fire

MDPI

Article

Methods of Extinguishing Fires in Objects with High Voltage

Miroslav Betuš *, Martin Konček, Marian Šofranko, Jozef Čambal and Marek Ondov

Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Košice, 040 01 Košice, Slovakia; martin.koncek@tuke.sk (M.K.); marian.sofranko@tuke.sk (M.Š.); jozef.cambal@tuke.sk (J.Č.); marek.ondov@tuke.sk (M.O.)

* Correspondence: m.betus@centrum.sk; Tel.: +421-917-433-352

Abstract: In this study, based on a real fire in an object intended to produce electricity, the method of fire extinguishing by fire protection units with components of the Integrated Rescue System was characterised. The goal was to examine the effectiveness of extinguishing the mentioned type of fire in cooperation with other components of the Integrated Rescue System and the effectiveness of the intervention, where the priority task was the rescue of people from a fire-endangered building with forces and resources deployed in the vicinity of the fire. In the study, the time factor of the arrival of individual components, material and technical equipment, and security was also considered and, based on calculations, the possibilities of the starting units to extinguish the fire and ensure the evacuation of people in the building. Subsequently, after evaluating and examining all possibilities, conclusions were chosen and determined from the results at the place of the intervention and recommendations were defined for future fires in similar objects.

Keywords: firefighter; fire; building; Integrated Rescue System

check for updates

Citation: Betuš, M.; Konček, M.; Šofranko, M.; Čambal, J.; Ondov, M. Methods of Extinguishing Fires in Objects with High Voltage. *Fire* **2023**, *6*, 442. https://doi.org/10.3390/fire6110442

Academic Editor: Grant Williamson

Received: 12 October 2023
Revised: 15 November 2023
Accepted: 17 November 2023
Published: 18 November 2023

1. Introduction

Electric energy has become an integral part of our lives, and with the current trend of energy consumption growth, the demands for its production are also increasing. Because of these increased requirements, new power plant blocks or sources of so-called green energy arise when the global demand for electrical energy has increased sharply. However, most countries generate electricity using fossil-fuel thermal power plants, which continue to play a significant role in energy systems worldwide. The electrification system, which includes elements for the production, transformation, transmission, distribution and consumption of electrical energy, is thus constantly growing. From the point of view of operational reliability, a fire protection system is fundamental, where the central unit or parameter is electrical protection. Its task is to determine, based on specific input values, information and set parameters, whether these objects are in an operational (permitted) state or a malfunction. A malfunction is understood as a short circuit, overload, overvoltage, asymmetric load, or reverse flow of power [1–6].

High-voltage overhead electrical transmission lines can be characterised as one of the cheapest and most efficient methods of electrical energy transmission, where their safe and continuous supply of electrical energy is vital for public services and users [7].

However, many errors disrupt high-voltage transmission lines, transmission line objects, and the transmission network itself. In many countries, fires under transmission lines are caused by many errors. For example, in South Africa, 1699 errors with fire were recorded, representing about 21% of all areas in 1993–2003 [8,9].

In Brazil, high-voltage transmission lines also suffered many failures, resulting in large-scale fires. Also, in China, long-distance high-voltage lines caused failures and subsequent fires. Research into the failure mechanism in these devices and measures to prevent them is crucial for supplying electrical energy. Research focuses as well on the mechanism of decomposition during fire. Due to its dielectric properties, the air is an insulating medium between the high-voltage line and the ground in the transmission line system. During a fire, the properties of the air change and a discharge or breakdown occurs where the first flame causes the breakdown due to the conductive properties present in the air gap. The second phase begins that the fault is caused by the reduced air density resulting from fire heating, and the third phase suggests that small smoke particles present in the fire cause distortions in the electric field that induce flashover [10–13].

Particles that occur in the air gap reduce the breakdown voltage by shorting part of the gap, but this effect is not significant for large air gaps (~10 m) in HV transmission lines. It is believed that the first and second phases are primarily responsible for fire-induced failures in HV transmission lines [14–16].

The issue of transmission line fires and related objects attracts the interest of many researchers, some of whom have already undertaken a lot of work, including the mechanism and analysis of firefighters' interventions, monitoring the fire itself, etc. [17].

For example, A. Robledo-Martinez et al. studied the dielectric characteristics of a model transmission line in the presence of fire [18].

Sukhnandan et al. discussed different flash models under different fire conditions. Li Peng et al. studied the dielectric characteristics of the transmission line gap under fire conditions [1,19].

When it comes to the method of evaluating the dispatch of fire brigades, some researchers presented some calculation methods. Fire hazard warning methods for transmission lines have been discussed in the research of Guo et al., Wu, Y. et al., Shi, S. et al. and others [20–26].

From the point of view of monitoring and analysing the spread of fire, a fire warning method based on satellite monitoring near the transmission line was proposed in the publications [15,27–29].

Regarding the earlier papers, their research only focuses on fire warnings for transmission lines. However, there needs to be an overall strategy for controlling fires near high-voltage transmission lines and their facilities. The difficulty and challenge in the field of fire protection in the mentioned objects lies in the fact that:

- Transmission lines work with high voltage, and firefighters are exposed to the risk of electric shock when extinguishing. Near the high-voltage transmission line, there is no effective fire extinguishing method that would ensure the safety of firefighters when extinguishing the fire;
- Fires near transmission lines and their facilities require timeless fire protection requirements [30–33].

2. Materials and Methods

2.1. The Current State of the Issue

Figure 1 and Tables 1–3 show the current state of the transmission system of the Slovak Republic.

Table 1. External electrical lines—lengths of lines (source: elaborated by authors).

Voltage (kV)	Simple (km)	Double (km)	Multi-System (km)	Completely (km)	Deployed Length (km)
400	1373.533	472.858	18.678	1865.069	2356.604
220	409.686	140.188	0.000	549.874	690.062
110	0.254	21.096	18.678	40.028	79.802
Overall	1783.473	634.142	37.356	2454.971	3126.468

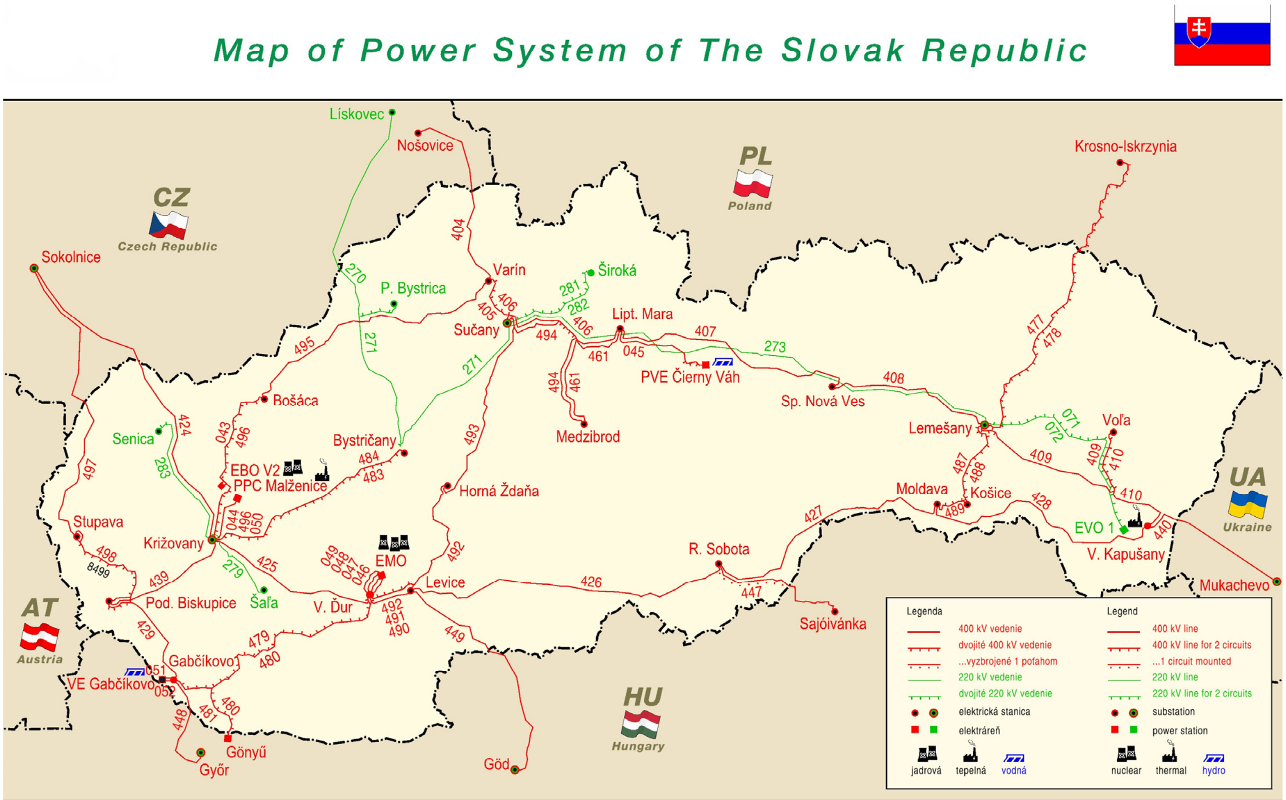

Figure 1. Map of power system of the Slovak Republic [34].

