EARTHING AND LIGHTNING PROTECTION IN THE MODERN INDUSTRIAL ENVIRONMENT

Ian McKechnie and Ian Jandrell
Innopro (Pty) Ltd, South Africa
University of the Witwatersrand, South Africa

ABSTRACT

This paper addresses the topic of earthing and lightning protection in the context of the modern industrial and plant environment. The modern industrial environment is characterised by integrated energy and information systems linking all of its parts, from the plant floor to the board room. Recognising the importance of data integrity, and energy and operational security, has underscored the importance of the earthing and lightning protection system as a critical part of the plant infrastructure and systems. This paper emphasises the importance of a structured engineering approach to achieve effective design, implementation and maintenance of these important systems. It further emphasises the importance of a holistic and systematic engineering approach both in a technical sense as well as in a plant life-cycle engineering sense. The important of an earthing and lightning protection system and plan framework, and the maintenance thereof, for human safety is emphasised

1. INTRODUCTION

Since the development of the first physical understanding of lightning and the proposals for the earliest lightning protection systems (LPS), the focus of our efforts has always been on the provision of human safety. It is for this reason that even the latest standards consider 'life hazard' and the primary risk factor relates to loss of life [1, 2].

More recently, particularly as electronic systems became more prevalent in industry, aspects such as system reliability and industrial electromagnetic compatibility (EMC) have also become germane to the design of proper lightning protection systems [3, 4].

As a consequence any LPS must be maintained to at least its design efficiency in order to offer adequate protection to personnel and systems. It is the authors' experience that this is seldom the case.

This paper will consider the life cycle management of an LPS and will emphasise the need for an on-going, holistic and coordinated approach to the provision of lighting protection at an industrial plant. Such an approach must by necessity also include a strategy to manage personnel during lightning activity.

2. BACKGROUND

The modern industrial environment is a complex multi-faceted environment. This complexity is evident in a technical context as well as in an engineering and plant management context. Financial performance as well as health and safety are also key drivers in managing the plant and its processes in this environment.

In this environment, the systems and equipment that are installed and maintained generally contain more sensitive equipment than in the past. Furthermore, these are typically interfaced on a broader basis, with increased plant networking and data communication systems for example. The impact of this is further compounded where the plant is spatially distributed. These factors increase the vulnerability of the modern plant to the potentially deleterious effects of lightning, as well as other industrial electromagnetic interference.

These factors imply that the establishment of effective lightning protection systems, as well as industrial EMC measures, are key to ensuring a safe and protection environment for industrial plant and personnel. As importantly, the effective ongoing maintenance of these measures is key to their successful implementation. It is well understood that a properly designed LPS can limit damage and loss of life [4], but that any compromise to the system due to lack of maintenance can immediately result in the levels of protection no longer limiting the risk to acceptable levels.

There has recently been more focus on lightning mortality rates in South Africa [5] and in 2006 Blumenthal formally proposed lightning autopsy guidelines [6]. These included a call for greater attention to detail in the medico-legal investigation and reporting of lightning-associated deaths. It is likely, therefore, that we will gain further insights into lightning related deaths, and that the LPS integrity at any site will need to be more rigorously evaluated on an ongoing basis by the plant engineers and management.

Whilst a standards-based technical approach has been found to be effective and to result in enhanced protection against the effects of lightning, a proper engineering approach to lightning protection is often not evident [4].

3. THE SOUTH AFRICAN CONTEXT

An extensive project by the CSIR over many years resulted in a mapping of the lightning ground flash density for South Africa. The table of ground flash density figures documented in SANS 10313 is derived from this study [1].

These tables indicate a general trend of increasing lightning ground flash density towards the central and eastern parts of the country, with good correlation with climatic and terrain characteristics. More recently, the South African Weather Service has installed a Lightning Detection Network (LDN) which has been operational since 2006. Discussing this system, Gill [7] has observed that the central and eastern parts of South Africa have the critical elements of unstable air with substantial heat, instability and water vapour present "in abundance" in the summer months. Gill noted that South Africa's climate and therefore distribution of lightning are particularly influenced by its geographic location and unique topography.

Whilst South Africa does not have the highest lightning ground flash density figures in the world, as is often erroneously alluded to, many parts of the country certainly do have above average to high figures. In many cases these also coincide with areas of economic activity and population [3, 5].

South Africa generally experiences relatively dry conditions and correspondingly high soil resistivity conditions. Establishing a good earth is therefore relatively difficult, although secondary effects such as soil ionisation can assist in ameliorating this. As lightning is effectively a current source, this translates into relatively high voltage gradients and ground potential rises (GPRs) of earthing systems being experienced. This results in an increase in the potential for galvanically coupled damage of equipment, as well as an increase in the potential for human being (and livestock) injury due to step and touch voltages developed due to a lightning strike.

