Learnings from The Down To Earth Conference

Based on attendance at the

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By

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Summary of DTEC 2014

In November 2014, the EEA sponsored me to attend the Down To Earth Conference (DTEC), held in Perth. The aim of the conference was to share the latest developments relating to earthing design, maintenance, and testing, from the perspective of utilities, equipment suppliers and consultants. A few of these presentations demonstrate evolving requirements for earth systems; others demonstrated an improved understanding of the complex nature of earthing. A summary of selected presentations that stood out in my mind is given below.

The conference was opened by Peter Willis from DIgSILENT Pacific, who looked at the possibility of incorporating the earth return path into network analysis software, with the aim of improving the inputs that feed into an earth design.

Franco D'Alessandro provided an overview of alternative techniques for evaluating a lightning design to the popular rolling sphere method. Of the alternative techniques, the method developed by Rizk appears promising, in that it provides a relatively simple way of accounting for the effect that the height of an object has on establishing ground leaders. This method, and the other methods, are discussed in a new section in IEEE 998, added in 2012. The revision has the aim of providing alternative tools for verifying the effectiveness of a lightning protection system for substations with high or critical importance.

My colleague Michael Saunders presented on the research that has gone into understanding the Equipotential Zone (EPZ) and how it can be applied to an electricity distribution system to keep workers and bystanders safe (similar to a presentation I made at the EEA conference in June 2014). It was apparent from discussion at the conference that the NZ practice of adding an integral earth to concrete poles contrasts with efforts made in Australia to develop concrete poles with a higher insulation rating. It does not appear that this topic has been subject to much industry wide collaboration across Australia, with each company adopting their own practices.

Stefan Oosthuizen from Western Power made a presentation that compares the effectiveness of different earth design options, by using probabilistic analysis to assess the residual risk inherent in each option. Stefan's presentation also explored the impact of proposed Australian standards, which seek to clarify the definition of As Low As Reasonable Practicable (ALARP), Value of Statistical Life (VoSL), Grossly Disproportionate (GD) and Disproportion Factor (DF). Naturally Stefan's presentation led to a prolonged discussion on the interpretation of these terms, as they have ethical implications.

Stefan Oosthuizen also presented on the effect that replacing metallic pipes with plastic pipes has on the Multiple Earthed Neutral (MEN) system. In areas of high resistivity, such as is commonly found across Western Australia, the disappearance of metallic pipes leads to a considerable increase in the combined impedance with respect to remote earth. This has implications for earthing systems that link to the MEN system, and may necessitate different assumptions when developing an earthing design. The presentation found that should the MV and LV earth be connected, then the earthing requirements at each LV connection may need to be revised to achieve a safe design.

Probabilistic Earth System Evaluation Methods

When summarising the content of the presentations made at DTEC, there appears to be widespread agreement over the main elements that work together to achieve a safe earthing system and the techniques that can be used to assess the effectiveness of a particular design.

However, I noticed that the level of discussion increased significantly for presentations that focused on the application of probabilistic techniques to evaluate the safety of earthing systems. The range of perspectives put forward in these discussions illustrated the difficulties in standardising the approach to evaluate the risks applicable to a given earthing system.

Of particular interest to all who attended DTEC 2014, was the planned inclusion of probabilistic earthing assessment techniques into a proposed revision of AS2067 – 'Substations and high voltage installations exceeding 1 kV a.c.'; and the effect that would have on their roles and responsibilities as engineers.

The revisions planned for use within the Australian industry are worthy of consideration and comparison with similar guidelines developed for New Zealand. Given that the majority of discussion and debate revolved around how probabilistic assessment techniques can be used effectively (and ethically), I have decided to focus on the use of probabilistic methods in this report.

Background of Risk Based (or Probabilistic) Earth Methods

In recent years, much research has focused on understanding and quantifying the individual probabilistic factors that contribute to the overall risk of injury or death from electric shock. In 2003, the EEA produced a guide to risk based earthing methods, and in 2009 produced a second set of guidelines with a wider context; Australia produced a guide on risk based earthing assessment methods in 2010. Both guides allow an engineer to apply risk based methods with confidence, and more understanding of the underlying principles.

