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Inefficacy of radioactive terminals and early streamer emission terminals

K.L. Chrzan [1], and Z.A. Hartono [2]
[1] Wroclaw University of Technology, Wroclaw, Poland
[2] Lightning Research Pte Ltd, Kuala Lumpur, Malaysia

Abstract: The paper reviews about research of radioactive lightning rods carried out 30 years ago and about new measurements of early streamer emission terminals. Lightning damage on over 100 buildings equipped with ESE terminals in Malaysia and on one family house in Poland is reported. The main measure criterion was the breakdown voltage of the air gap consisted of the high voltage electrode (rod or plate) and a grounded radioactive or ESE terminal. These careful measurements show that the air gaps with ESE terminals have the same breakdown voltages as the air gaps with standard rods. Therefore the big protection zone of ESE terminals as claimed by their manufactures seem to be impossible.

1. Introduction

Benjamin Franklin discovered the lightning rod 250 years ago. The invention's usefulness was very quickly confirmed by successful operations on the first protected objects [1]. In the 19th century the steel prices decreased and lightning protection became very popular. It was first observed in this century that the lightning discharge could not be attracted by the lightning rods and damaged the protected objects [2]. The lightning rods inefficacy was noted more frequently in the 20th century when lightning rods were used to protect very high structures e.g. skyscrapers, TV towers. The known unsuccessful efforts to increase the lightning rods efficiency were radioactive devices [3].

The new generation devices appeared on the market since about 20 years. The early streamer emission terminals (ESE) are equipped with special tools, which should emit the upward streamer a bit earlier than the classical rods do. The physical principle of ESE terminals and the claimed protection zone were never proved and were not recognised by scientific authorities [4, 5]. In spite of this the ESE terminals are produced in many countries and installed on thousands of structures all over the world. The research carried out at the Darmstadt University of Technology shows that the concept of ESE terminals (similarly like radioactive rods) is missing and their protection zone is exactly the same as the protection zone of Franklin rods.

2. Radioactive terminals

Szilard, a co-worker of Maria Curie-Sklodowska, proposed in 1914 an improvement of Franklin rod by adding a radioactive element at the vicinity of its edge [3]. The radioactive lightning rods were installed in 1930s and later in many countries. Some papers reported about fantastic interception area of 250 m [3]. As the radioactive source the americium Am 241, radium Ra 226, cesium Cs 137, cobalt Co 60, krypton Kr 85, polonium Po 210, thorium Th 90 with the radioactivity from 0.7 μCi up to 200 mCi (Curie) were used. The radioactive elements were put in small containers in the vicinity of the terminal tip (fig. 1).

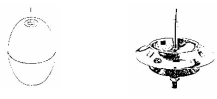


Fig. 1. The radioactive terminals [6]

The radioactive elements emit α, β, γ radiation which is able to ionize the air in a very small volume, only 1 – 3 cm apart from the tip. The 100 mCi (milli Curie) source produces $2{,}8 \cdot 10^{12}$ ions per second which generates a current of 0,87 μA only [3]. There are a high number of free electrons, which can start the further air ionization.

Baatz studied the radioactive terminals in 1971[3]. Fig. 2b illustrates the current emitted by terminal with (or without) a radioactive source. The measurement was carried out in the arrangement shown in fig. 2a.

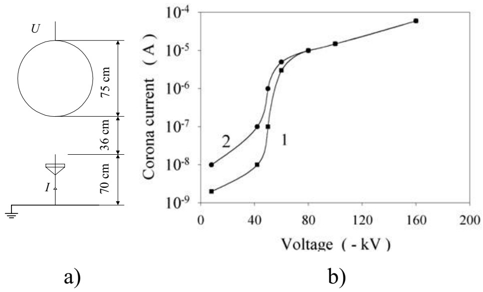


Fig. 2. Terminal currents under electrostatic field [5]. a – the used electrodes, b – voltage-current characteristics, 1 – terminal without radioactive element, 2 – terminal with radioactive element 440 μCi

At the voltage smaller than 50 kV the current flowing through the radioactive terminal was a few times greater than current of the classical terminal. At the voltage greater than 70 kV up to breakdown (200 kV) the both current were similar. This experiment shows that under dc voltage the radioactive elements are not able to lower electrical strength of air.