Table 2. External power lines—number of masts (source: elaborated by authors).

Voltage (kV)	Simple (pcs)	Double (pcs)	Multi-System (pcs)	Completely (pcs)
400	3958	1480	64	5502
220	1251	454	0	1705
110	1	81	0	82
Overall	5210	2015	64	7289

Table 3. Electric station (source: elaborated by authors).

Voltage (kV)	Number of Substations (pcs)	Number of Fields (pcs)
400	20	147
220	5	31
110	1	24
Overall	26	202

A fire in the vicinity of transmission lines and their objects is understood as an extraordinary event when a certain period elapses from the start of the fire to the failure of the transmission line. The transmission line may in time in case of fire should lead to broken circuit or failure. It is, therefore, essential to know the time from the fire's start to the transmission line's shutdown, which is important information for carrying out rescue operations in case of transmission line fires. It is assumed that the distance between fire and transmission line is d, and the average burning velocity of vegetation in the direction of the vertical transmission line is v_f, as shown in Figure 2 [35–37].

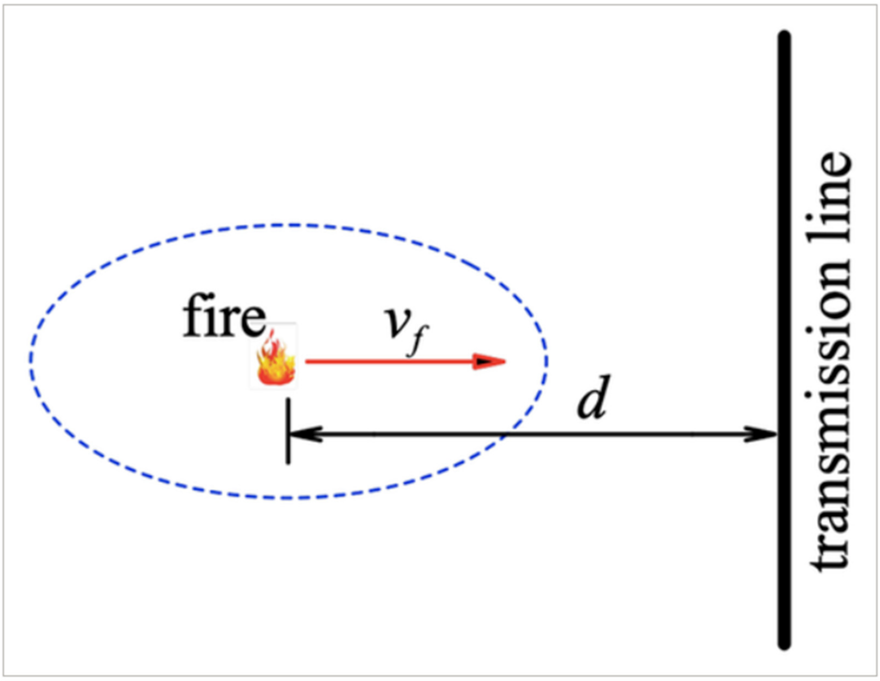

Figure 2. Description of fire spreading [38].

According to individual statistics, more than 78.6% of fires affecting transmission line objects are caused by power line breaks, which are generally far from rescue services. It takes a significantly long time for workers and fire protection systems to get the fire under control. Also, for this reason, the requirements for the timely rescue of transmission lines in case of fire are very high. It is, therefore, essential to detect the future risk of fire in advance and to deploy fire prevention measures, which requires an integrated control strategy for fire suppression [39–43].

A fire control strategy near transmission lines is proposed to avoid transmission line shutdowns caused by fires, as shown in Figure 3.

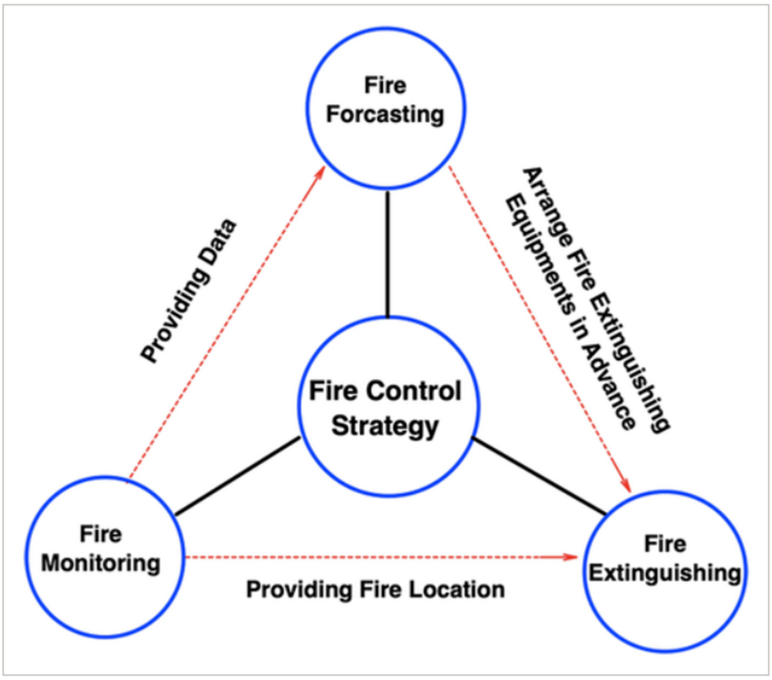

Figure 3. Control strategy for fires near transmission lines [16].

As shown in Figure 3, the strategy includes three key steps, which are:

1. Predicting the possibility of fire.
2. Fire monitoring.
3. Firefighting and rescue work [44–46].

The time and sequence of extinguishing a fire on a transmission line are shown in Figure 4. The fire risk in the vicinity of transmission lines can be clarified by the method of fire prediction, and then fire extinguishing equipment can be activated. In the event of a fire, these devices can, with high-quality monitoring in real-time, locate and subsequently eliminate the arising fire, i.e., reach the fire field in time. Finally, active systems can ensure that power workers can extinguish a fire safely and quickly under high voltage, thus preventing the line from being shut down without the risk of electric shock. These three basic steps are a particular whole, and have internal relationships with each other from fire prediction, the arrangement of active fire protection systems and shortening the reach distance of firefighting units [47–50].

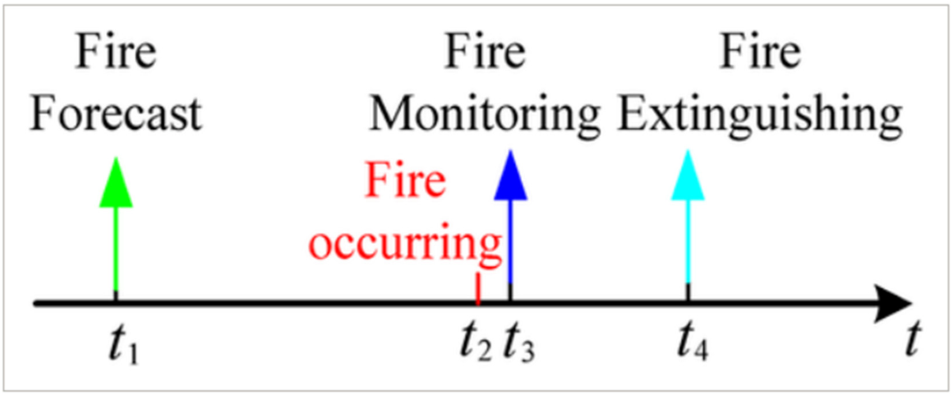

Figure 4. Transmission line fires rescue sequence diagram [16].

2.2. Methodology

The intervention occurred during a fire in the company's compressor station Eustream a. s., Veľké Kapušany, Energoblok E building (Figure 5).

Figure 5. Object Eustream a. s. (source: elaborated by authors).

The intervention was carried out by units from the District Directorate of the Fire and Rescue Service in Michalovce on 13 April 2023, from the fire stations in Michalovce, Veľké Kapušany, Sobrance and the volunteer fire brigade of the village Čičarovce.

The goal of the intervention was to eliminate the fire in the compressor station of the company Eustream a.s. Veľké Kapušany, in building number 201 (Figure 5), on the premises of the thyristor factory, connected with the evacuation of employees. In addition to the activities associated with extinguishing, evacuation and rescue, it is necessary to analyse the abilities and skills of the command during the intervention, the establishment of the command staff, and the management of forces and resources simultaneously with the coordination with the participating components of the Integrated Rescue System.

