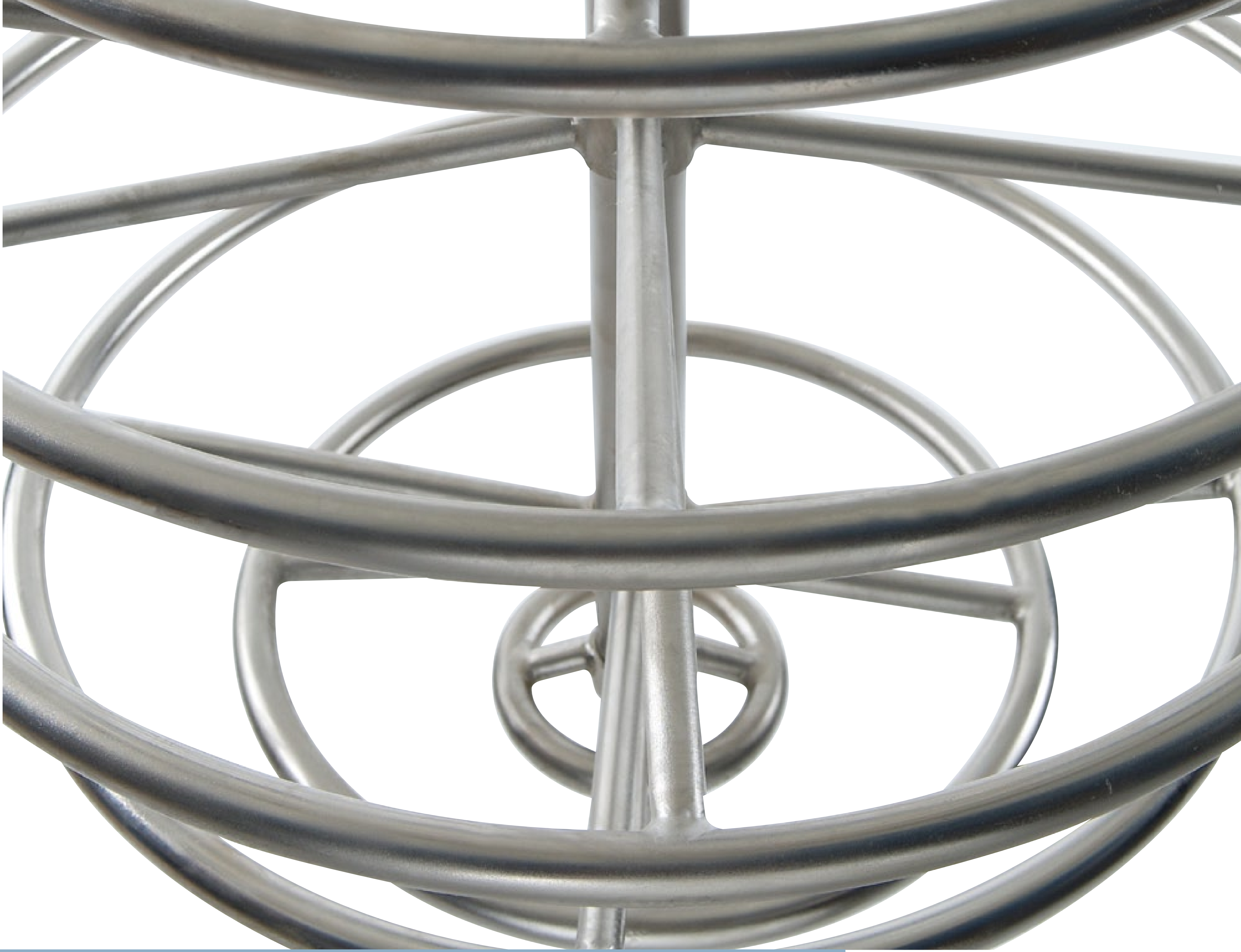


Lightning
ElectroTechnologies

# Field Sensitive Air Terminal (F-SAT)

Simply the Best Lightning Rod

## Background (Physics of a Lightning Strike)

It is well known that most lightning discharges are associated with predominantly negatively charged clouds. Two main categories of lightning strikes are encountered: Upward flashes from very tall structures and the more prevalent strikes associated with negative descending stepped leaders [1], [2]. The negative descending lightning leader is surrounded with a negative space charge sheath which, as the negative lightning leader approaches the ground, induces positive (image) charges on any grounded object. The higher the grounded structure and the nearer it is to the path of the descending negative lightning leader, the more significant the induced charge on the grounded structure.