The breakdown voltage under switching impulse (the rise time 270 μs) were measured for the rod-rod electrodes with 5,4 m distance (fig. 3). The electrical strength of air measured with grounded radioactive terminal was practically the same as with terminal without radioactive element (Table 1).

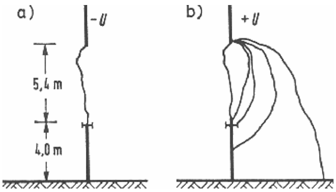


Fig. 3. Discharge pattern between rod electrodes with the 5,4 m distance [3]. a – negative polarity, b – positive polarity

Table 1. The 50% breakdown voltage measured under switching impulse measured for the test arrangement shown in fig. 3. [3]

Polarity	Radioactive terminal	Classical terminal
Negative $U_{50\%\,-}$	3030 kV	3010 kV
Positive $U_{50\%\,+}$	1740 kV	1730 kV

Similarly as under dc voltage, the electrical strength of air under impulse voltage does not depend on ionization caused by radioactive element. The electrostatic field under the storm cloud can reach 10 kV/m. The ionization from sharp points e.g. from leaves can start under the field of 1 kV/m. Therefore the corona discharges develops from sharp tips of classical terminals under the storm cloud. The radioactive elements radiation is to weak to change the breakdown mechanism of air gap with a distance in the range of 1 m or more.

The striking distance (which determines the protection zone dimensions) can depend not only on lightning current amplitude but on current polarity too. The discharge with negative polarity cross the air gap between rods through the shortest way (fig. 3a). The discharge path under the positive switching impulse can be very different (fig. 3b). A part of discharges missed the opposite rod and hit the ground plate in spite that this path was nearly two times longer than the distance between rods. Similar behavior was observed on insulators tested under switching impulses [7].

3. Hypothesis describing the operation of ESE terminals

There are few types of ESE terminals working on different principle:

- the air ionization at the tip is produced by piezo-electric element using the wind energy
- the air ionization is caused by electrical impulses delivered by a micro-generator. The electrical field of downward leader charges a capacitor which supplies the micro-generator,
- the high voltage impulse is induced by the electro-magnetic impulse in a coil.

The Dynasphere produced by ERICO (called earlier as ESE terminal, now as Controlled Leader Terminal) uses a special shape electrodes. The tip of Dynasphere terminal is grounded directly. The sphere surrounding the tip is grounded through a resistor. When the lightning downward discharge approaches to the terminal the sphere is charged to a higher potential than the tip and the gap between these two elements sparks over.

The French standard NF C 17-102 describes the testing condition and evaluation criteria for ESE terminals. Over the grounded terminal (classical or ESE) the plane electrode is suspended at the distance of 1 m. Then the switching voltage is applied to the plate and the time to upward streamer initiation is measured. Under these conditions the active terminals emit the upward streamer 10 – 120 μs earlier than classical terminals. The average time ΔT is calculated (equation 1) on the base of 100 voltage probes.

It is assumed that the earlier streamer "elongates" the height of ESE terminal and by this manner the attractive area of active devices increases by the distance of ΔL. If the upward streamer velocity V_+ were in the range of 10^6 m/s, the distance ΔL would range from 10 to 120 m [8].

$$\Delta T = T_F - T_{ESE} \qquad (1)$$

$$\Delta L = V_+ \cdot \Delta T \qquad (2)$$

where:

T_F ; T_{ESE} - initiation time of upward streamer for Franklin terminal and ESE terminal (fig. 4a)

The ESE opponents suggest that the same protection effect can be achieved by a prolongation of Franklin terminal and the use of ESE terminals is not economical. They showed that the assumption of a very high and constant velocity of upward streamer is false. Many experiments revealed that it is lower and only few μs before the junction of downward leader with upward streamer increases to 2 m/μs. The velocity V_+ in equation (2) shall be in the range of $2 \cdot 10^4$ m/s [5]. Under such conditions the evaluated distance ΔL amounts only from 0.2 m up to 1 m.