Operational-Tactical Characteristics of the Object

Object 201 Energoblok is part of a set of three construction objects (Figure 6):

1. Object 111—substation object.
2. Compressor hall E (object 201).
3. Building 171 Control room E.

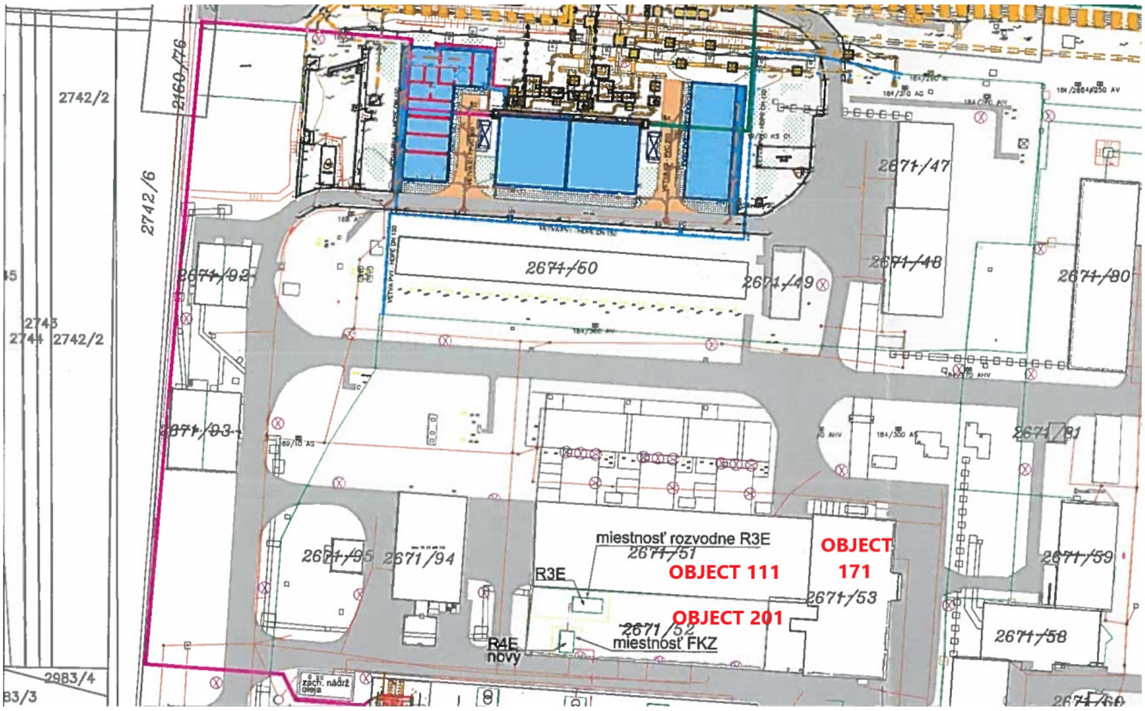

Figure 6. Location on the object on cadastral map (source: elaborated by authors).

These are combined into a monoblock. Energoblok is located on the south side of this monoblock. In the Energoblok are electrical devices that are functionally an intermediate link between the 110 kV substation and the electrical aggregate for powering the electrical station. It also contains air conditioning equipment for air conditioning in the electrical equipment rooms of building 201. The building is connected to the control room through communication and electrical lines. It is connected to the 110 kV substation by an overhead line and cable ducts in communication. It is connected to the object 111 by passage tunnels. The building of the Energoblok is a four-storey made of steel structures. The perimeter shell comprises gas silicate panels anchored to the supporting frame with steel brackets and fasteners. The roof and ceilings are reinforced concrete.

In a separate area of the control room on the level of the first above-ground floor, there is a spare source of electricity in hall E with an operating tank of 0.3 m^3 of diesel fuel. The stairwell connecting the individual floors of the control room building forms a separate fire section.

The Energoblok building is divided into five sections. On the individual floors, technological devices ensure the power supply of 3 units of electrical station E.

Oil condensers ES1 and ES2 are in a separate room (not separated from the fire) on the first above-ground floor. The condenser room ES1 has a dry transformer TR9 of the KS 22.4 kV backup power supply. Automatic electric fire alarm detectors protect the premises of the condensers. In addition to the condenser rooms, on the first above-ground floor, there is a cable riser of control cables leading from the external 110 kV substation to the Energoblok.

On the second above-ground floor, under the self-consumption substation, there is a cable space (not separated by fire). On the second floor, there is also a machine room of a stable gas (CO_2) fire extinguishing device by Karosa Vysoké Mýto, intended for extinguishing fires in the Eustream dungeons in hall E. The second floor is connected to the first floor of the Energoblok through mounting holes.

On the third floor, there is a high voltage (HV) cable area and a self-consumption substation. An above-ground cable bridge (non-separated by fire) leads to coolers and gas filters from the self-consumption substation. Entrances to individual cable rooms are equipped with fire shutters. Transitions of cable routes through fire separation structures are not sealed. Automatic EPS detectors protect all premises.

On the fourth floor, HVAC machine rooms are in two structurally separate spaces. The air ducts are equipped with fire dampers at the inlets and outlets. Automatic EPS detectors are installed in the rooms of the HVAC machine room. In two rooms (separated by fire), oil tanks are placed in emergency tanks, which are used to cool the ES.

In Figure 7, there is object 171, which is a control object.

Figure 7. Control room E (source: elaborated by authors).

On the first floor are warehouses, an HVAC machine room for the control room, an exchange station, an alternate source of electricity, and a gas boiler room.

On the second floor are workshops, electrical, cable room, UPS room and kitchen.

On the third floor, a cable area leads to the cable bridge, an electrical substation, air conditioning and warehouses.

On the fourth floor are control rooms for compressor halls E and T, electrical protection, social areas and offices. There is no permanent service in the control room. While the EPS Schrack switchboard of halls E and T is located there, the control panel of the Sieger gas detection system is also located here, and at the same time, the machine room switchboards of halls E and T are in the control room. All signals from the EPS and machine room switchboards are taken to control room no. 2, where permanent service exists.

3. Results

As a result of an electrical short circuit in the thyristor plant, a fire occurred in the cooling system of the equipment in which the oil is located. The EPS automatic detector signals to the operator in the control room that a malfunction has occurred in the given room and automatically switches off the electricity supply in the building.

During the inspection, one of the employees discovers that the room has been engulfed in fire, because of which the enclosed spaces will very quickly become heavily smoky. Because of this, he can no longer return to the control room and runs up the metal stairs to the roof of the building, reports the fire to the gatehouse and waits for rescue. An employee of the gatehouse reports the fire to the Integrated Rescue System line 112. Two other people are in the control room. One person is unconscious, and the other is disoriented. As a result of the short circuit, the electrical system in the control room building failed. The first unit from the Veľké Kapušany fire station will arrive after the alarm is announced. Based on initial information, the commander of the intervention requests additional forces and resources from the District Directorate of the Fire and Rescue Service in Michalovce and the Sobrance fire station, volunteer fire brigade Čičarovce and other components of the Integrated Rescue System through the operations centre of the Regional Directorate of the Fire and Rescue Service in Košice. Due to the considerable number of deployed forces and resources, the intervention commander establishes a control staff.

Based on the request, the members of the Police force are thinning the traffic at the turn-off from the state road no. 555 towards the Eustream plant. Extinguishing the fire in the closed spaces of the thyristor plant will take place with an extinguishing agent—heavy foam.

Water sources in the company are built through the fire water distribution. Above-ground hydrants are located near hall E. Water can be added to tank car sprinklers directly from a hydrant or by connecting to a fire water pumping station.

Access roads to the area are possible through several car entrances. The intra-campus roads are circular, reinforced, concrete, at least 3.0 m wide, and capable of withstanding a pressure of at least 80 kN per vehicle axle. Deploying mobile high-altitude firefighting equipment for firefighting is possible at every facility. No pipelines or conveyor bridges would limit the movement of firefighting equipment over the external intra-campus roads.

The access road to the intra-campus roads is located at approx. 600 m and connects to the state road no. 555 Michalovce—Veľké Kapušany—Kráľovský Chlmec.

The main tasks:

1. Search to determine the presence of persons at risk, possible hiding places, dangerous materials, paths of fire spread, the state of building structures, and possible emergency routes.
2. Carry out the evacuation and rescue of all persons at risk, ensure that the power is turned off, and take measures to remove heat and smoke (natural or forced ventilation).
3. Carry out the localisation and liquidation of the fire using a suitable extinguishing agent and additives to increase the extinguishing effects.
4. Use the optimal amount of supplied extinguishing agent regarding fire extinguishing efficiency (streamline P6).
5. Take measures to protect property from the foam used for extinguishing.
6. To improve cooperation in fighting fires in industrial buildings, members' skills in using ADP and providing first aid to injured persons are used.

Intervention sections:

1. Intervention section no. 1: searching for people, evacuating people, locating and extinguishing the fire and providing first aid to injured people.
2. Intervention section no. 2: searching for people, evacuating people with the help of high-altitude equipment and providing first aid to injured people.
3. Intervention section no. 3: Ensure the cooling of the gas coolers E and T hall and the ventilation of smoky areas.
4. Intervention section no. 4: performing air quality monitoring using detection technology.

