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EARLY STREAMER EMISSION VS CONVENTIONAL LIGHTNING PROTECTION SYSTEMS

GROMOBRANSKE HVATALJKE S RANIM STARTOVANJEM ILI KLASIČNI SISTEMI GROMOBRANSKE ZAŠTITE

Mladen Banjanin[1], Svetozar Banjanin[2]

Abstract: This paper analyses and compares the conventional lightning protection systems proposed in IEC 62305 to the lightning protection systems based on the application of early streamer emission lightning rods proposed in NF C 17-102. Comparison between the two approaches to the lightning protection of structures was presented, both from a technical and economic point of view. Some inconsistencies in the conventional air termination system design methods are pointed out. The critical attitude of the scientific community regarding the declared protection characteristics of the early streamer emission lightning rods is discussed.

Keywords: lightning protection, lightning air termination system, early streamer emission lightning rod, lightning protection system design

Sažetak: U ovome radu analizirani su i upoređeni konvencionalni sistemi gromobranske zaštite objekata koji su predloženi u standardu IEC 62305, sa sistemima zaštite koji se baziraju na primjeni gromobranskih hvataljki s ranim startovanjem, predložene u standardu NF C 17-102. Na jednostavnim primjerima je s tehničkog i ekonomskog aspekta izvršeno poređenje ovih dvaju pristupa gromobranskoj zaštiti objekata. Ukazano je na određene nedosljednosti kod konvencionalnih metoda za projektovanje prihvatnog sistema gromobranske zaštite objekata. Također je ukazano i na kritički stav naučne zajednice koji se odnosi na deklarisane zaštite karakteristike gromobranskih hvataljki s ranim startovanjem.

Ključne riječi: gromobranska zaštita, gromobranska hvataljka, hvataljka sa ranim startovanjem, projektovanje gromobrana

INTRODUCTION

Efficient lightning protection of structures is very important for their reliable exploitation over a long period of time. Lightning protection systems of structures consist of external and internal lightning protection systems. An external lightning protection system has the role to accept the lightning discharge and to conduct its current into the ground. An internal lightning protection installation has the role to limit surges that occur in the facility and to protect persons and devices from injuries and malfunctions respectively.

The external lightning protection installation of each object consists of three components [1]:

- Air termination system, which has the role to accept the lightning discharge.
- Down-conductors, which have the role to conduct lightning current from the air termination system to the grounding system.
- Grounding system, which has the role to conduct lightning current into the ground.

To ensure adequate efficiency and reliability of the external lightning protection system, all three components must be properly designed. In order to reduce the investment costs, but also to simplify realization of protection, these protection systems can be implemented by using natural components [2]. For example, in the case of structures with a glass facade it is not possible to use standard down-conductors, so the solution is to use reinforcement of concrete pillars as down-conductors, or to put down-conductors in the concrete of pillars. Metallic roof of the building can serve as the air termination system if it has the minimum thickness defined in [2]. Reinforced concrete foundations of a building can serve as the natural grounding system. In this way, the design and implementation of the lightning protection system can be significantly simplified.

[1]University of East Sarajevo – Faculty of Electrical Engineering, Bosnia and Herzegovina
[2]Ban-Ko Inžinjering, Bosnia and Herzegovina
mladen.banjanin@etf.ues.rs.ba, banjaninsvetozar@gmail.com,
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An internal lightning protection system is implemented by equalizing the potential (equipotential bonding) of all metallic installations within the facility in order to prevent sparking between the metallic components at different potentials [2]. Sparks could cause a fire, malfunctions of the electric and electronic equipment or injury of the people operating devices during the occurrence of atmospheric discharges. In addition to the potential equalization, a very important aspect of the internal lightning protection is application of the surge protection devices (SPD) [3].

This paper deals with the air termination systems and particularly down-conductors system design and different possibilities for their implementation. Two concepts of the air termination system and corresponding down-conductors system design are analysed:

- Conventional air termination systems (CATS), which are based on the application of standard Franklin rods, catenary wires or meshes [2].
- Early streamer emission air termination systems (ESEATS) [4].

Comparisons of these two lightning protection philosophies from the aspect of economy, engineering and science are presented in this paper.

1. LIGHTNING PROTECTION OF STRUCTURES

This paper analyses the lightning protection of structures lower than 60 m. According to [2], lightning strikes to the side of such structures are not possible. Because of that, only the air termination system of the roofing roofing structure is analysed.

1.1. Risk management

When dealing with the structure lightning protection the first step is to calculate risks. Risk is defined as value of probable average annual loss (humans and goods) due to lightning, relative to the total value (humans and goods) of the object to be protected [5]. This means that it is not possible to achieve 100% efficient protection against direct lightning strikes and lightning surges, but it is possible to achieve acceptable low risk values of such scenarios. The risk assessment calculation procedure is presented in [5].

The procedure to evaluate the need for lightning protection of a structure is given in Figure 1 [5]. It is important to note that the engineering practice, as well as many professional papers and books in Bosnia and Herzegovina, frequently use old or hybrid procedures to evaluate the need for lightning protection of the structures. Those procedures were suggested in some withdrawn standards (for example IEC 1024-1-1:1993). It is very important to update such procedures in accordance with [5].

According to [1], the following risks must be considered to evaluate the need for lightning protection of the structures or services:

- risks R_1, R_2, R_3 for structures,
- risks R_1 and R_2 for services.

Risks R_1, R_2, R_3 are defined as follows:

- R_1 - risk of loss of human life,
- R_2 - risk of loss of service to the public,
- R_3 - risk of loss of cultural heritage.

