# Designing for Arc Fault Containment in Modern Switchboards

- *Safety in Design – consider the whole life cycle.*

Five principles lie at the heart of the current approach to arc fault incident safety standards;

1. Energy intensity exposure need only be limited to survivable 2nd degree burns.
2. What we determine today as OK, holds true for the life of the asset.
3. Smarter devices can reliably limit the incident energy.
4. Arc flash incidents don't happen that often.
5. People will do the right thing, following their safety rules and wearing their PPE.

National and State legislation that sets decision making standards for directors and officers of organisations has paralleled increased community expectations of WHSE within and beyond the workplace. High profile incidents, like Dreamworld in 2016, raised the bar for protecting the public, by introducing "industrial manslaughter" into our governance consideration.

As engineers, we have a range of methods (and standards) to establish, by calculation, that designs will ensure 'adequate' reasonable protection from arc flash incidents; at least sufficient to protect decision-makers from legal redress.

*However, safety in design priority should be protecting people and assets into the future, by recognising the 'state of the art', not ticking the box to just meet today's standards.*

## Two Standards; IEEE 1584 and NFPA 70E

- *How arc flash hazards are quantified*

Arc Flash Hazard studies, commonly performed in conjunction with a power system analysis (PSA) are usually centred around two standards, IEEE 1584 and NFPA 70E. Neither document is legislated within Australia, however are adopted by many Australian workplaces in lieu of Australian Standards, particularly in the highly regulated mining, energy and infrastructure sectors.

The first standard, IEEE 1584:2018 Guide for Performing Arc Flash Hazard Calculations (1) is a widely adopted and industry accepted standard that includes procedures to calculate and predict arc flash hazard levels. The most recent release of the standard (Nov-2018) supported by independent testing has identified that horizontal incident energy levels can be up to *330% greater* than calculated in previous revisions (2). This significant change should trigger the re-calculation of arc flash assessments performed under previous reversions.

The second standard (NFPA 70E) forms part of the North America's equivalent to the Australian Wiring Rules, AS/NZS 3000. This standard focus is protection against arc burn injuries and does not consider the arc blast, flying shrapnel and pressure related injuries, nor does it consider equipment protection.

IEEE 1584 quantifies the hazard based on testing, to provide the best prediction of the hazard. NFPA 70E uses this result to set out our administrative and PPE controls to protect against the calculated arc-burn hazard.

*Designs must be physically tested to prove and certify they work in the real world.*

## Two Testing Standards for Arc Fault Containment

- *Physical testing of modern switchboards*

Arc fault containment is the verification of increased security provided by a switchboard against the occurrence or effects of an internal arcing fault with all doors and covers securely closed and all covers and internal barriers in place (3).

There are two arc fault containment test methods for Australian switchboards, AS/NZS 61439.1 Appendix ZD and IEC TR 61641. Both standards carry out similar tests, however IEC TR 61641 has a greater focus on the entire switchboard requiring cotton indicators be located at the front, back and sides during testing whilst AS/NZS 61439.1 only requires indicators at the front. A successful result complying to IEC TR 61641 will meet the following criteria;

- Doors and covers remain closed
- No parts are ejected
- No holes in external parts
- Cotton indicators do not ignite
- Protective circuit is still effective
- The arc was confined to the functional unit
- The remainder of the switchboard can be placed back into service

*Personal Protection Components*

*Assembly Protection*

*For Limited Operation*

*Our choice should be based on what's safest for the 25-year life of the asset, not what we can get away with now, which also doesn't meet ethical duty of care considerations.*

## Second Degree Burns Should Not Be OK

- *Consideration for a people and public*

Assessing what degree of burn is survivable and therefore acceptable, certainly provides a baseline. In technical terms of incident energy exposure level, it's 1.2 cal/cm$^2$, which defines the safe boundary where one only gets 2nd degree burns. *(Try holding a finger in the blue flame of a lighter for 1 sec.)* [4].

In human terms it looks like this;

A second degree burn causes damage deeper than the top layer of skin. It still represents intense pain and significant suffering from blisters and swelling. However, despite the mental health impact of a near miss incident, 2$^{nd}$ degree burns are physically survivable injuries.

Under our duty of care, it is ethically unacceptable for engineers to be designing to just meet this standard of care for our electrical maintenance personnel, operators and nearby public. More so when low, or no cost arc fault containment technology is known to asset owners.

*In accepting the minimum standards we accept our personnel's exposure to 2nd degree burns.*

## Legislation Standards for Decision Makers

- *Work Health and Safety Legislation*

Clause 19 of the Queensland Work Health and Safety Act 2011[5] (WHSA) states that a person conducting a business or undertaking (PCBU) must ensure as far as is *reasonably practicable*, the health and safety of workers and any other people who may be at risk.

*Reasonably practicable* is defined in clause 18 of the WHSA as what was reasonably able to be done, or should have been done, to ensure health and safety considering the following matters;

- Likelihood of the hazard or risk
- Degree of harm of the hazard or risk
- Knowledge of the hazard and ways of eliminating or minimising the risk
- Availability and suitability of ways of eliminating or minimising the risk
- The cost of ways of eliminating or minimising risk is not grossly disproportionate to the risk

The Australian Institute of Company Directors Risk Management guide [6] refers to Principle 7 of the ASX Recommendations that places "ultimate responsibility" for deciding the nature and extent of risks, and ensuring that an "appropriate framework" exits for managing risk.

Legislation puts the onus on directors and officers is to make themselves aware of such methods and technology, not to rely on the say so of others. Guides published by Safe Work Australia detail offenses and penalties [9].