3.1. Calculation of Forces and Means

Calculation of the free fire development time (t_{vr}) and the consequences of the event (Figure 8):

$$t_{vr} = t_{sp} + t_{oh} + t_{do} + t_{br}\ [\text{min}] \tag{1}$$

where:

t_{sp}—the time from the expected occurrence of the fire to the observation of the fire = 1 min,
t_{oh}—the time from observation to notification of fire = 2 min,
t_{do}—the time from the alarm alert to the arrival of the fire brigade = 6 min,
t_{br}—the development time = 3 min,

$$t_{vr} = 1 + 2 + 6 + 3 = 12\ \text{min}$$

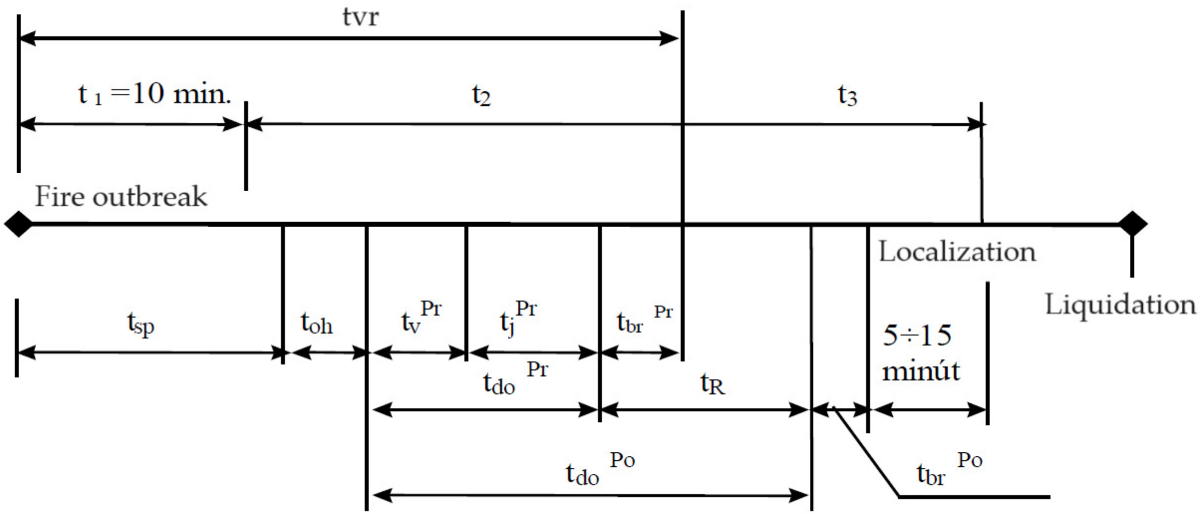

Figure 8. The free fire development time [51].

The arrival time of the Veľké Kapušany fire brigade:

$$t_{do} = t_v + t_j \quad [\text{min.}] \tag{2}$$

t_v—the dispatch time = 1 min,

$$t_j = (60 \times L)/v_j$$

t_j—the unit's driving time to the fire,
L—distance in km,
v_j—average vehicle speed in kmh^{-1} (45 kmh^{-1}),

$$t_j = (60 \times 4)/45 = 6\ \text{min},$$

$$t_{do} = 1 + 5 = 6\ \text{min}.$$

The arrival time of the DD FRS Michalovce fire brigade:

$$t_{do} = t_v + t_j \quad [\text{min.}] \tag{3}$$

t_v—the dispatch time = 1 min,

$$t_j = (60 \times L)/v_j$$

t_j—the unit's driving time to the fire,
L—distance in km,

v_j—average vehicle speed in kmh^{-1} (45 kmh^{-1}),

$$t_j = (60 \times 34)/45 = 45 \text{ min},$$

$$t_{do} = 1 + 45 = 46 \text{ min}.$$

The arrival time of the Sobrance fire brigade:

$$t_{do} = t_v + t_j \quad [\text{min.}] \tag{4}$$

t_v—the dispatch time = 1 min,

$$t_j = (60 \times L)/v_j$$

t_j—the unit's driving time to the fire,
L—distance in km,
v_j—average vehicle speed in kmh^{-1} (45 kmh^{-1}),

$$t_j = (60 \times 38)/45 = 50 \text{ min},$$

$$t_{do} = 1 + 50 = 51 \text{ min}.$$

The arrival time of the volunteer fire brigade Čičarovce:

At the time of dispatch, the volunteer fire brigade Čičarovce was already on standby at the fire station.

$$t_{do} = t_v + t_j \quad [\text{min.}] \tag{5}$$

t_v—the dispatch time = 10 min,

$$t_j = (60 \times L)/v_j$$

t_j—the unit's driving time to the fire,
L—distance in km,
v_j—average vehicle speed in kmh^{-1} (45 kmh^{-1}),

$$t_j = (60 \times 5)/45 = 7 \text{ min},$$

$$t_{do} = 10 + 7 = 17 \text{ min}.$$

Fire area in the room:

$$\begin{gathered} Sp = n \times a \times l \quad [m^2] \\ Sp = 2 \times 4 \times 10 \\ Sp = 80 \text{ m}^2 \end{gathered} \tag{6}$$

where:

n—the number of spreading directions = 2,
a—the width of the room = 4 m,
l—the distance of the fire spread from the fire core = 10 m.

Fire spread distance (fire radius) r—with a burning time of more than ten minutes until the first streams are deployed:

$$t_2 = t_{vr} - t_1 \quad [\text{min}] \tag{7}$$

where:

t_2—the time of free spread of fire (till first streams),
t_{vr}—the free fire development time = 14 or 12 min,
t_1—the burn-up time (0–10 min) = 10 min,

$$t_2 = 14 - 10 \quad [\text{min}]$$

$$t_2 = 4 \text{ min}.$$

Due to the rapid fire spread of electrical installation material in combination with flowing transformer oil, including cable bridges, a value of twice the linear speed of fire spread was chosen:

$$\begin{gathered} r = 5 \times v + v \times t_2 \quad [\text{m}] \\ r = 5 \times 0.5 + 0.5 \times 4 = 4.5 \text{ m}, \end{gathered} \tag{8}$$

where:

v—the linear speed of fire spread [m.min^{-1}] [51],

v = 0.5 [m.min^{-1}].

The radius of the fire r can reach a maximum of half the room's width, and the fire starts to spread in a straight-angle form (Figure 9), where:

h—extinguishing depth [m],

n—number of fire propagation directions,

a—room width [m],

l—the distance to which the fire spread from the core [m] [51–55].

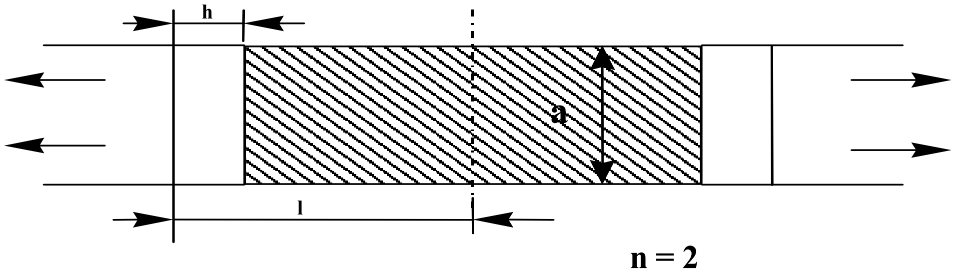

Figure 9. The form of fire spread [51–55].

3.2. Consumption of Fire Extinguishing Foam

To ensure the successful liquidation of a fire with foam, it is necessary to ensure its uninterrupted supply for at least 10 min. When extinguishing with foam, it is necessary to ensure a triple foam supply at the place. A foaming agent called M51 + 3% with 3% mixing was used during the intervention.

The fire in the thyristor room was extinguished using two streams of heavy foam with a foam generator P6. The P6 heavy foam generator has a foaming solution flow rate of 680 l.min at a pressure of 0.6 MPa. Foam consumption at 3% mixing is 20.4 l.min, and the resulting water consumption is 659.6 l.min.

According to Table 4 of the FRS president's instruction no. 39/2003 on the content and procedure for processing documentation on fighting fires, the extinguishing area with one foam generator P6 is 56 m^2.

The required amount of water and foaming agent is determined according to the formula (V_p—the amount of foaming agent):

$$V_p = n_{pr} \times q_p \times t_n \times z \; [\text{l}] \tag{9}$$

where:

n_{pr}—the number of foam generators = 2 pcs,

q_p—the foam flow through the foam generator = 20.4 l.min^{-1},

t_n—the normative fire extinguishing time = 10 min,

z—the foam supply coefficient = 3.

Amount of foaming agent for heavy foam:

$$\begin{gathered} V_p = n_{pr} \times q_p \times t_n \times z \; [\text{l}] \\ V_p = 2 \times 20.4 \times 10 \times 3 = 1224 \text{ l (before 1440 l)} \end{gathered} \tag{10}$$

Water consumption in the production of heavy foam V_v:

$$V_v = n_{pr} \times Q_v \times t_n \times z \text{ [l]}$$
$$V_v = 2 \times 659.6 \times 10 \times 3 = 39{,}576 \text{ l (predtým 39,360 l)}; \quad (11)$$

where:

Q_v—water flow through the foam generator.

Table 4. Information about intervening fire stations (source: elaborated by authors).

Equipment	Number of Members	Distance from the Fire Station (km)	Arrival Time (min)
Fire station Veľké Kapušany		4	6
Mercedes Benz Vario	1 + 3		
CAS 30 Iveco Trakker	1 + 1		
Škoda Fabia	1 + 2		
Fire station Michalovce		34	46
Mercedes Benz Vario	1 + 4		
Nissan Navara	1 + 2		
AR 39 Mercedes—Benz Atego 1629 4 × 2	1 + 1		
Mercedes—Benz Actros KHA	1 + 1		
Fire equipment Sobrance		38	51
CAS 30 T 815-7	1 + 3		
Fire equipment VFB Čičarovce		5	17
CAS Iveco Daily	1 + 3		

3.3. Number of Streams for Fire Extinguishing

Necessary supply of extinguishing agent

$$Q_{ph} = S_h \times I_p$$
$$Q_{ph} = 80 \times 14.7 \quad (12)$$
$$Q_{ph} = 1176 \text{ l.min}^{-1},$$

where:

S_h—fire area = 80 m^2

I_p—the required intensity of supply according to instruction 39/2003 (Table 1, Annex no. 2—A. Production, workshops, maintenance—electrical substations, transformers, substations and cable lines of electrical objects).