For each risk (R_1, R_2, R_3) of interest the following steps shall be taken:

- identification of the components R_X which make up the particular risk (R_1, R_2, R_3),
- calculation of the identified risk components R_X,
- calculation of the total risk R (R_1, R_2, R_3),
- identification of the tolerable risk value R_T (R_{T1}, R_{T2}, R_{T3}),
- comparison of the calculated risk value R (R_1, R_2, R_3) with the tolerable value R_T (R_{T1}, R_{T2}, R_{T3}). In the case of $R \leq R_T$, lightning protection is not necessary, but in the case of $R > R_T$ lightning protection measures must be applied in order to satisfy the condition $R \leq R_T$ for all risks of interest.

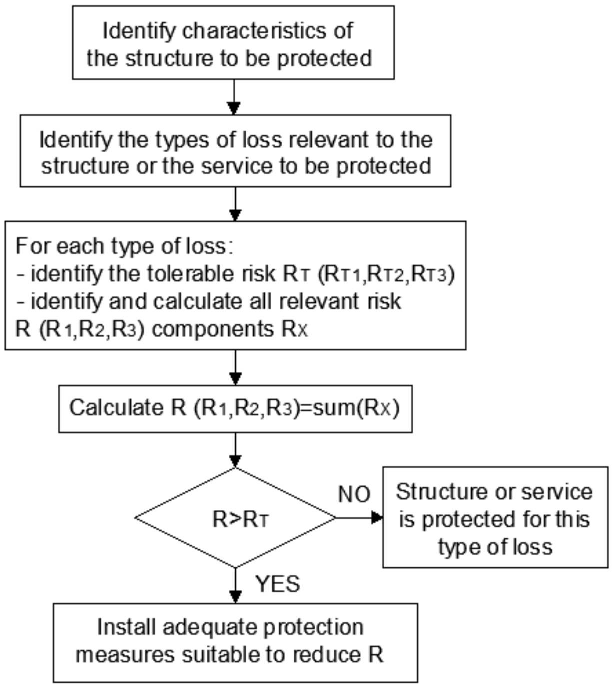


Figure 1: The procedure to evaluate the need for lightning protection of the structure

Suggested values of the tolerable risks R_T (R_{T1}, R_{T2}, R_{T3}) are given in Table I [5].

Table I: Typical values of the tolerable risks R_T [5]

Types of loss	R_T (1/year)
Loss of human life or permanent injuries	10^{-5}
Loss of service to the public	10^{-3}
Loss of cultural heritage	10^{-4}

Procedures for calculation of risks R_1, R_2, R_3 can be found in [5]. However, suggested procedures can be complicated for the engineering application. Because of that, there are many software solutions that can be used to perform risk assessment calculations as Furse StrikeRisk v6.0, DEHNsupport Toolbox, or some freeware online programs as [6].

1.2. Conventional air termination systems (CATS) design as per IEC 62305

After the risk calculations are performed it is possible to decide if the structure needs to have lightning protection system or not. In the case that lighting protection system is needed, the following three methods, or a combination of those, can be used to design CATS [2]:

1) Mesh method,
2) Protective angle method,
3) The rolling sphere method.

These methods are well known and widely used in engineering practice. Application examples of all three methods are presented in Figure 2.

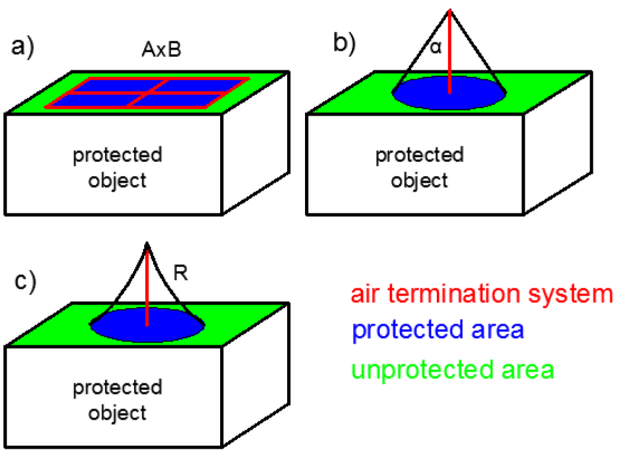


Figure 2: Application of the: a) mesh method, b) protective angle method and c) the rolling sphere method for CATS design

Mesh method is the simplest to use. In accordance with the required lightning protection level (LPL) of the structure, the mesh dimensions can be determined from the Table II [2]. This method is extremely suitable for the flat, horizontal or inclined roofs. If the roof has chimneys or other prominent parts, the mesh method can be used in combination with other methods, which must be emphasized. The mesh method defines the protection area of the conductors' grid placed on or above the protected surface, as in Figure 2 a). According to this method, the mesh of the conductors placed on or above the protected surface, can assure its required LPL.

Table II: The values of mesh size and rolling sphere radius corresponding to the selected LPL [2]

Parameter	LPL			
	I	II	III	IV
Minimum peak current Imin	3 kA	5 kA	10 kA	16 kA
Probability that I > Imin	99%	97%	91%	84%
Mesh size [m]	5×5	10×10	15×15	20×20
Rolling sphere radius	20 m	30 m	45 m	60 m

Protection angle method is also easy to use. It can be applied for estimation of the lightning protection zone of vertical rods or catenary wires, as in Figure 2 b). The protection angle values as a function of the required LPL are defined in Figure 3 [2]. More precise values of the protection angle can be found in [7]. Protection angle method can be applied only for values defined in Figure 3, while in other cases mesh method or the rolling sphere method must be used.