The relationship between individual risk factors and overall risk of death can be summarised as follows:

$$P_{contact} \times P_{fault} \times P_{fibrillation} = P_{death}$$

Where $P_{contact}$ = The probability of a person/persons in contact with the hazard

P_{fault} = The probability of a fault occurring on the electrical system

$P_{fibrillation}$ = The probability of fibrillation

P_{death} = The probability of death

Each component of probability shown above is almost always quantified on a 'per annum' basis.

The arrangement of an earth system primarily influences the probability of fibrillation, as it alters the voltages that a person is exposed to. For this reason, traditional safety evaluation methods (such as that given by early versions of IEEE80 and IEC 60479) focus on determining, and reducing, the risk of fibrillation – this is referred to in NZ as the ‘deterministic’ method.

The shortcoming of the traditional method becomes apparent when considering two earth systems with the same arrangement; one in an urban environment, another in a remote location. The probability of death is higher in an urban environment, as there are increased chances for contact to occur, even though both scenarios may be considered equally safe when evaluated with deterministic methods.

Newer evaluation methods consider all of the individual factors with the following goals: 1) to determine the overall probability of death; 2) to demonstrate when risk is sufficiently low as to be considered acceptable; 3) allowing for the comparison of the probabilities of different systems, so the efforts of an asset owner can be prioritised.

In other words, the newer, ‘probabilistic’ methods give results which are then interpreted on a scale of acceptability, rather than a strict ‘pass’ or ‘fail’.

The scale of acceptability widely accepted for assessing risk is given in Table 1. The numbers used in this table have links to many applications of risk assessment methods; they form part of the planning criteria in New South Wales (and earthing guidelines developed in Australia and NZ make reference to this criteria). Similar thresholds of acceptability are suggested by literature from UK, Netherlands and the US for risk assessment.

Table 1: Risk Evaluation Criteria– EEA Guide to Power System Earthing Practice

Probability of death	Resulting Action
$> 10^{-4}$	Intolerable; must prevent occurrence regardless of costs
10^{-4} - 10^{-6}	ALARP – Intermediate Risk; Must minimise occurrence unless risk reduction is impractical, and costs are grossly disproportionate to safety gained
$< 10^{-6}$	ALARP – Low Risk; Minimise occurrence unless risk reduction is impractical, and costs are grossly disproportionate to safety gained

Inclusion of risk based earthing assessment in Australian Standards

In recent years a working committee has been formed to revise the AS2067 standard, which outlines the minimum requirements for substations and high voltage installations exceeding 1 kV a.c. A draft version of this standard (DR AS 2067:2014) was released on the 20th of November 2014, for public comment. DR AS 2067:2014 includes a revised section on minimum earthing requirements, and introduces a probabilistic approach to designing and evaluating earthing systems (shown in Figure 1 below).