Number of extinguishing streams:

$$N_{prh} = Q_{ph}/Q_{pr}$$
$$N_{prh} = 1176/680 = 1.78 = 2 \text{ P6}. \quad (13)$$

where:

Q_{ph}—Necessary supply of extinguishing agent

Q_{pr}—the flow of the foaming solution through the foam generator.

Necessary supply of extinguishing agent for cooling:

$$Q_{ph} = S_o \times I_p$$
$$Q_{ph} = 40 \times 10.8 \quad (14)$$
$$Q_{ph} = 432 \text{ l.min}^{-1}$$

where:

S_o—cooling area in square meters, i.e., the area of another object that needs to be cooled

I_p—The intensity of the supply of extinguishing agent.

Number of streams for cooling:

$$N_{pro} = Q_{po}/Q_{pr} \qquad (15)$$
$$N_{pro} = 432/280$$

where:

N_{pro} = 2 combined streamlines (in this case, 2 C hoses with nozzles),

Q_{po}—the necessary amount of extinguishing agent intended for cooling,

Q_{pr}—streamline flow.

3.4. Actual Consumption of Extinguishing Agent

Calculation of the actual consumption of the extinguishing agent:

$$Q_p = N_{prh} \times Q_{pr} + N_{pro} \times Q_{pr}\ [\text{l.min}^{-1}] \qquad (16)$$
$$Q_p = N_{prh} \times Q_{pr} = 2 \times 656 + 2 \times 280 = 1872\ \text{l.min}^{-1}$$

where:

N_{prh}—number of extinguishing streams [pcs]

Q_{pr}—The P6 heavy foam generator has a foaming solution flow rate of 680 l.min at a pressure of 0.6 MPa.

Foam agent consumption at 3% mixing 24 l.min and the resulting water consumption 656 l.min. A combined flow line at a pressure of 0.6 MPa 280 l.min is used for cooling the technological equipment.

3.5. Determining the Number of Members of FRS

Calculation of the number of members:

$$N_{ph} = 2 \times n_{pc} \times 1.25 \qquad (17)$$

where:

n_{pc}—number of streams "P6"

$$N_{ph} = 2 \times 2 \times 1.25 = 5$$

members for working with streams to locate and extinguish the fire.

$$N_{po} = 2 \times 2 \times 1.25 = 5$$

members for cooling the gas pipeline.

Evacuation of persons:

- Number of members for evacuation at least 6 (3 persons);
- Evacuation of people using MB Atego AR L 39 Metz high-altitude equipment.

Other members involved in the intervention ensure the command during the intervention, the engineer's function, search, monitoring of air quality using detection technology, provision of first aid in the rescue nest and provision of positive pressure ventilation. Volunteer Fire Brigade Čičarovce, in cooperation with the staff, ensures the connection of fire trucks to the fire water pumping station and cooperates in traffic management and other activities required by the commander. Overpressure ventilation was used to remove smoke from the space, and natural ventilation through open windows and doors leading to the open space.

Calculation of the number of cisterns for the supply of water for extinguishing and cooling:

$$N_A = Q_p / q_A \quad [\text{pcs}] \tag{18}$$

where:

N_A—the number of fire trucks,

Q_p—necessary supply of extinguishing agent for extinguishing and protection [l.min^{-1}],

q_A—supply of extinguishing agent, which can be provided by the fire brigade from its truck [l.min^{-1}],

$$N_A = 1312/0.75 \times 3000 = 1 \text{ pcs CAS 30 to extinguish the fire,}$$

$$N_A = 560/0.75 \times 3000 = 1 \text{ pcs CAS 30 for cooling.}$$

The connection of the pumps at the given event is as follows. From the tank and the pump of the CAS 30 IVECO Trakker outlet, the attack line 1B, distributor and 2C streams were created. Additions to CAS 30 IVECO Trakker secured by connection to the existing hydrant network. Delivery of the foam agent is ensured by KHA Mercedes-Benz AROCS 6 × 6.

3.6. Analysis of Results

In Table 4, we can see the equipment involved in the intervention, the number of intervention members and the timetable for the arrival of the fire brigades.

In Table 5, we can see the schedule of the activities of the firefighting units.

Table 5. Schedule of activities (source: elaborated by authors).

Time	Situation on the Spot	Orders and Regulations	The Activity of Fire Brigades and Other Participating Units
8:00	The inception of a fire in a thyristor room obj. 201		
8:01	Free spread of fire		
8:03	Free spread of fire		Gatehouse employee—reporting a fire to the IRS 112 line.
8:03	Declaration of alarm by operational officer of RD FRS in Košice	The commander of the intervention requests the operation centre of RD FRS Košice for additional forces and resources	Departure of the Veľké Kapušany fire brigade to the place of the fire with equipment. Alarm announcement for units from DD FRS Michalovce and fire station Sobrance.
8:09	Free spread of fire, initial search	The intervention commander issues an instruction to conduct an initial search. With the help of responsible personnel, he ensures the evacuation of people.	Arrival of the fire brigade. Upon search, they find heavy smoke in the building. There are supposed to be three people in hall E.
8:12	Situation scouting	The intervention commander ordered a traffic and attack line to the building to locate the fire and search for people and their subsequent evacuation.	Establishment of intervention section no. 1 (commander of HS Veľké Kapušany team)—for evacuating people, searching for people and locating the fire in the thyristor plant.
8:20	Fumigation of the thyristor room, corridors and control room		Alarm announcement to VFB Čičarovce and the crew of emergency medical aid. Establishing a management staff in connection with an emergency.
8:25	First person saved	The intervention commander reports the events to the management staff	Found an adult in the control room. The person is conscious—removing the person and providing pre-medical assistance.

Table 5. *Cont.*

Time	Situation on the Spot	Orders and Regulations	The Activity of Fire Brigades and Other Participating Units
8:27	Fire localisation	The intervention commander reports the events to the management staff	The first attack stream reports the location of the fire
8:30	Arrival of a unit from DD FRS Michalovce	The intervention commander will hand over command to the commander from the Michalovce fire brigade. The commander of the intervention orders to carry out the second attack stream, help in the first IS and evacuation of the person by high-altitude technique.	Establishment of intervention section No. 2, north side of hall E—to evacuate people. Assistance in intervention section no. 1.—ongoing search for additional persons.
8:35	Second person rescued	The intervention commander reports events to the incident management staff	An adult person was found unconscious, taken to a safe area using a stretcher and handed over to the care of paramedics.
8:40	Arrival of a unit from Sobrance	The commander of the intervention issues an order to cool the pipes of the gas coolers of the E and T hall	Establishment of intervention section no. 3 (commander of the Sobrance team)—for cooling the pipes of the gas coolers of the E and T hall
8:42	Fire suppression	The intervention commander reports events to the incident management staff	Firefighters on the attack streams report that the fire has been extinguished.
8:47	Ventilation of premises	The intervention commander orders the unit from Michalovce to create overpressure ventilation in IS no. 1.	The unit performs ventilation using an overpressure fan.
8:50	Arrival of the volunteer Čičarovce unit	The intervention commander orders assistance in the evacuation of employees and assistance to firefighting units in various operations.	The unit performs tasks on the instruction of the intervention commander.
9:15	Search and evacuation of all persons and final search	The intervention commander orders a final search to be carried out	The intervention commander performs with commander IS No. 1 a final search of the building object.
9:28	Termination of intervention	The intervention commander announces the end of the intervention	Completion of intervention and concentration of equipment at the specified location.

3.7. Organisation of Connection and Determination of Radio Networks

The radio connection was made on the default frequency through the Regional Directorate of the Fire and Rescue Service operations centre in Košice (OC RD FRS in Košice) (Figure 10).

Connections during the intervention between OC RD FRS Košice and the intervention commander:

- Base radio station Matra OC RD FRS Košice—channel 605—PKO—1;
- Matra handheld radio station—channel 605—PMI—50.

The connection between the commander of the intervention, the chief of staff and the commanders of the intervention sections was ensured through the SITNO digital network—channel 606 (backup talk group).

The connection between the management staff and OC RD FRS Košice was ensured using the SITNO digital network—channel 605.