These soil conditions and the effects thereof must therefore be factored into risk assessments related to lightning even in areas of relatively low lightning ground flash density.

In South Africa therefore, the risk exposure (injury and/or damage related) due to lightning must be considered in the context of an environment where a combination of factors collectively compound the risk exposure. The compounding factors include:

- A high proportion of the South African population live in areas with relatively high lightning ground flash densities.
- A significant proportion of our industries and areas of economic activity are located in areas characterised by lightning ground flash densities greater than 6 ground flashes/km^2/annum.

Jandrell *et al* recently noted an analysis by Evert of recorded data from the South African Lightning Detection Network (SALDN) suggesting that the ground flash density values for areas with a ground flash density (N_g) > 8 may have however been previously underestimated [5, 8]. This has obvious implications in terms of the risk exposure and risk management of the potential impact of lightning in South Africa. Whilst further research and analysis is obviously required, including *inter alia* analysis of data collected over a greater length of time, consideration of the above-mentioned information suggests that in the interim a conservative approach to lightning risk management would be prudent.

4. LIGHTNING RISK MANAGEMENT

It is important to understand that lightning protection is a risk management exercise (not risk elimination), and that this risk management must be applied throughout the plant or application lifetime as is discussed later in this paper (the "life-cycle approach").

Risk assessment and management is required to understand the potential risks for a particular application, and to minimise the potentially damaging effects of lightning. Effective risk management must take account of the effects of both direct and adjacent (indirect) lightning. A holistic technical approach must also be followed to ensure that protection includes the consequential effects of a direct or indirect strike (ie the "internal lightning protection system" as well as the "external lightning protection system" as discussed later in this paper.

A holistic approach also implies that risk assessment and management is required from a more general engineering and application perspective. This ensures that design, integration, operational, maintenance and other life-cycle risks are factored into the assessment and management process, and that the lightning protection specific risk assessment and management is not done in an "engineering vacuum".

This implies that the risk assessment and management, and engineering design of the lightning protection measures must be done by persons with a good understanding of:

- Lightning and lightning protection system technical design.
- The application environment and technologies utilised.
- The engineering design and project process.
- The plant operational and environmental (in a broader sense) context and relevant risks and challenges that must be factored in as part of a holistic engineering approach. This includes incorporating the various technical disciplines and different departments in a typical plant environment in a co-ordinated manner during the entire lightning protection system life cycle processes.

The role of the LPS therefore, in conjunction with other measures such as the safety and maintenance plans, is to manage the risks associated with direct and indirect strikes in a holistic manner.

A number of potential consequences need to be managed in the typical industrial plant context, in respect of lightning. These include:

- Structural damage.
- Equipment damage.
- Personal injury.
- Fire.
- Economic loss (direct and indirect or consequential).

The potential for consequential economic loss also needs to be understood in a broader context than, for example, lost production. This is illustrated by a recently reported case in South Africa in January 2010 where a mine operation suffered significant damage and plant outage as a result of a lightning strike. The mine owner's listed share price immediately slipped down nearly 9% after market opening [9].

It is therefore clear that the key objectives of lightning protection are to:

- Ensure safety of living beings.
- Protect infrastructure and systems against direct and indirect or consequential losses.

It is also important to understand and appreciate that these objectives are interrelated, in that, for example, infrastructure and systems protection contribute to safety (directly and indirectly), in addition to specific safety measures and precautions.

In this respect, it is therefore important not to overlook the importance of human safety in the industrial environment. Various factors pose particular risks to personnel in the industrial and mining environment in respect of lightning activity. These include, for example,

- The size and geographic extent of these plants, and personnel potentially in exposed locations with limited immediate lightning protection shelter options (or warning of potential danger).
- Exposure to touch and step potentials in the plant, the latter particularly in open (and remote) locations.
- Hazardous locations and associated explosion, fire and injury risks.

It is therefore imperative that a holistic view be taken in respect of lightning protection and that lightning protection risk management be incorporated in an integrated manner in the overall health and safety planning, provisions, procedures and actions for the plant or mine. Other particular recommended measures include:

- Implementation of an appropriate lighting warning/alarm system, together with appropriate procedures and awareness training.
- Provision of properly designed (and designated) lightning protection shelters and/or protected locations in the plant, coupled with appropriate procedures and awareness training

5. AN EFFECTIVE ENGINEERING MANAGEMENT LIFE-CYCLE APPROACH

Effective lightning protection requires the adoption of an effective engineering management life-cycle approach, as a continuous process as illustrated in Figure 1. The authors describe this as the Integrated Lightning Protection Solution (iLPS).

