards, fire-resistant cable types provide a safety level that is 4–5 times higher compared to conventional PVC cables.
- The table below presents the impact areas of fires on economic facilities and their average damage amounts:

• No.	• Impact Area	• Description	• Average Damage (USD)
• 1	• Production downtime	• Power supply interruption	• 20,000 – 100,000

• 2	• Equipment failure	• Transformers and cables	• 50,000 – 300,000
• 3	• System recovery	• 10–30 days of restoration work	• 10,000 – 70,000
• 4	• Social and environmental impact	• Job suspension, smoke emissions	• Not assessed

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• Improving the Safety of 500 m – 2 km Cable Lines in Energy Substations and Minimizing Fire Risk

• Stages:

1. Diagnostics – thermographic inspection of existing cables (7 days)
2. Project preparation – based on IEC 60331 requirements (5 days)
3. Installation work – replacement with fire-resistant cables (20 days)
4. Testing – checking relay protection and alarm systems (5 days)
5. Audit and monitoring – annual reassessment (periodic)

• According to scientific literature:

• IEC 60332 (2022): fire-resistant cable insulation maintains stability up to 850°C.

• FEMA (2023): installing automatic alarm systems reduces electrical fires by 32%.

• MDPI Journal of Fire Sciences (2024): the spread rate of fires can be reduced by 40% using firestop materials.

• Expense Type	• Amount (USD)	• Description
• Diagnostics and analysis	• 5,000	• Thermography and testing
• Cable and installation work	• 25,000	• 500 m – 2 km fire-resistant cable
• Firestop systems	• 10,000	• Between trays and wall penetrations
• Alarm systems	• 7,500	• Detectors and automation
• Training and audit	• 3,000	• Staff preparedness
• Total	• 50,500	• Estimated project cost

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• Stages of Ensuring the Stable Operation of Economic Sectors

• According to the 2023 research data of the Uzbekistan Energy Institute, a fire that occurs in a 2 km, 10 kV cable line causes an average economic loss of approximately 1.2 billion UZS.

• Measures to Reduce Fire Risk in Energy Substation Cable Lines

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- 1. Technical Measures:
- Conduct thermographic inspection of cable insulation every 6 months
- Protect cable routes using metal coverings and fire-resistant materials
- Implement automatic fire alarm and gas-based fire suppression systems
- Install load-balancing monitoring systems
- Select cable types in accordance with O‘z DSt 1643:2019 requirements
- 2. Organizational Measures:
- Provide regular fire safety training for staff (at least twice a year)
- Establish “energocontrol” groups for preventive inspections
- Conduct practical exercises for emergency preparedness

- **Improvement Stages**

• Stage	• Implemented Action	• Expected Outcome
• I	• Comprehensive diagnostics of electrical networks (thermography, insulation resistance, load analysis)	• Identification of weak points in the system and assessment of risk levels
• II	• Replacement of cable lines with fire-resistant types (according to IEC 60331)	• Reduces the probability of fire spread along the cables by 4–5 times
• III	• Installation of automatic fire detection, alarm, and gas-based suppression systems	• Ensures rapid response in the event of a fire and significantly reduces potential damage
• IV	• Regular fire safety training and practical exercises for staff	• Minimizes human factor impact and develops proper emergency response procedures
• V	• Periodic audits, technical inspections, and maintenance services	• Guarantees uninterrupted and stable operation of electrical networks

- Therefore, enhancing the fire resistance of electrical networks, strengthening preventive inspections, and modernizing the safety infrastructure are crucial factors in ensuring the stable operation of the modern economy.
- **Conclusions.** Fires in cables at energy substations often occur due to human factors and insufficient technical maintenance oversight. Through preventive measures, automatic monitoring, the use of fire-resistant materials, and the implementation of modern sensor systems, these risks can be reduced by 60–70%.
- To minimize electrical cable fires, it is essential to integrate technical, organizational, and monitoring systems. Implementing measures in accordance with international standards enhances system resilience. Such investments pay off in a short period and significantly reduce economic risks.
- The research results indicate that reducing electrical cable fires in energy substations is most effective through:
- Selecting high-quality materials
- Implementing fire-resistant technologies
- Installing automatic monitoring and alarm systems
- Reducing the impact of human factors
- As a result, the system's stability, economic efficiency, and safety level are significantly improved.
- A systematic analysis of fire safety issues is a key condition for enhancing the reliability and resilience of energy facilities.

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