Further Southern African experiences with the application of the IEC lightning protection standards based on their application at four major installations

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Abstract: Over the past decade there has been a move toward the installation of integrated earthing and lightning protection systems at a variety of South African industries. This paper reviews the experiences gained from the diligent application of the International Electrotechnical Commission standards for earthing and lightning protection at four major sites. As each site had very specific interventions, these are presented in detail. It is noted that in some cases there was initial resistance to the introduction of many of these interventions, but it is concluded that these methods have had a very significant positive effect on performance of the installations.

Keywords: equipotentialisation, integrated earth electrodes, LPS.

1. Introduction

Southern Africa is generally characterised by relatively high lightning ground flash densities and poor soil conditions in areas in which a large proportion of the major industries are located. This paper reviews the successes achieved at four major industrial sites within the Southern African region from a lightning performance perspective. Monitoring has been for a period of a minimum of three years. It must be noted that other performance enhancements were also achieved, and these are also reported on.

The primary interventions at these sites have been based on the recommendations of the IEC Standards on Lightning protection, including the 61024 [1], 61312 [2] and 61662 [3] suites. These recommendations strive to achieve a holistic lightning protection system. Local standards, where applicable, have also been used [4, 5, 6]. This paper aims to build on the experiences reported previously [7]. In that case the focus was primarily on the internal lightning protection system. In this paper the complete LPS is considered. The chosen sites are quite different, and are broadly categorised as follows:

- International airport, including all structures, control and energy systems, and including the airfield power infrastructure.
- National electricity supply utility control centre and associated facilities.
- National television and radio broadcasting earth station and control centre.
- International financial institution.

Table 1 lists the sites and provides salient information for each.

2. Background

Methods of protecting structures against direct strikes have been well understood and established for decades [8]. However, more recently, the recognition of proper lightning protection as a part of EMC has had profound effect on the establishment of a complete lightning protection system [9]. A variety of EMC principles such as for example equipment zoning [10], cable grounding [11] and the recognition of the need for wide band performance of earthing and grounding systems [12] have been incorporated into the recent standards.

As a consequence, in the four cases reported, the following aspects are identified as requiring special attention:

- Site wide equipotentialisation.
- Defining and maintaining the integrity of lightning protection (equipment) zones (LPZs) [2].
- Establishment of local equipotential platforms (zero signal reference grids (ZSRGS) [2, 12]).
- The use of structural and cable support metal work as part of the equipotential platform (EP) and as a part of the cable "screen" [1, 4].

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- The use of natural components for each of the various elements of the LPS [1, 2].
- The extent and geometry of the earth electrode system and the establishment of a single, integrated, earth electrode system for the site [1, 6].
- The need to ensure that any system must be easily maintained after installation.

3. The four sites

In this section we describe each of the sites at which the new lightning protection methodologies were applied. However, in the following section the results achieved will be described based on a collation of the information available from each.

As these were existing sites all of the interventions were applied as remedial measures, and it is important to understand how this was achieved, and what compromises had to be made in each case. Where possible, major deficiencies that were identified are noted.

In each of the cases presented the interventions were as a result of a comprehensive earthing and lightning protection survey at the site stimulated usually by a lightning-associated failure at the site. Such a survey included *inter-alia* the following:

- Location and study of as-built drawings and other documentation for the site.
- Study of any site history files.
- Risk assessment for various areas of the site.
- Physical examination of existing installed systems.
- Comparison between as-built drawings, installed systems and site requirements.
- Various measurements as appropriate

In all cases the requirement was to design and install a comprehensive LPS while the site was in normal operation. As a consequence many of the projects took months or years to complete.

3.1 International airport

<u>Description of the site</u>: The site is a large international airport, located in a region with a lightning ground flash density of 7 to 8 ground flashes/km^2/annum. The site extent is approximately 35 km^2.

<u>Intervention basis</u>: The interventions were originally performed due to extensive problems experienced through lightning events, including equipment damage and loss of services. Subsequent interventions were due to extensions and maintenance reasons. The interventions included the airfield, terminal buildings and freight areas of the airport.

<u>Interventions</u>: The interventions at the site included the external and internal lightning protection systems of the airfield substations, the terminal buildings and the freight warehouses, as well as office buildings.

