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2016 IFAP SAFETY INNOVATION AWARD
CASE STUDY

LightningMat Earth Potential Rise (EPR) Safety Mat

A New Innovation in Lightning Safety for Remote Workgroups

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ABSTRACT

Australian and international mining and resource sectors have a greater risk associated with the incidence of lightning injuring their workforce, inherently due to the large numbers of outdoor workers involved in these sectors, many of whom will be working in regions of higher "ground flash density" (GFD) and above average "thunder-day" (TD) activity.

Lightning and High Voltage (HV) electrical discharge events present as a significant risk injury hazard to humans, primarily via a risk mechanism known as "earth potential rise" (EPR). Many people believe that if a direct-strike Lightning Protection System (LPS) is installed, people would be considered safe if situated within the "lightning protected zone" (LPZ), however this ignores the significant and lethal effects posed through EPR.

In this paper, lightning EPR is demonstrated to have been responsible for more than 50% of all lightning injury and death statistics. However, until now, an effective, commercially-available product that can control EPR events, in conjunction with being practical and portable, has not been available.

This paper outlines some particularly relevant aspects surrounding the EPR risk, and presents a new and innovative product development by which higher risk operations can now significantly deal with and mitigate EPR.

This new EPR mitigation control will be particularly useful to remote workgroups such as remote exploration camp workers, who up until this point will have been precluded from any level of lightning risk mitigation, unlike their counterparts conducting activities at traditional mining and processing plant operations.

INTRODUCTION

Lightning is a well-known and catastrophic risk, to which the worldwide mining and resource sectors have figured disproportionately and prominently within the recent fatality and injury statistics. This is not hard to understand considering mining and resource activities are typified by large numbers of people carrying on their normal workplace activities whilst outdoors and often working in close proximity to large plant and equipment that inherently exhibits a higher disposition to being struck by lightning.

Risks posed by lightning are generally considered to be low likelihood, however in any such event the resulting consequences are usually always severe and catastrophic All reputable lightning safety researchers acknowledge that the vast majority of all lightning injury statistics had been outdoors when they sustained their injuries.

HSEC departments are required to develop, and implement appropriate "safe working procedures" (SWP) across higher risk operations, by outlining the required response to be undertaken by all personnel during thunderstorms. As such the provision of suitable safe shelter also forms an integral aspect of any SWP implementation, and operators should nominate lightning safe shelters, and apply placards to ensure as far that as is practicable, all personnel are aware of safe refuge areas, and are never exposed to lightning risks during higher risk conditions.

However there will still be some personnel that due to their normal activities, remoteness, and/or current situation, may not have any timely access to any safe refuge.

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Such activities may typically include:

- tented exploration camps
- exploration drilling workers
- environmental scientists
- geologists
- surveyors
- railway maintenance
- pipeline maintenance
- electrical linesman
- fencing contractors

Defining the risk

Lightning is not an easily definable risk as are some other common threats, as it is impossible to predict where, when, or even if lightning will strike, where each and every lightning strike will be fundamentally unique, where it is impossible to predict whether the current magnitude of any particular lightning event will comprise of several thousand, to tens or hundreds of thousands of amps.

Soil resistivity will also have a dramatic effect on the EPR developed, as when lightning current strikes the earth, the local soil being highly resistive, results in a large EPR, roughly proportional to current (I) x resistance (R). In the instance where a large magnitude lightning current was injected in soil exhibiting a high resistivity, the resulting EPR can be exponentially magnified, resulting in much larger areas of ground electrification, which we refer to throughout this paper as the EPR "hot zone".

This area of hot zone electrification is very non-specific, making risk determinations as to what might be considered safe and unsafe ground even more difficult, although it is highly probable that any person situated within this EPR hot zone is highly likely to be severely injured, or even killed.

A lightning strike at the recent "2016 Rock Am Ring" music festival in Germany saw over 80 people seriously injured as a result of lightning EPR. Interestingly 12 months earlier at the same music festival, (2015 Rock Am Ring) there was a similar EPR incident, where over 30 persons were also injured. Lightning EPR can affect large areas.

Lightning Risk Mechanism Statistics

Despite a common belief that "direct strikes" account for the majority of injury and fatality statistics, the most common lightning injury risk mechanisms involve "Step' and "Touch" potential injuries, caused through "contact" and "ground" currents that are attributed to EPR.

In terms of actual injury and death statistics, US based researchers have conducted some of the more detailed studies and collating the best databases, hence US data will be represented here. The data would also be fairly representative of Australian statistics, given our similar rates of GFD and TD, but would substantially underestimate the proportion of incidents that would occur in higher lightning areas throughout Asia, Africa, and Central America.

US lightning fatality and injury statistics taken over a 6.5 year period have been obtained from an article published by well-known researcher "Dr Mary Ann Cooper within www.emedecine/medscape.com which is a highly regarded online medical website (http://emedicine.medscape.com/article/770642-overview). The results are summarized below in Table 1.

