We connect and protect

From Passive to Proactive: Revolutionizing Lightning Protection Through Active Shielding

CASE STUDY

System 3000 Substation

Figure 1: There are roughly 100 lightning strikes per second worldwide—over 8 million each day.

Traditional passive lightning shielding systems, like those using conventional lightning rods ("Franklin rods"), have long been employed to divert strikes away from buildings and structures. However, in today's technologically advanced landscape, **active lightning shielding systems** are stepping in to offer a proactive stance against strikes—a choice that can reap many rewards when it comes to minimizing damage and disruption.

If you own or operate built infrastructure, this article will help you understand the latest non-conventional option for lightning shielding that is now included in Institute of Electrical and Electronics Engineers (IEEE) guidelines. To facilitate inclusion in Codes of Practice, a design method must be technically sound but relatively simple to implement, thus minimizing complexity while maximizing protection as is demonstrated by an increasing number of active shielding systems.

From utility substations to skyscrapers to industrial facilities, these systems offer an improved approach to preventing damage before it occurs.

Rolling Back Established Thinking

One of the key components of any lightning shielding system is the type of air terminal placed on the structure. Its primary purpose is to capture the lightning stroke at a preferred point, so that the discharge current can be safely directed into the downconductor for connection to the ground.

Two important aspects must be considered in the design of any lightning shielding system: the protection area afforded by each air terminal and the location of the air terminals on the structure. Thus, a fundamental aspect of lightning shielding design methodology is identifying the optimal locations for the air terminals. Over time a number of methods have been proposed, some of which are in common use today, notably the **Rolling Sphere Method (RSM)**.

The RSM, emerging in the 1960s within the realm of the electric power industry, derives its foundation from the Electro-Geometric Model (EGM) which assesses the probability of lightning striking a structure, drawing its insights from extensive research on the dynamics of lightning formation. To apply this technique, an imaginary sphere (typically 150 feet/45 meters in radius) is rolled over the structure. Subsequently, all surface contact points are deemed to require an air terminal. A structure is considered protected when the sphere can pass over it and only touch air terminals. Any points underneath the sphere are considered protected.

The average lightning strike packs an incredibly powerful—and potentially damaging—punch.

Instantaneous Power:	1+ megawatts
Total Energy:	+250 kilojoules
Sound Pressure:	90 atmospheres at 500 meters distance
Temperature:	~30,000 Kelvin (5 x Sun's surface)
Rise Time:	0.1 to 5 microseconds
Average Current:	30 kiloamperes
Duration:	300 microseconds (and repeats)
Channel Length:	5 kilometers

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Simplicity is the main advantage of the RSM in real field application. The fundamental technical problem, however, is that the method assigns an equal leader initiation ability to all contact points on the structure (note the leader is not the lightning strike, rather it maps the course the strike will follow). In other words, for a given prospective peak stroke current, the striking distance is a constant value. This oversimplification can result in overdesigning on flat horizontal and vertical surfaces, and under designing when structural points with significant electric field intensification are outside the sphere radius. As a result, more irregular structures will test the limitations of the RSM methodology.

"The RSM produces satisfactory results for simple geometric structures of relatively low height; however, the deficiencies of the method make it difficult to apply to complex or taller structures," says Ray Stripling, North America Lightning Protection Marketing Manager for nVent ERICO.

Hence, a more physically based method, able to differentiate between points on a structure having high and low leader initiation probability, is necessary for some of the more complex, modern-day lightning protection designs. Recently, the **Collection Volume Method (CVM)** has gained momentum as an alternative technique that addresses some of the limitations of the RSM by providing a more rigorous, scientific basis for air terminal placement. In essence, it is an improved version of the basic RSM.

"CVM actually dates to the 1980s, but it did not take hold immediately because the RSM was prevalent in North America as deemed by different standards like NFPA 780 and UL 96A," adds Stripling.

