ACTIVE LIGHTNING PROTECTION SYSTEMS AND A MEANS OF CALCULATING THE PROTECTIVE AREA

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CAPTURING THE LIGHTNING DISCHARGE

The role of a lightning air termination system is to effectively launch an upward leader earlier than any other competing feature on the structure, thereby ensuring that this becomes the preferred attachment point for the approaching down leader.

As the down leader approaches the ground, the ambient electric field rapidly escalates to the point where any sharpened structures projecting into this field begin to cause air breakdown and launch upward streamer currents. If the ambient field into which such streamers are emitted is high enough, the partially ionised streamer will convert to a fully ionised up-leader. The ability of the air termination to launch a successful up-leader <u>before</u> any other point on the structure, determines it's effectiveness as an imminent lightning attachment point.

The ability of a Franklin Rod to concentrate electric fields and form corona under electric storm conditions is well known. The corona is only observed in the near vicinity of the tip as the field concentration created by its geometric shape will decrease rapidly with distance. This corona is actually a form of space charge.

The effect of the space charge as shown in Figure 1 is to mask the electric field observed at the grounded tip during the leader approach. There is almost a "voltage regulator" effect because, as the leader approaches, the space charge increases and further masks the electric field observed at the tip. Ultimately the leader may approach close enough to trigger an intercepting upward leader from some other part of the structure. This then becomes the preferred attachment point on the structure and the lightning protection system is by-passed, with the potential of damage to the building.

The Franklin Rod or conventional approach to lightning protection has served the industry well, although there have been recorded incidences where such terminals have been by-passed by lightning. As the understanding of the physical mechanism behind the lightning discharge becomes better understood, new and better lightning terminals are being developed.

In response to technological advances and market demands, *non-conventional or enhanced type* air terminals have evolved. One such terminal is the Dynasphere™ Controlled Leader Emission (CLT) air terminal. This terminal comprises a floating spheroid which acts to reduce electric field distortion and the resulting corona. This product provides the design engineer with an air termination relatively free of space charges which is capable of creating photo-ionisation and which concentrates electric field to release free electrons on the approach of a lightning leader.

The Dynasphere is a <u>passive terminal</u>, which requires no external power source, relying solely on the energy contained in the approaching leader for its dynamic operation. This terminal has the ability to concentrate only that electric field which occurs in the millisecond time slots as the leader charge approaches the ground.

In the air breakdown process, the first stage comprises an upward propagating streamer discharge. This is like a corona burst that reaches out about 0.75 meters and generally ionises a volume of air above the terminal. Because the electric fields are so strong, small filamentary white discharges form inside this corona burst. These are thermalised and quite conductive. Eventually one of these fingers becomes dominant to form an established up-streamer which then becomes the root for the next corona burst. The process then repeats. Early streamer means that the first streamer reaches the thermal stage before others.

The lightning protection industry has for many years debated the concept of Early Streamer Emission terminals and the relative time advantages being claimed. Unfortunately, the physical process of an "early streamer" is often little understood and often over simplified.
In essence, a terminal can be too early in it's emission of a streamer! To better understand this statement we need to consider the physical process beyond the initial microsecond or so at which the streamer forms.

The first streamer to become thermalising and conductive only reaches about 3000C so we say it is semi-thermalised. As explained above, this semi-thermalised streamer then becomes the root for the next corona burst from which a new streamer has to form, the first one then has to supply current for the second. During this stage, the initial streamer fully thermalises up to 7000C. At this stage it becomes so conductive that it is equivalent to raising a ground rod to the same height!

In essence, when the first up-discharge is fully thermalised, there is above it a semi-thermalised streamer, and ahead of that a corona burst. This is the macro-physical mechanism behind a propagating up-leader.

One problem with streamers is that after the first corona burst, the ambient electric fields into which they have launched themselves may not be high enough to sustain the next discharge and the whole process collapses. In other words, streamers may not necessarily convert to propagating up-leaders.

What is crucial is that the streamer from the air terminal only launches when the ambient field is high enough to sustain the discharge and convert it into a thermalised up-leader. Since the magnitude of the ambient field is a direct function of the fast approaching (2m/us) downward stepped leader, it is important that the air terminal only launches it's streamer at the instant when the up-propagation will prove sustainable and a successful interception of down-leader and up-leader will occur.

If a streamer is emitted too early, and the ambient field has not yet risen to a sufficient level to sustain it (because the approaching down leader is still too far away), the steamer will collapse leaving behind it a greatly reduced (neutralised) electric field. This means that before the charge ahead of the air terminal can reconstitute to repeat the process, the down leader will have approached close enough for some other point on the structure to start a competitive up-leader, and hence become the preferred strike point. The lightning terminal has now been by-passed and an uncontrolled point has taken the brunt of the discharge.