Particular issues addressed included:

- Large flat waterproofed roof areas, necessitating the use of elevated air termination conductors. Refer *Figure 1*.
- Integration of multiple earthing systems found at various installations.
- Extensive use was made of structural steelwork, from a performance, maintenance, theft and aesthetic perspective, as well as due to the constraints imposed by the existing site developments.
- A generic specification was prepared as a baseline guide for future projects and installations, in order to ensure engineering and implementation consistency.
- Internal LPS aspects were treated holistically, and included the application of EMC principles.

Figure 1: Illustration of elevated horizontal air termination conductors

3.2 National control centre

<u>Description of the site</u>: The site is the National Control Centre (NCC) for a national electricity supply utility, and is located on a hill in an area of very high lightning ground flash density of >10 ground flashes/km^2/annum [13]. The NCC is located in a dedicated wing attached to the main office building.

LPS designs were also provided for the various remote radio telemetry high sites, on the basis of a generic specification and design.

<u>Intervention basis</u>: The NCC was a new installation contained within a newly constructed building wing. The

nearby old NCC, which was converted into a standby control centre (and which formed a part of the LPS project), had previously experienced equipment damage and system downtime.

Equipment damage and downtime had also previously been experienced at the remote high sites.

Interventions: The interventions at the NCC and standby site, as well as the remote high sites, included the internal and external LPS.

The external LPS comprised discrete down conductors bonded to the steel sheet roof which formed a natural air termination system, and to the earth electrode system.

Particular attention was paid to equipotentialisation within the building interior, both within and between equipment areas. Particular use was made of the access floor and cable support infrastructure (cable trays) for bonding and equipotentialisation purposes.

Surge protection was installed on the power and data interfaces at or as close as possible to zone boundaries. Use was also made of an isolation transformer on the main power feed (output of main UPS).

3.3 National transmitter station

Description of the site: The site is the main earth station for a national radio and television broadcaster. The site includes Ku and C-band earth stations as well as a control room. The main headquarters office block is located at the same site. Refer *Figure 2*.

The site is located in an area of above average ground flash density of 7.5 ground flashes/km^2/annum, and is located on the site of a hill.

Figure 2: Earth Station site views

Intervention basis: Equipment damage and system failure had been experienced at the site, also resulting in unacceptable loss of service to the public.

Interventions: The external LPS of the various site buildings and equipment rooms was enhanced and extended as necessary. In general discrete air termination and down conductors were used. The earth electrodes systems were combinations of trench and rod electrodes, and equipotentialising links were implemented where feasible between buildings.

Particular attention was paid to internal equipotentialisation, using available natural components such as access floor and cable support infrastructure to achieve low impedance bonding. Refer *Figure 3*. In particular, great care was taken to implement galvanically solid bonding between cable tray sections, through cleaning of painted surfaces and implementation of new bonds across joints.

Surge protection was implemented at (or as close as possible) to zone boundaries (power and data).

Figure 3: Example of equipment installation. Note orange cable trays utilised for local equipotential bonding after their galvanic continuity was ensured.

3.4 International financial institution

Description of the site: The site is the headquarters of an international financial institution. Facilities and operations housed within the multi-storey office building include the main operational computer server centre, dealing room and associated equipment room, and general operations offices.

Intervention basis: Equipment failures had been experienced in the dealing room and support equipment environment, resulting in unacceptable interruption of dealing operations.

The client required that the overall infrastructure, including main computer server and communications installations be included in the intervention.

Interventions: External LPS interventions entailed repair and extension of the air termination and down conductor systems, and enhanced use of the structural steel in the foundations as the earth electrode. This was particularly

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problematic due to the hardness of the concrete – the original construction had been build to withstand explosive forces! A particular requirement was to hide external discrete conductors for aesthetic reasons, whilst achieving the necessary technical specifications.

Internal LPS interventions entailed enhancement of equipotentialisation through the establishment of localised ZSRGs in various sensitive locations. These included the main server and network rooms, and the dealer equipment and dealing rooms, where the achievement of bonding integration between the respective related rooms also received particular attention. Particular use was made where possible of the access floor structure for bonding and equipotentialisation purposes.

4. Site performance information

Although the sites were monitored on an ongoing basis, during March 2004 a questionnaire was completed by the responsible personnel at each site to serve as a summary on which the results presented in this paper could be based.

It was fortunate that site personnel remained virtually unchanged during the years immediately preceding each project to the present. This made it possible to get valid comparative data for each site for the periods before, during and after the interventions were completed.

