

**Equipotential Zones (EPZ) – Lessons Learnt**

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## **Abstract**

On the 10th of January 2005 a linesman received a fatal electric shock during a pole replacement in the Arahura Valley, South Island. What factors contributed to this accident? And more importantly have safeguards been established within the electricity industry to prevent more accidents of this nature? In years following this accident the EEA commissioned a guide to summarise the lessons learnt, and show how the systematic failure of safe work practices can be prevented by altering standard work procedures. The guide focused on the importance of using Equipotential Zones (EPZ) while undertaking electrical work, including isolation of electric shock hazards should the line/equipment become accidentally energised.

This paper discusses some of the key points within the EEA guide, with the aim of highlighting the importance of implementing a complete worksite protection scheme, consisting of temporary earthing and creation of equipotential zones, to reduce the risk of accidents around electricity networks.

In the years following the introduction of the guide, there have been six further incidents involving the inadvertent energization of lines or structures within the worksite. In one of these incidents, the implementation of a complete worksite protection scheme avoided injury of those present. However in many of the remaining incidents, injury has occurred either in the establishment/dismantling of the worksite – or during transitions between stages of the project. These parts of the project represent the highest risk as the worksite protection scheme may be not present, or incomplete.

These incidents suggest that there is an opportunity to reduce the risk to workers during the high risk phases of the project. Further collaboration in this area will help to improve the readiness within the electricity industry to align with new legislation to replace the Health and Safety in Employment act due in 2014.

## **Background**

### **Arahura Accident**

Just before the Arahura accident, at 11am on the 10<sup>th</sup> of January 2005, a linesman was in the process of shifting conductors from an old pole to a new pole, during routine maintenance of the Arahura-Otira 66 kV line.

The connection of the conductors to the new pole required the conductor tension to be adjusted, so that the position of the conductor had enough clearance from the ground and other conductors over the span to the adjacent pole.

While re-tensioning the blue phase conductor, the linesman inadvertently added more tension than was required to maintain the correct position. While there was no impact of the added tension in the span where the linesman was working, the position of the conductor also shifted in the adjacent span, and either touched or became too close to the live blue phase conductor of the Hokitika-Kumara 1 circuit. This resulted in a flashover to the de-energized conductor, and delivered a fatal electric shock to the linesman.

Weather conditions were not a contributing factor to the flashover, with clear skies and light winds. Earth switches were applied at Otira and Hokitika substations on the de-energized circuit and helped the protection clear the fault in approximately 500ms.

A protective earth was applied at the pole, however the voltage on the 'de-energized' conductor still rose to approximately 9 kV (calculated) for 500ms before protection operated due to high ground impedance of the earth rod.

The difference in potential across the linesman and pole was high enough to drive current through the linesman and wooden pole/lightning conductor as an alternative path back to the source, and was calculated to be approximately 5 A.

There were many additional factors that contributed to the accident at Arahura, however these primarily fall into either one or both of the two following categories:

1. Failures in the procedure that resulted in the flashover from the live circuit to the circuit being worked on;
2. Inadequacies of the temporary earthing arrangement at the pole to protect the linesman from the fault once it was initiated.

At the time the accident occurred, it was thought that many of the contributing factors were not widely known or understood across the industry. Furthermore, the report found that any lessons to be learnt required a united effort across the industry to improve the awareness of the risks when performing work near electrical equipment, as well as providing additional clarification of the control measures that are put in place to avoid serious harm.

## **Subsequent Developments**

Following the Arahura incident, the EEA explored how to prevent similar accidents from occurring in the future, with contributions from stakeholders across the power industry.

The findings from all of the contributions were then used to develop the EEA Guide to Work on De-Energized Distribution Overhead Lines, with the aim of providing all stakeholders the information necessary to prevent accidents of this nature in the future.

# The EEA Guide to Work on De-Energised Distribution Overhead Lines

The primary purpose of the EEA guide is to assist in the understanding and application of the safety rules (Safety Manual – Electricity Industry, SM-EI). The information in the guide has been determined to be good industry practice, as a result of the industry wide collaboration that went into its development.