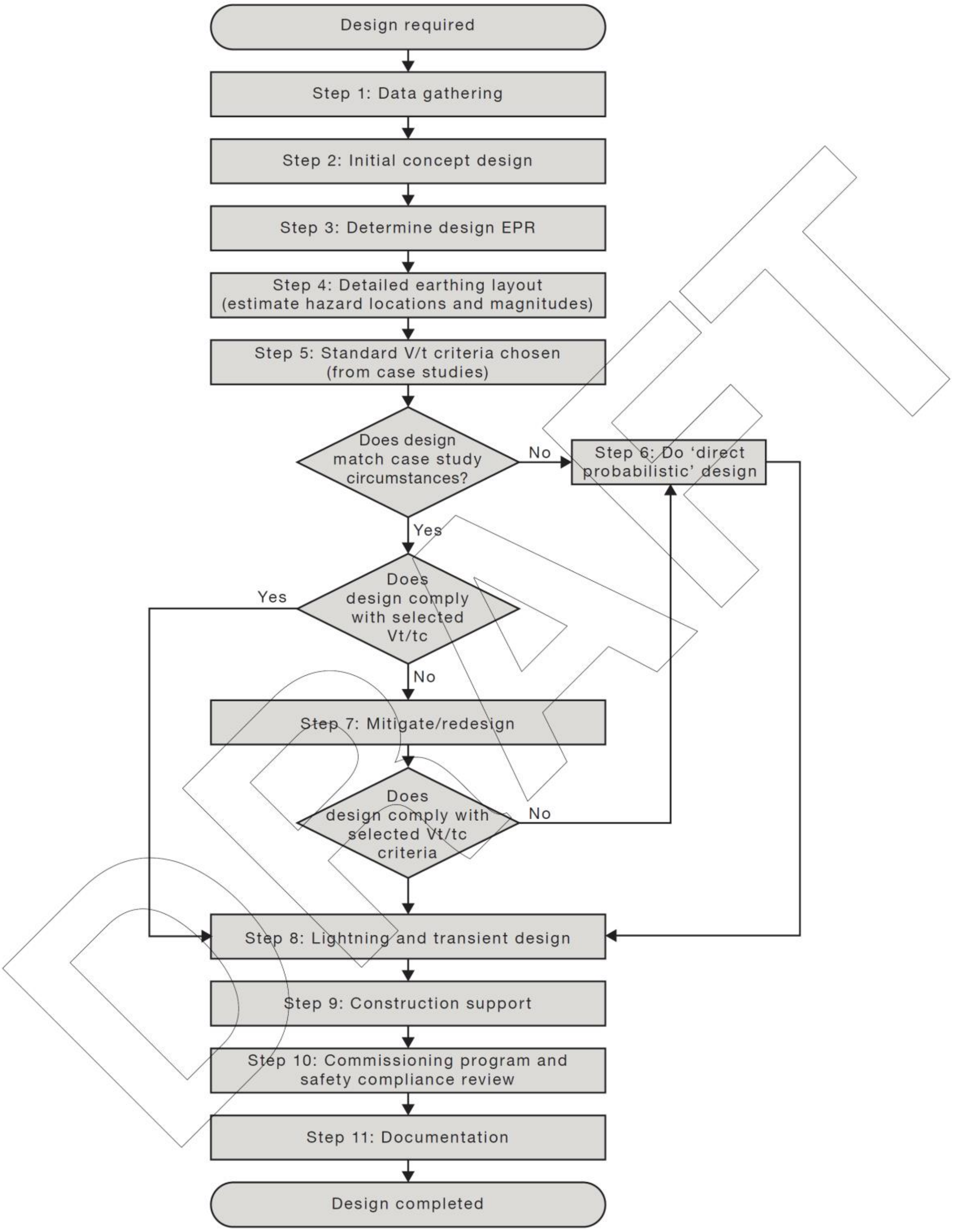

Figure 1: Draft Earthing Design Procedure (DR AS 2067:2014)

The procedure adopted by DR AS 2067:2014 focuses solely on the use of risk based earthing methods, and all references to traditional methods are removed. The AS2067 carries more significance than previous industry guidelines for the following reasons:

1) It specifies the minimum criteria to be considered when developing and evaluating the design of earth systems.
2) The standards framework is recognised by a wider portion of society, increasing the responsibility of engineers to follow the standard.

Consequently, it is necessary for engineers assessing earth systems in Australia to become familiar with risk based earthing evaluation methods, as it will be part of the minimum criteria to be considered in the assessment of every earth system.

The DR AS 2067:2014 represents a positive move for the overall safety of people around electrical networks, as it can lead to a more detailed, accurate, assessment of risk.

However, to carry out a robust probabilistic evaluation of an earth system, an engineer will need to understand in greater detail the individual probability factors that contribute to the overall probability of death. Whereas previously an engineer could focus on the probability of fibrillation, an engineer now needs to calculate the probability of fault events and the probability of contact with the earth system.

The EG-0 Power System Earthing Guide, on which DR AS 2067:2014 is based, provides an engineer with a significant amount of information to make it easier to quantify each individual risk factor. Case studies are given, which indicate the typical levels of risk for different categories of earth systems; and the Argon software package was created to make it easier to view the influence that each individual factor has on lowering the overall probability of death.

However there are some caveats in the application of EG-0 and Argon software, which have been discussed in forums such as DTEC. I have attempted to summarise these issues below:

1) **Reliance on typical data for uncontrollable quantities** – the probability of a person coming into contact with a specific piece of equipment is uncontrollable in a public area. While the typical probability of exposure can be calculated based on predictable behaviour, many engineers are reluctant to rely on this factor as it is outside the influence of their design. What happens when a location previously considered remote is encroached upon by future development?
2) **Difficulty in identification of atypical contact scenarios** – Engineers carrying out the evaluation of an earth grid are unlikely to spend much time onsite. Consequently it will be difficult to discern when typical contact information is not appropriate.

