Biogas plant explosion protected early streamer emission (ESE) air terminal

Ing. Jiří Kutáč, Union of Court's Expert
Doc. Ing. Zbyněk Martínek, CSc., University of West Bohemia, Faculty of Electrical Engineering
Ing. Jan Mikeš, Czech Technical University, Faculty of Electrical Engineering
nprap. (CW-1) Martin Petrák, HZS JčK territorial Division Tábor

Abstract

The designer suggested the lightning protection of biogas plant according to French standard NF C 17-102. Yet there was a direct lightning strike to the top of the fermenter, which lay in the protected space ESE air terminal. After a lightning explosion occurred and fire broke out subsequently biogas plant. Control measurement ESE air terminal demonstrated its full functionality at the time of intervention. 10 minutes before the lightning and the subsequent explosion of biogas leaving 4 workers that area due to changes in climatic conditions (rain beginning).

1. Introduction

The completion of the very first functional lightning rod in the Czech lands is attributed to Václav Prokop Diviš at the end of the 18th century. The principle of this type of protective system has remained unchanged to this days. Upsurge in measurement techniques and new scientific findings in the physics of lightning discharge have been accompanied by efforts to modify the established systems.

Already in the 19th century, improved lightning rods were offered by different trade organizations. Leo Szilard, a colleague of Marie Curie, proposed application of radioactive elements to improve the protective effects of lightning rods. In the 20th century his idea was brought to fruition by the company Helita [1]. In the Czech literature, mention about the concept of active lightning rods in the field of lightning protection comes from 1957 under the title *Bouřky a ochrana před bleskem* (Thunderstorms and Protection Against Lightning) [2]:

Radioactive lightning rod uses on lightning conductors radioactive salts that cause air ionization and, to a certain extent, enhance the overall efficiency of lightning rods. This type was used mainly in France but no longer appears in practical use.

Today this kind of protection is prohibited, having been replaced by a system of lightning rods known as ESE (*Early Streamer Emission*). Thus far, manufacturers of commercially designated active ESE lightning rods have failed to persuade the International Electrical Engineering Commission IEC TC 81 (*Lightning Protection*) of the efficiency of this particular technology as compared with the classical, often also called passive or Franklin, lightning conductors.

The Commission IEC TC 81 has been intensely following developments of new technologies in the field of lightning protection. Once these technologies are accepted by the International Council on Large Electrical Systems (CIGRE), they can be accepted by the relevant Commission. Discussions on the issues concerned culminated in March 2010 when, during voting, the member countries of the European Committee for Electrotechnical Standardization (CENELEC) refused to accept the French standard NF C 17-102 [3] as the European standard EN.

2. Research of ESE Lightning Conductors

The Institute for Science and Technology at the University of Manchester in UK has compared ESE lightning conductors (see Note 1) and the Franklin-type lightning rod according to the French standard NF C 17-102. Given below are the results of 420 experiments:

– 55 (13.1 %) without a discharge;
– ESE lightning conductor was struck 165 times (39.3 %);
– classical lightning conductor was struck 200 times (47.6 %).

Note 1: 1 – classical lightning conductor (Franklin type), 2 – Dynasphere, GLT Australia, 3 – Pulsar 60, Helita France, 4 – Prevectron S6, Indelec France.

The conclusion of the measurement protocol from the laboratory of the University of Manchester does not speak quite unequivocally of any advantages of either of the given systems in relation to one other [4].

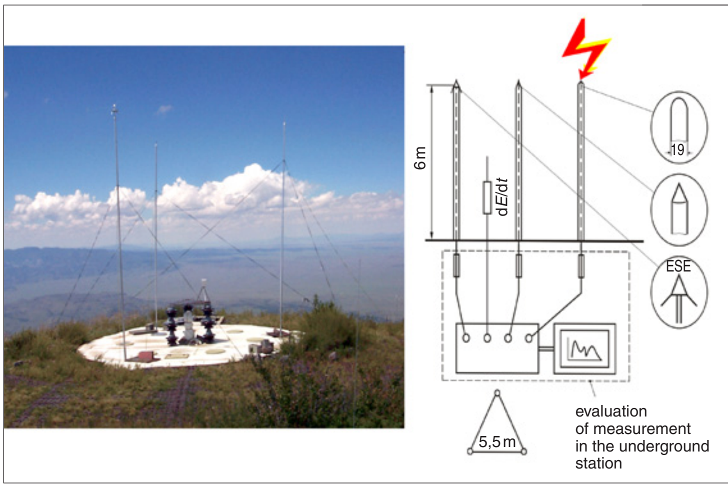


Fig. 1. Measuring system at the peak of South Baldy in New Mexico (USA)

