So - you want to be a Lightning Engineer ?

Part I - Protection System Design and Specification

1) Introduction

Few of us are so blasé or sophisticated as never to have felt our pulse quicken during a thunderstorm or to have never been entranced at sight of a lightning display.

Primitive people ascribed many different explanations to the causes of lightning and thunder and at the dawn of the 21st Century - for all of our education and sophistication - the huge forces unleashed during a lightning strike are still capable of imbuing us with a deep sense of awe.

The science of lightning protection is a fascinating field of study. Until recently however, it was a subject which was rarely treated in detail in engineering courses in our colleges and universities.

The protection of buildings, and particularly electrical installations, against lightning induced damage is traditionally approached from two directions. Let's call them top down and bottom up.

Following the top down approach on the one hand, a protection system of air terminations, down conductors and earth terminations may be considered - usually based around the traditional Faraday Cage or Franklin Rod Constructions. Such a protection system aims to protect a building structurally and electrically by the installation of components which will provide a most attractive strike point, and path to earth, for any lightning strokes. The principal components of such a system are:

- Air Terminals
- Down Conductors
- Earth Termination System

It is important to remember, in this context, that lightning cannot be reliably predicted or prevented and traditional protection systems are designed to do neither.

The second - from the bottom - approach relates purely to electrical and electronic equipment ; consideration is given to the protection of alarm /instrument/ communications / electrical systems from the effects of lightning strikes and the associated phenomena. Protective measures for this second (or bottom-up) approach, usually take the form of surge protection devices and a sensibly designed earthing system. In considering such protection systems, it is necessary to account for the possibility that damaging surges and voltage irregularities may be caused by remote lightning strikes and propagated over electrical lines.

The provision of a lightning protection system for a complete building or installation is normally part of the design or construction responsibility of an electrical engineer - as is the design of an earthing system.

The implementation of the individual protection of components, devices or networks is the responsibility of the designer of the particular system in question, who may be a transmission, control or instrumentation engineer, an electrical engineer, a network systems administrator or may in fact be called by any title which is calculated to inspire respect and the payment of a high hourly rate.

In this article, I propose to deal almost exclusively with the first approach as applied to industrial facilities.

- In Part I, I will attempt to give a brief overview of system design as usually practised in Ireland along with some comments.
- In Part II, three case studies will be presented which, hopefully, will serve to illuminate the points discussed, in the light of 'real life' installations. The first of these has been included to illustrate that a protection system will not always be deemed necessary in this country depending on the type of facility being designed and the risk of lightning induced damage. The second case study will show the type of problems which are normally encountered during the design process and the third case study deals with an overseas project in which Australian standards were preferred over the British Standard which forms the basis of most lightning system design in this country.

2) Overview

The need for a Lightning Protection system in a new facility or building in a country like Ireland is debatable. The first step in designing a system should be a careful assessment of the risks of a lightning strike, the consequences of damage and the cost of protection. The relevant section in BS 6651 is an invaluable aid in this kind of assessment; however there will,

of course, be factors individual to each project. Like any engineering tool, the assessment method in the BS is only that -- an engineering tool -- and not a substitute for thought or engineering judgement.
Sometimes an engineer is asked to design a lightning protection system because it is an owner or an insurer requirement. While the demands of insurance companies will generally require absolute compliance, an Owner's brief may arise from a lack of understanding, on the part of the person preparing the design brief, of the nature of lightning protection and the benefits to be gained.

A few points to bear in mind are:

- Locations in Ireland generally subject to only 2-4 'lightning days' per year.
- Conventional lightning protection systems, do not keep lightning away, they merely provide a path to route it safely to earth - some damage is to be expected even if such a system functions perfectly during a lightning strike.
- Industrial facilities in Ireland are generally steel framed buildings with metal wall claddings. Except for high risk processes, for example, or for plants in which the initial (protection system) investment is negligible compared to the cost of damage repair and loss of production, or for areas in which an explosion hazard is to be expected, the benefits of installing a protective system in such a building are questionable.

Where a system is installed however, it is usually possible to reduce costs whilst maintaining functionality by integrating the lightning protection system with the building design - i.e. by utilising parts of the building structure as air terminations, down conductors or earth terminations.