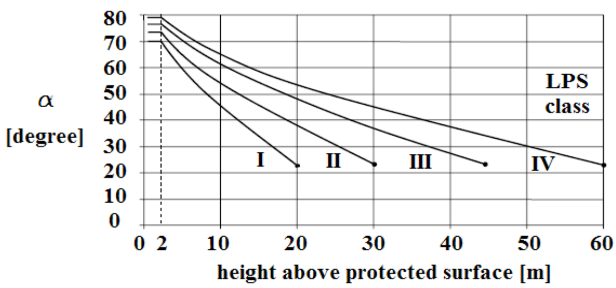


Figure 3: The protection angle (α) values [2]

When applying the protection angle method, it is very important to use the protection angle corresponding to the height of the rod tip above the protected surface, as illustrated in Figure 4. The protected object has roofs at two heights above the ground. Therefore, two protection angles must be used in calculations. The first protection angle α corresponds to the height H of the rod tip above the protected surface, while the second protection angle β corresponds to the height h of the rod tip above the protected surface. Advantage of the protection angle method is that the equivalent protection zone of many lightning rods can be estimated by superposing the protection zones of individual rods. The protection angle method is applied in the way that equivalent protection zone of all rods must fully cover protected object.

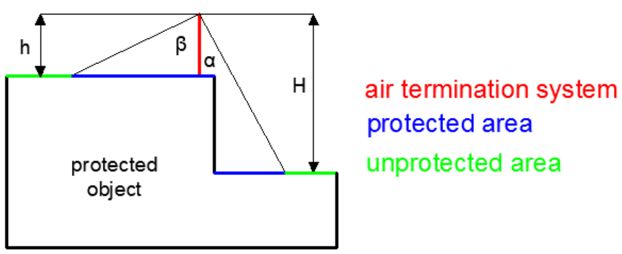


Figure 4: Determination of the protection angle value

The rolling sphere method is the most difficult to apply in comparison to the other two analysed methods, but it is an universal method, which can be applied to design almost every lightning air termination system. When using this method, the equivalent protection zone of many lightning rods cannot be estimated by superposing the protection zones of individual rods. Due to that, this method is more complicated for application compared to the mesh method or the protection angle method. The rolling sphere method is based on the electro-geometric model. The rolling sphere radius values corresponding to the required LPL are defined in Table II [2]. When using the rolling sphere method, the ball with radius *R* is rolling around the object to be protected and its air termination system, Figure 2.c) and Figure 5. Air termination system is properly designed if the ball cannot touch the protected object, but only its air termination system and surrounding ground.

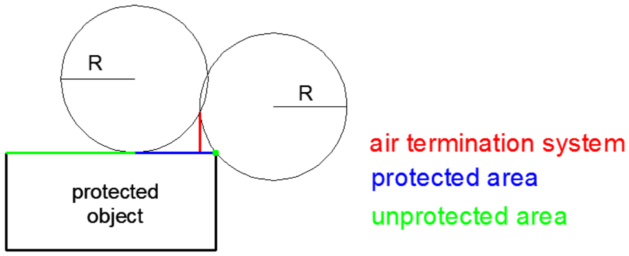


Figure 5: Application of the rolling sphere method

In engineering practice, the air termination systems can be designed by using specialized software [8]. In this paper, the numerical calculation of the air termination system protection zone is performed by using MATLAB and protection angle method. Input data preparation is performed in MS Excel software.

Analysed configuration is presented in Figure 6. The air termination system in Figure 6 is implemented by using 6 vertical Franklin rods of 5 m in width. Protected object has dimensions of 60×30 m. The equivalent lightning protection zones of this air termination system for LPL I and LPL IV are presented in Figure 7 and Figure 8 respectively. Protection angles corresponding to the LPL I and LPL IV in this example are 59° and 72° respectively [7]. The air termination system presented in Figure 6 cannot ensure LPL I for the protected structure because some parts of the roofing structure are unprotected against direct lightning strikes, Figure 7. However, the same air termination system can ensure LPL IV for the protected structure, Figure 8.