It is known that a lightning stroke current is a statistical variable that varies in a wide range from a few kA to a few hundred kA with a median of 25-35 kA. The attractive radius of a structure i.e. the maximum radial distance around the structure in which a descending lightning leader would be captured by the structure increases with both the stroke current, which is associated with the negative space charge jacket and the structure height.

In recent years, based on progress in research on the physics of breakdown of long air gaps, our understanding of the mechanisms by which different ground structures are hit by lightning have been substantially improved. In particular the role played by the grounded object in the strike mechanism has been clarified. Modeling has shown that the attractive radius comprises two parts: a major part spanned by the positive leader emanating from the structure and the lesser part constituting the final jump between the negative and positive leader tips.

Electrostatic field analysis shows that the early stage electric field enhancement at the surface of and in the vicinity of any grounded structure is predominately caused by the positive charge that has been induced onto the grounded structure by the cloud charge and/or the descending negative lightning leader and that this far exceeds the background field due to the cloud charge and/or the descending leader itself. Depending on the structural characteristics of the grounded object an inception electric field caused by the induced charge is reached when ionization of the surrounding air takes place causing corona discharge and positive streamer formation. Depending on the geometry of the grounded structure and the amount of induced positive charge, the length of the positive streamer can grow into the meter range.

If the positive streamer reaches a critical size [3], [4] a highly conducting stem is formed at the streamer junction to the structure and a positive leader is thereby formed. Contrary to the positive streamer which has a mean gradient of approximately 400-500 kV/m, the leader gradient is a function of both the leader current and the time duration of its existence. For a current of 1 A the leader gradient could be 30-50 kV/m i.e. approximately one tenth of the positive streamer gradient but for a leader current of the order of 100 A the leader gradient could go down to as low as 2-3 kV/m. This shows that contrary to the positive streamer, a positive leader is capable of traveling distances in the 100m range without requiring unrealistically high electric potential.

It is important to note that not every positive leader emanating from a ground structure will complete the trajectory to encounter the descending negative lightning leader in a final jump. As the positive leader travels farther and farther from the structure its motion will be governed more and more by such parameters as space potential and the electric field ahead of the leader tip, which are determined more and more by the descending leader charge and less and less by the grounded structure. When conditions are not appropriate for continued propagation, the positive leader stops and the concerned grounded structure which started the positive streamer/positive leader process is not struck.

Objects that are struck by downward negative lightning are those which, due to their induced positive charge, "succeed" in creating long positive streamers resulting in the formation of a positive leader. This upward positive leader then progresses in a zone of increasing electric field strength and meets the approaching descending negative lightning leader in what is termed the final jump. The final jump takes place when the mean voltage gradient between the tip of the ascending positive leader and the tip of the descending negative lightning leader reaches 500-600 kV/m.

Therefore if the objective is to Maximize the probability of a strike to a lightning rod relative to the corresponding probability of a direct strike to the protected object. It will be of great advantage if conditions at the tip of the lightning rod are ideal for creating long positive ascending streamers/leaders at the instant of arrival of the descending lightning leader.

## Why Do Conventional Lightning Rods Fail?

"Lightning struck the Ostankino Television Tower 200m below its top, i.e. the Tower could not protect itself. This is not an exception to the rule. Most descending discharges missed the tower top more or less closely, contrary to had been expected" [E.M Bazelyan and Yuri P. Raizer, "Lightning Physics and Lightning Protection", Book, Institute of Physics Publishing, 2000, p21.]

Under thunderstorm conditions, lightning rods are exposed to two kinds of electric fields. The first type of electric field, which is due to the electric charges distributed throughout the moving clouds, is characterized as: slowly varying. These electric fields can rise to peak values and decline again in tens of seconds or even minutes. The other kind of electric field is due to the descending lightning leader; these electric fields can rise to peak values in 10 milliseconds with most of the activity occurring in the last 200 to 500 microseconds.