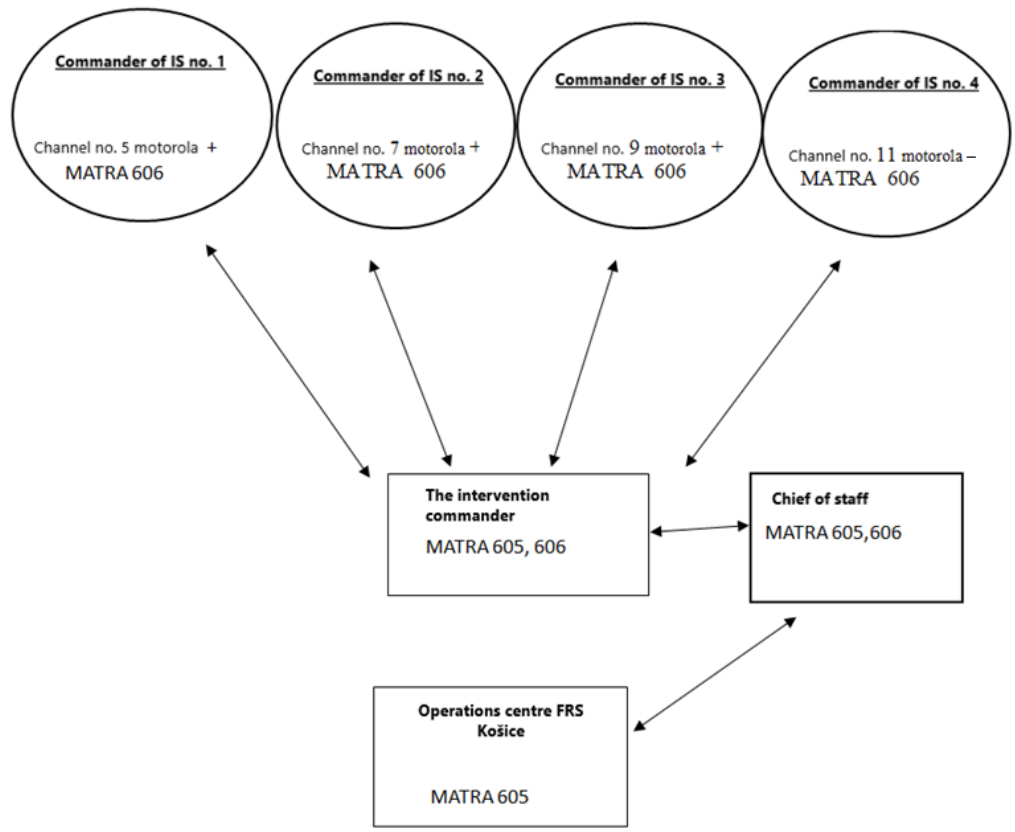

Figure 10. Radio connection scheme (source: elaborated by authors).

Connection between fire stations:

- Base radio station Matra DD FRS Michalovce—channel 605—PMI—1;
- Base radio station Matra FS Sobrance—channel 605—PMI—2;
- Primary radio station FS Veľké Kapušany—channel 605—PMI—3.

Connection at the point of intervention analogue network channel no. 5, channel no. 7, channel no. 9 and channel no. 11 (vehicles according to individual intervention sections).

Fire station Veľké Kapušany

- Car of the fire rescue service: Mercedes Benz Vario—PMI—353;
- CAS 30 Iveco Trakker—PMI—306.

Fire station Sobrance

- CAS 30 T815-7(SO)—PMI—207.

Fire station Michalovce

- Car of the fire rescue service: Mercedes Benz Vario—PMI—153;
- MB Atego AR L 39 Metz—PMI—133;
- KHA AROCS 6 × 6—PMI—150;
- Nissan Navara—PMI—183.

Volunteer Fire Brigade Čičarovce

- IVECO Daily without radio stations.

Figures 11 and 12 shows the deployment of forces and resources at the site of the intervention.

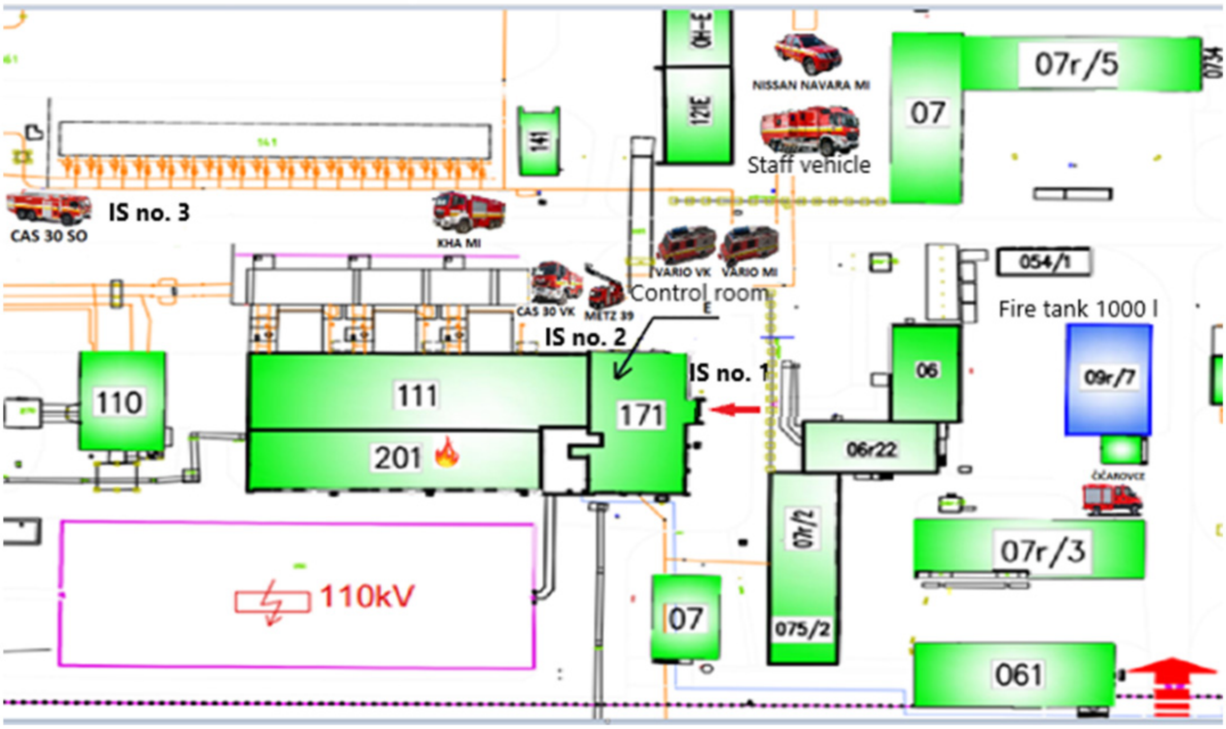

Figure 11. Deployment of forces and resources at the site of the intervention (source: elaborated by authors).

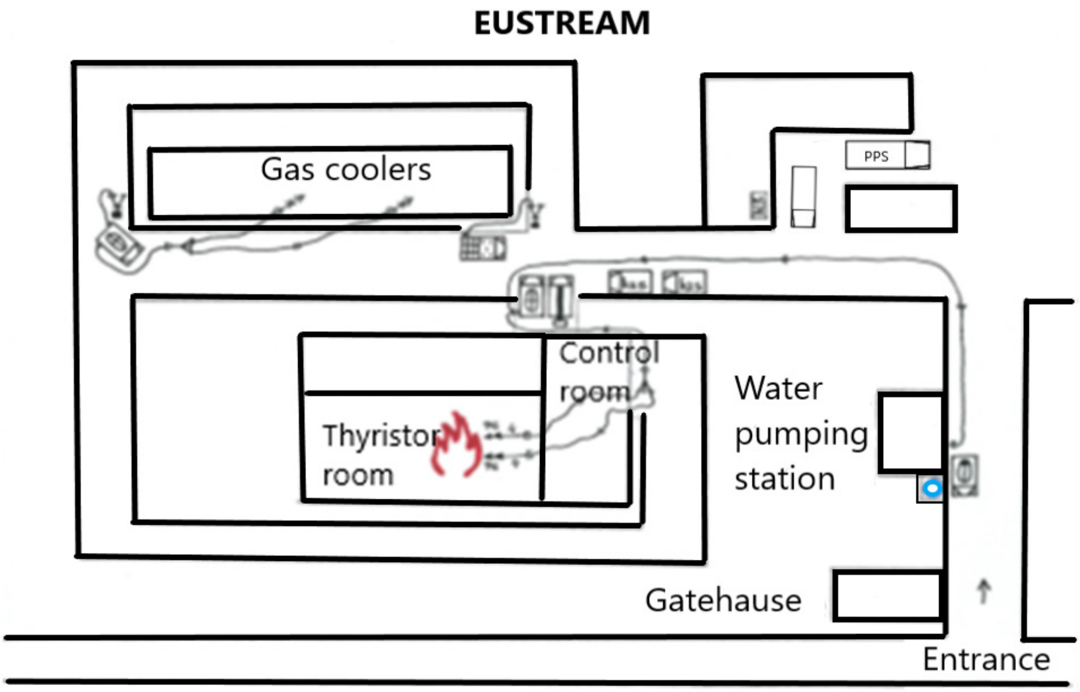

Figure 12. Intervention management (source: elaborated by authors).

4. Conclusions

The mentioned method of extinguishing the fire was determined on the basis of an assessment of the operational-tactical use of forces and resources of the area of intervention, the documentation of fire safety of the building in connection with the individual methodological sheets, and based on the evaluation of this intervention, it is possible to summarize the results in the following evaluation and discussion conclusions.