"However, as we move into the 2000s these systems are really starting to be installed globally, and now the panel data is coming together where you're seeing protection levels—that is, interception efficiencies—in the range of 84% at Level IV to 99% at Level I as defined by IEC 62305, so the validation is there. There's still a lot of education ongoing in the U.S. but globally we're seeing how these systems have really changed the game."

Accounting for Irregularities

Stripling explains how the CVM takes a more physical approach than the RSM by using the well-known fact that the striking distance is dependent on both the peak stroke current (the upward/downward leader charge ratio) and the degree of electric field enhancement (the field intensification factor or Ki) of the prospective strike point. To a large extent, Ki is determined by the height and width of structures; however, the shape and radius of curvature of a structure and its features are also important.

Regarding air terminals, Ki is likewise dependent upon the height and tip radius of curvature. When air terminals are placed on buildings, Ki's are multiplied by a factor depending on the structure's dimensions and the interaction of competing electric fields. Hence, an improved approach would see all points on a structure able to launch an intercepting upward leader, but able to differentiate those points based on the local Ki. In this way, more reliable and efficient lightning shielding systems can be designed.

"If you imagine a building, there are electric fields all around—the wiring, the equipment, the machinery—and each field has its own signature or pattern that might be more prone to upward leader formation. So, the question becomes how to account for the influence of that unique field upon its potential to be struck. What's happening is the shielding system design is factoring for all these e-fields. It creates a collective zone of protection so that when the leaders start coming down, the zone will generate intercepting upward leaders.

"A conventional shielding system cannot create the same zone of awareness. As an analogy, imagine the CVM as a defensive player in football who excels at anticipating when a quarterback will deliver a pass and where the receiver will be, then moving quickly to intercept the ball. Using the CVM, that zone of awareness can be two or three times larger than what the RSM can achieve."

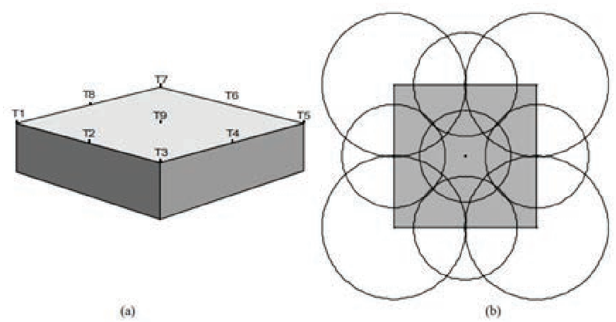
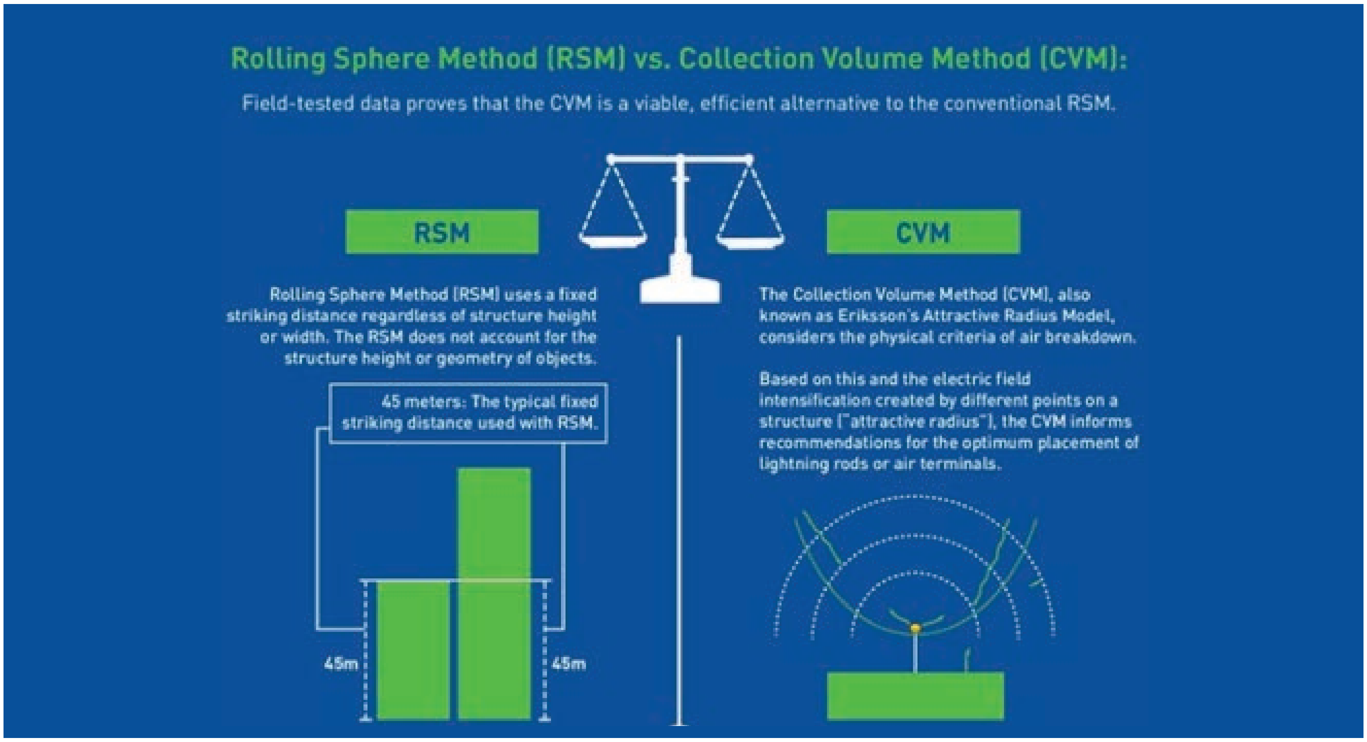