Attraction range calculation for ESE terminals according to equations (2) led to unrealistic results. Time ΔT is measured under laboratory conditions described by NF C 17-102 standard. The function describing the dependence of striking distance D on lightning current I for classical terminals was given by Love.

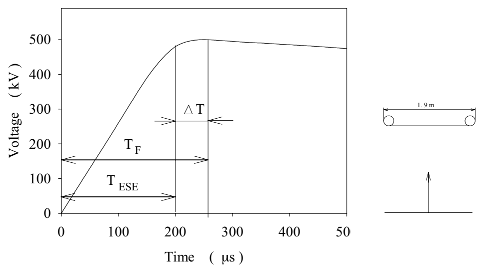
$$D = 10 \cdot I^{0.65} \qquad (3)$$

But it is not clear how (if any) D depends on initiation time of upward streamer emitted from terminals with low height.

4. Laboratory test of ESE terminals

Testing with negative polarity switching impulses (250 microsecond front), with the gap configuration being rod-to-rod, is considered to best represent the behaviour under natural lightning [6]. The other cases considered in this paper are provided so as to fully explore the performance of this type of active lightning rod.

The experiments were curried out with three ESE terminals manufactured by different firms at the High Voltage laboratory of Darmstadt University of Technology. The breakdown voltages and times to breakdown were measured for electrode arrangements consisted of grounded rod and high voltage electrode in the form of a rod or a plate. The electrode distance ranged from 10 cm up to 4 m. The standard lightning impulse 1.2/50 µs and switching impulse 250/2500 µs with negative or positive polarity were applied. As grounded rods the ESE terminals or Franklin terminals were used. The Franklin terminals were formed from ESE terminals after grounding the tips of ESE terminals. Such procedure ensured that the shape of ESE terminals and Franklin terminals were identical. The tips of used ESE terminals were isolated from ground potential. The diameter of plate electrode amounted 1.9 m (fig. 4b). The high voltage rod electrode consisted of the 4 m long pipe with a diameter of 5 cm ended by a cone (cone angle 45°).



a) b)

Fig. 4. Definition of upward leader initiation times T_F and T_{ESE} (a) and the electrode arrangement plate - rod (b)

The breakdown voltage was estimated according to series method. Each series consisted of 10 voltage impulses with the same amplitude. The amplitude of next series was about 1% higher for lightning impulses and about 1,5% higher for switching impulses. When breakdown occurred the time to breakdown was measured from oscillogram by means of LabView program. The maximum voltage was found at which 10 times the withstand was recorded, called "withstand voltage"- $U_{0\%}$ and the voltage at which 10 times the breakdown was noted – $U_{100\%}$. When the voltages $U_{0\%}$, $U_{100\%}$ and times to breakdowns were evaluated for the electrode arrangements with ESE terminal, the tip of ESE terminal was immediately grounded and the tests were repeated for so prepared Franklin terminal. This measure cycles for ESE terminal and Franklin terminal (at the same electrode distance and voltage polarity) lasted about 2 hours. It can be assumed that during so short time the climatic conditions in the laboratory were the same and a correction for voltage results was not need.

An example of breakdown voltages for electrodes distances of 1 m is given in Table 2, the average difference between time to breakdown for electrodes with Franklin rod and time to breakdown for electrodes with ESE terminal is listed in Table 3.