3) **Treatment of low risk as a target** – the process outlined by EG-0 offers a simplified probabilistic evaluation approach by ignoring the calculation of $P_{fibrillation}$ in a case where $P_{contact}$ x P_{fault} is already lower than the low risk threshold (10^{-6}). While this might be a low risk, the acceptability of the design has a larger reliance on the uncontrollable $P_{contact}$ factor, as described in 1). The wording in DR AS 2067:2014 around risk thresholds states that a low risk, while being considered negligible, is not necessarily considered tolerable.

   Furthermore, in cases where there is intermediate risk, the Argon software will determine the probability of fibrillation that brings the overall risk level down to a low level. In a case where $P_{contact}$ x P_{fault} = 2 x 10^{-6}, then the Argon software would set the probability of fibrillation to 0.5, in order to achieve a low risk classification. While the EG-0 standard does recommend an engineer follows due diligence to determine if this low risk is tolerable, an automated software calculation will lead an engineer towards settling at the threshold.

Earthing Evaluation Approach in New Zealand

The EEA Guide to Power System Earthing Practice (2009) has kept the use of 'deterministic' based evaluation method while introducing probabilistic earthing evaluation methods. This allows an engineer to use a traditional evaluation method in the first instance, and then apply further probabilistic assessment methods if hazards are found.

In effect, this means that initial evaluations based on the EEA Guide focus on controlling $P_{fibrillation}$ by limiting the voltage differences present across the earth system. This has an advantage in that $P_{fibrillation}$ is the generally most controllable factor when determining appropriate mitigation options for an earth system.

In the event that hazards are found in the initial assessment, then a detailed risk assessment can be carried out, as shown in Figure 2.