Figure 2: Unlike the Rolling Sphere Method, which employs a hypothetical rolling sphere to encompass the structure, the Collection Volume Method utilizes a 3D geometric model encompassing the entirety of the structure. Here is shown a CVM design example for shielding a building 20 meters high and 50 meters wide and deep (a = 3D view; b = plan view).



Field Validation

In fact, as Stripling notes, the CVM has been used since the 1980s to protect thousands of structures worldwide in various domains including electric utility substations, facilities with elaborate layouts such as power, chemical and manufacturing plants, tall structures with nonconventional shapes like wind turbines and communication antennas, as well as skyscrapers, architectural landmarks, and other intricately shaped structures.

In a major study, nVent ERICO gathered lightning strike data from several hundred real field installations to assess the performance of CVM-based shielding systems. Over an eight-year period, data was analyzed for more than 160 structures in Hong Kong, while a similar investigation was conducted in Malaysia over a 13-year span to capture data from more than 30 buildings. Lightning event counters recorded the number of strikes to the structures' shielding system, with the field data showing strong agreement with the predictions of the CVM model.

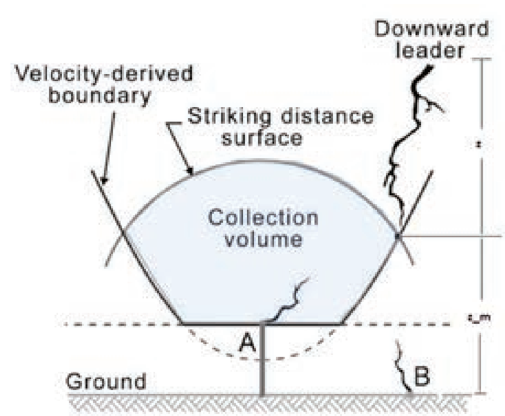
"The validated interception efficiency was between 84% and 99%, where the actual efficiency of the CVM-placed air terminals differed only 0.2% from predicted, proving that reliable and efficient lightning shielding can be achieved using the CVM," says Stripling.