5. Review of the interventions and site performance

At all four sites, no significant damage to equipment or disruption of service has been experienced since completion of the interventions. All four sites have experienced at least three lightning seasons since completion of the interventions. The airport and the transmitter station have experienced six lightning seasons since completion.

Before discussing the results of the interventions described in *Section 3* above, a number of important general observations can be made regarding the sites described. It is the authors' experience that these observations are representative of Southern African industry in general and probably of most other parts of the world.

5.1 General observations

<u>Site documentation</u>: In general, site documentation for the earthing and lightning protections systems was poor. In addition, the correlation between as-built drawings and the existing systems was also poor. This is due to a lack a formalised maintenance strategy at the sites for the earthing and lightning protection system.

<u>The concept of a holistic LPS</u>: At all sites, the concept of an LPS which incorporated external and internal requirements in an integrated manner and accounting for EMC aspects, had not previously been adopted. This is symptomatic of the legacy role of an LPS to divert direct lightning strikes to earth – with no emphasis on the LPS as part of an EMC system.

Furthermore, each site was experiencing significant lightning-related problems prior to each project. In some cases, the earthing system had been repaired to meet the original specifications and/or in a piece-meal fashion – but with little improvement in the overall site performance.

<u>Conceptual issues</u>: Some of the conceptual issues that were the topic of lengthy discussions with clients included:

- The use of elevated horizontal air termination conductors for the protection of extensive flat waterproofed non-metallic roof structures.
- The integration of separate earthing systems, such as power/electronics, analogue/digital etc.
- The focus on earth electrode geometry rather than earth electrode resistance value as a design criterion.
- The importance of using inherently available natural components (such as cable support structures) to achieve equipotential bonding, and the need to ensure that these are made galvanically continuous along their length.

In some cases, the initial resistance was because the concepts were unknown, or because they were considered to be inconvenient to implement.

Historically many industrial sites have separate, dedicated earthing and bonding systems for electronics or instrumentation. In some cases this has taken the form of a single (usually 70 to 90 mm^2) insulated copper continuity conductor interconnecting the earth bars of widely distributed instrument cabinets. This emphasises the previous focus on low resistance between systems rather than low impedance. Discussions regarding the need to ensure broadband performance have generally resolved this matter. In addition, a fuller appreciation of how transients enter, interfere with and damage systems has been found to be helpful. At two sites the personnel have attended university training courses addressing these and other issues. This aspect has been found to be critical to success.

The earth electrode geometry and the use of structural metal work can also be related to moving the focus away from resistance values to impedance values, and an appreciation that a wide connection has a lower impedance than a narrow (but possibly low resistance) interconnect. Galvanic discontinuities at particularly the end points and at points of transition of cable support structures were noted as a common deficiency at most sites.

Nevertheless, these specific issues have been noted by all of the clients as having made a significant contribution to the success of the solution.

5.2 Equipotentialisation

All sites identified site wide equipotentialisation as the most significant intervention. This is based on their perception of the effectiveness of this approach as well as the fact that at no site had any effort previously been put into establishing a site wide equipotential platform.

Previously, the only galvanic interconnections between structures at the sites had been via cable systems. Now interconnections between structures have been implemented using the earth electrode systems and by making use of galvanically continuous natural components (cable support structures etc). Care was taken to ensure that where power cables run between structures the armouring or parallel bonding conductors were solidly bonded off to the bonding bars in each structure.

The concept of establishing a single integrated earthing and bonding system was identified as a new approach by two of the sites. (It is common to find separate earthing systems at South African sites, and at three of these sites this had been the case. For example, at one structure at one of the sites four separate earth electrodes were identified.)

Once the concept of a single integrated earthing system had been discussed it was accepted. This acceptance has been reinforced by the proven success of this approach.

5.3 LPZs and local ZSRGs

Within each structure at the site LPZs were defined and established. This included the implementation of localised equipotential bonding.

One of the clients highlighted the significance of limiting the number of LPZ interface points as being a significant intervention. The possibility of optimising this aspect was limited by the existing site infrastructure in all cases.

At three of the sites where high speed data networks and sensitive electronic systems were installed, the broad band performance was enhanced through the establishment of a grid-like bonding network (using access flooring components, cable support structures, cabinets etc) to establish a ZSRG. All equipment, as well as the local bonding bars, was solidly connected to this ZSRG. Refer *Figure 4*.