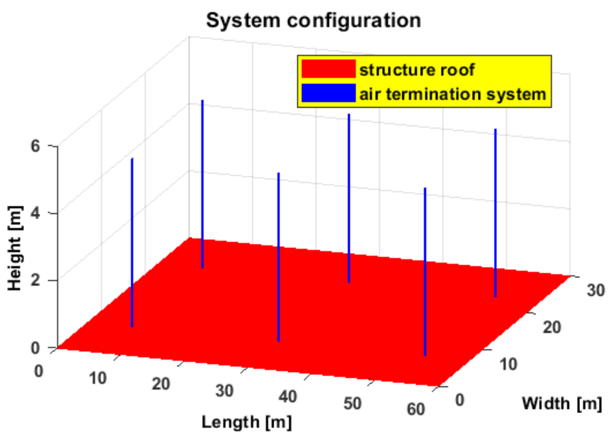


Figure 6: Configuration of the protected roof and Franklin rods

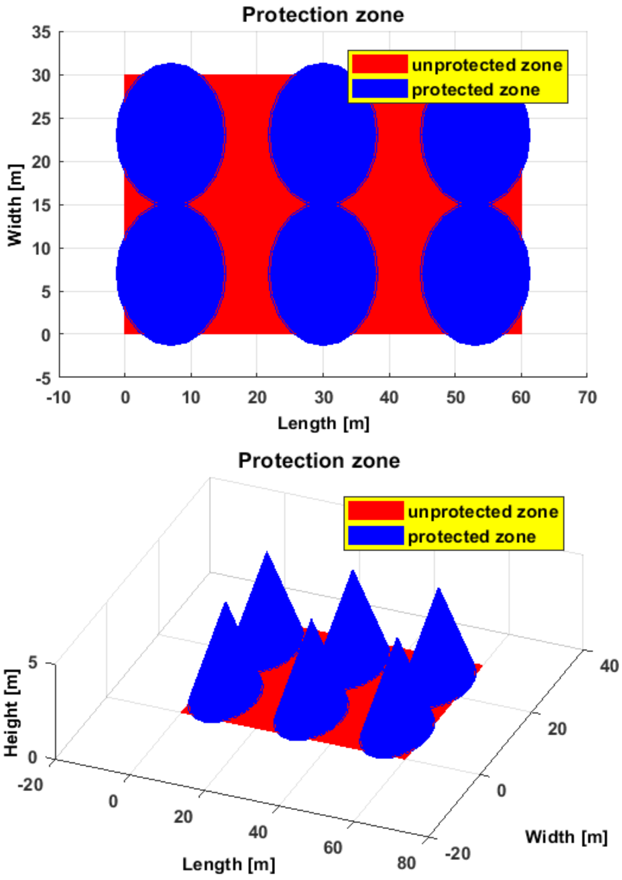


Figure 7: Inefficient air termination system for the LPL I implemented by using 6 Franklin rods

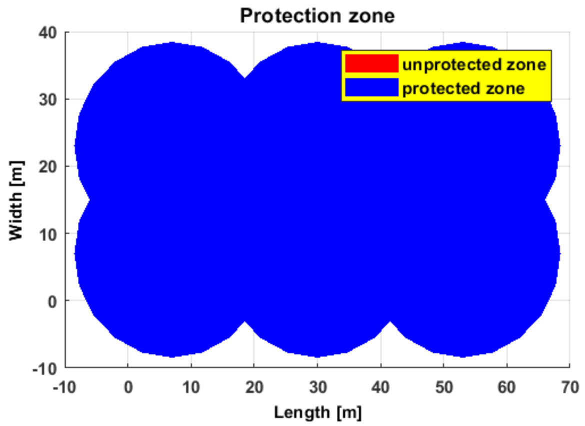


Figure 8: Efficient air termination system for the LPL IV implemented by using 6 Franklin rods

In the previous example, the lightning protection of the structure is implemented by using 6 vertical Franklin rods. However, protection angle method can also be applied to calculate lightning protection zones of the catenary wires. The catenary wires are used to design lightning air termination system for the equipment placed on the roofing structureroofing structure in cases when visual effects are not important.

Analysed configuration and corresponding lightning protection zone are presented in Figure 9. In this case air termination system is implemented by using two catenary wires of 60 m of length. It is assumed that air termination systems have LPL I with a corresponding protection angle of 590. The air termination system presented in Figure 9 cannot ensure LPL I for the protected structure. In Figure 10 the air termination system configuration is modified with the aim to ensure LPL I for the protected structure. In this case all parts of the protected roofing structure are in the protection zone of the air termination system.

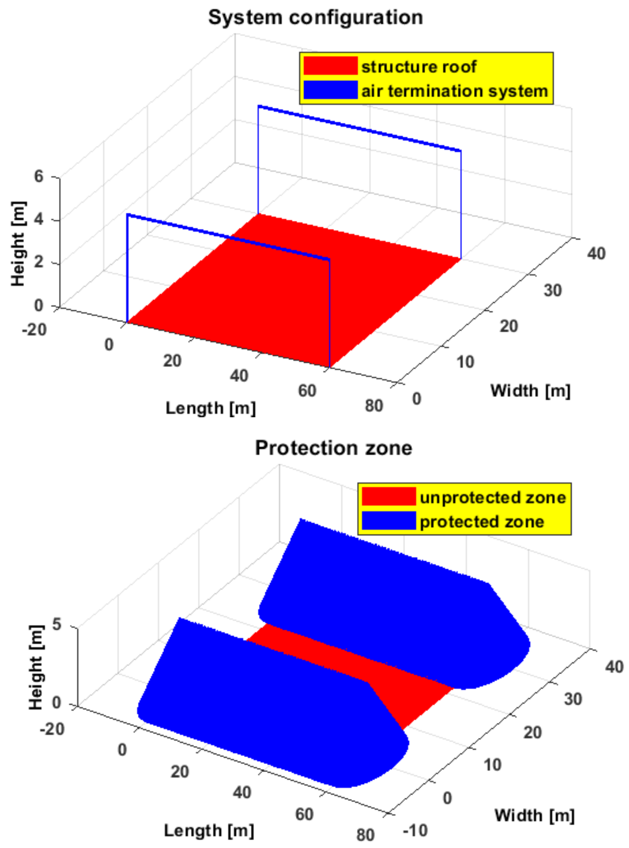
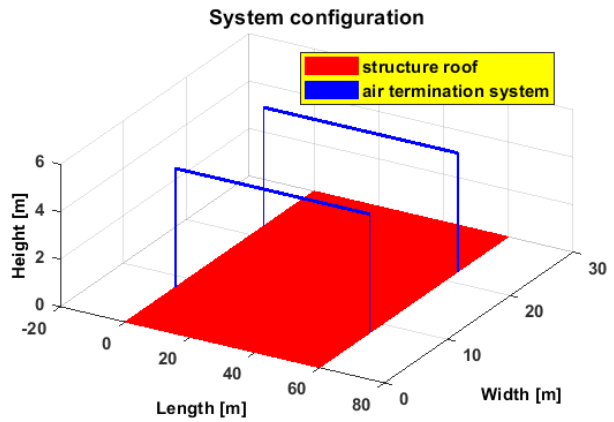