The design of a lightning protection system will normally be carried out in accordance with the recommendations of one or more of the internationally recognised design standards. Unlike the rather prosaic style which is the norm for engineering codes (no colourful cover shots or pictures of scantily clad models), lightning protection codes can be mysterious and wonderful documents awash with fascinating odds and ends of information (you can tell that I don't get out much). For example, British Standard (BS) 6651 contains a table showing the calculated risk of fatality associated with activities as diverse as smoking, mountaineering and driving a car.

NFPA 78 from the US National Fire Protection Association has a section on personal lightning protection; including a list of good places to be during a thunderstorm (inside a large building) and bad places (inside a small tent). It also describes how you know that you are about to be struck by lightning (your hair will stand on end) and the recommended posture to be adopted - one which is suspiciously reminiscent of the old schoolboy joke about the posture to adopt during a nuclear attack - i.e. put your head between your knees and give the seat of your trousers a good-bye kiss (that is the posture recommended in the joke of course, not in the NFPA).

The standard which is normally used in these islands is BS 6651. Many Irish designers are surprised to find that significant differences exist in the approach to lightning protection system design which is taken by standards and codes in other parts of the world (refer to Case Studies 2 and 3 in Part II of this article). If BS 6651 is adopted, then the design process will be broken down into the following steps:

a) Risk assessment - Is Protection required ?
This will take the considerations mentioned above into account and apply simple (and I do mean simple) statistical techniques to determine whether the level of risk justifies the installation of a protective system.

b) System layout - design and routing of termination networks, down-conductors etc.
The initial layout work for an industrial facility is normally quite simple once the major decisions such as the type of air termination network have been taken. The BS is well written and very easy to follow and it's recommendations can be interpreted to give guidance on all but very few of the situations which are encountered in the normal design process for industrial installations. The resulting layout drawings should show the roof termination system as well as the number and location of down-conductors and earth termination points.

c) Specification and detailing
Steps b and c are really one step (but I hope to get paid by the word). Along with the overall layout work it will be necessary to give detailed instructions as to how items such as earth termination points, connections, test links etc. are to be constructed. Detailed sketches will normally be prepared - either as part of an overall layout drawing or as an attachment to the specification documents.

A specification will be necessary to detail such items as the materials to be used, the final resistance to earth of the earth termination network and so on. This information must be presented in a form which treads the thin line between too much information (which merely repeats or conflicts with code recommendations) and too little information which makes the installation difficult to price and the design intent open to different interpretations thus making control of the installation quality more difficult.

Part II - Case Studies

In Part I of this article, I gave a brief overview of the design of lightning protection systems with particular reference to the design of industrial facilities here in Ireland.

This month, I will present some case studies to try and illustrate some of the thrills and spills (precious few of either alas) which await the designer as he embarks on the design and construction process.

Case Study 1:

Project: Refurbishment of IDA advance factory to be refitted as a secondary pharmaceutical production facility (i.e. a 'finishing plant' factory that makes finished drugs in the bottled, tableted, powdered or whatever form in which they will retail; as opposed to a 'primary' or 'bulk' plant which processes chemicals but does not carry out the production of the 'finished product'). Production was to be on a batch basis in a high grade clean room suite situated within the building. There was a large water treatment plant within the building while the boiler house, cooling tower and chiller were all external.

Location: Rural / industrial estate. Other Buildings well separated.

Building: Steel Framed, aluminium clad office / production / warehouse building. 48m x 90 m x 7 m high.

Discussion: On carrying out a preliminary assessment we found that the calculated risk factor was such that the BS recommended protection - but only just (i.e. the calculated risk was just on the border of the range for which protection was recommended). Our assessment of the cost of this system was of the order of IRP 20,000. My feeling, based on the estimated cost, the building structure and the nature of the process was that this would not be money well spent. Much of the potential cost was due to the fixing of the lightning protection tape to the roofing system which was proposed. This would be very time consuming. Furthermore, we were informed that, for this type of roofing material, the fixing of the lightning protection components could only be carried out during a spell of fine weather. The above considerations were presented to our client and the requirement for a system was deleted from our scope.

Case Study 2:

Project: A greenfield development of a new production facility for the healthcare industry. Production was to be carried out in a sealed production line within a large low-grade clean room. The process was to be continuous and if it were halted for any period of time, all of the product on the lines would have to be scrapped or reworked. The client regarded occasional stoppages as acceptable and on that basis the building power distribution was secondary selective (two transformers feeding a split switchboard with a normally-open tie circuit breaker) with manual changeover - no backup power system being installed for production or utility equipment. A substantial utilities suite consisting of boiler room, compressor room, chiller area and water treatment plant was located within the building while cooling towers and inert gas storage were external.