The slowly varying electric field, which is due to the cloud charges, is known to vary in intensity from about 3kV/m to 20kV/m for the height range most commonly associated with ground structures. Therefore and depending on the height of the lightning rod, the electric field due to the cloud charges can easily be sufficiently high so as to cause the lightning rod to produce limited electric discharges (corona). These limited electric discharges result in charges or ions, which are of opposite polarity to the cloud charges. When these ions of opposite polarity to the cloud charges are still in close proximity to the lightning rod, they have the effect of momentarily shielding the lightning rod from the effects of the electric fields produced by the cloud charges or the descending lightning leader. This is due to the fact that the ions of opposite polarity to the cloud charge induce a charge on the lightning rod that is of opposite polarity to that which is induced on the lightning rod by the cloud charges or the descending lightning leader. Since these two charges are of opposite polarity and the created ions or space charges are much closer to the lightning rod than the cloud charges or the descending lightning leader, they have the effect of reducing the overall

induced charge or the net induced charge on the lightning rod. Therefore as compared to the lightning rod, the object to be protected is more susceptible to the creation of an upward connecting leader and the object to be protected itself is struck. This effect is termed: Lightning Rod Self-Protection.

Therefore if the slowly varying electric field intensity to which the lightning rod is exposed happens to be high enough so as to cause electric discharges from the lightning rod tip immediately prior to the descent of the lightning leader, the lightning rod has a high probability of failure.

This mode of failure is common to all previous air terminal designs and will occur more frequently on taller structures.

## Sharp Vs Blunt?

In recent years there has been a lot of interest in the comparative performance of sharp versus blunt lightning rods. This has primarily been due to field experiments in New Mexico, USA by Moore [C.B. Moore, W. Rison, J. Mathis, G. Aulich, “Lightning rod improvements” J. Appl. Meteorology, 39, 2000, pp 593-609.] in which a number of air terminals were installed and monitored in an area of high lightning activity. The air terminals were installed on masts approximately 6meters high and were separated by a distance of 6meters. The test objects included sharp lightning rods, moderately blunt rods and extremely blunt rods as well as some other commercially available lightning protection devices.

The data showed that the moderately blunt rods were struck most frequently. The explanation given for this related to some apparent ratio between the height and radius of curvature of the moderately blunt rod. However the data can be better understood by the mechanism outlined above. Quite simply the sharp rod, by virtue of its geometry, is most prone to the production of electric charges or ions under the slowly varying electric fields that commonly precede lightning strikes. The sharp rods produce electric discharges at lower electric field intensities than the other test objects and therefore when the descending lightning leader arrived, the sharp rods had more ions in their immediate vicinity. These charges in the vicinity of a sharp rod shielded it from the effects of the descending lightning leader. The moderately blunt rod having had less electric discharge activity from its tip prior to the arrival of the descending lightning leader and thus having fewer ions in its vicinity was more willing to participate in the lightning attachment process.

The extremely blunt rod had a radius of curvature sufficiently large so as to allow raindrops and other natural contaminants to rest on the top of the rod. The presence of such contaminant can easily cause the electric performance of the extremely blunt rod to be similar to that of a sharp rod. In fact any object that is prone to the collection of rain drops or other contaminants on its surface will have lightning performance similar to that of a sharp tipped lightning rod.

It is important to note that the chosen height of 6m for the masts upon which the air terminals were mounted is of critical importance in these field experiments by Moore et al. Since, for a given electric field, any air terminal would be subjected to more intense electric discharge activity at greater heights. The difference in this regard between the moderately blunt rod and the sharp rod is more dramatic at 6meters than at say 100meters. That is to say that for a given electric field, under the intense discharge activity associated with greater heights, the difference in the amounts of ions produced by the two air terminals would not be significant at 100meters, whereas the difference was significant at 6meters.

## Domes and Hemispheres

In an effort to limit the effects of the slowly varying electric fields that precede lightning strikes, some lightning protection devices use domes or hemispheres. It is well known that domes, hemispheres and spheres are more resistant to the production of electric discharges as compared to rods but this is only true under dry, clean, laboratory conditions. Under rain or other natural contaminants the electrical performance of the domes and hemispheres installed on these devices will be similar to that of any sharp rod.

## Early Streamer Emitters (ESEs)

There is sufficient literature in a variety of reputable technical journals and publications which question the premise and claims associated with Early Streamer Emitters such that there is no need for a repetition of these materials in this document.

Some commercially available Early Streamer Emitters were used in the field experiments by Moore cited above and their performance was no better than that of the sharp rods.

A new criticism of the Early Streamer Emitters would be that since they are intentionally designed to produce early discharges, they are also highly prone to the failure mechanism outlined above.