Table 2. Breakdown voltages for the arrangement plate – rod at the electrode distance 1 m and switching impulses

	⊕ SI		Θ SI	
	$U_{0\%}$	$U_{100\%}$	$U_{0\%}$	$U_{100\%}$
	kV	kV	kV	KV
ESE1	1060	1180	470	530
ESE1s	1060	1180	470	550
ESE2	1150	1180	445	500
ESE2s	1150	1180	460	500
ESE3	1150	1180	460	500
ESE3s	1150	1180	460	500

Table 3. Times to breakdown ΔT_b (in µs) for ESE terminals at the plate – rod arrangement and switching impulses

	⊕ SI			Θ SI			
	distance			distance			
	0.5 m	1 m	2 m	0,5 m	1 m	2 m	3 m
ESE1		32			9		
ESE2	**-122**	2	-29	20	-2	19	15
ESE3	-38	1	37	-36	-46	6	-14

Table 2 shows that electrical strength of air for electrode arrangements with ESE terminals is the same as with Franklin terminals. Times to breakdown measured with ESE terminals can be shorter than with Franklin rod ($\Delta T_b > 0$) or longer ($\Delta T_b < 0$, Tab. 3). If the active terminals had the properties claimed by their manufactures, then the breakdown voltages of electrode arrangements containing ESE terminals should be lower than the arrangements with Franklin terminals. In this case the times to breakdown measured for the set up containing ESE terminals should be shorter too ($\Delta T_b > 0$).

Times to breakdown scatters for electrode arrangements with non-uniform field are usually big. At one series there are possible breakdown on the impulse front (e.g. time to breakdown T_b = 84 µs) or on the tail (e.g. T_b = 720 µs). The large value ΔT_b = -122 µs in the Table 3 results from shorter time to breakdown for electrode arrangement containing Franklin rod and longer times to breakdown with ESE terminals (quite opposite to the claimed properties of ESE terminals).

In spite of shorter times to breakdown for the arrangement with Franklin rod this set up has practically the same electrical strength, the voltages $U_{0\%}$ and $U_{100\%}$ are very similar. This example shows that the time for breakdown is not a parameter, which decides about the value of breakdown voltage. The time to breakdown consists of two main components: the statistical time lag of discharge onset and the discharge development time. In the plate - rod arrangement, the discharge develops from the rod electrode. In this electrode arrangement and relatively small distance, the statistical time lag of discharge onset shall be shorter for ESE terminal at least. We did not measure this time. But generally, this time is not important very much. The deciding criterion is the breakdown voltage. The ESE terminals do not cause the lowering of electrical strength in the distance from 10 cm to 4 m. Do they do this at larger distances which were not included in the author's study ? It is quite impossible. The concept of ESE terminals is based on the parameter ΔT (see equation 2) measured for the plate - rod arrangement at the distance of 1 m. From that, the conclusion is drawn about the electrical strength of the arrangement lightning discharge – ESE terminal at the distance of 20 m at least. But it was shown, this concept does not work at the distance ranging from 10 cm to 4 m. Therefore the concept of ESE terminals seems to be misleading.

5. Failures of ESE and radioactive terminals in the field

Baatz's and our results carried out in fully controlled conditions show that radioactive terminals and ESE terminals have the same properties as classical Franklin rods. The observed failures of these devices suggest that active terminals are not better than Franklin rods in the field too. Many cases of ESE and radioactive terminal failures in Malaysia were recorded in recent years [9]. The failures in Kuala Lumpur were often detected on buildings higher than 60 m. These cases were also noted on family houses.

Fig. 5. Family Wieczorkowski house in Kamieniec Wroclawski

The house of family Wieczorkowski in Kamieniec Wroclawski (Poland) was struck by lightning in the summer 2002. The house was equipped with one ESE terminal on the highest place, point A on fig. 5. In spite of claimed protection radius of 30 m the lightning struck the point B, which is only 18 m away from the point A. As a result the ESE manufacturer installed additional ESE terminal on 3 m pole at the point B on own cost. The protection radius of ESE terminals was therefore reduced from claimed 30 m to 9 m only.

Conclusions

- The breakdown impulse voltage of arrangements containing the grounded active terminal is the same as the arrangements containing grounded Franklin rod. This shows that the protection zone of active terminals is the same as Franklin terminals at small laboratory distances.
- The concept of ESE terminals, which is based on the time to initiation of upward streamer, is misleading.
- The observed failures in the field suggest that under natural conditions the protection zone of active terminals is also the same as the protection zone of Franklin rods.

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