Location: **Rural/industrial estate. Other Buildings well separated.**

Building: **Steel framed aluminium clad production/warehouse/office building with a large canteen/restaurant. The front face of the building was to be a glass curtain wall, side walls were to be of nonmetallic panelling for approximately 60% of the building length, while the rear of the building was to be clad almost to ground level with aluminium cladding.**

Discussion: **A preliminary calculation indicated that protection was required.**

For the reasons outlined in Case Study 1 above, our feeling was that a protection system was not necessary. We briefed our client on the factors involved and informed them that we felt a protection system was not required. In addition to the factors which I have mentioned already, the initial design brief for this facility was closely modelled on a similar production plant in the Southern United States which was subject to in excess of 90 lightning days per year - obviously the new facility would be much less prone to lightning damage. However on consideration the client decided that a system was merited on the following grounds:

- **The building would contain a number of through-roof projections leading directly to the production clean room envelope.**
- **ANY loss of production would be expensive but a breach in the structure of the production envelope could lead to a prolonged shutdown which was to be avoided if at all possible.**
- **The total building investment was of the order of IRP 150 M including the production equipment. Serious lightning damage (for example due to a large fire) could lead to the loss of the complete investment, not to mention a shutdown which could halt production for over a year if the building were gutted.**
- **The existing plant in the US was protected by a system of vertical finials which were connected to a system of down-conductors. For the new system, we decided on a flat tape network in accordance with BS 6651.**

Even more so than with most electrical systems, the installation of lightning protection demands close coordination with the work carried out by non-electrical trades - particularly if components of the building structure are connected to the system as outlined above. Any electrical system in construction work which requires a significant interface with other disciplines has the potential to cause major expense and lost time unless the coordination is properly managed. The work of the disciplines involved must be scheduled to allow the correct interfacing and then the installation contractors must be monitored so that they do not impede each other's progress *(note that when two groups of workers from different companies are working side by side and under pressure, any breakages or damages will usually be the other group's fault;*

***any lost time will usually be due to delays incurred by having to work around the other group and any responsibility for either of the above is virtually impossible to allocate. Moreover, claims of damage or impeded progress are very often based on fact. It is not unknown for installation workers to damage work already installed because it impedes the installation of their own equipment*).**

On a well-managed site, with professional installation contractors and good construction management, problems of this nature will rarely arise or - if they do, will be dealt with quickly and calmly. If the necessary coordination exercise is neglected then the whole issue can quickly deteriorate into a complete mess and will be a thorn in somebody's side regardless of how responsibility is allocated contractually. All that the designer can do is to make sure that firstly, the risk of such a situation arising is minimised and secondly, if it does arise, that specifications and scopes of work clearly define that the 'somebody' in question (that is, the person in whose side the thorn finally sticks) is not himself (or herself or their client).

In our system, we decided that at the sides and rear of the building we would use the structural columns as the down-conductors and the reinforcing bars in the column feet as the earth electrodes. Using the reinforcing bars in this manner meant that a cable would have to be welded or bolted to the reinforcing bars, protected from future corrosion, protected from damage while the concrete was being poured and then protected from damage during the remainder of the construction process. Lastly if the cable was not installed or the connection was broken the responsible party would have to be made to pay for the substantial rework and expense which would be caused. To successfully achieve the above five - in particular the last - on a construction site is a feat that is difficult to fully appreciate unless one has actually been involved in the construction process. Likewise the installation of the roof network would require careful interfacing with the roofing contractor. Lastly the lightning protection system would have to be tested during construction.

The main design issues to be addressed were as follows:

i)
Should we use a common termination network for the earthing and lightning protection systems? (i.e. connect them above ground and bring them to earth together as opposed to keeping the two networks segregated and bringing them to earth separately).
ii)
How would we design a system that could be tested periodically during the life of the plant (as is required by the relevant code and common engineering sense)
iii)
To what extent should metalwork on the building sides be bonded to the Lightning Protection System and how was this bonding to be achieved.

i) The British Standard for Lightning Protection systems recommends that a common earth termination network be used for lightning protection and other earthing systems. The BS for earthing, on the other hand, only states that the two systems should be connected together at the main earthing terminal so as to prevent damage to the electrical systems in the event of a lightning strike. There was some concern that this could be taken to mean that separate termination networks were preferred.