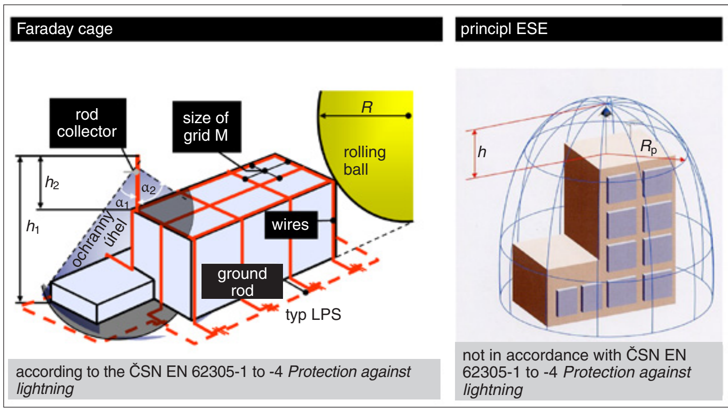


Fig. 2. Comparison the different designs of collector system

Three types of lightning conductors, each 6 metres long (Fig. 1), were installed in a outdoor laboratory in New Mexico, USA, on Mount South Baldy at an altitude of 3,287 metres above sea level:

– ESE lightning conductor,
– Lightning conductor topped with a pointed head,
– Lightning conductor topped with a round head.

The distance between each lightning rod was 5.5 metres and devices for measuring lightning current were installed underground. Only strikes to the lightning rods topped with a round head were registered during a period of eight years.

Basic comparative measurements of the efficiency of the active (ESE) and passive lightning rod, under comparable geometric and electrical conditions, were performed in the specialized laboratories at the Faculty of Electrical Engineering of the Czech Technical University in Prague. No greater differences in the efficiency of one or the other type of lightning rod have been found when a screen measuring (1.5 × 2.5 m), fed by an impulse generator, was selected as the main electrodes. Frequency measurement of the circuit of an active lightning rod indicates that this involves the principle of a resonating source, which needs external energy for its excitation to oscillate with a frequency defined by the value of inductance and capacity of the circuit. In practice, such a circuit is difficult to excite by means of an atmospheric discharge.

3. Czech Legislation

According to the (Czech Republic's) Building Act No. 183/2006 Coll, § 159, section 2 [5]:

Designer shall be responsible for the correctness, integrity, completeness and safety of the structure erected according to the project documentation elaborated by him/her, and for the feasibility of such a structure according to this documentation, as well as for the technical and economic standards of the design of technological equipment, including environmental impacts. Designer shall be obliged to adhere to the legal regulations and general requirements placed on construction relating to a specific building project.

In keeping with the Regulation No. 268/ /2009 Coll. on technical requirements for buildings [6] pursuant to § 36, an analysis of eventual damage risks has to be carried out according to the standard-forming values, for instance for the following types of structures:

a) threat to life or health of people, especially in a residential building, a building housing an inner assembly space, a building destined for trade, health care and education, a building housing accommodation facilities or a building housing a greater number of animals,
b) breakdown resulting in large-scale consequences in public services, especially in a power station, gas plant, waterworks, building housing communication equipment, and railway station,
c) explosion primarily in production and storage facilities of explosives and inflammables, liquids and gases,
d) damage caused to cultural heritage, eventually to other values, especially in picture gallery, library, archive, museum, building listed as a cultural monument,

Fig. 3. The damaged technological part of fermenter after lightning strike in a protective area ESE

Fig. 4. Comparison of the upper parts of fermenters after and before lightning strike

Fig. 5. Throw away the cover of the repumping tank after explosion

e) spread of fire from one structure to adjoining buildings which, pursuant to letters a) to d), have to be protected against lightning,
f) threat to a structure which poses a greater danger of being struck by lightning as a result of its elevated position on a hill or as a result of jutting out above its surroundings, particularly in case of factory stack, tower, lookout tower and broadcasting tower.

According to Technical harmonization digest (*Sborník technické harmonizace 2004*) [7] a standard value, as specified in the Regulation, spells out a technical requirement contained in the relevant Czech standard ČSN. In case of lightning protection, this applies to the package of Czech technical standards designated ČSN EN 62305-1 to -4 [8 to 11].

For its part, the French national standard NF C 17-102 [3] is not valid in the territory of the Czech Republic since it does not meet the provisions of § 36 of the Regulation No. 268/2009 Coll. [6] and can be implemented solely by applying the valid ČSN standard (Fig. 2). The NF C 17-102 standard [3] is valid for structures falling under the French jurisdiction and, furthermore, is in contradiction [12] both with the ČSN EN 62305-1 to -4, and the relevant EN 62305-1 to -4 [13 to 16] and, therefore, lacks any legal support whatsoever.