Year	Deaths	Injuries	Est. EPR Injuries	Probability
2008	27	305	229	7.6×10^{-7}
2009	34	256	192	6.4×10^{-7}
2010	28	241	181	6.0×10^{-7}
2011	26	248	186	6.2×10^{-7}
2012	28	212	159	5.3×10^{-7}
2013	23	235	176	5.9×10^{-7}
2014	20	144	108	3.6×10^{-7}

Table 1: Lightning injury data for the USA from 2007 to the present. The probability value is based on a total population of 300 million. (2014) has only partial data.

Additionally Mills et al (2009) had also published the mean lighting death and injury data rates for Canada for the period 1986 to 2005. Summary data is shown in Table 2.

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Deaths	Injuries	Est. EPR Injuries	Probability
53	277	208	5.9×10^{-6}

Table 2: Mean annual lightning injury data for Canada from 1986 to 2005.
The probability value is based on a total population of 35 million.

Similar tables for Australian statistics aren't readily available, although we understand that the corresponding mean numbers for Australian lightning fatality and injury statistics will be around 10 deaths, and over 100 injuries per annum. For an Australian population of 22 million people, this represents a probability of roughly 3.4×10^{-6}.

Cooper, Holle and Andrews have collaborated on various extensive and detailed studies of the North American lightning related injuries and deaths, and had found that around 50% of all lightning injury/ fatality statistics have been attributed to ground current EPR as being the single largest risk factor.

Additionally they found that 15-25% of injuries had been attributed through contact/touch potential exposure, which incidentally is also an EPR related mechanism. Hence, 55-75% of all lightning injuries are EPR related, in which case the mitigation of lightning EPR is absolutely essential for reducing lightning fatality and injuries to persons.

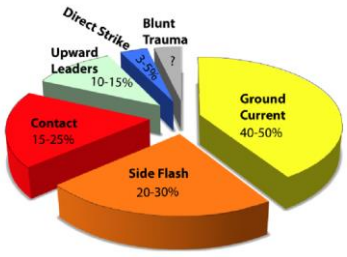

Figure 1: Injury mechanism breakdown (Courtesy Cooper, Holle and Andrews)

Mandated EPR Regulations

EPR is a recognized primary risk within all electrical regulatory requirements worldwide and is mandated for application within all High Voltage *(HV)* electrical switchyards and substations, and any other facilities where HV switching operations are undertaken.

In Australia AS/NZS 3000, AS/NZS2067, AS/NZS4871.1, AS/NZS2081, ENA EG0 and ENA EG1, all describe the maximum acceptable step and touch potential voltages, where a voltage/time relationship is outlined to determine the permissible limits of any prospective fault current that may be attributed through EPR.

Traditionally EPR controls are comprised of large earth grids that are constructed insitu using large cross sectional area copper conductors that are then formed and bonded into a large direct buried mesh that extends across the total extent of the switchyard. All transformers, HV switchgear, metallic equipment frames, lightning masts and any metallic objects that are located within the confines of, *(and including the perimeter fence)* are all required to be equipotentially bonded to this buried earth grid.

Earth resistance must not exceed specified limits, where additionally "step" and "touch" voltages must be calculated to be within the maximum permissible limits. Additionally a thick layer of high resistance rock aggregate is then applied to the surface layer, to help reduce the magnitude of any EPR that electrical workers may be exposed to whilst performing their duties.

So whilst EPR controls are mandated for use in all HV applications, up until this point there has been no commercially available or cost effective EPR control that could be easily applied to other higher risk EPR applications, for example lightning. This is despite the known and ongoing statistics involving some higher risk activities, workgroups, and recreational campers within tents, which had resulted due to close proximity lightning, strikes, and which could have been reduced through the use of a portable EPR control.

Remote tented exploration and work camps are prime examples where personnel can be mobilized to regions of higher lightning activity, whereby personnel are provided with no adequate protection against localized lightning, nor will they have access to any nearby safe shelter. This is partly due to it being impracticable to construct appropriate lightning protection, grounding, and EPR controls, given the short term and transient nature of these camps, notwithstanding that helicopter access is often the only way in and out of these temporary camp sites.

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LightningMat EPR Safety Mat

Back in 2010, this author in collaboration with leading Australian Lightning researcher "Dr Franco D'Alessandro", looked to investigate innovation in this area of personnel lightning safety, and lightning risk mitigation.

Amongst many other lightning safety projects, EPR risk mitigation was a key area of focus, to which it was decided that if some lightweight and highly "portable" EPR control could be developed, this would prove an important risk innovation for reducing the greater % of overall lightning risk to the aforementioned higher risk workgroups.