My preference is for a common network. This must be taken in the context of the position from which I view the design of electrical systems, i.e. as a designer of electrical power distribution and services systems rather than as a person who has to implement the design or the operation of sensitive communications or instrumentation systems. My reasoning may be summarised as follows:

The lightning protection earth termination network is by it's nature extensive and easily accessible. The provision of a separate earth termination network is difficult to justify in terms of the time and materials involved.

The provision of so-called 'clean earth' networks (separate earthing systems for communications, control or instrumentation systems) is difficult to justify in many installations. It is often far more practical to maintain a system which seeks to obviate earth 'pollution' through extensive bonding of different systems AND prevention of earth loops etc. than one in which coupling or connection between systems is to be avoided completely Moreover, if separate systems are provided and then taken to earth separately, dangerous voltages may appear between the different earth termination networks in the event of a lightning strike

Naturally each installation must be considered as a separate case. Facilities which require the installation of equipment which is extremely sensitive to the effects of stray voltages and surges, or equipment which is 'intrinsically safe' (a design philosophy for equipment which is to be installed in areas in which a - gas or vapour - potentially explosive atmosphere may exist), for example will demand special consideration.

Our decision in this case was for a common termination network.

ii) Another area in which slight differences in the approach taken by the two related standards occurs is with respect to testing of an earthing installation. BS 6651 (lightning protection systems) allows the use of the structural steelwork as part of the lightning protection system where practical and also permits the use of reinforcing bars in column bases as an earth electrode network. However it also stipulates that each earth electrode must be provided with a means of isolation for testing. These two concepts are clearly at odds

Any column in a system of structural columns, be it of steel or reinforced concrete, which is suitable for connection as part of an earth conductor network, will necessarily be in continuous electrical contact with the remainder of the building structure - unless that structure is electrically non-conductive. Such a 'conductor' cannot be interrupted for testing in the sense that a single length of earth bar or tape leading to an earth pit can be interrupted.

The code does state that where structural columns are used as down conductors that sufficient points of test shall be provided to enable verification of the resistance to earth of the structure as a whole to be carried out, however concern was voiced that this could not be taken to mean any relaxation of the stipulation with regard to the testing of earth electrodes.

BS 7430 (earthing) however lacks any inherent contradiction in this regard. It also admits the use of structural steelwork as part of the earthing system however it recognises the impracticability of attempting to interrupt or isolate part of the structural steel system for earthing and instead includes an alternative procedure for carrying out testing.

Our solution to the need for testing of the system was to provide connection points on the building face to allow the connection of test instruments. We also provided for a test earth electrode in a remote part of the site (which was large enough that the test electrode could be sited 700 m away). In hindsight however, this last was not necessary as temporary electrodes can easily be used for this purpose.

iii) A potentially serious issue was the bonding of extraneous metal on the building sides to the lightning protection system.

The need for such bonding is easily demonstrated. When carrying the large currents with extremely rapid rise-time which occur during a lightning strike, the elements of a lightning protection system can be raised to a high voltage level, despite being ultimately connected to earth. The most significant results of this are the danger of side-flashing (arcing from the lightning protection system to adjacent, unconnected metalwork) and the danger that a person inadvertently connecting metalwork which is connected to the lightning protection system and adjacent, unconnected metalwork or earth, may be subjected to a dangerously high voltage - so called 'touch voltages'.

The accepted solutions to this problem are to rigorously bond all metalwork which may be a source of side flashing or dangerous potential differences, to the lightning protection system - or to rigorously ensure, not only electrical isolation, but also segregation from the lightning protection system for all such metalwork.

This sounds quite simple and often is. However, many installations include metallic items which fall into a grey area in which it is unclear if bonding is required.

A commonly asked question, for example, is whether or not metallic window frames should be bonded to the lightning protection system (no - unless you have an EXTREMELY unusual window design) or water downpipes (sometimes). Some guidance to the determination of the need for bonding is given in the lightning code which includes a calculation method which acts as an aid to determining whether or not building metalwork should be bonded at each end, at one point, or not at all, to the protection system.

Our 'grey area ' was occasioned by the discovery that the building design called for the use of metallic plaster stops around exterior wall panels. That is to say that the wall covering for much of the building exterior comprised a number of panels, each of which had a metal band around it's border.