Figure 9: Inefficient air termination system for LPL I implemented by using 2 catenary wires



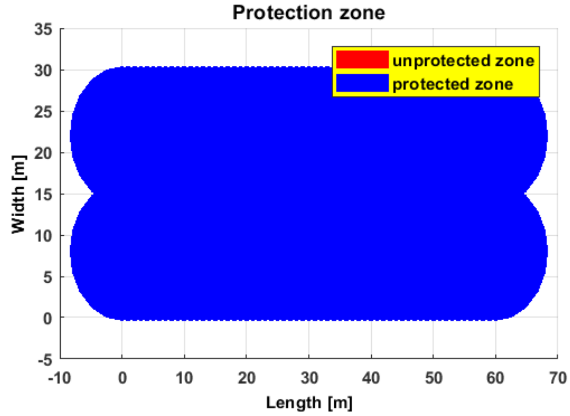


Figure 10: Efficient air termination system for LPL I implemented by using 2 catenary wires

1.3. Early streamer emission air termination system (ESEATS) design as per NF C 17-102

French national standard NF C 17-102 [9] describes and suggests application of the early streamer emission lightning rods for the implementation of the air termination system. This kind of lightning protection is accepted in some other national standards as UNE 21186 (Spain), SRPS N.B4.810 (Serbia), I 20 (Romania), STN 3-1391 (Slovakia), IRAM 2426 (Argentina), MKS N.B4.810 (Macedonia), NP 4426 (Portugal) etc [10]. The ESEATS are not supported, but also not prohibited in the IEC 62305 standards (radioactive air terminals are prohibited). Today, ESEATS are increasingly used worldwide, including Bosnia and Herzegovina. Some of the examples of their application in Bosnia and Herzegovina include hospitals (Serbia in East Sarajevo), hotels (Termag on the Jahorina Mountain), Administrative Centres of the Government of Republika Srpska in Banja Luka and in East Sarajevo, many residential buildings, stone quarries etc. Up to now, inefficiency of ESEATS on these structures has not been reported, while one lightning strike to the ESEATS at the Hotel Termag appeared few years ago.

First types of ESEATS were based on the radioactive isotopes as a source of ionization and they were used up to 1980s. After they were banned, modern ESEATS have been introduced.

ESEATS are devices capable to generate upward streamers and leaders earlier than a classic Franklin rod when used under the same conditions. The time difference between moments when ESEATS and classic Franklin rod generate upward streamers is marked as ΔT. Typical values of ΔT are 25 μs, 30 μs, 40 μs, 50 μs and 60 μs. According to [9] the maximum value for ΔT is 60 μs, no matter what the laboratory test results are. Suggested speed of the upward leader is 1 m/μs [9]. It is easy to calculate that ESEATS will generate upward leader with length equal to $L=\Delta T\times 10^6$ [m] up to the moment when upward streamers and leaders appear from the tip of the classic Franklin rod. Because of that ESEATS manufacturers declare much larger protection zone of this devices in comparison to the classic Franklin rods.

The protection radius of the ESEATS can be calculated by using equation (1) [9]:

$$R_P = \sqrt{h(2R-h)+L(2R+L)} \quad , \quad h \geq 5\,\mathrm{m}$$
$$R_P = h \cdot R_P(5\mathrm{m})/5 \quad , \quad 2\,\mathrm{m} \leq h \leq 5\,\mathrm{m} \qquad (1)$$

where: h is the height of the ESEATS tip relative to the surface to be protected [m], R is the striking distance from the classic Franklin rod, 20 m for LPL I, 30 m for LPL II, 45 m for LPL III and 60 m for LPL IV, L is equal to $\Delta T \times 10^6$ [m], where ΔT is characteristic of the applied ESEATS.

Minimum height of the ESEATS tip relative to the surface to be protected is 2 m [9]. In Figure 11 graphical explanation of the ESEATS protection radius estimation is given.

Another important advantage of the ESEATS based lightning protection systems is reduced required number of down-conductors. According to [9] required number of down-conductors is two for non-isolated down-conductors, or even only one in the case of the special isolated down-conductor.

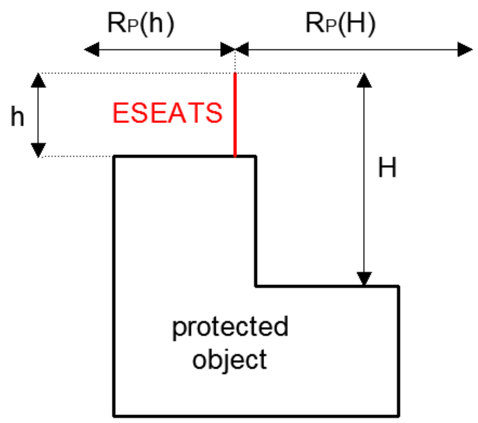


Figure 11: Protection radius of the ESEATS related to its height above the surface to be protected

1.4. Comparison of CATS and ESEATS solutions

Lightning protection of the structure with the dimensions 50×50 m is presented in Figure 12. The structure height is 20 m. CATS is implemented by using the mesh method, being a common solution for the structures with flat roof. Calculations are performed for the LPL I, LPL II, LPL III and LPL IV. Mesh sizes are applied as defined in Table II. Suggested values of the distance between down-conductors as a function of the required LPL are defined in Table III [2].