"Our work also concluded that an air terminal with the ability to launch a streamer 'early' is not necessarily the most efficient. Rather, it is important to launch a streamer at the optimal time when it can convert into a stable, propagating leader. Streamers and leaders derive the required propagation energy from the electric field, so if the field strength is too low, the streamer or leader will cease to propagate. Hence, air terminal geometry is vitally important."

As a validated approach, CVM is now also included in IEEE Standard 998—Direct Lightning Stroke Shielding of Substations—as electric utility operators gravitate in greater numbers to active lightning shielding solutions. Often, these systems offer the added benefits of less overhead components and lower maintenance costs.

"Conventional RSM-based systems tend to use fixed angle or mast protection components that are effective where a sufficient number of overhead wires and masts are installed," says Stripling. "As the coverage area of any one mast is small, however, this can increase costs where more masts are required. There is also the constant risk of overhead wire failing and falling into the equipment."

"Other times it's a cosmetic consideration, where the architect does not want a large number of air terminals protruding from the building, so here you have an alternative approach to those conventional systems that tends to be a neater, tidier installation that is also easier to maintain."



The CVM factors for the effect of height and structure geometry to determine the most likely lightning strike points. Importantly, this method:

- Accounts for the competing features of the building or structure.
- Accounts for the physical criteria for leader inception.
- Gives greater weight to taller air terminals.
- Optimizes positioning of air terminals.
- Results in more detailed calculations involving the electric field distribution.
- Enables more cost-effective shielding system designs.

Ask the Experts

When considering any lightning shielding system, it's essential to work with reputable experts in the field. Be it passive or active, RSM- or CVM-based, a professional assessment of a structure's vulnerabilities will guide the design and installation of the most suitable system.

nVent ERICO is a bipartisan supplier of lightning shielding solutions, offering both conventional passive systems in accordance with international standards such as NFPA 780 and IEC 62305, as well as non-conventional active systems that are CVM-based. These are designated as nVent ERICO System 2000 and nVent ERICO System 3000 respectively. For all situations, the company is dedicated to providing the best lightning shielding solution whether this involves the use of conventional or nonconventional systems, or a hybrid design employing aspects of both.

Simultaneously, nVent ERICO recognizes that current conventional systems and design methodology, as prescribed in various Codes of Practice, can be improved. It also recognizes that sound scientific principles must be at the heart of any nonconventional system. This is why the company continues to invest in applied lightning shielding research that employs a mix of theoretical, computer modelling, laboratory and field investigation techniques.

It is the opinion of nVent ERICO that the CVM is best implemented as a computer program. The advantages of using computer software relate to flexibility. For example, the site altitude, cloud base height, leader charge, structure height and shape, field intensification factors and leader velocity ratio are stored or computed within the program, being readily available when an optimized lightning protection design is requested by a customer.

Finally, it is important to note that the CVM can be used for any conventional or nonconventional air termination system designed to capture lightning, with designs involving standard terminals being the most simple. If nonstandard air terminals are used, any claimed enhancement of their capture ability is above and beyond the designs described in this paper.

Conclusion

In an era marked by climate volatility and technological dependency, the decision to invest in an active lightning shielding system is a forward-thinking choice.

As the demand for accurate and tailored lightning protection solutions grows, the Collection Volume Method is emerging as a game changer in the field. Its ability to provide precision, customization and enhanced safety position it as a compelling alternative to the traditional Rolling Sphere Method. With the advancements in modeling and simulation technologies, engineers and designers can confidently embrace the use of CVM-based, active lightning shielding systems to ensure the safety of both structures and individuals.

References

"A Modern Perspective on Direct Strike Lightning Protection"; Dr. F. D'Alessandro, B.App.Sc., B.Ed., PhD, MIREE, GradIEAust; nVent ERICO Lightning Technologies, Australia

"Collection Volume Method: Computation Details"; nVent ERICO; 2009.

"Electric Utility System 3000: Lightning Protection and IEEE 998"; nVent ERICO; EUI Meeting Presentation; 2023.