Our concern was to ensure that in the event of a lightning strike that these would not be the cause of side-flashing off the lightning protection system with the attendant dangers of fire and electrocution and of course marking on the side of the building. Although this may seem remote, we could not say that the cross sectional area of the metallic strips was so small and the discontinuities between the plaster panels so large that such side flashing could not occur. We consulted the plaster-stop supplier who said:

- Well we never see this as a problem here in Germany.

(It should be noted that the Supplier's advice would be useful only up to a certain point.

If they said:

- Yes we always bond these items to the lightning protection system.

or better still

- Yes we always bond these items to the lightning protection system and here's how.

Then we could investigate their solution and review its applicability to our situation.

An answer to the effect that they did not consider this to be a problem told us nothing as we could not base decisions pertaining to lightning protection system bonding solely on the word of somebody who sells plaster panels for a living - such people are not noted for being experts on electrical engineering matters.

In short, we were checking to see if they had encountered this problem before and could help us to find a solution and not to see if they could provide a solution for us).

After further study of the codes, we concluded that bonding was not required - particularly in the light of the statement in Appendix 1 of BS 6651 to the effect that short isolated pieces of metal which are merely in fortuitous contact with the ground through the rain covered surface of the structure need not be bonded.

Case Study 3:

Project: **Extension to an existing oil refinery. The proposed extension was a large refinery development in it's own right and may be considered as a greenfield development.**

Location: **Tropical (close to the equator). Coastal.**

Building: **A number of interconnected pipe racks, tank farms and process units / vessels, of metallic construction all located outdoors. Isolated control rooms and substation buildings were located around the site. The electrical system was secondary selective with automatic changeover. The highest voltage level on site was 132 kV. Sophisticated process control and shutdown systems were incorporated in the design giving a high degree of automation to the plant operations.**

Discussion:

The location in question is subject to up to 140 lightning days per year (though to the residents of the surrounding area, it often seems that the true figure must be closer to 350 days). The existing site had suffered extensive damage to instrumentation, communications, fire alarm and electrical equipment due to lightning strikes, surge voltages and induced currents.

Lightning Protection was a very sensitive issue on this project.

The Project Specification (based on the 'Collection Volume' method of Australian Standard NZS/AS 1768) was for a system of the enhancing type - that would actively attract lightning strokes and safely conduct them to earth. This was to be achieved by the installation of air terminations which would actively respond to the presence of a lightning downleader in their vicinity by producing free electrons and thus attract downleaders from within a defined volume.

The specification for this system was a proprietary one - that is to say, it was a specification which could only be met by one company's equipment. Proprietary specifications are, naturally enough, the supplier's dream and the contractor's

nightmare. An equipment supplier who has no competition in preparing a bid is under much less pressure to make it commercially attractive.

The project Turnkey (design, buy, build and commission) Engineering Contractor suggested an alternative system based on BS 6651 and JIS (Japanese Industrial Standard) A 4201 as modified by Oil Industry Standards and the Institute of Petroleum (IP) Code. It was felt that the 'Rolling Sphere' method (as advocated by the BS) of determining the protected area around lightning protection system elements was more onerous than the method advocated by the Australian Standard. This would result in smaller protected areas being calculated and require more air terminations and down conductors, resulting in a higher degree of protection. It was also proposed to counter the high surge impedance of earth electrodes by embedding them in conductive concrete.

The Owner's view was that the BS was not really applicable for this sort of installation and was written more with buildings in mind. They felt also that the BS could be interpreted as to mean that very few downconductors would be required. Some of the information available on the existing installation indicated that the existing lightning protection system (which was to the same specification) was operating satisfactorily and that the equipment failures were primarily due to inadequate surge protection and poor earthing practise (for example multiple earth cables, connected to separate termination networks, entering the same control rooms). Concern was voiced regarding the long-term performance of conductive concrete.

It was decided to retain the original specification. The application of conductive concrete would be restricted to specific locations and deep driven electrodes would be used to lower the surge impedance.

2) Conclusion

It is impossible to deal properly with such a complex subject in a mere 4940 or so words. I hope though, that the case studies and discussions which I have presented will illustrate some of the design and construction issues which are faced in trying to wrap science about what is - in many ways - still the *ART* of Lightning Protection System design.