Proceeding from the abovementioned legislative requirements, it may be said that biogas stations belong to the category for which a genuine risk analysis must be calculated according to the ČSN EN 62305-2 [14] for a given specific structure.

4. Damage Caused to the Biogas Station at Malšice

According to weather reports of the Czech Hydrometeorological Institute, in the evening of June 22, 2011 an irregular cold front was moving across Bohemia from the West. There was a westerly wind blowing at a speed of 5 to 6 $m{\cdot}s^{-1}$, gushing wind at some 13 $m{\cdot}s^{-1}$. Between 7:00 and 8:00 p. m. air temperature dropped from 27 to 18 °C. According to observation of the nearby, radar, reflections and registration of lightnings, some 10 negative lightnings with a peak value of 18 kA striking the ground were recorded near the village of Malšice. Approximate rainfall during the thunderstorms totalled 14 mm.

A lightning struck the upper section of the fermenter of the biogas station at Malšice (Fig. 3) [17] probably after 8:00 p. m. that day. A fire broke out and a partial explosion occurred on the technological parts of the fermenter (Fig. 4) due to the physical effects of the lightning according to the ČSN EN 62305-1. Four workers of an assembly company were very lucky indeed since they had left the premises of the fermenter because of rain just ten minutes before the lightning struck.

The first unit of the fire rescue corps arrived on the site at 8:23 p. m. The inner as well as outer containment, particularly on the southern side of the fermenter, was hit by fire (Fig. 6). The outer containment, forming the roof protective shield against atmospheric effects, is made of layered fabric composed of the following:

– PVC foil,
– polyester fabric,
– PVC foil.

To achieve the required safe load and strength of the outer sheet, polyester straps are woven into the fabric, being anchored in the upper section on a steel head of the wooden pole and on the outside of the circumferential pit of the fermenter (Fig. 7). The inner sheet serves as a membrane gas tank and is made of a fabric composed of the following:

– PVC foil,
– polyester fabric,
– PVC foil.

Note 2: The volume weight of the sheet is 850 g·m^{-2}.

The foil is attached in the upper section on the head of the wooden pole and on the inside of the circumferential pit of the fermenter. Thermal effects of the fire of the above-mentioned cover resulted in the damage of part of the thermal insulation of the fermenter's circumferential structure (thermal insulation made of mineral wool and a sheet containment made of trapeze templates). The upper closing cover of the plastic repumping tank was also damaged and torn off. The upper closing cover was found some 6 metres southeast of the tank. The plastic repumping tank is interconnected with the fermenter's tank through open piping, thus forming communicating vessels. The plastic cover was torn off by the explosive burnout (explosion) of accumulated biogas in the space above the level of the digest (biomass) and the fermenter's holding sheet.

At the time of fire in the fermenter's storage tank, the stored biomass reached the height of approximately 3,000 mm. Biogas originates by means of microbiological decomposition of organic components of biomass (biogas composition: approximately 60 % methane, 35 % carbon dioxide, 4 % water vapour, 1 % other trace gases).

Note 3: Technical and combustive characteristics of the substances taking part in combustion:

– *Methane: gas and air mixtures are explosive, gas lighter than air, insoluble in water, gasifies above the surface, creating explosive mixtures, calorific value 10 kW·h·m^{-3}, density 0,72 kg·m^{-3}, density-to-air ratio 0,55, ignition temperature 595 °C, inflammability limits (gas in air) 4,4 to 16,5 %, theoretical need of air 9,5 m^{3}·m^{-3},*

Fig. 6. View into the damaged inner tank of fermenter, which is located in the protective area of ESE

Fig. 7. Overall view of the location of the ESE, which is located 13 m from the edge of the fermentor

– *Biogas: calorific value 6 kW·h·m^{3}, density 1,21 kg·m^{-3}, density-to-air ratio 0,9, ignition temperature 700 °C, inflammability limits (gas in air) 6 to 22 %, theoretical need of air 5,7 m^{3}·m^{-3},*

– *PVC – polyvinylchloride: inflammation temperatures in the range 300 to 410 °C, ignition temperatures in the range 420 to 435 °C,*
– *PES – polyester, netting: inflammation temperatures in the range 445 to 455 °C, ignition temperatures in the range 470 to 475 °C,*
– *textile impregnated by PVAC: inflammation temperatures 375 °C.*

5. Project documentation and Inspection report

Project documentation was elaborated by an authorized expert of the ČKAIT (*Czech Chamber of Authorized Engineers and Technicians*) according to the French standard NF C 17-102 [3] and a set of Czech technical standards ČSN EN 62305-1 to -4 [8] to [11]. A paradox in this case is that in the following items [12], [18] the afore-mentioned standards are in direct contradiction:

a) construction of the protective space of lightning conductor:
   – NF C 17-102 – pursuant to Article 2.2 [3] method of protective radius R_p, given by the speed of streamer v = 100 cm/µs [1]. This prerequisite does not respect the natural behaviour of lightning discharge (Fig. 8),
   – ČSN EN 62305-3 – pursuant to Article 5.2 [10] method:
   – rolling sphere,
   – protective angle,
   – the mesh method.