## Themes Covered in the EEA Guide

The content of the EEA Guide follows two main themes that define good working practice on de-energized overhead lines:

1. A **comprehensive work plan** is necessary to be aware of all worksite hazards;
2. **Work zone protection**, consisting of **temporary earthing** and **equipotential zones**, applied in the event that the electrical equipment being worked on becomes inadvertently energized.

Put simply, the comprehensive work plan works to minimize the probability that the equipment becomes energized, and the equipotential zone provides a ‘safety net’ should the improbable happen, or should there be any deviation from the intended plan.

It is important that any work plan addresses both aspects i.e.

- 1) What hazards are present during the work procedure?
- 2) How is the safety of workers and others protected in the event that the work site is inadvertently energized?

## Work Planning

A significant contributing factor to the Arahura accident was the lack of understanding that actions performed at the worksite created hazards in adjacent conductor spans.

The EEA Guide identifies two elements that are key parts to any work plan:

- 1) Hazard Identification;
- 2) Control Measures – Eliminate, Isolate, Minimize.

For the work plan to be comprehensive, the design arrangement of the line needs to be well understood:

- Whether the line is single circuit or double circuit;
- The whereabouts of over and under crossings in relation to the field worksite;
- Whether a parallel circuit is to remain in service, either supported on the same poles as the circuit to be worked on or running alongside for some distance;
- Whether the circuit to be worked on has installed earth switches at a line terminal;
- Whether it is a spur line or ring;
- Whether there is any local generation connected;

- Whether there are any changes in line configuration along the length of the line;
- The types of poles used on the line, e.g. concrete (with or without integral earthing), wooden, steel etc.

Once the layout of the network is well understood, then the prospective hazards can be assessed. Some examples of prospective hazards are given below:

- Re-tensioning, replacing, or re-clamping conductors;
- Car vs. Pole;
- Over-height vehicle;
- Live conductors crossing over or under the span being worked on, or adjacent spans;
- Mobile plant;
- Lightning;
- Inadvertent energisation by distributed generation.

Based on the line characteristics and presence of hazards determined in the work plan, an appropriate work zone protection scheme can be put in place.

### Principles of Work Zone Protection

Work Zone Protection is a necessary part of a comprehensive work plan, as it is difficult to fully consider, and accurately determine all of the hazards that may be present when performing electrical work. In many cases it is virtually impossible to control the hazard at the source. As a result, the combined practice of temporary earthing and equipotential zones form the safety net for any residual, or uncontrolled hazards. Figure 1 illustrates the function of each part of a work zone protection arrangement.

