Air Terminal Placement: The Key to An Effective Lightning Protection of Structures

by Mr. Hartono Zainal Abidin

Mr. Hartono graduated with a B.Eng (Hons) Electrical and Electronics from the Loughborough University of Technology in 1979. He took the lead role in forensic analysis of lightning damages to electronic and IT systems and has been conducting forensic analyses and providing lightning protection design services for various clients including at the Dallas-Fort Worth International Airport, USA. His interest is in analyzing buildings damaged by lightning. He co-developed a new lightning air terminal placement method which is included in the lightning protection standards of Australia (AS1768 2003) and the IEC (IEC62305 2006). He became the first Malaysian invited to give a lecture at the Asian Lightning Protection Forum and the International Nathiagali Summer College. He was also a member of CIGRE Working Group C4.410 "Lightning Protection of Very Tall Structures". He has written and co-authored over 50 reports and conference papers on building lightning protection.

When Benjamin Franklin invented the lightning air terminal (i.e. lightning rod) in 1752, he gave man a means to protect his home and workplace from the devastating effects of lightning. When it was discovered that the air terminal neither prevented nor attracted lightning strokes, early scientists devised novel methods for placing the air terminals on the roof to protect the structures.

With the construction of higher structures in lightning prone areas in the last 50 years, there has been significant progress in the quest to improve the protection of these structures against lightning. The air terminal placement on a structure is now recognised as the most important criteria in the design and construction of an effective conventional lightning protection (LP) system.

A correctly positioned air termination system can result in almost zero bypasses (i.e. Lightning damages to buildings) since it can intercept all or most lightning strokes while an incorrectly positioned system can render part of or the entire LP system ineffective. In the non-conventional LP system, the air terminal placement was based on erroneous assumptions of lightning behaviour, resulting in multiple bypasses to many tall buildings in the last 25 years.

AIR TERMINAL PLACEMENT METHODS

Several air terminal placement methods have been developed since the 19th Century and these can be found in present day LP standards (Figure 1). These have enabled engineers to design air termination systems that are effective in intercepting lightning strokes. They are described in the recognised LP standards e.g. AS1768, IEC62305, NFPA780.

The Protection Angle Method (PAM) was developed by French scientist Gay Lussac (19th Century). In this method, the elevated air terminal provides a limited shielded zone near its base and it can be applied either singly or in pairs of 2 or more depending on the shielding area required. It can be applied on any flat surface, whether on the ground or on the roof top. A special version of the method applied in conjunction with overhead shield wires (OSW) can provide a wider protection zone.

British scientist James Clerk Maxwell (19th Century) developed The Mesh Method (MM) to address the problem of lightning strikes to flat horizontal and vertical surfaces. In this method, the conductor was placed in grid form on the exposed horizontal and vertical surfaces of the building. It was very unpopular with architects and building owners due to its negative aesthetics and cost issues.

The Rolling Sphere Method (RSM), developed by Hungarian scientist Professor Tibor Horvath in the mid-20th Century, was first applied in the Hungarian LP standard in the 1960s. The RSM later appeared in the western LP standards (e.g. BS6651, NFPA780) a decade later. The method was based on studies of lightning interception (i.e. strikes) to high voltage power transmission lines and was later applied to tall buildings. In this method, an imaginary sphere is rolled over and around the structure in order to determine the lightning shielded zones (shaded areas). Although the method is applicable to both simple and complex structures, it is not capable of identifying the more vulnerable parts of the structure which are at higher risk of lightning interception.

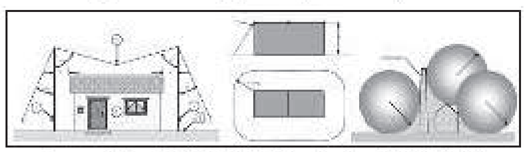

Figure 1: The PAM (left), MM (centre) and RSM (right) (Source: IEC62305)

The Collection Surface Method (CSM) was developed by Malaysian engineers Hartono Zainal Abidin and Robiah Ibrahim in 1995 (1) (2). In this method, the effective air terminal placement was derived from the observed bypass locations on more than 100 buildings in Malaysia and Singapore. The algorithm for determining the collection surface was similar to that used in the RSM but inversed, hence the size of the collection surface at a particular position on the structure determines its vulnerability i.e. the bigger the collection surface, the higher the risk (Figure 2).