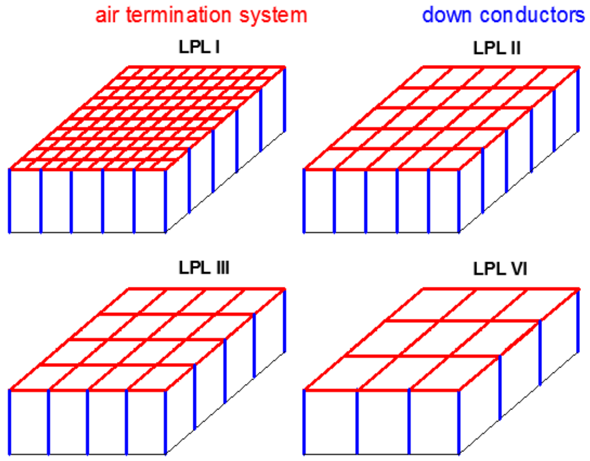


Figure 12: CATS and corresponding down-conductors systems for the structure with dimensions 50×50 m designed by using mesh method

Table III: Typical values of the distance between down-conductors as a function of the required LPL [2]

LPL	Typical distance
I	10 m
II	10 m
III	15 m
IV	20 m

Based on the presented results from Figure 12 it can be concluded that implementation of the CATS with high LPL (LPL I or LPL II) at the structures with large dimensions can be difficult task. For example, mesh air termination system with LPL I from Figure 12 is implemented by using 22 conductors with length of 50 m (in total 1100 m of wires), while down-conductors system is implemented by using 20 wires. In many cases implementation of the large number of down-conductors is extremely difficult, despite the application of the natural down-conductors. For example, if the structure has glass facade it is not possible to apply standard down-conductors at the walls, while their integration in pillars of the building in most cases cannot assure required distance of 10 m. Also, installation of the large number of down-conductors can be very difficult in the underground garages or some other specific structures.

Implementation of the air termination system with LPL I on large structures can easily be done by using early streamer emission lightning rods. In Figure 13 lightning protection of the same structure as in Figure 12 (dimensions 50×50 m) is designed by using ESEATS. For all four LPLs air termination system can be implemented by using only one early streamer emission rod, but with different time ΔT. When applying ESEATS, rod height above the protected surface is assumed to be 5 m, which is an optimum solution. In the case that height of the rod tip over the protected surface is lower than 5 m, protection radius of the rod is linearly reduced, equation (1). In the case where the height of the rod tip over the protected surface is more than 5 m, protection efficiency remains the same or slightly increases. In the case when ESEATS are applied, required number of down-conductors is two for non-isolated systems, or even only one for the special isolated systems [9]. In Figure 13 down-conductors are designed with the aim to achieve their minimum length.

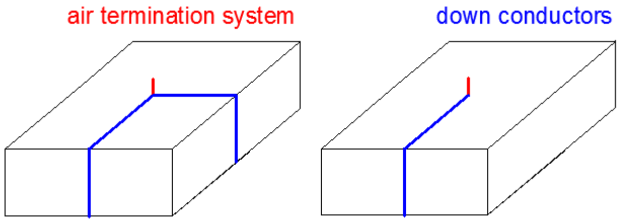


Figure 13: ESEATS and corresponding down-conductors systems for the structure with dimensions 50×50 m designed by using a) non-isolated and b) isolated down-conductors

It is important to note that lightning protection of the structure from Figure 12 and Figure 13 can be implemented by using catenary wires only if visual effects are not of interest and if some sensitive equipment placed on the roofing structure need to be protected with this isolated lightning protection systems. This solution is not common in engineering practice. Application of the standard Franklin rods for protection of large buildings is also rarely used because of the huge number of the required rods.

By comparing designs of the lightning protection systems from Figure 12 and Figure 13 it is clear that ESEATS based solution is much simpler to implement in comparison to CATS solution, especially for higher required LPLs. However, when searching for the optimum solution, it is necessary to perform economic analysis.

In Table IV the technical and economic analyses of the CATS and ESEATS with corresponding down-conductor systems for the structure analysed in Figure 12 and Figure 13 are presented. Following prices are assumed in the calculations:

- Mesh conductors in the CATS and down-conductors in CATS and ESEATS are implemented by using Fe-Zn conductors with dimensions 20×3 mm2 which price is 1.1 €/m.
- Holder of roof conductors' price is 1.3 €/piece.
- Roof conductors' joints price is 0.8 €/piece.
- Wall holders of down-conductors price is 0.7 €/piece.

Distance between the roof holders is assumed to be 1 m, while the distance between the down-conductors holders is assumed to be 1.5 m. These values are frequently applied in engineering practice. Roof conductors' joints are applied at the intersection points of two conductors. Protection radius of the early streamer emission rods is calculated by using equation (1). In the case of ESEATS non-isolated down-conductors are applied and, in that case, at least two conductors must be used [9]. In economic analysis only the price of material is analysed, while labour cost is not included.

In the case of the LPL III and LPL IV CATS solution is slightly cheaper than ESEATS. However, in the case of LPL I and LPL II ESEATS solution is cheaper than CATS. Important fact in the case of CATS is very difficult implementation procedure of the system with LPL I. This fact is of primary importance in many situations. To implement CATS with LPL I for the structure with dimensions 50×50 m, 1100 m of Fe-Zn wire must be placed at the roofing structure and 121 roof conductors' holders must be installed. Also, 20 down-conductors must be used to implement LPL I or LPL II for this structure. In the case of ESEATS, only one early streamer emission lightning rod and two down-conductors can be used.