The DYNASPHERE CLT is designed to ensure that it only launches an up-streamer when it has sensed that the electric field ahead of it is high enough to ensure propagation. This is unlike the way in which many other so called Early Streamer Emission terminals operate.

The principle of operation of this terminal relies on the capacitive coupling of the outer sphere of the terminal to the approaching leader charge. This in turn raises the voltage of the spherical surface to produce a field concentration across the insulated air gap between the outer sphere and grounded central finial. As the leader continues to approach, the voltage on the sphere rises until a point is reached where the air gap between the central finial and outer surface breaks down. This breakdown creates local photo-ionisation and the release of excess free ions. These then accelerate under the intensified field to initiate an avalanche condition and the formation of an up streamer begins.

Unlike the CLT, pointed rods and other types of enhancement terminals tend to create a corona space charge above the emission point, which serves to reduce the electric field there by inhibiting streamer initiation. Also, unlike other air terminals using battery or corona generated discharges, the CLT is radio-quiet only producing a spark discharge the as the leader approaches and when it senses the electric field has risen to a level at which this streamer will fully thermalise into an up-leader.

Figure 2- Dynasphere™ Controlled Leader Emission (CLT) Air Terminal

Extensive research and testing of this air terminal has been carried out in Australia, Indonesia and the United States of America. These tests are performed in High Voltage laboratories where lightning impulse conditions are simulated and the comparative performance of such enhanced terminals are compared to conventional Franklin Rod terminals. Unfortunately, high voltage laboratory conditions are not very representative of the naturally occurring lightning discharge. To obtain more representative data it is necessary to go to nature and evaluate the performance of different air terminals under actual storm conditions. Such experimentation is know as Rocket Triggered lightning since small gun powder rockets are fired into developing storm clouds trailing grounded wires to create a discharge. Using high speed digitiser recording equipment, the formation of upward leader emission from the different terminals can then be evaluated.

The results have shown that these enhanced type terminals can indeed launch upward emissions earlier in time and of greater magnitude that the conventional Franklin Rod. More than 6000 successful installations of these terminals in some of the world's most lightning prone areas stand witness to the Dynasphere's superior performance.

Calculation of the Protective Coverage offered by an air terminal

a) Rolling Sphere Design Method

The most common design method used by conventional lightning protection designers is the "Rolling Sphere". This is an imaginary sphere which is rolled over the structure. All contact points are deemed to require air terminations. The sphere is a specified radius (45 m) for standard level protection (strikes 10kA and above or 93% statistical level). A radius of 20m is recommended for protection of structures housing explosive or flammable contents.

The main limitation of the Rolling Sphere is that it assigns equal leader initiation ability to all touch points of the structure, irrespective of the electric field intensification created by geometric shape.

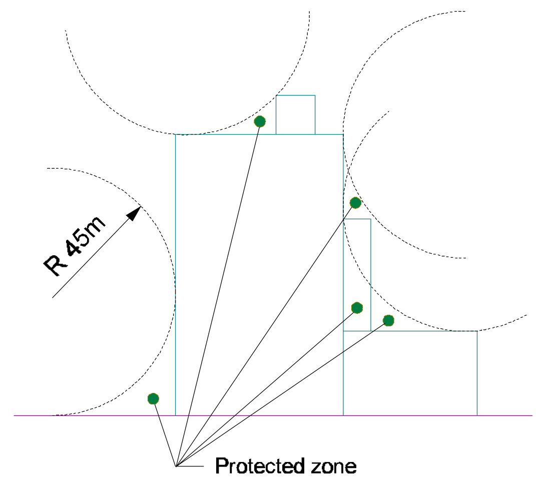

Figure 2. Protection design using Rolling Sphere Method

The Rolling Sphere model calls for an extensive array of air terminations on tall buildings. This includes flat vertical and horizontal surfaces with no inherent electric field intensification - one of the limitations of this model. Protection Systems designed using Rolling Sphere can be very expensive as the method can lead to over-design. Application of this method often makes provision for air terminations in locations where a strike would be extremely rare.

b) Collection Volume Design Method - an alternative model to the Rolling Sphere Method

An alternative design method to the Franklin, Faraday, and Rolling Sphere approaches is the "Collection Volume" method. This method is based on the work of Dr A.J. Eriksson. A detailed description can be found in the Australian Lightning Protection Standards NZS/AS1768-1991, section A8.

Unlike the Cone of Protection method, the Collection Volume provides an imperial and quantitative method based on design parameters such as, the structure height, field intensification of structural projections, leader charge, site height and relative propagation velocities of the intercepting leaders. The model can be developed for three dimension structures and offers a more rigorous approach to lightning protection design.