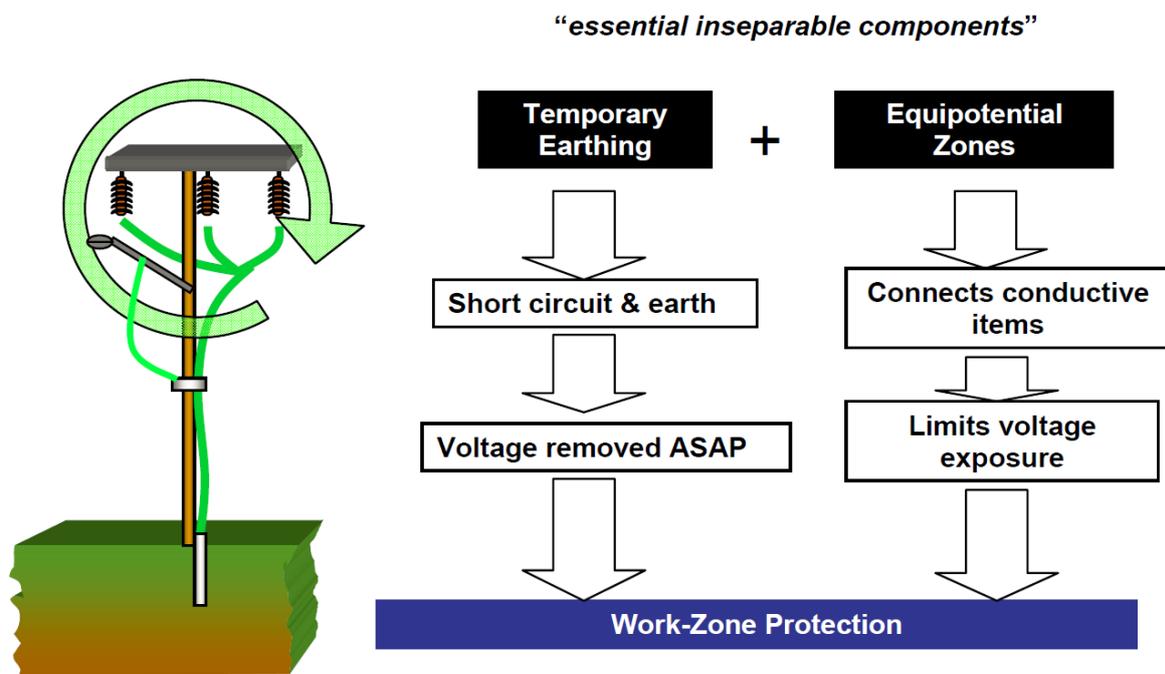


Figure 1: Work Zone Protection using Temporary Earthing and Equipotential Zones [1]

Traditionally, the temporary earthing part of the work zone protection arrangement has been well understood and consistently implemented. However, the Arahura accident and more recent events suggest that there is room for improvement in the understanding and implementation of equipotential zones.

An effective work zone protection arrangement hinges on the implementation of both **temporary earthing** and **equipotential zones** – they are **essential inseparable components**. Implementation of a single element of protection is like having a safety net that initially catches a fall, but immediately breaks.

The de-energization of a conductor and single temporary earth rod does not guarantee an equipotential zone for the worker, or for those in the vicinity of the work being carried out. In **the minority** of cases a single temporary earth may be enough to keep the potential of the earth and conductor at similar levels, but this is virtually impossible to establish without carrying out a detailed study of the earthing system. If multiple poles along a line are being maintained, then carrying out a study for each pole may take more time than the maintenance itself, making this approach impractical.

As a result the guide recommends establishing a more comprehensive earthing system by default. This uses additional earth leads, or Equipotential Bonding (EQB), between the temporary earth and metallic objects within areas where people are working, creating an equipotential zone.

The creation of an equipotential zone to protect workers and others from voltage hazards relies on two factors:

- 1) **Bringing objects into the EPZ:** Connecting a conductor between all points that may be contacted by the worker or other persons while the work is being completed, giving a path for fault current that is much lower resistance than the body;
- 2) **Enclosing objects out of the EPZ:** Placing an insulating barrier between the worker and an object of a different potential, such as a purpose designed electrical insulating mat, gloves, or boots, all with the appropriate voltage rating.

### **Not All Poles Are Equipotential**

In the distribution context, much work is carried out at the top of a pole. Unfortunately, the use of different materials in distribution power poles means that a single uniform approach of either bringing into, or enclosing out of the EPZ as described above cannot be adopted for all pole types. Figure 2 shows the effect that different pole materials have on the establishment of equipotential zones.