All these methods are known to respect the natural behaviour of lightning discharge, thus taking into account the speed of streamer v = 1 to 2 cm/µs [1].

b) proposed number of earthing wires:
   – NF C 17-102 pursuant to Article 2.2 [3] the number of down conductors (one or two) is determined according to the height of the given structure and comparison of the projection into the horizontal and vertical plane,

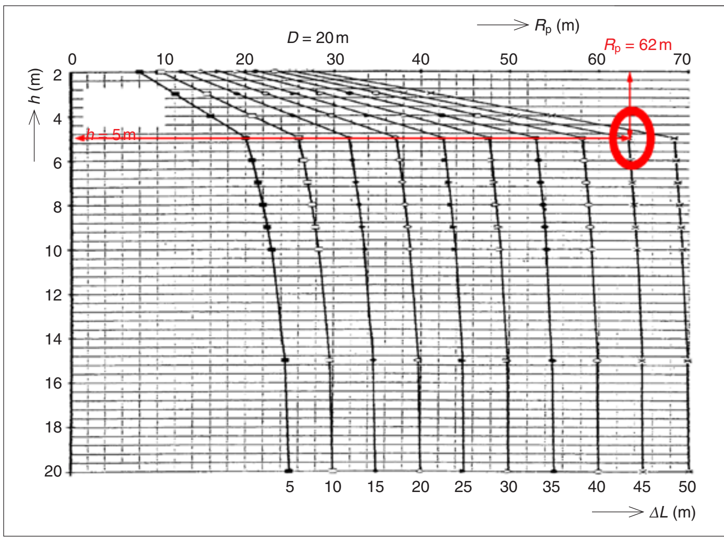


Fig. 8. Table for determination of the protective radius Rp according to the NF C 17-102

- ČSN EN 62305-3 pursuant to Article 5.3 and Fig. 4 [10] the number of earthing wires is calculated according to the circumference of the given structure.

At the same time, the project documentation was, quite unequivocally, elaborated only according to the French standard NF C 17-102 [3]. The system of lightning conductors consisted of a self-standing pole mounted with an active lightning rod at its top. The pole is 16 m high. The pole was connected with an earthing system and entire ground resistance totalled 1 Ω.

The outcome of the incorrect design of lightning protection pursuant to the NF C 17-102 standard [3] is that lightning struck the upper section of the fermenter, situated only 26.05 metres from the ESE lightning conductor. However, the protective radius (protective cone) of the given ESE lightning conductor amounts to R_p = 62 metres (Fig. 9).

One day after the lightning struck, the active (ESE) lightning conductor was dismantled and dispatched for control measurements. The result of the measurements: **Equipment is fully functional**.

That was why the lightning conductor was reinstalled at the biogas station as lightning protection.

6. Conclusion of Inspection report

The lightning protection device (lightning rod) and earthing was executed according to project documentation, manufacturer's documentation, the ČSN 33 2000-5-54 standard, and in compliance with the French standard NF C 17-102 [3]. Seen from the safety point of view, the equipment is fully operational.

The Inspection report, elaborated by an inspection technician, does not comply with the technical requirements contained in the standard ČSN 33 1500 [19] due to the following reasons:

- the French standard NF C 17-102 [3] is not valid in the territory of the Czech Republic, there is no official translation of this standard published by the ÚNMZ (Czech Office for Standards, Metrology and Testing),
- inspection technicians are not tested by the Technical Inspection of the Czech Republic and, therefore, are not aware of the requirements of the NF C 17-102 standard [3].