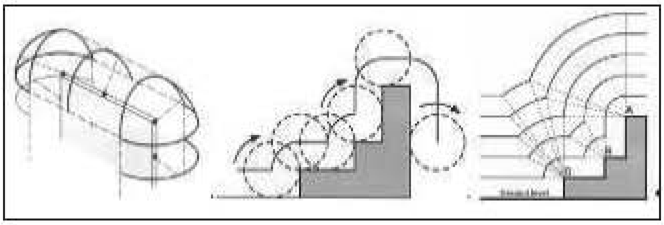

Figure 2: A sample graphical concept of the CSM

The validity of the method was based on the bypass data that corresponded closely with the CSM model. The identified high risk locations on the structures are as shown in Figure 3:

A : >>90%
B : <5%
C : <2%
D : <1%
E : 0%

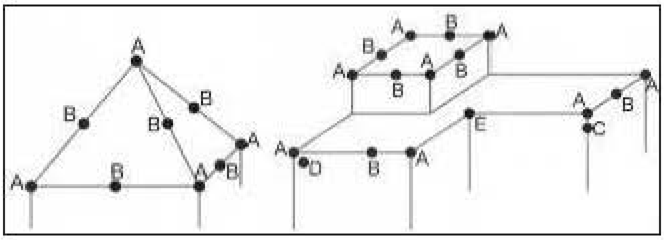

Figure 3: High risk lightning interception locations on structures

THE CSM IN CURRENT LP STANDARDS

The introduction of the CSM in modern LP standards suffered an early setback when it was rejected by the SIRIM working group on lightning protection in 1998. However, it was accepted by the Standards Australia and the IEC TC81 working groups when their respective standards were undergoing revision in 1999 and 2000 respectively.

The basic principle of the CSM (i.e. the placement of air terminals at the high risk positions) has since been included in the Australian Standard AS1768:2003 and the International Standard IEC62305:2006. In 2007, the IEC62305 was adopted as the new Malaysian LP standard, MS-IEC62305 as well as the new British Standard, BS-EN62305.

In the IEC standard, the principle of the CSM is stated as follows: "Air termination components installed on a structure shall be located at corners, exposed points and edges (especially on the upper level of any facades) in accordance with one of the following methods (i.e. PAM, MM or RSM)".

ADVANCEMENTS TO THE CSM CONCEPT

After the CSM was accepted in the IEC standard, some western LP experts conducted further research to improve it. In 2008, Josef and Marek Dudas (3) developed a software application that could determine the high risk locations on a structure in 3-D. Alexander Kern (4) developed more advanced software that could numerically determine the lightning interception levels on the various high risk locations. The software suggested that air terminals positioned at building corners could intercept nearly 99% of the lightning strokes (Figure 4).

The Kern software also suggested that a single tall air terminal placed in the centre of a flat roof could only intercept about 60% of the lightning strokes. This explained the high number of bypasses observed on tall structures installed with the non-conventional LP systems in the country.

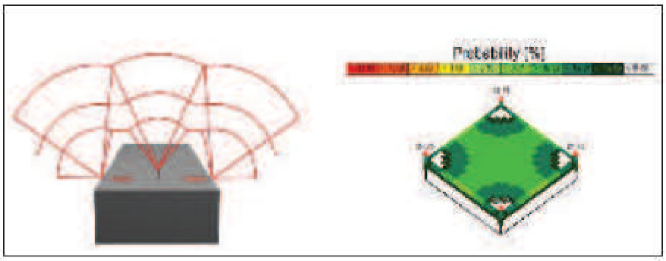

Figure 4: Dudas (left) and Kern (right) software models as depicted in their respective conference papers

COMMON ERRORS IN AIR TERMINAL PLACEMENT OF CONVENTIONAL LP SYSTEMS

A study of conventional LP systems in Malaysia suggested that more than 90% of air terminal placements did not comply with past or current standards (5). This resulted in a significant number of bypasses on buildings that had been installed with the conventional air terminal. Misconceptions about lightning and conventional air terminal which seems to be prevalent among Malaysians engineers have contributed to the widespread errors in air termination system design.

The first misconception is that lightning is attracted to metallic objects and electromagnetic radiation (e.g. from mobile phones). The second misconception is that a conventional air terminal can attract lightning. These misconceptions must be eradicated from the minds of engineers if they are to design effective LP systems.

MISCONCEPTIONS TAUGHT IN LOCAL EDUCATIONAL INSTITUTIONS

The above misconceptions were initially propagated by non-conventional LP system vendors in order to mislead and confuse engineers and the public about lightning protection. Unfortunately, some university lecturers were also found to be teaching these misconceptions to their students and to engineers while some even added new ones. Two local universities that had applied these misconceptions were Universiti Teknologi Malaysia (UTM) and Universiti Putra Malaysia (UPM).