## F-SAT: Field Sensitive Air Terminal

An F-SAT is a revolutionary lightning rod that is specifically designed to resist the production of electric discharges during the slowly varying electric fields that precede a lightning strike. In addition, it is carefully tuned to the dimensions of the structure upon which it is placed such that under the rapidly varying electric field of the descending lightning leader, the F-SAT will reliably launch an upward connecting leader to intercept the lightning strike. Furthermore these physical properties are stable and insensitive to the effects of raindrops and other natural contaminants.

Under the same thunderstorm conditions, lightning rods placed on structures of different dimensions are not exposed to the same electric field intensities. Structure height is a critical factor but so are the overall dimensions of the structure as a whole. Under identical thunderstorm conditions, a lightning rod situated a top a slender 200m-tall radio tower is not exposed to the same electric field intensities as a lightning rod placed a top a 200m-tall office building.

Therefore the F-SAT is not a one-size-fits-all solution. F-SATs come in a variety of sizes determined by the number of toriods as well as variations in the major and minor diameters of the toriods that constitute each F-SAT. An F-SAT must be properly matched with the structure it is designed to protect.

All F-SAT designs comply with NFPA 780, UL96 and IEC 62305 and meet or exceed minimum cross-section dimensional requirements.

## Laboratory Validation of Insensitivity to Rain

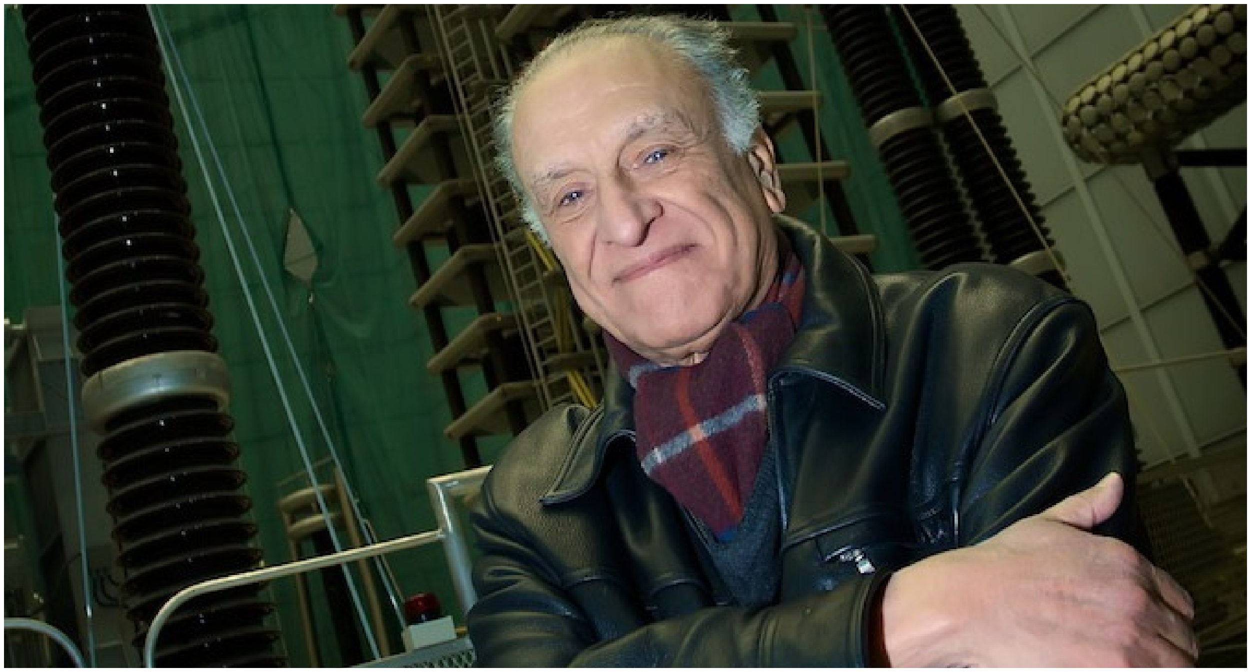
The claimed insensitivity to rain of the F-SAT has been confirmed by positive switching impulse tests on long air gaps. For an F-SAT with an overall radius R of 75 cm, a tube radius r of 1.25 cm and number of toroids n=8, the positive switching impulse 50% sparkover voltage of a 2.5m gap under dry conditions amounted to 987 kV while under artificial rain, satisfying IEC Standard 60, it amounted to 982 kV. This shows that rain has practically no influence on the breakdown and accordingly on the positive leader inception voltage of the designed F-SAT. For the same gap with a completely covered 1m diameter smooth spherical electrode, the corresponding breakdown voltage drops from 1481 kV under dry conditions to 897 kV under rain, close to that of a sharp rod under the same conditions.