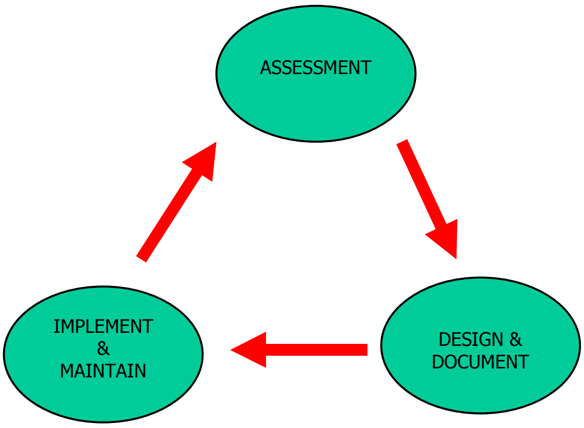

Figure 1. The life cycle approach

Key elements of the various stages in this iLPS process include:

- Assessment
  - Lightning risk assessment;
  - Technical and engineering risk assessment.
- Design and Document
  - Appropriate design and technology for the ILPS and ELPS (integrated approach);
  - Maintenance strategy and plan;
  - Safety plan and OHS integration;
  - Engineering/technical co-ordination and plan;
  - Training Plan;
  - Awareness Plan;
  - Documentation.
- Implement and Maintain
  - Implementation and oversight;
  - Maintenance plan implementation and oversight;
  - Ongoing training, awareness, change management and coordination across the plant.

It is important to understand that effective lightning protection is not about a “cookbook” approach simply using technical standards as “recipe books”. It is about an ***engineering approach*** where these standards play an important technical role, but are applied within a structured, systematic and integrated engineering framework, taking account of a dynamic plant or application environment.

The proposed Integrated Lightning Engineering Plan (ILEP) provides a core mechanism and engineering management framework to ensure a holistic and systematic approach to achieve effective lightning safety and protection at a facility [10]. This paper also argues that ownership of this plan must be at the highest level as a key component of both occupational health and safety, and of plant/facility management, engineering, operations and ongoing integrity.

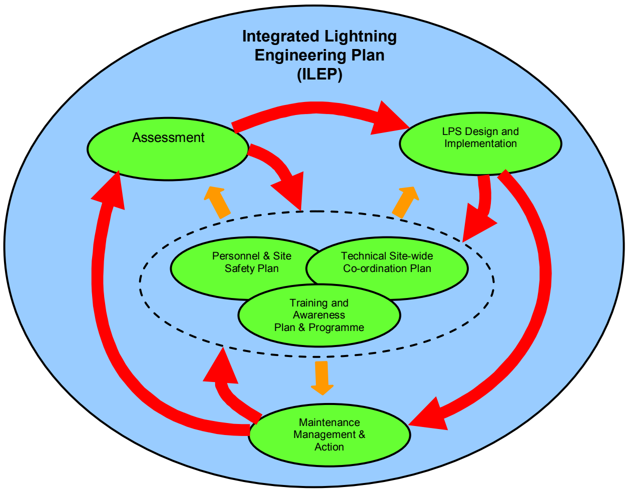

Figure 2. The Integrated Lightning Engineering Plan

6. THE HOLISTIC TECHNICAL SOLUTION

A holistic technical solution requires that the effects of both direct and indirect (or adjacent) lightning are addressed. The holistic solution is typically described as comprising the external lightning protection system (ELPS) and the internal lightning protection system (ILPS).

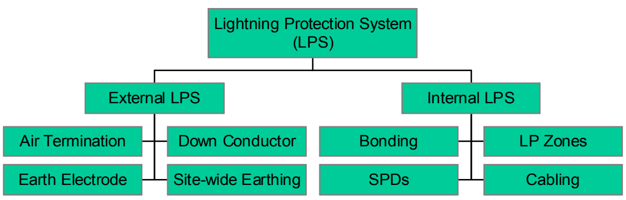

Figure 3: The Holistic Lightning Protection System

The role of the external LPS is to manage the effects of a direct lightning strike. These include:

- Managing the strike termination point (through the air termination system) and the safe and efficient conduct of lightning current to the earthing system (via the down conductor system or network).
- Providing an effective earthing system to conduct the lightning current into the ground, whilst managing the resultant ground potential rise and resultant effects such as the development of step and touch voltages.
- Implementing local and site-wide equipotentialisation, and an integrated site-wide earthing system.
- Implementing a low impedance (as opposed to low resistance) bonding and earthing network.