In the book *"Kilat dan Perlindungan"*(6), several new misconceptions were introduced by the author such as:

1. *"Perlindungan yang diberi oleh pengalir rod berdasarkan prinsip iaitu setiap 'ketua' tertapak yang memasuki zon perlindungan konakan tertarik kepada pengalir rod tersebut"* (Translation: The protection provided by the rod conductor is based on the principle that every stepped leader that enters the conical protection zone will be attracted to the said rod conductor).
2. *"Zaman dahulu manusia membina tempat perlindungan daripada kayu adalah untuk melindungi rumah dari terbakar dan rosak disebabkan oleh panahan kilat. Kini manusia telah mendirikan rumah dan bangunan dengan sokongan bahan besi, mengakibatkan ia mudah dipanah kilat dan menyebabkan lebih banyak kerosakan"* (Translation: In the past, mankind built shelters out of wood so that their homes would not be burnt and damaged by lightning strikes. Nowadays, mankind have built their homes and buildings with the support of steel components, thus making them easy to be struck by lightning and causing more damages).
3. *"Kedudukan pengkalan udara mestilah 24 inci dari bucu penjuru rumah"*(Translation: The placement of an air terminal must be 24 inches from the ridge end of the house).

In 2011, UPM applied the same misconceptions that were popularised by the non-conventional LP vendors two decades earlier. In its website, the Centre of Excellence on Lightning Protection (CELP) described the LP system as follows: "When a downward (lightning) channel comes from a cloud, the air termination sends an upward channel (i.e. streamer) much faster than the other parts of the building thus the lightning is attracted to one of the rods (or to the metallic mesh)..... Thus, instead of repelling, a LP system attracts a lightning channel."

The impact of the above misconceptions could be seen in most public and private buildings nationwide, where the air terminals were not positioned at the high risk locations as according to the LP standard i.e. ridge ends and corners (Figures 5 & 6).

Figure 5: Incorrectly positioned conventional air terminal on a house

Figure 6: Incorrectly positioned conventional air terminal on a school

NON-CONVENTIONAL AIR TERMINALS

Public awareness of the non-conventional air terminals had been raised several times locally since 1993 through the mass media, at a public forum (7) and in a technical journal (8). However, lack of action by the authorities to stop their sale and use resulted in the widespread use of these non-scientific and dangerous devices in the country.

Non-conventional air terminals are categorised as either lightning attractor devices e.g. Early Streamer Emission (ESE) and Collection Volume (CV) air terminals (Figure 7), lightning eliminator/rejection devices e.g. Charge Transfer System (CTS), Dissipation Array System (DAS) and Compound Air-Plasma Lightning Rejection system (CPLR) or lightning current reduction devices e.g. Semiconductor Lightning Extender (SLE) (Figure 8).

In 2007, a UTM lecturer and his colleagues invented a non-conventional air terminal known as the HAS system (Figure 9). However, in order to justify the project budget, they claimed that it was a conventional air terminal but with "attractive powers".

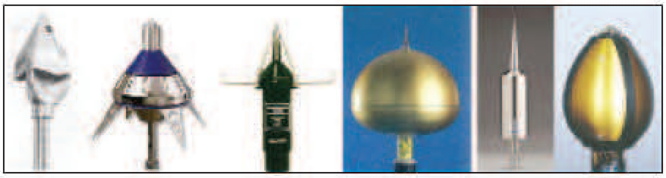

Figure 7: Examples of lightning attractor air terminals

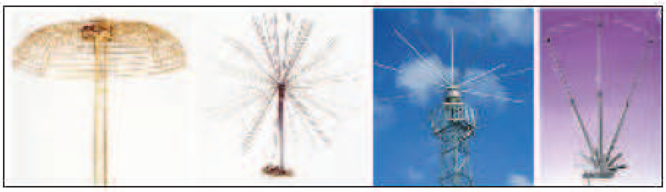

Figure 8: Examples of lightning prevention and lightning reduction air terminals

Figure 9: The conventional lightning air terminal with "attractive powers" invented by UTM

More than 95% of non-conventional air terminals used in the country consists of lightning attractor (i.e. ESE and CV) air terminals which were usually placed at the centre of the roof. One or more bypasses have been observed in most tall or large buildings that have been installed with one or more of these non-conventional air terminals (Figures 10 & 11). Many LP experts have published peer reviewed papers and books on the failures of the ESE and CV air terminals in Malaysia (9) (10) (11) (12). These experts regarded the observed bypasses as indisputable evidence of the failure of such air terminals (13).

Figure 10: A college building installed with the ESE and CV air terminals before lightning struck

Figure 11: The same college building displaying a bypass after lightning struck a corner of the roof

SUMMARY

The application of the Malaysian-developed CSM in the Australian and IEC standards marked the end of two centuries of western monopoly on building lightning protection which began with the invention of the lightning rod.

A conventional LP system that is designed and installed according to the IEC62305 standard, can achieve a high level of protection. An air termination system design that fully complies with the standard can intercept up to 99% of the lightning strokes. The application of the IEC standard in LP design can lead to the reduction or even elimination of bypasses on structures of all shapes and sizes. This increase in safety factor can mean a hefty reduction in losses due to lightning.

The use of the non-conventional air terminals must be discontinued immediately in order to minimise losses in monetary terms and human lives. Since the non-conventional LP systems proved to be non-scientific and dangerous to use, engineers must refrain from using them, in accordance with the respective institutional codes of conduct on public safety. ■