From the point of view of the danger to the health of not only the responding firefighters, but also the personnel who may be in similar buildings, it is necessary to ensure that the supply of electricity and gas is turned off through the operation centre.

Based on the experience of interventions and the knowledge of extinguishing agents, it is possible to state that extinguishing fires under high voltage is impossible, as extinguishing agents as such do not allow fire to be extinguished at such high voltages.

After stopping the supplies of the mentioned energy sources, it is possible to carry out a survey, which will consist of several search groups, while immediately after finding people in the given objects, it is necessary to ensure evacuation based on the instructions of the intervention commander and to start providing pre-medical first aid to the affected persons. After carrying out the survey, the intervention commander must determine whether the necessary material and technical equipment and security at the intervention site will be sufficient for the localization and subsequent liquidation of the fire.

In addition to the already mentioned tasks, this survey must also consist of marking the places where the survey itself took place, ensuring the transport of injured and disabled persons to a medical facility, determining the degree of protection not only of the responding firefighters, but also of persons evacuated from the given object. This must be determined in advance based on the initial decision whether the forces and resources will be sufficient for such a complex intervention.

As for the use of the extinguishing agent, it must be determined in advance during the survey, taking into account the danger of high temperatures, where classic extinguishing agents such as water, classic types of foams without extra admixtures can cause an explosion and endanger all participating intervention units.

During the actual use of the extinguishing agent and the execution of extinguishing works, it is necessary to ensure ventilation of the interior spaces, where it is necessary to consider the use of positive pressure ventilation with regard to the height of the neutral plane in the building and the possibility of controlling the fire with ventilation. Despite the risks of the work of fire fighters, it is necessary to observe the rules of occupational safety applicable to all types of activities that will be carried out during the intervention, with a reminder that human life is the most valuable and has priority over possible damage to property.

The most important step in launching an intervention, from its announcement until its liquidation, where the intervention itself consists of the already mentioned steps, is communication with the operations centre, which forms information support for the intervention commander and the entire intervention unit and also, based on communication, provides the necessary forces and means of other rescue components that are needed at the scene of the intervention, from the police force, medical rescue service to volunteers, who will provide secondary activities.

As already mentioned, delivery of any extinguishing agent (water, foam, powder ABC, BC, D, inert gases and other alternative combinations) is not possible if objects, equipment and technologies are under high voltage. For this reason, as already explained, it is first necessary to ensure that the supply of electricity and gas is shut off.

As a possible suggestion and recommendation, it is to reevaluate the current active fire protection systems in these objects and incorporate into the legislative process the necessity to secure these objects with a certain type of EPS, but that is no longer the purpose of this publication.

Author Contributions: Each author (M.B., M.K., M.Š., J.Č. and M.O.) has equally contributed to this publication. Conceptualisation, M.B. and M.K.; methodology, M.B.; software, M.K.; validation, M.Š., J.Č.; formal analysis, J.Č.; investigation, M.Š. and M.O.; resources, M.B.; data curation, M.K and J.Č.; writing—original draft preparation, J.Č. and M.O.; writing—review and editing, M.B. and M.K.; visualisation, M.Š.; supervision, M.B.; project administration, M.K. and M.Š.; funding acquisition, M.Š. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by the Scientific Grant Agency of the Ministry of Education, Science, Research, and Sport of the Slovak Republic and the Slovak Academy Sciences as part of the research project VEGA 1/0588/21: "The research and development of new methods based on the principles of modelling, logistics and simulation in managing the interaction of mining and back-filling processes with regard to economic efficiency and the safety of raw materials extraction" and as part of the research project VEGA 1/0430/22 "Research, development and concept creation of new solutions based on TestBed in the context of Industry 4.0 to streamline production and logistics for Mining 4.0.".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this article are available on request from the corresponding author.

Acknowledgments: The authors would like to thank the anonymous referees for their valuable comments that improved the quality of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Madejski, P. Thermal Power Plants–New Trends and Recent Developments. In *Power Plant Engineering*; IntechOpen: Rijeka, Croatia, 2018; 170p, ISBN 978-1-83881-408-3. [CrossRef]
2. Sukhnandan, A.; Hoch, D.A. Fire induced Flashovers of Transmission lines: Theoretical models. In Proceedings of the 6th Africon Conference in Africa, George, South Africa, 2–4 October 2002; Volume 6, pp. 617–622. [CrossRef]
3. Torero, O.L. Ignition Handbook, Principles and Applications to Fire Safety Engineering, Fire Investigation, Risk Management and Forensic Science by Vytenis Babrauskas, PhD. *J. Fire Prot. Eng.* **2004**, *14*, 229–232. [CrossRef]
4. Babrauskas, V. Mechanisms and modes for ignition of low-voltage, PVC-insulated electrotechnical products. *Fire Mater.* **2005**, *30*, 151–174. [CrossRef]
5. Liu, Y.; Li, B.; Wu, C.; Chen, B.; Pan, B. Effectiveness Test and Evaluation of Transformer Fire Extinguishing System. *Fire Technol.* **2022**, *58*, 3167–3190. [CrossRef]
6. El-Harbawi, M. Fire and Explosion Risks and Consequences in Electrical Substations—A Transformer Case Study. *ASME Open J. Eng.* **2022**, *1*, 014501. [CrossRef]
7. Chen, H.; Zhang, Y.; Zhang, L. A method to assess the wildfire induced breakdown of high-voltage transmission lines. *J. Phys.* **2018**, *1074*, 012152. [CrossRef]
8. Minnaar, U.J.; Gaunt, C.T.; Nicolls, F. Characterisation of Power Systems Events on South African Transmission Power Lines. *Electr. Power Syst. Res.* **2012**, *88*, 25–32. [CrossRef]
9. Allaev, K.R.; Mirzabaev, A.M.; Makhmudov, T.F.; Makhkamov, T.A. Simplified Criterion of Steady-State Stability of Electric Power Systems. *J. Power Energy Eng.* **2015**, *3*, 4. [CrossRef]
10. Fialkov, A.B. Investigations on ions in flames. *Prog. Energy Combust. Sci.* **1997**, *23*, 399–528. [CrossRef]
11. Gan, Y.; Luo, Y.; Wang, M.; Shi, Y. Effect of alternating electric fields on the behaviour of small-scale laminar diffusion flames. *Appl. Therm. Eng.* **2015**, *89*, 306–315. [CrossRef]
12. Xiong, Y.; Park, D.G.; Lee, B.J.; Chung, S.H.; Cha, M.S. DC field response of one-dimensional flames using an ionised layer model. *Combust. Flame* **2016**, *163*, 317–325. [CrossRef]
13. Karani, S.; Dunn-Rankin, D. Detailed characterisation of DC electric field effects on small non-premixed flames. *Combust. Flame* **2015**, *162*, 2865–2872. [CrossRef]
14. Chen, T.; Zhang, J.; Zhao, T.; Li, X.; Yu, H.; Yang, X. Development Status of Dynamic Distributed Transmission and Distribution System in Chinese. *Procedia Eng.* **2015**, *121*, 2083–2090. [CrossRef]
15. Frost, P.; Annegarn, H.J. Providing satellite-based early warnings of fires to reduce fire flashovers on South Africa's transmission lines. In Proceedings of the 2007 IEEE International Geoscience and Remote Sensing Symposium, Barcelona, Spain, 23–28 July 2007. [CrossRef]
16. Wu, C.; Lu, J.; Chen, B.; Zhou, Y.L.; Zhou, T. Control strategy for large-scale fires near power transmission lines and its application. *IET Gener. Transm. Distrib.* **2020**, *15*, 704–715. [CrossRef]
17. Anagnostatos, S.D.; Halevidis, C.D.; Polykrati, A.D.; Koufakis, E.I.; Bourkas, P.D. High-Voltage Lines in Fire Environment. *IEEE Trans. Power Deliv.* **2011**, *26*, 2053–2054. [CrossRef]
18. Robledo-Martinez, A.; Guzman, E.; Hernandez, J. Dielectric characteristics of a model transmission line in the presence of fire. *IEEE Trans. Eletr.* **1991**, *26*, 776–782. [CrossRef]
19. Li, P.; Huang, D.; Ruan, J.; Wei, H.; Qin, Z.; Qiu, Z.; Chen, X. Study on the dielectric characteristics of simulation transmission line gap under fire conditions. In Proceedings of the IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP) 2015, Ann Arbor, MI, USA, 18–21 October 2015. [CrossRef]