The role of an internal lightning protection system (ILPS) is to manage the effects of indirect (adjacent lightning) as well as coupled effects due to a direct lightning strike. These effects include galvanically coupled as well as those due to electromagnetic coupling (electrical and magnetic fields). The ILPS includes:

- Adoption of the lightning protection zoning concept, and the associate zone definition and zone boundary management, as a structured engineering tool.
- Appropriate cabling strategies and bonding methodologies.
- Application of appropriate surge protective devices (SPDs) in a coordinated manner, and in a manner consistent with the LPZ boundary management.

7. THE IMPORTANCE OF MAINTENANCE

7.1 MAINTENANCE INTRODUCTION

It is obvious that once the lightning protection system has been installed, it is important that its integrity and performance is not compromised over the LPS operational life time (life cycle). Whilst this may be obvious, it is however the experience of the authors that this is often not achieved in practice.

As with any other aspect of a plant, effective maintenance of the lightning protection systems requires a properly coordinated, planned and well managed, executed (and funded) strategy.

Furthermore, maintenance must be implemented in both a reactive and a proactive manner. This in turn implies, inter alia,

- The preparation and use of define maintenance plans to address both these aspects;
- Appropriately training personnel;

- Ready availability of relevant documentation including specifications and drawings.

Maintenance of a lightning protection system is not just about the periodic measurement of earth electrode resistance values, or unstructured and ad-hoc inspections. It must be a structured and holistic process in order to be effective and meaningful.

7.2 CHANGE MANAGEMENT

Change management is a key facet of the maintenance management (and indeed the overall engineering coordination) of the lightning protection system.

Key aspects of change management include:

- Managing the effects of the LPS installation (and/or changes to the LPS installation) on other installations and systems, and on other internal designs and standard specifications.
- Ensuring compliance with change management and other plans.
- Technical and awareness training (directly and indirectly involved personnel).
- Manage the incorporation of lightning protection strategies, plans and implementation in facility OHS plans and procedures, and other engineering protocols and procedures.
- Site-wide (plant-wide) coordination

These change management issues are critical and are incorporated in the Integrated Lightning Engineering Plan (ILEP) as discussed earlier in this paper.

7.3 MAINTENANCE LEVELS AND RECORDS

Various levels of maintenance of a lightning protection system are typically defined. These can be associated with both proactive and reactive maintenance activities, and can be linked to different types of events. In such a structured and layered model, higher levels of maintenance typically have more extensive requirements.

These maintenance levels can for example, comprise basic visual, full visual and detailed maintenance actions. Detailed pro-forma checklists can be associated with each, as can recommended intervals (proactive) or trigger events and/or results (reactive).

Maintenance and remedial actions are also facilitated by appropriate record keeping. In the author's experience, inadequate record keeping often results in fault finding and remedial actions being adversely impacted. Records must be kept of inspections, maintenance actions and fault histories related to lightning. These records must also be readily accessible to enable information capture as well as retrieval. The establishment and maintenance of an appropriate site history file is therefore recommended. The custodial responsibility for such a file, and for its regular updating, must be specifically allocated as part of the lightning and site maintenance planning, and as part of the Integrated Lightning Engineering Plan for the facility.

7.4 KEY OUTPUTS AND RESPONSIBILITIES

Key outputs of the maintenance and change management processes include:

- Regular maintenance and reports (including reassessment) as per the maintenance plans.
- Training and awareness programme(s).
- Other change management and other engineering coordination and management actions as defined and/or required by the maintenance plan.
- Re-initiation of the management process as necessary.

Specifically designated and appropriately trained personnel must be assigned responsibility to manage and implement the maintenance plans. They must be supported by specialist subcontractors as required. The responsible lighting protection engineer should also be used as required (eg for specific assessment or design actions, oversight, and engineering management and coordination).

8. CONCLUSION

The risks and hazards due to lightning can generally be well managed in the industrial plant environment.

A well defined, structured and documented engineered approach is essential to ensure design, implementation and ongoing integrity of the overall lightning protection system. As part of this approach, a well defined, managed and documented maintenance process must be implemented as a key component of this structured engineering approach.

An integrated and life-cycle approach is required as described in this paper as the Integrated Lightning Engineering Plan. This plan accounts for protection of plant and equipment, as well as personnel

9. REFERENCES

[1] SANS 10313:2010: "South African National Standard: Protection against lightning – Physical damage to structures and life hazard". South African Bureau of Standards, Private Bag X191, Pretoria, 2001.