# Application

Depending on the objectives, F-SATs can be deployed to protect structures in two ways. Firstly, if placed on a sufficiently tall mast and depending on the horizontal dimensions of the structure, a single F-SAT placed in a central location can be used to reliably protect a structure. Alternatively a number of smaller F-SATs can be placed strategically around the structure top to ensure adequate protection.

The basic dimensions of the structure will determine a number of installation options with the properly dimensioned F-SATs.

# The Inventor



Farouk A.M. Rizk holds a B.Sc. Eng. and M.Sc. from Cairo University, a Ph.D degree from the Royal Institute of Technology, Stockholm, and a Doctor of Technology degree from Chalmers University of Technology, Gothenburg, Sweden.

Dr. Rizk worked as a research engineer with ASEA (ABB), Sweden, in the High Power Laboratory, Ludvika, in 1960-1963 and in the Computer Department, Vasteras, in 1963. He worked for the Egyptian Electricity Authority (1964 - 1971), becoming Manager, High Voltage, in 1968. He joined the Institut de Recherche d'Hydro-Quebec (IREQ) as a senior research scientist in 1972, subsequently passing from scientific director (1976) to Vice-President Laboratories (1986) and held the title of fellow research scientist (1986-1996).

His research work covers a wide range of topics in high voltage and high power engineering: arc dynamics in circuit breakers, polluted insulators, single pole switching, electromagnetic shielding, compressed gas and liquid breakdown, long air gaps and lightning attachment.

Dr. Rizk was elected IEEE Fellow in 1982 "for contributions to the science of high voltage technology and for technical leadership in the advancement of the electric power industry". He has been chairman of the 10th International Symposium on High Voltage Engineering (ISH) in 1997 and chairman of ISH steering committee. Dr. Rizk received prize paper awards from the IEEE Transmission and Distribution Committee in 1989, 1991 and 1995 and from the Power Engineering Society of IEEE in 1996. He was awarded the IEEE Herman Halperin Electric Transmission Award in 1996 for outstanding contributions to electric power transmission and distribution. He is a Distinguished Member of the International Council on Large High Voltage Electrical Systems (CIGRE) and a recipient of the CIGRE Technical Committee Award, 1997.

Dr. Rizk made major contributions to standardization work, particularly during his tenure as international chairman of IEC Technical Committee 28: Insulation Co-ordination, 1983-1996. Under his leadership the whole area of insulation co-ordination was revised, which led to the new standards IEC 71-1 and IEC 71-2. His efforts to promote insulation co-ordination of high voltage dc transmission led to standardization work now undertaken by IEC TC 28.

Dr. Rizk is the author of “the Rizk Equation” which is the recommended equation for calculation of lightning strike distances to transmission lines as per the Electric Power Research Institute (EPRI) AC Transmission Line Reference Book. More recently Dr. Rizk authored the Chapter on Lightning Performance in the technical update of the June 2008 EPRI HVDC Reference Book; Overhead Lines for HVDC Transmission. A number of IEEE publications that expand on those subjects are currently under preparation.

In the 2008 Publication “The Art and Science of Lightning Protection” by Dr. Martin A. Uman, on page 52, Dr. Uman states: “The various representative views of the proper attachment process model according to the electric power research community are expressed in the papers of Rizk (1990, 1994a,b) which include the discussions of other researchers who question Rizk’s model”. Although the comment is appreciated and with all due respect to Dr. Uman, since Dr. Rizk’s publication is an original work and not a review of previous models it would have been more accurate to state: “The electric power research community has adopted the work of Rizk as the proper attachment process model. (1990, 1994ab) in which, the discussions include rebuttals to other researchers who question Rizk’s Model.”

Dr. Rizk is now President of Lightning Electrotechnologies Inc in Montreal. He is also an adjunct Professor at the Electrical Engineering Department, McGill University and invited professor at INRS-Energie. Dr. Rizk continues to engage in research, and publish new works.

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