Previous analyses present that ESEATS solutions are much more cost effective than CATS in the case when high LPL must be achieved at the structures with large dimensions. In Table V technical and economic analyses of the CATS and ESEATS and corresponding down-conductors systems are presented for the LPL I of the structures with different dimensions. All calculation parameters are the same as in the

Table IV: Technical and economic analysis of CATS and ESEATS and corresponding down-conductors systems for the structure with dimensions 50×50 m for different required LPLs

LPL	Technical analysis					Total cost (air termination + down-conductors)	
	Air termination system			Down-conductors system			
	CATS		ESEATS ΔT	CATS	ESEATS	CATS price	ESEATS price
	Fe-Zn wire length	Number of roof holders and conductors' joints		Number of down - conductors and wall holders			
I	1100 m	1001 and 121	25 µs	20 and 280	2 and 28	3244 € (2608 €+636 €)	1519 € (1400 € +119 €)
II	600 m	576 and 36		20 and 280		2074 € (1438 €+636 €)	
III	434 m	424 and 19		14 and 187		1481 € (1042 €+439 €)	
I V	350 m	345 and 13		10 and 140		1161 € (843 €+318 €)	

Table V: Technical and economic analysis of CATS and ESEATS and corresponding down-conductors systems with LPL I for structures with different dimensions

Structure size [m]	Technical analysis					Total cost (air termination + down-conductors)	
	Air termination system			Down-conductors system			
	CATS		ESEATS ΔT	CATS	ESEATS	CATS price	ESEATS price
	Fe-Zn wire length	Number of roof holders and conductors' joints		Number of down - conductors and wall holders			
10×10	60 m	57 and 9	25	4 and 56	2 and 28	247 € (147 €+127 €)	1475 € (1400 €+75 €)
30×30	420 m	385 and 49	25	12 and 168		1382 € (1001 €+381 €)	1497 € (1400 €+97 €)
50×50	1100 m	1001 and 121	25	20 and 280		3244 € (2608 €+636 €)	1519 € (1400 €+119 €)
80×80	2720 m	2465 and 289	40	32 and 448		7444 € (6427 €+1017€)	1852 € (1700 €+152€)
100×100	4200 m	3801 and 441	60	40 and 560		11186 € (9914 €+1272 €)	2174 € (2000 €+174 €)

previous calculation. The aim is to present influence of the structure dimensions to the selection of the optimum lightning protection solution.

According to the Table V CATS solutions are more cost effective at the structures with small dimensions. In the analysed examples, prices of the two solutions are nearly equal for the structure with dimensions 30×30 m, while for the larger structures ESEATS based solution become much more cost effective. For the structure with dimensions 100×100 m. ESEATS based solution for the LPL I is almost 6 times cheaper in comparison to CATS. Also, on structures of big dimensions it is very difficult to implement CATS and corresponding down-conductors, especially for LPL I or LPL II. For example, at the structure with dimensions 100×100 m length of roof conductors necessary for mesh implementation in CATS system is 4200 m, while required number of roof conductors' holders is 3801. Required number of roof conductors' joints is 441. Also, 40 down-conductors must be used to implement LPL I or LPL II for this structure.

Even though natural components can be used as down-conductors, the large number of down-conductors is still necessary to implement CATS with LPL I or LPL II at large structures. In the case of ESEATS, only one early streamer emission lightning rod and two down-conductors can be used. This is the main reasons for the frequent ESEATS application at large and important buildings.

2. SCIENTIFIC COMMUNITY CRITICISM OF THE AIR TERMINATION SYSTEM DESIGN METHODS

2.1. Criticism of the CATS design methods

The CATS design methods suggested in IEC 62305 are used for decades and even centuries and their efficiency has been proven over a long period of exploitation. However, those methods have some uncertainties, as discussed in [11]. As per [2] mesh of conductors can be placed at the roofing structure and in that way efficient air termination system can be implemented. However, the rolling sphere method predicts that direct lightning strikes can attach the protected structure between the mesh conductors unless the mesh is elevated above the top of the structure [11]. This situation is illustrated in Figure 14.

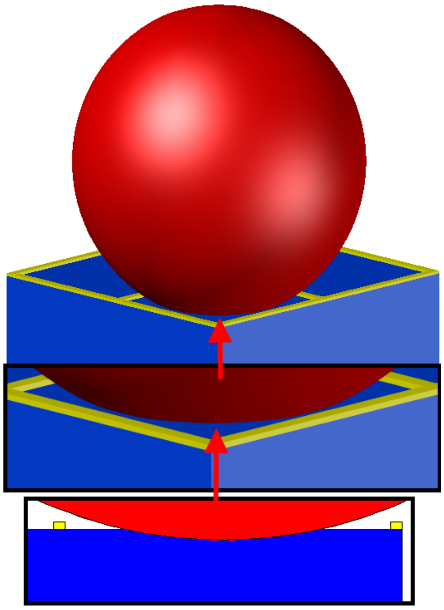


Figure 14: The rolling sphere method predicts possibility of direct lightning strikes to the protected structure if the mesh is placed directly on the protected surface

In [11] it is noticed that the relations between the striking distances and the return stroke peak currents given in Table II [2] are very rough. Next important issue defined in [11] is that the specified relations between mesh sizes and striking distance values from Table II [2] are based on the practical experience rather than on the theory.

It is important to note that the rolling sphere method predicts lightning strikes to the side of the structures lower than 60 m, but in [2] such lightning strikes are neglected, Figure 15.