[2] SANS (IEC) 62305 suite: "Protection against lightning". South African Bureau of Standards, Private Bag X191, Pretoria, 2001

[3] I.S. McKechnie, I.R. Jandrell, "Best practices in lightning protection and earthing of structures and

systems". Seminar notes, Innopro (Pty) Ltd (in association with the School of Electrical & Information Engineering, University of the Witwatersrand), Centurion South Africa 0046, November 2009
This seminar is accredited for CPD with ECSA by Wits University (validation number ELEN0003).

[4] I.S. McKechnie, I.R. Jandrell, "Further Southern African experiences with the application of the IEC lightning protection standards based on their application at four major installations". Proceedings of the 27th International Conference on Lightning Protection (ICLP 2004), Avignon, France, September 2004.

[5] I.R. Jandrell, R. Blumenthal, R.B. Anderson, E. Trengove. "Recent lightning research in South Africa with a special focus on keraunopathology." Invited lecture, Proceedings of the 16th International Symposium on High Voltage Engineering (ISH 2009) Conference, Cape Town, South Africa, August 2009.

[6] R. Blumenthal. "When thunder roars – go indoors! Lightning autopsy guidelines." South African Medical Journal. Volume 96, no 1, January 2006.

[7] T. Gill. "A lightning climatology of South Africa for the first two years of operation of the South African Weather Service Lightning Detection Network: 2006-2007". Proceedings of the 20th International Lightning Detection Conference, Tucson, Arizona, USA, April 2008.

[8] R. Evert. "Adapting electric power utility insulation coordination procedures to incorporate accurate lightning data." Proceedings of the Cigré Regional Conference, Cape Town, South Africa, August 2009.

[9] Business Financial Newswire. "Lightning strike hits Platinum Australia mine." Investegate – A Financial Express Website, January 2010.
www.investegate.co.uk/invarticle.aspx?id=57022

[10] I.S. McKechnie, I.R. Jandrell, "The Integrated Lightning Engineering Plan as an overarching and coordinating framework for an effective and holistic lightning protection solution". Proceedings of the 30th International Conference on Lightning Protection (ICLP 2004), Cagliari, Sardinia (Italy), September 2010.

Principal Author: **Ian S McKechnie** [PrEng, PrCPM, BSc(Eng), FSAIEE, AA Arb]

Ian McKechnie is the Managing Director of Innopro (Pty) Ltd. Ian holds a BSc(Eng)(Electrical & Electronic) degree from the University of Cape Town. He is a registered Professional Engineer (PrEng) and a registered Professional Construction Project Manager (PrCPM). He is appointed as an Honorary Research Fellow at the University of the Witwatersrand (School of Electrical and Information Engineering). He is a Past President of the South African Institute of Electrical Engineers (SAIEE).

Ian has consulted extensively in the fields of Lightning Protection, Earthing and Industrial EMC, as well as in engineering design and development in the electrical and electronic sectors, in South Africa and internationally. He also has extensive forensic engineering experience and a variety of experience in project consulting, management and engineering including systems engineering, as well as experience in areas such as dispute resolution and project and engineering investigations. He is the author or co-author of a number of papers and technical articles in these fields, and has presented at various conferences and courses.

Co-author: **Ian R Jandrell** [PrEng, BSc(Eng), GDE, PhD, FSAIEE, MIEEE]

Ian R Jandrell is a Director of Innopro (Pty) Ltd, and has extensive consulting engineering experience in the fields of High Voltage, Power Systems, Earthing, Lightning Protection and Industrial EMC, in South Africa and internationally . Ian is a registered Professional Engineer (PrEng).

Ian is a Personal Professor, CBI-electric Professor of Lightning, and Head of the School of Electrical and Information Engineering at the University of the Witwatersrand, where he is also joint leader of the Lightning/EMC Research Group and of the High Voltage and Power Systems Research Group.

He has consulted to numerous local and international organisations, including international research agencies, and is a regular presenter of specialised training courses for industrial practitioners. He is a National Research Foundation (NRF) C-rated researcher and author or co-author of more than 100 papers in High Voltage Engineering, Lightning Protection and Industrial EMC. He is a member of the Scientific Committee of the International Conference on Lightning Protection and an Associate Editor of the Journal of Lightning Research.

Innopro (Pty) Ltd
Specialist Consulting Engineers & Solution Providers
Tel: +27(0)12-6675151
ianmac@gafrica.com
www.lightning.co.za

The one day seminar "Best Practices in Lightning Protection and Earthing of Structures and Systems" is accredited for Continuing Professional Development (CPD) with the Engineering Council of SA (ECSA) by Wits University (validation number ELEN0003), for 1 credit in the compulsory Category 1. It can be presented in-house on request.