Five years on, we have now commercialized and patented an innovative and highly portable EPR risk mitigation control, the LightningMat "EPR Safety Mat" which has been developed primarily for ease of portability, and to provide a cost effective and simple means for mitigating EPR hazards to remote personnel via a unique three (3) layer flexible mat design, comprising of:

- A central, electrically-conductive mesh layer that rapidly equalizes electrical potential developed across the mat.
- An upper insulating layer that insulates personnel /and assets from the electrically conductive central layer.
- A lower electrically-conductive layer that protects the central layer, and provides electrical continuity to the central layer.

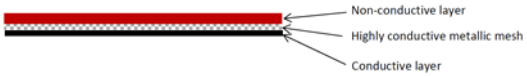

Figure 2: LightningMat EPR Safety Mat cross sectional view

This three (3) layer mat arrangement provides a method and apparatus for mitigating EPR hazards arising from nearby "cloud-to-ground" *(C-G)* lightning discharges, and other electrical phenomena involving large fault currents being injected into the ground.

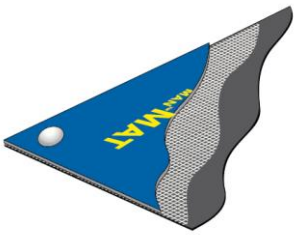

Figure 3: LightningMat EPR Safety Mat isometric cutaway view

The LightningMat works by redistributing the surface voltage profile associated with EPR, so as to reduce differential potential gradients across the mats structure. Any persons situated upon the LightningMat during an EPR event, should be equipotential with the mat, such that they should not be exposed to significantly differing and dangerous voltage gradients resulting from EPR.

The LightningMat concept is very simple. Think of a bird perched upon a HV powerline completely unaffected by its direct contact with the High Voltage, until such time as the bird comes into contact with another phase wire, or earthed object, at which point the differential voltage will flow across the differential contact points.

Key practical features of the LightningMat have been considered whereby all of the layers are sufficiently flexible so as to enable the LightningMat to be simply rolled and unrolled as may be required, making it suitable for use in temporary, semi-permanent, or even use in permanent applications. Individual LightningMats can also be joined together, so as to make a larger LightningMat, as some applications may require.

The LightningMat will prove invaluable to remote field personnel working exposed to the elements, and who may have limited or no access to appropriate safe shelter during the period of a lightning threat. Additionally, LightningMat will provide safer working environments to those personnel working in contact with, or in close proximity to long conductive elements *(including railway lines, pipelines, and fences*).

Attaching a bonding kit to these long conducting elements, brings the LightningMat to the same electrical potential as the long conducting element, thereby equalizing any dangerous voltage differentials. And whilst the LightningMat can be used without an electrical bond to nearby touchable objects *(since it redistributes the surface voltage profile)*, enhanced performance and voltage reduction is achieved wherever an electrical bond is used.

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Whilst LightningMat does not cater to, nor does it remove the risk posed through direct strike, *(statistics highlight as around 3-5% of all lightning injuries)*, LightningMat does cater to the 55-75% of lightning injury statistics that up until now, have had no commercially available risk mitigation control.

When used in conjunction with overhead catenary shield wires, this arrangement now offers remote tented camp sites a robust means by which a significant reduction in their overall lightning risk profile can be achieved.

TESTING

The following testing has been carried out:

- CDEGS computer modelling.
- Compliance to IEC 61111:2009 – Electrical Insulating Matting.
- Verification of the function of the EPR Safety Mat via a full-scale current injection testing in the field. (Lightning Protection International)
- Independent review and validation of the testing methodology applied to EPR Safety Mat. Power Quality Research Centre - University of Wollongong, Australia.

(All reports are available upon request)

CONCLUSION

LightningMat is a unique and highly portable EPR risk mitigation innovation.

As a newly released product with very limited marketing taken place, significant orders have already recently been taken from Australia, with exports to Indonesia, and Laos, and with an increasing interest globally.

- MMG Ltd (Laos) have been supplied 50 x LightningMats for their external field personnel.
- MMG Ltd (Golden Grove) have been supplied 4 x LightningMats for their external field personnel.
- Newcrest Mining (Indonesia) have ordered LightningMats for four large exploration tents.
- MMG Ltd (Peru) have specified and been quoted on 50 x LightningMats for their external field personnel.
- Roy Hill (Pilbara) have expressed strong interest for LightningMats across their rail and wayside areas.

The inventors have signed licensing agreements with:

- Lightning Protection International Pty Ltd
- Lightningman Pty Ltd.

The 2016 IFAP Safety Innovation Award represents a huge opportunity for highlighting this unique and new innovation that was born and conceptualized within Western Australia.

REFERENCES

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ACKNOWLEDGEMENT

My thanks go to Dr Franco D’Alessandro of Physelec Solutions Pty Ltd *(Co-Inventor of the EPR Safety Mat)* for his trust in the initial concept presented, and for his significant efforts in championing this project throughout the projects development, field testing, methodology validation, technical elucidation, intellectual property issues, and manufacture.

Without his significant involvement this project would not have happened.