20. Guo, Y.; Chen, R.; Shi, J.; Wan, J.; Yi, H.; Zhong, J. Determination of the power transmission line ageing failure probability due to the impact of forest fire. *IET Gener. Transm. Distrib.* **2018**, *12*, 3812–3819. [CrossRef]
21. Wu, Y.; Xue, Y.; Lu, J.; Xie, Y.; Xu, T.; Li, W.; Wu, C. Space-time of forest fire on power grid fault probability. *Autom. Electr. Power Syst.* **2016**, *40*, 14–20. [CrossRef]
22. Shi, S.; Yao, C.; Wang, S.; Han, W. A Model Design for Risk Assessment of Line Tripping Caused by Wildfires. *Sensors* **2018**, *18*, 1941. [CrossRef]
23. Wang, J.; Ma, W.; Song, S.; Xu, F. Fuzzy comprehensive evaluation of forest fire risk on transmission lines based on entropy weight method. In Proceedings of the 2013 International Conference on Advanced Mechatronic Systems, Luoyang, China, 25–27 September 2013; pp. 666–670. [CrossRef]
24. Zhou, J.; Ma, W.; Miao, J. Fire risk assessment of transmission line based on BP neural network. *Int. J. Smart Home* **2014**, *8*, 119–130. [CrossRef]
25. Dian, S.; Cheng, P.; Ye, Q.; Wu, J.; Luo, R.; Wang, C.; Hui, D.; Zhou, N.; Zou, D.; Yu, Q.; et al. Integrating fires propagation prediction into early warning of electrical transmission line outages. *IEEE Access* **2019**, *7*, 27586–27603. [CrossRef]
26. Xu, K.; Zhang, X.; Chen, Z.; Wu, W.; Li, T. Risk assessment for wildfire occurrence in high-voltage power line corridors by using remote-sensing techniques: A case study in Hubei province, China. *Int. J. Remote Sens.* **2016**, *37*, 4818–4837. [CrossRef]
27. Zhou, F.; Ma, Y.; Wang, H. Research on transmission line fire monitoring technology based on remote sensing satellite data. In Proceedings of the 2020 International Conference on Urban Engineering and Management Science (ICUEMS), Zhuhai, China, 24–26 April 2020; pp. 314–317. [CrossRef]
28. Li, C.; Jing, Z.; Tang, B.; Zhang, Y. Analysis of forest fire spread trend surrounding transmission line based on rothermel model and huygens principle. *Int. J. Multimed. Ubiquitous Eng.* **2014**, *9*, 51–60. [CrossRef]
29. Vadrevu, K.P.; Csiszar, I.; Ellicott, E.; Giglio, L.; Badarinath, K.V.S.; Vermote, E.; Justice, C. Hotspot analysis of vegetation fires and intensity in the Indian region. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **2013**, *6*, 224–238. [CrossRef]
30. Su, H.; Sun, M.; Shang, J. Research on Stereoscopic Monitoring and Positioning Technology of Mountain Fire in EHV Transmission Lines. In Proceedings of the 2019 IEEE 3rd International Electrical and Energy Conference (CIEEC), Beijing, China, 7–9 September 2019; pp. 222–227. [CrossRef]
31. Lu, J.; Zhou, T.; Wu, C.; Li, B.; Tan, Y.; Zhu, Y. Fault statistics and analysis of 220 kV and above power transmission line in province-level power grid. *High Volt. Eng.* **2016**, *42*, 200–207. [CrossRef]
32. Chen, B. Fault statistics and analysis of 220-kV and above transmission lines in a southern coastal provincial power grid of China. *IEEE Open Access J. Power Energy* **2020**, *7*, 122–129. [CrossRef]
33. Jazebi, S.; de Leon, F.; Nelson, A. Review of wildfire management techniques_Part I: Causes, prevention, detection, suppression, and data analytics. *IEEE Trans. Power Deliv.* **2020**, *35*, 430–439. [CrossRef]
34. Map of Power System of The Slovak Republic Home Page. Available online: https://www.sepsas.sk/pre-partnerov/technicke-parametre/schemy-siete/ (accessed on 10 September 2023).
35. Peng, Y. Numerical simulation of smoke movement under typical cable fire conditions. *Chuanhai Eng.* **2016**, *45*, 65–68.
36. Shu, S.; Chen, Y.; Cao, S.; Zhang, B.; Fang, C.; Xu, J. Monitoring and alarm method for wildfires near transmission lines with multi-Doppler weather radars. *IET Gener. Transm. Distrib.* **2023**, *17*, 2055–2069. [CrossRef]
37. Yang, R.; Khan, F.; Neto, T.E.; Rusli, R.; Ji, J. Could pool fire alone cause a domino effect? *Reliab. Eng. Syst. Saf.* **2020**, *202*, 106976. [CrossRef]
38. Yang, H.; Zou, L.; Wang, X.; Song, Z.; Duan, Y.; Zhang, H. Analysis of Fire Spread in High Voltage Cable Trench under Different Cable Laying Modes. In Proceedings of the IEEE International Conference on Advanced Electrical Equipment and Reliable Operation (AEERO) 2021, Beijing, China, 15–17 October 2021. [CrossRef]
39. Chen, W.; Zhou, Y.; Zhou, E.; Xiang, Z.; Zhou, W.; Lu, J. Wildfire Risk Assessment of Transmission-Line Corridors Based on Naïve Bayes Network and Remote Sensing Data. *Sensors* **2021**, *21*, 634. [CrossRef] [PubMed]
40. Landucci, G.; Antonini, G.; Tugnoli, A.; Cozzani, V. Probabilistic Assessment of Domino Effect Triggered by Fire: Implementation in Quantitative Risk Assessment. *Chem. Eng. Trans.* **2012**, *26*, 195–200. [CrossRef]
41. You, F.; Zhang, Y.; Chen, H.-X.; Zhang, L.-H.; Zhu, J.-P.; Zhou, J.-J. Preliminary Studies on Flashovers of High-voltage Transmission Lines Induced by Wildfires by Field Survey and Experimental Tests. *Procedia Eng.* **2013**, *52*, 557–565. [CrossRef]
42. Liu, Y.; Li, B.; Wu, C.; Chen, B.; Zhou, T. Risk warning technology for the whole process of overhead transmission line trip caused by wildfire. *Nat. Hazards* **2021**, *107*, 195–212. [CrossRef]
43. Chen, C.; Xu, T.; Cao, S.; Wang, X. Study on risk assessment of trans-regional transmission lines tripping dis-aster induced by wildfire. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *452*, 032121. [CrossRef]
44. Wu, C.; Zou, T.; Chen, B.-H.; Liang, P. Experimental Study on Burning Characteristics of the Large-Scale Transformer Oil Pool Fire with Different Extinguishing Methods. *Fire Technol.* **2020**, *57*, 461–481. [CrossRef]
45. Duarte, D. A performance overview about fire risk management in the Brazilian hydroelectric generating plants and transmission network. *J. Loss Prev. Process Ind.* **2004**, *17*, 65–75. [CrossRef]
46. Lu, J.; Liu, Y.; Wu, C.; Zhang, H.; Zhou, T. Study on satellite monitoring and alarm calculation algorithm of wild fire near transmission lines. *Proc. CSEE* **2015**, *35*, 5511–5519. [CrossRef]
47. Cui, L.; Gorur, R.S.; Chipman, D. Evaluating flashover performance of insulators under fire fighting conditions. *IEEE Trans. Dielectr. Electr. Insul.* **2017**, *24*, 1051–1056. [CrossRef]

48. Banik, A.; Dalai, S.; Chatterjee, B. Studies the Effect of Equivalent Salt Deposit Density on Leakage Current and Flashover Voltage of Artificially Contaminated Disc Insulators. *IEEE Trans. Dielectr. Electr. Insul.* **2012**, *19*, 1037–1043. [CrossRef]
49. Zhang, J.; Zhang, B.; Xie, H.; Fan, M.; Wang, L. On Data Analysis in Forest Fire Induced Breakdown of the Transmission Line. Advances in Intelligent Systems and Computing. In Proceedings of the International Conference on Intelligent and Interactive Systems and Applications 2018, Hongkong, China, 29–30 June 2018. [CrossRef]
50. Lee, J. Numerical Analysis of the Effects of Droplets Characteristics of Water Spray on Fire Suppression. *Fire Sci. Eng.* **2019**, *33*, 1–8. [CrossRef]
51. Ministry of the Interior of The Slovak Republic Home Page. Presidium of the Fire and Rescue Service. Collection of Instructions of the President of the Fire and Rescue Service. About the Content and Procedure for Processing Documentation on Fighting Fires. Available online: https://www.minv.sk/?interne-predpisy-1 (accessed on 11 September 2023).
52. Presidium of the Fire and Rescue Service Home Page. Order of the President of the Fire and Rescue Service. Tactical-Methodical Procedure for Carrying Out Interventions no. 22. Extinguishing Fires in Heavy Smoke. Available online: https://elearnhazz-sk.webnode.sk/subory-na-stiahnutie/metodicke-listy/ (accessed on 11 September 2023).
53. Presidium of the Fire and Rescue Service Home Page. Tactical-Methodical Procedure for Carrying Out Interventions no. 23. Overpressure Ventilation in Fire Fighting. Available online: https://elearnhazz-sk.webnode.sk/subory-na-stiahnutie/metodicke-listy/ (accessed on 11 September 2023).
54. Presidium of the Fire and Rescue Service Home Page. Order of the President of the Fire and Rescue Service. Tactical-Methodical Procedure for the Execution of Interventions no. 46. Energy Industry. Available online: https://elearnhazz-sk.webnode.sk/subory-na-stiahnutie/metodicke-listy/ (accessed on 11 September 2023).
55. Presidium of the Fire and Rescue Service Home Page. Order of the President of the Fire and Rescue Service. Tactical-Methodical Procedure for Carrying Out Interventions no. 47. Energy Industry (Production Equipment). Available online: https://elearnhazz-sk.webnode.sk/subory-na-stiahnutie/metodicke-listy/ (accessed on 11 September 2023).