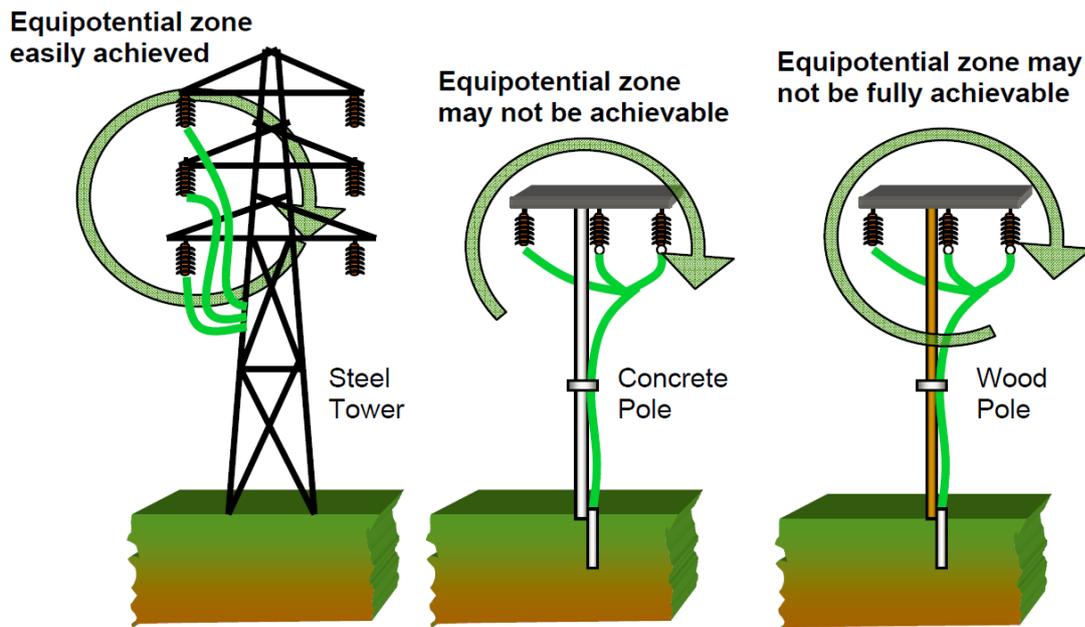


Figure 2: Establishment of Equipotential Zones on Poles of Different Materials [1]

It is vital to understand the differences between pole materials; while concrete and wood may be thought of as good insulators, they can still allow enough current to pass through them to cause a fatal electric shock.

### Working on Wooden Poles

Wooden poles present a considerable risk to a worker located at the top of the pole, when not properly bonded to the earthing system. Moisture in the core of the pole will help the core stay close to earth potential, and is a low resistance path for current to flow. In this case, only a couple of centimetres of dry wood on the pole surface may insulate a worker between phase potential and earth potential, unless there has been a prolonged period of dry weather (eg drought conditions).

Metallic pegs on which the worker stands will be at the same potential as the core of the pole, in which case the boot is the only insulation between the conductor potential and earth. Likewise any metallic cross arms will sit close to earth potential via the bolts that attach them to the pole, and can form another path for current to flow to earth in the event of the conductor being energized inadvertently.

The solution for a wooden pole is to provide a metallic path between the de-energized conductors and the core close to where the worker is standing, as this will provide a much easier and safer route for current to flow to ground. This can be done by screwing coach bolts into the core and attaching these to the temporary earth, or directly to the de-energized conductors (refer to the EEA Guide for further information). This method is also referred to as Equipotential Bonding (EQB).

## **Working on Concrete Poles**

Concrete poles are quite similar to wooden poles in many ways, in that they have a very conductive steel core, and an outer skin with unreliable resistance, depending on its moisture content.

Concrete is very porous, and when wet will easily allow current to flow through it. Even after a dry week, the moisture may have evaporated off the pole's surface, however the pole remains moist in its centre just like a sponge. The part of the pole below ground will likely have moisture in it, and consequently keep the potential of the pole close to the potential of the surrounding earth.

As is the case with wooden poles, a shallow layer of dry concrete on the outer surface of the pole may be all there is insulating a worker between phase and earth potential. And with concrete poles, it is more difficult to establish the potential of attachments to the pole.

In this case, unless the pole has an integral earthing connection (bonding point which is directly connected to the reinforcing), it is wise to connect all metallic attachments that the worker may come into contact with to the temporary earth. Areas where the worker may be leaning against the pole should be covered with an insulating mat to avoid flashover between the worker and the pole itself.

## **Working on Steel Poles/Towers**

Steel poles allow for an equipotential zone to be set up easily around a worker located above ground level, by connecting a conductor that runs between the de-energized conductor, and the steel itself.