7. Summary

- To date, it has not been scientifically proved in independent laboratories (under natural conditions or according to the NF C 17-102 [3]) that the active ESE lightning conductors really represent better protection solution.
- According to officials representing the active ESE lightning conductors, the decisive factors in designing lightning protection are as follows: price, ease of installation, and aesthetic design.
- In actual fact, the set of Czech technical standards ČSN EN 62305-1 to -4 (*Lightning Protection*) [8 to 11] does not distinguish between conventional (classical) or unconventional ESE (active) lightning conductors.
- Active ESE lightning conductors may be used in the territory of the Czech Republic but solely as part of lightning protection systems pursuant to the ČSN EN 62305-1 to -4 [8] to [11].
- Only a technical solution according to the valid Czech technical standards (ČSN EN 62305-1 to -4 [8] to [11]) constitutes the suitable solution of lightning protection, and should be part of each contractual relation between business partners. This applies to a set of prescribed safety standards.
- Lightning struck directly in the middle of an *alleged protective radius* R_p of the ESE lightning conductor protecting the fermenter against lightning (Fig. 9).
- Lightning caused damage to the equipment of the biogas station which has been estimated at 5,000,000 CZK. It started raining 10 minutes before the lightning struck and that was why workers of an assembly company had left the premises of the fermenter.
- Will the competent state administration authorities be able correctly to evaluate this particular emergency event or will they be just sitting back until the first injury or even death caused by lightning?

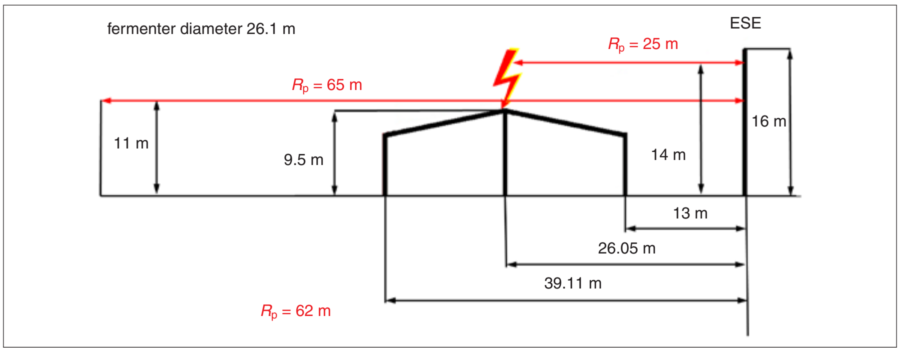
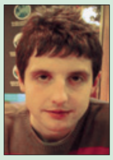


Fig. 9. Stroke to the upper part of fermenter, i. e. right in the middle of the ESE protective cone

Ing. Jiří Kutáč
Ing. Jiří Kutáč, was born on 8. 11. 1964. In 1983 he graduated at electrical engineering second school of SPSE in Frenstat p. R. and in 1988 he graduated at the department of electrical drives and power electronics of the Faculty of Electrical Engineering at University of VUT in Brno. Since 2001 he has worked for the company Dehn + Söhne. In 2009 he was appointed District Court in Ostrava in field of electrical engineering and in 2011 in field of electroenergetics. He is guarantor of international cooperation of technical committee CZ by IEC TC 81, CLC TC 81X and is president of Sub-Commission *Protection against lightning* at technical standards committee TNK 97 and also member of technical standards committee TNK 97 Electrical Power and member of technical standards committee TNK 22 Electrical regulations.

Doc. Ing. Zbyněk Martínek, CSc.
Assoc. Prof. Dr. Ing. Zbyněk Martínek, was born on 22. 4. 1955. In 1983 he graduated (MSc) with distinction at the department of Power Engineering of the Faculty of Electrical Engineering at University of West Bohemia in Pilsen. He defended his PhD in the field of Reliability of Power Grid in 1990; his habilitation title was *Synthesis of reliability of power plant unit in the Czech Republic*. Since 1990 he is working as a tutor with the Department of Computers and Informatics. His scientific research is focusing on reliability of power grid and devices in power engineering, heating industry and electrical installation design. From the year 1990 he is regularly named as a member of commission at final exams. These commissions are at the Department of Electric Power Engineering and Ecology and also a chairman of bachelor commission from the year 2005.



Ing. Jan Mikeš
He has A-level of the secondary school – electrical technologies, in Prague. At Czech Technical University in Prague (CVUT), he graduated in electrical energy engineering in 2006. His thesis is called: *The outdoor protection against the over-voltage effects in atmosphere*. Nowadays, he is post-gradual student at the same university and his work is aimed to the high voltage technology. He engages the high voltage phenomenon, lightning discharge influence of lightning discharge on the technical equipment, and over-voltage effects. Simultaneously, he offers consultation for the commercial subjects.

nprap. (CW-1) **Martin Petrák**
Nprap. Martin Petrák was born on 10. 11. 1972. He graduated at High School in Czech Budejovice field of building construction. Since 2000 he worked at South County Fire Rescue Department Territorial Camp Tabor. Currently he holds the position of Chief Inspector.

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