Item	Lightning Characteristic	Percentage of events having value of characteristics greater than value shown below							Unit
		99	90	75	50	25	10	1	
1	Number of component strokes	1	1	2	3	5	7	12	
2	Time interval between strokes	10	25	35	55	90	150	400	ms
3	First stroke current I_{max}	5	12	20	30	50	80	130	kA
4	Subsequent stroke peak current I_{max}	3	6	10	15	20	30	40	kA
5	First strokr $(dI/dt)_{max}$	6	10	15	25	30	40	70	GA/s
6	Subsequent stroke $(dI/dt)_{max}$	6	15	25	45	80	100	200	GA/s
7	Total charge delivered	1	3	6	15	40	70	200	C
8	Continuing current charge	6	10	20	30	40	70	100	C
9	Continuing current I_{max}	30	50	80	100	150	200	400	A
10	Overall duration of flash	50	100	250	400	600	900	1500	ms
11	Action integral	10^2	$3x10^2$	10^3	$5x10^3$	$3x10^4$	10^5	$5x10^5$	$A^2.s$

Table 1 (Table A1 NZS/AS1768-1991)
Distribution of the Main Characteristics of the Lightning Flash to Ground

Table 1 (taken from NZS/AS1768-1991) illustrates the statistical distribution of lightning parameters. Item 3 in the table can be used in determining the statistical levels of protection. Using the equation below, protection levels directly relating to peak current discharge, I, and the corresponding leader charge, Q, are derived:-

$$I = 10.6\ Q^{0.7}$$

where I is measured in kA and Q in Coulombs. From Table 2 a discharge having a peak current of 5kA would correspond to a leader charge of approximately 0.5 coulombs. Further calculation and extrapolation from Table 1 are shown in Table 2.

Leader Charge (Q)	Peak Current (I)	Percent Exceeding Value	Protection Level
0.5C	6.5kA	98%	High
0.9C	10kA	93%	Medium
1.5C	16kA	85%	Standard

Table 2 - Statistical probability of a down-leader exceeding the peak current indicated

Figure 3 shows a downward leader approaching an isolated ground point. A striking distance hemisphere is set up about this point. The radius is dependent on the charge on the leader head and corresponds to the distance where the electric field strength will exceed critical value. That is, the field strength becomes adequate to launch an intercepting upward leader.

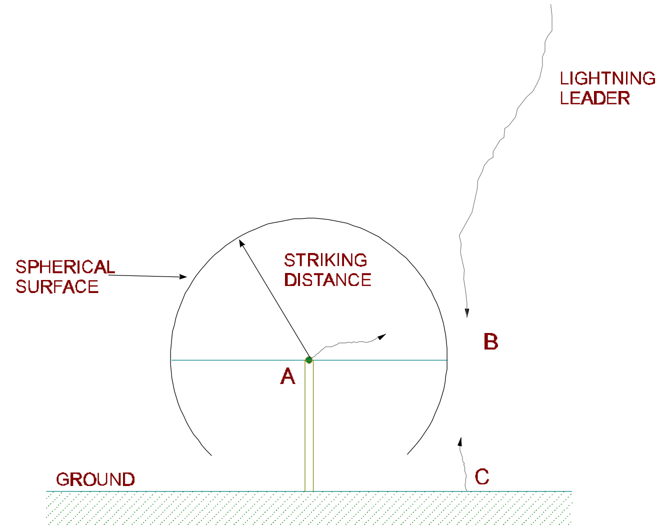

Figure 3 Spherical Surface with Striking Distance radius about point A

The striking distance hemisphere reveals that lightning leaders with weak electric charge approach much closer to the ground point before achieving the critical conditions for initiation of the upward leader. The higher the magnitude of charge, the greater the distance between leader and ground point when critical conditions are achieved. For design purposes a hemisphere radius can be selected which relates to a desired level of protection. The Collection Volume method takes into account the relative velocities of the upward and downward leaders. Not all leaders which enter a striking distance hemisphere will proceed to interception. Leaders entering the outer periphery of the hemispheres are likely to continue their downward movement and to intercept a different upward leader (issuing from an alternative structure or feature on the ground). This leads to the development of a limiting parabola. The enclosed volume is known as the Collection Volume. A downward progressing leader entering this volume is assured of interception. Figure 4 shows how the velocity parabola limits the size of the Collection Volume.

Designing with Collection Volumes using statistically derived lightning parameters as in Table 3 will provide designers with better risk analysis. Magnitudes of Collection Volumes are determined according to peak current. That is, if the designer desires a High Level of protection (peak current 6.5kA), 98% of all lightning exceeds this value. Discharges of greater magnitude will have larger Collection Volumes which create greater overlap in the capture area of air terminals. A design based on lightning with small peak current can be considered conservative. The design performed to 98%

High level does not mean that all lightning less than that level will miss an air termination. There is simply a statistical chance some lightning may not intercept with an upward leader emanating from within the Collection Volume.