## Equipotential Zones on the Ground

Even after fault current has made it into the ground, there is the possibility for large voltage differences to be present around the fault location. These hazards can be managed by creating an equipotential zone on the ground, as shown in Figure 3.

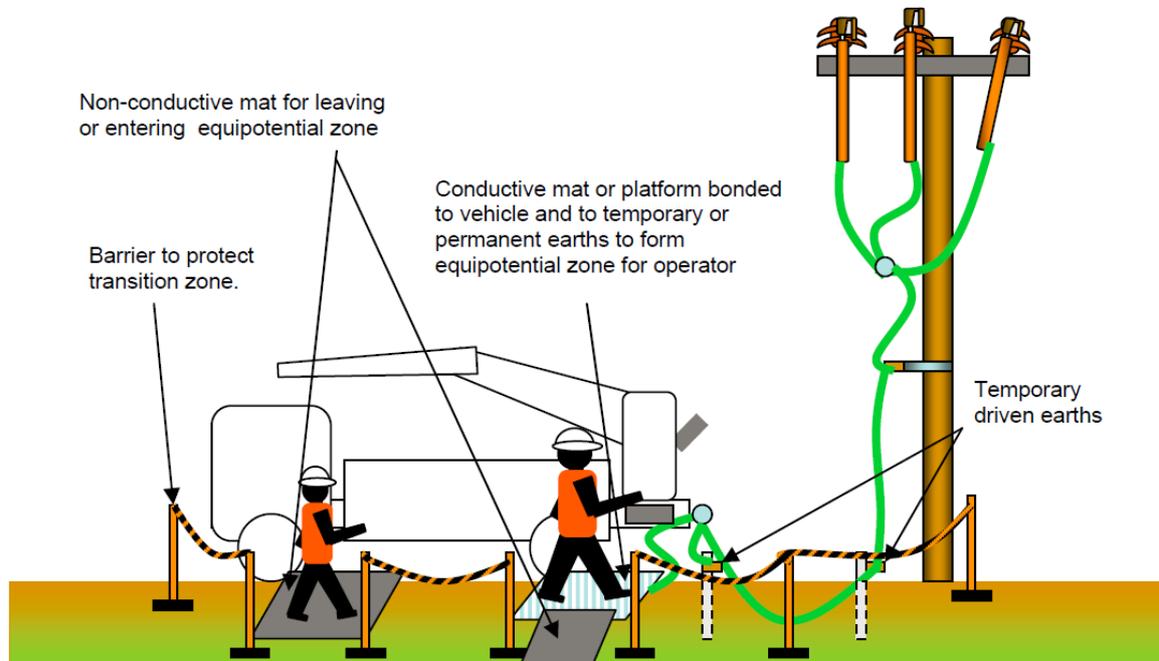


Figure 3: Establishment of Equipotential Zones on the Ground [1]

## PPE and worksite protection

PPE is the final barrier that can avoid a flashover event leading to fatal electric shock. Ideally, the body would be completely covered by an insulating barrier appropriate for the voltages exposed to, however this is impractical for most situations.

One contractor in New Zealand adopts the use of gumboots rated to withstand 10 kV for up to one minute, which will reduce the probability of flashover up to the top of the gumboot. Additionally, the use of gloves, and other barriers could be used during parts of the work procedure that represent the highest risk i.e. during set up/dismantling of work site protection, or work that is close to other energized conductors.

## 2014: Where Are We At?

### Review of Recent Incidents

Since the Arahura accident there has been a focus on improving worksite protection and awareness of safe practices across the electricity industry. However, over the same period, multiple incidents have been reported involving inadvertent energisation or flashovers, which highlight the need for continued improvement in this area. Examples of recent incidents are given below:

**2 September 2013 – Restraining Hazards:** An employee was fatally injured after coming into contact with an energized overhead power line. The incident related to a part of the work procedure that involved restringing, retensioning or removal of conductors.

While this fatality occurred in Australia, it underlines the risks that are present while re-tensioning, and re-conductoring lines.