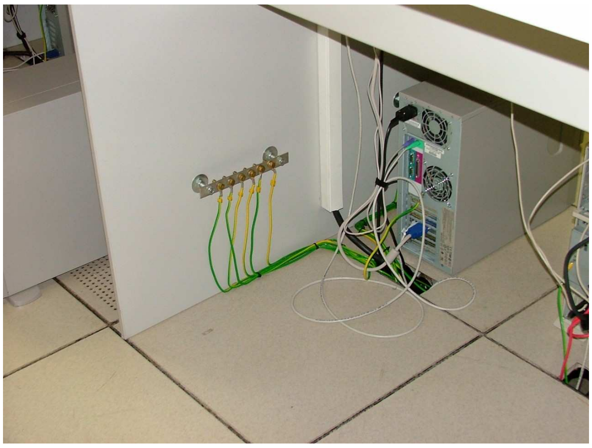

Figure 4. This illustrates typical bonding between discrete servers and the access floor (whose galvanic continuity was ensured). Bonding was implemented via local bonding bars for maintenance convenience.

The international financial institution highlighted this as a very significant intervention. It is important to note that a marked improvement in data network performance through a reduction in the data error rate was achieved through this approach.

5.3 Use of internal and external structural metalwork

Extensive use was made of natural components such as rebars, structural metalwork, cable support structures and down pipes because:

- It ensured enhances broadband performance
- There were constraints due to space and aesthetics and the built nature of the sites

Refer F*igure 5*.

At the airport early access could be gained to structural metalwork (such as rebars) during an extension phase. Defined use was made of this for earth electrode, down conductor and equipotentialising purposes. This was viewed as a new approach in this case and required close liaison with the client and the construction team.

Figure 5. Illustration of typical bonding of an air termination conductor to rebar on an existing structure. Sealing of bonds was given particular attention. The large hole was through non-structural cement screed (to then

access structural concrete and rebar through the smallest practical hole).

5.4 Earth electrode system

While the importance of a low earth electrode resistance value is recognised, it should be noted that at all sites only the earth electrode value was previously considered as a design criteria. At one site, a very deep single element of the earth electrode had been previously installed to achieve the target earth electrode resistance. The contribution of this element to equipotentialisation was negligible. (In extreme cases, electrodes driven down to many tens of metres depth have been encountered on other sites.)

At all sites, addressing issues relating to electrode geometry to ensure broad band performance met the earth electrode resistance target value.

5.5 Maintenance

All sites acknowledged that maintenance on the existing system had been difficult, and had not been an integral part of their site management strategy.

In all cases, maintenance and change management have now been understood as key to maintaining the reliability and integrity of the installed systems.

6. Conclusion

For the four sites examined in this paper the legacy LPSs were designed to protect structures against direct lightning strikes only. No emphasis had been placed on the role of an LPS as a part of EMC. In addition, LPS maintenance was generally poor, and supporting documentation inadequate, inaccurate or both.

Site wide equipotentialisation supported by the definition of LPZs and the establishment and integration of local ZSRGs has been key to improved performance.

The traditional approach of designing an earthing system to meet earth electrode resistance values alone was found to be inappropriate for modern distributed sites where sensitive electronic systems operate at high frequencies.

Use of structure and cable support metal work was shown to be a highly effective method of achieving site wide equipotentialsation as well as providing screening against electric and magnetic fields. Continuity of cable trays and the bonding of cable trays to bonding bars at the boundaries of each LPS (in same cases also a ZSRG) or terminal cabinets was shown to be highly effective.

Where high speed computer networks existed, the establishment of a ZSRG using existing floor metal work was shown to improve the system performance and reliability.

At all four sites there have been no significant lightning related failures of loss of service to the public since the completion of the interventions described in this paper.

SITE	N_g [gnd flashes/km^2/annum]	ρ [Ω.m]	Rainfall ave [mm/annum]	IEC Risk Cat
International Airport	7.5	3 - 965	713	II,III,IV *
Broadcasting site	7.5	-	713	III,IV*
National Control Centre	>10 (16 **)	95 - 196	-	III
Major financial institution	7.5	-	713	III
** depending on nature and type of installation at site* *** client supplied information [13]*				

Table 1 : Salient data for each site

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