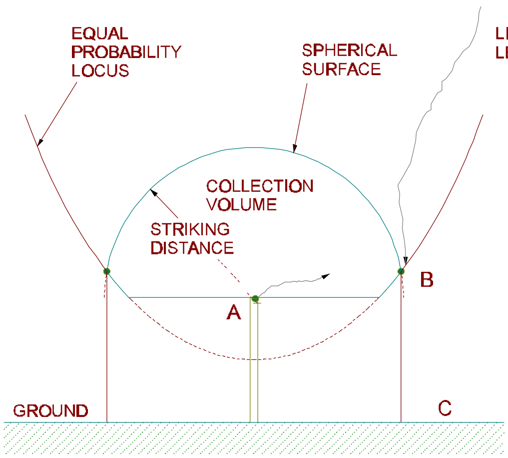

Figure 4. Collection Volume formed by equal-probability locus and spherical surface

The Collection Volume model assumes all points on the structure are potential strike points, and as such exhibit natural Collection Volumes.

A computer program has been developed by ERICO Inc. It evaluates the corresponding electric field intensity at each stage and compares the electric field intensification of competing points (building corners and edges, antennae, equipment, masts etc). The program then evaluates which point will first generate the upward moving leader which meets the downward leader. The main discharge return stroke follows the upward/downward leader path. An attractive radius for each relevant point can then be calculated.

The larger collection volumes of enhanced air terminals means that fewer such terminals are required on a structure. They should be positioned such that their collection volumes overlap the natural small Collection Volumes of the structure projections.

Figure 5 shows the Collection Volume Concept when applied to a structure.

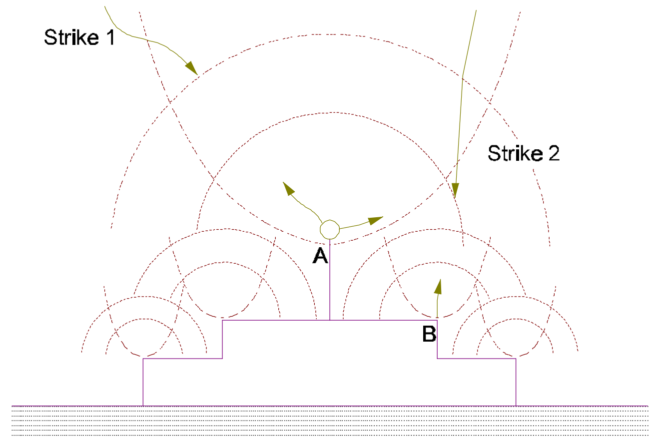

Figure 5. The Collection Volume Design Concept

Comparison of Collection Volume Method to Rolling Sphere Method

Both models serve the primary aim of lightning protection designers in providing design rules which can be applied with relative easy to structures of varying geometry. The rolling sphere model, despite gaining general industry acceptance, exhibits deficiencies in its allocation of strike probabilities to various parts of a building. The collection volume model attempts to address some of these deficiencies by associating with various points on the structure degrees of probability based on statistical probabilities. Both models can be applied to CAD design packages to allow a degree of automation to the placement of air terminals on varying structural geometry's.

Conclusions

The subject of air terminal research is an area of intense interest today. E-field modelling techniques using finite element analysis, and field research using HV laboratories and rocket triggered lightning is yielding greater understanding into the fundamental physics of the air breakdown process. This in turn is leading to a better understanding of the behaviour of different types of air terminals under varying physical and environmental conditions. The long established use of sharp Franklin rods is being questioned as alternative technologies evolve. This said, it is important to realise that both approaches have merits and need to be regarded as alternatives with particular applicability.

THE AUTHOR:

Tony Surtees holds a BSc(Eng) and PhD from the University of Cape Town, South Africa as well as a GMQ from the Australian Graduate School of Management and MBA from the University of Tasmania. He has worked extensively in the field of telecommunications holding positions of Senior Development Engineer and Senior Projects Manager R&D with the International Plessey Communications group (GEC-Siemens Plessey). Upon emigrating in 1990 to Australia, he joined Global Lightning Technologies where he held the positions of Director - International & Technical Marketing responsible for the group's international activities.

He has undertaken lightning protection consultancy on behalf of the Group throughout the world, as well as participating in their fundamental lightning research programmes such as the Rocket Triggered Lightning research in Florida (USA) and Darwin (Australia). He is a well known presenter on Lightning Protection theory and practices. Following the acquisition of GLT by ERICO Inc. in May 1997, he was transferred to the USA Head Office where he now holds the post of Technical Manager, within the Facility Electrical Protection division. His regional responsibilities include the North and South American markets.