**9 November 2012 – Risk of Inadvertent Contact:** During the repair of a broken conductor on an overhead 11 kV line, a line mechanic made contact with a live 11 kV overhead line while working off a ladder at the top of a pole structure. The line mechanic was fatally injured in the process. What kind of work site protection had been set up at the time the incident occurred? Was it appropriate for the risks present at the pole?

**6 May 2011 – Restraining Hazards:** A 110 kV conductor inadvertently came into contact with a live 11 kV circuit during reconductoring. There were no injuries or electric shock to personnel onsite. Effective earthing and equipotential zones at the wiring sites proved effective in protecting personnel against the transferred potentials.

In this case a failure to recognize a contact hazard with the 11 kV circuit did not result in serious injury, simply by having a complete work site protection scheme, consisting of both temporary earthing and the creation of equipotential zones.

**19 January 2011 – Inadvertent Contact:** Contact with a live 33 kV overhead circuit was made while carrying out general maintenance work on 11 kV equipment. One worker received a shock and electrical burns.

The incidents involving inadvertent contact highlight the need for more consideration in the work plan about the size of the equipotential zone required, as well as risks to the worker before adequate worksite protection has been set up. Any conductor not connected to the temporary earth or covered by an insulating barrier presents an uncontrolled risk to the workers involved. Should live line PPE be worn during parts of the procedure when there is significant risk of contact with live conductor?

What is good practice for poles that have more than one circuit? Should the 33 kV circuit have been de-energized for maintenance on the 11 kV circuit to avoid an incident like the one that occurred on 19 January 2011? Should the guide provide more examples of good practice for particular work procedures?

Does the worksite protection scheme allow for wind gusts, or malfunction/incorrect operation of mobile plant etc.?

**February 2009 – Inadequate EPZ Creation:** A worker received a burn on the leg and electric shock while on the ground due to inadvertent contact between mobile plant and live conductor. The worker may have been in contact with the earth rod at the time, which is thought to have been the cause of the burn. How could the earth rod be better protected?

In this incident, lack of insulating covers led to improvisation on site, and deviation from the original work procedure. How can the industry learn from this kind of incident?

**2008 – Induction Shock:** A linesman received a shock during dismantling of a temporary earth on a de-energized line. A gust of wind caught the elevated work platform he was in causing the linesman to fend off a conductor (made live by induction) with his free hand.

This incident shows that a comprehensive work plan is still required to manage the risk while worksite protection is being established, and dismantled.

## Conclusions

The awareness and understanding around establishing a comprehensive worksite protection scheme has made significant advances in the years following the Arahura incident in 2005.

While there has been good progress made, other incidents highlight the fact that the equipotential zone and temporary earthing ‘safety net’ are only effective once properly set up, and significant risks still remain in the establishment and dismantling of the worksite. The order that tasks are carried out at these stages are crucial in ensuring the safety of all involved.

There is certainly opportunity to improve both work practices and knowledge across the industry regarding equipotential zones and temporary earthing. The incidents above highlight the need for more collaboration across the industry in developing and following safe work site establishment and dismantling techniques, as well as managing the transition between project stages. Further collaboration in this area will help to improve the readiness within the electricity industry to align with new legislation to replace the Health and Safety in Employment act due in 2014.

## Acknowledgements

- [1] The diagrams used in this report, and overall concepts have been obtained from The EEA Guide to Work on De-Energised Distribution Overhead Lines – available at: [http://www.eea.co.nz/Story?Action=View&Story\\_id=2410](http://www.eea.co.nz/Story?Action=View&Story_id=2410)

## Speaker contact details

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Rob has nine years of experience in the power industry, spread across the Asia-Pacific region.

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



Most recently Rob has worked in Singapore with Vestas, providing grid connection studies and value engineering services for wind farms being tendered in all regions, as well as providing post-sales support to existing sites. Rob is familiar with steady state and dynamic studies using DigSILENT, PSCAD, CDEGS and PSS-SINCAL.

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