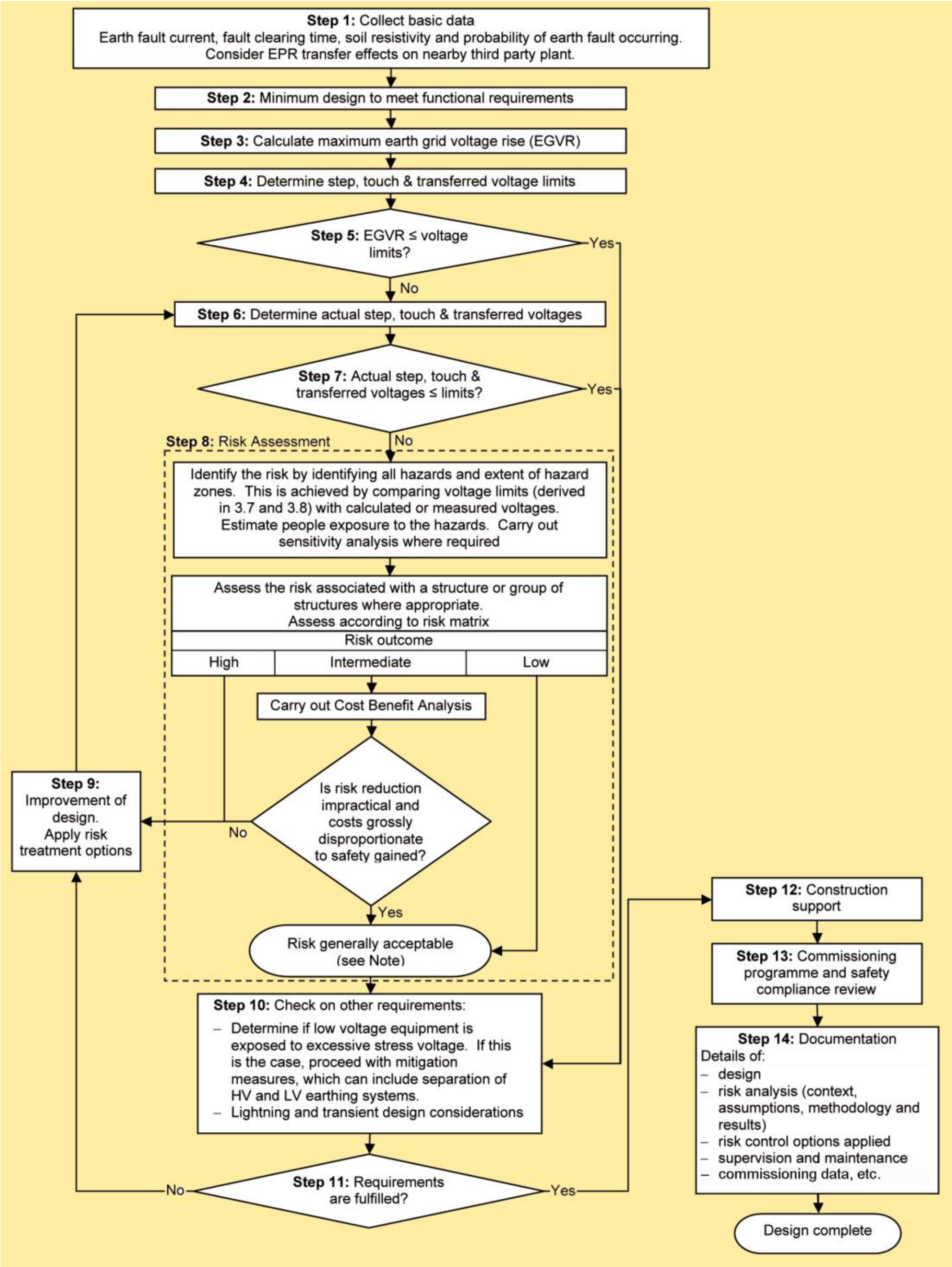

Figure 2: Probabilistic Method – EEA Guide to Power System Earthing Practice

The approach taken by the EEA means that any voltages found to be hazardous in the initial assessment are then treated as having a $P_{fibrillation}$ of 1, while allowing the engineer to determine the other probabilistic factors $P_{contact}$ and P_{fault}. There are some advantages in this approach:

1) The elimination of $P_{fibrillation}$ means that the engineer will focus efforts on reducing the probability of an electric shock occurring in the first instance (regardless of the actual probability of fibrillation). This will reduce injuries from electric shock;

2) The elimination of $P_{fibrillation}$ allows for simpler calculation of the overall probability of death.

When determining the combined probability of $P_{contact}$ x P_{fault}, we suggest that P_{fault} is quantified first, which then allows an engineer to determine the boundary limits of acceptability for $P_{contact}$.

The quantification of P_{fault} for site specific conditions is relatively easy when compared to trying to quantify $P_{contact}$. Logged fault information is available from most modern protection systems, which requires substantially less time to gather than site specific contact information.

The boundary conditions for $P_{contact}$ then make it easier for an engineer to understand the threshold of acceptability for a particular risk; if a person needed to be present at the hazardous location for one third of a year before there is an intermediate risk of electrocution, then it could be more easily discounted by an engineer, given the extreme unlikeliness of that situation.

While the approach adopted in the EEA Guide to Power System Earthing Practice is straight forward, care is needed when using the 'deterministic' method to consider $P_{fibrillation}$ curves for the site conditions. The C2 curve, as defined by IEC 60479:2005, is typically used to derive hazardous voltages for restricted access areas, which is based on a $P_{fibrillation}$ value of 0.05. If the earth system is thought to experience a large amount of faults, or has regular personnel onsite, then a more conservative curve may be appropriate, to ensure that the outcome from a deterministic approach is consistent with the outcomes reached using more detailed probabilistic methods.

Conclusions

The level of discussion at the Down To Earth Conference demonstrates the effort that engineers are continuing to invest, to ensure the safety of all people from electrical hazards. On the surface it appears difficult to observe tangible results from all of this discussion, however recent developments within Australian and NZ standards relating to earthing show that this discussion is not going to waste.

I am sure that many engineers have been introduced to the Ford Pinto example at some point in their professional development. In this case risk management principles were used unethically to justify the inaction of Ford to repair a defect in the Pinto vehicle, as the estimated cost of lawsuits appeared to be cheaper than the cost to fix the defect. For this reason, it is worthwhile continuing the discussion of how we can apply risk assessment methods in an ethical manner, despite the difficulty of making progress.

Contact details

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Rob is currently employed by Mitton Electronet Ltd as a Senior Electrical Engineer, and mainly involved in earthing and grid connection studies.

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