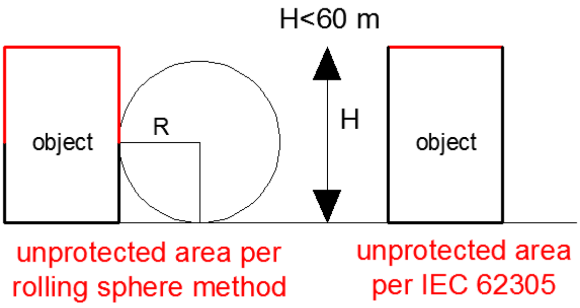


Figure 15: The rolling sphere method predicts lightning strikes to the side of the structures lower than 60 m, while probability of such lightning strikes per [2] is negligible

2.2. Criticism of the ESEATS

When dealing with the ESEATS it is important to keep in mind that scientific community has a very critical attitude towards these devices, although manufacturers claim that their efficiency is proven both in the laboratories and in the exploitation.

ESEATS manufacturers test their devices in high voltage laboratories with the switching impulses 250/2500 μs in accordance with NF C 17-102 [9], or with composite voltages consisting of high DC voltage and superimposed switching impulse voltage as in [12]. Such a test has proven better protection efficiency of the ESEATS over the standard Franklin rods [12], [13]. However, many leading physicists stated that laboratory tests of the ESEATS suggested in [9] cannot be used to prove their efficiency in natural conditions [11], [13], [14]. Main reasons are listed as follows:

- In natural conditions the lightning electric fields changes from slow to fast, while the switching electric field produced in laboratory changes from fast to slow. Because of that the development of leaders from the air terminals under these conditions is different [13], [14].
- The length of individual steps in the natural stepped leader is tens of meters and that is considerably larger than the length of laboratory sparks used to test and certify ESEATS [11].
- A high voltage pulses that are being generated at the tip of the ESE lightning rods will be produced by a stepped leader at any standard Franklin rod. Because of that ESE rods have the same protection radius as the standard Franklin rods [15].

Physicists also do not support upward leader speed equal to 1 m/μs which is suggested in [9]. According to [11] this value of the upward positive leader speed is arbitrary. The results of the experimental measurements of the upward leader speed are as follows:

- Between 4×10^4 m/s and about 10^6 m/s for seven detected upward positive leaders, while for four of the seven leader speeds ranging from 4×10^4 m/s to $7{,}5\times10^4$ m/s [16],
- Between $0{,}8\times10^5$ m/s and $2{,}7\times10^5$ m/s for three detected upward leaders [17],
- Typically, about 10^4 m/s for positive upward-connecting leaders in laboratory experiments [11].

Two triggered lightning events are described in [18] which are frequently used to prove ESEATS efficiency. However, critical review of this experiment is given in [11] where it is stated that experiment is not properly utilized to prove ESEATS efficiency.

In [19], a seven-year experimental test of lightning rods is described. The experiment was performed in natural conditions in Magdalena Mountains in New Mexico, USA. It is stated that Franklin rods with diameter of 9.5 mm and 51 mm. as well as the radioactive ESEATS did not receive any lightning strike during the seven-year experiment, while the most strikes hit the 19 mm diameter rods. It must be emphasized that in these experiments old radioactive rods were tested.

In [20]-[23] some examples of the ESEATS inefficiency in exploitations in high lightning activity region of Malaysia (keraunic level >200 days per year) are reported. Cases of lightning striking parts of the structures, which fall in the protection zone of the ESEATS, were reported. These results are frequently mentioned by the engineers and scientist who are opponents of the ESEATS. However, in these papers some important facts are not adequately discussed, including: exact configuration of the protected structure, characteristics and manufacturers of the applied ESE rods, date of rods manufacture and installation, comments about the initial and periodic inspections of the rods functionality and correctness of the installation, number of the collected lightning strikes by ESEATS and number of lightning strikes penetrating to the protected structures etc. Also, detection of the direct lightning strikes to the protected structure are not performed using real time lightning localization systems or cameras, but through the minor damages at the surface of the protected structures!

3. CONCLUSION

In this paper CATS and ESEATS and corresponding down-conductors systems are analysed. It is presented that an ESEATS can be several times cheaper and much simpler for implementation at large structures with high required LPL (for example LPL I) than CATS based solutions. The same applies to the down-conductors system. This is why the use of ESEATS is on the increase. However, it is noticed that physicist dealing with the lightning discharge process do not support declared characteristics and protection efficiency of the ESEATS. Because of that standard IEC 62305 suggest only CATS which prove their efficiency in the decades and centuries of exploitation. In the scientific literature there are a lot of papers in which ESEATS are analysed. Some of the papers present their good protection characteristics, which are in accordance with the manufacturers' declarations, while some other papers present their inefficiencies, both from the theoretical aspect and exploitation experience. It seems that additional experimental analysis with the natural lightning are necessary to prove or disprove efficiency of the ESEATS.

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BIOGRAPHY

Mladen Banjanin was born in Sarajevo, Yugoslavia, in 1988. He received his BSc degree in 2011 from the Faculty of Electrical Engineering in East Sarajevo, Bosnia and Herzegovina, and MSc and PhD degrees in 2012 and 2017 years, respectively, from the School of Electrical Engineering in Belgrade, Serbia. He has been working at the Faculty of Electrical Engineering in East Sarajevo since 2011. Presently, he is an assistant professor and Head of the Department of Electric Power Systems. His main area of interest covers high voltage engineering and lighting protection.

Svetozar Banjanin was born in Dobro Polje, Yugoslavia, in 1955. He received his BSc degree in 1978 from the Faculty of Electrical Engineering in Sarajevo, Yugoslavia. Over the past 30 years, he has been a director and one of the leading engineers in company Ban-Ko Inžinjering, East Sarajevo, Bosnia and Herzegovina. This company deals with the design of electrical installation projects. They carried out several different projects in Bosnia and Herzegovina, Serbia and Montenegro.