Beyond the initial and direct cost of the incident, which for example may be $100,000, organisations also become exposed to operating losses, reputational loss, future litigation, and ongoing disability claims that can elevate the incident cost towards $1M per incident.

*When new technology, like arc fault containment switchboards comes into being that satisfies the above tests, liable decision makers should be erring towards safer outcomes.*

## Unreliability of Input to Calculations

- *Selecting Criteria for Best Results*

The results from calculations and testing are sensitive to the input assumptions. In selecting our input data, engineers should deal with what's reasonable and representative. The IEEE 1584:2018 standard just released should trigger a reassessment of previous arc flash calculations, based on new learnings highlighted in the latest revision of the standard, which tested horizontal electrodes and revealed *330% higher* incident energy levels [2].

Calculations are based on laboratory tests using parameters that may not apply to real world, over time. Outdoor switchboards operating in a hot wet humid climate are highly exposed to environmental factors over a long period asset life. Dust and impureness, corrosion, condensation of water and water dropping are all factors affect the reliability of calculations to represent risk over time.

So is the ingress of wildlife in outdoor switchboards.

Stochastic nature of arcs themselves also means they cannot be reliably modelled, they are mean numbers, not the upper end of the incident level distribution.

Also, the reliability of an engineer's PSA modelling is contingent on the reliability of the drawings to properly reflect the current configuration, (vs as designed).

*Arc flash calculations rely on probable input conditions rather than physical laws. Prudent engineers should be mindful of future social and physical conditions to select conservative input assumptions.*

## Technology & Asset Changes Over Time

- *What exists today, will change with new technology and exposure*

Over time the electrical network has and will continue to have many changes that may influence the intensity or risk of arc faults over the life of a switchboard; especially in outdoor infrastructure applications.

Growth in the electrical network may introduce unintended increased risks from equipment change-outs; an upgraded transformer upstream, upsized mains, changed protection settings in supply authority network. Also, co-generation, incorporating increased PV solar / battery generation is ever evolving the risk.

There are other risks that will change over the life of the asset; number of staff that works on an asset; complexity of systems; system condition and maintenance; environment degradation.

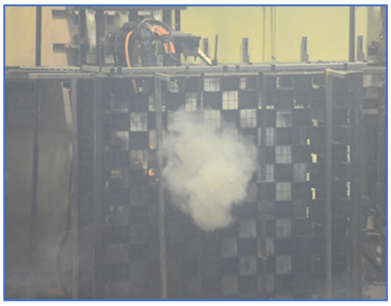
*It is unreasonable to assume that will be no future technologies to affect switchboard arc flash safety characteristics in the future.*

## Smart Equipment Must Work

- *Passive engineered protection not reliant on devices operating*

Many new smart technologies are becoming available that can detect arcs developing and operating protection devices or detect the presence of personnel in proximity to switchboard to change protection device setting to operate quicker. These quicker operating times feed back into the arc flash assessment, however these assessments are fundamentally based on all protection devices operating correctly and as predicted, it does not consider equipment failure. Protection devices have been known to fail under fault conditions well within their specifications *(Ref, PTAS ABCD Testing).*

Additionally, Australian businesses are adopting NFPA 70E standard to implement PPE requirements based the arc flash assessment to protect against the arc burn injuries. However, a non-arc fault contained switchboard presents additional hazards during an arc fault from the rapid increase in air pressure.



A bystander or operator standing next to an operating switchboard for example are at risk of blunt trauma as arc fault pressure wave ejects door mounted switchgear or blow off/open door strikes the bystander or operator.

Arc fault contained switchboards provide a passive solution to these hazards. By being engineered and physically tested to contain an arc fault whilst maintaining structural integrity, the risk to operators and bystanders has been minimised without the reliance on a device operation.

*It is now reasonable and commercially practicable to have both active and passive protection.*

## Arc Flash Injuries Are Not Insignificant

- *Arc Flash Incidents Represent about 50% of All Electrical Injury Costs*

In November 2018, Workplace Health and Safety Queensland (7) published that since 2013 there have been 32 *reported* incidents involving an arc flash. Of these, 20 resulted in injuries requiring hospitalisation. It's generally known many incidents remain unreported, being treated as outpatients.

NSW reported that between 2005 and 2015 (8), that there were on average 11.6 people burned working on or near electrical apparatus each year from arc faults. 81 of the 129 reported incidents for the period involved switchboards. Burns to the head/face area was the second most common burn site, involved in 57% of injuries.

A report published in Industrial Safety and Hygiene News(9) estimated that, on average, there are 30,000 arc flash incidents in the USA every year. The report went on to estimate that those incidents resulted in average annual totals of 7,000 burn injuries, 2,000 hospitalizations, and 400 fatalities per year.

*Arc flash incidents have low representation in electrical accidents (about 5%), but cost about 50%, so risk mitigation requires deeper consideration.*

## Multiple Factor Failure

- *High reliance on unreliable controls and people doing the right thing.*

Managers correctly assume that their personnel will choose to work safe and in the organisation's best interests. However human nature too often kicks in to take a short-cut or avoid an onerous activity like wearing hot, bulky, uncomfortable productivity sapping PPE.

Most accidents can be traced back as multiple factor failures, where different levels of decision risk have arrived in the 'swiss cheese effect'; a serious arc fault has occurred to seriously injure personnel.

Well-designed outdoor switchboards will have an operating life of 20 -25 years, 99.5% of the time in remote operating mode. The highest risk of an arc fault incident occurs when an operator opens the outer doors, or electrical staff may do maintenance; multiple failure factors are all present.

When an active protection device is the only protection, it is required to operate under a real fault scenario, this usually is the first opportunity for the asset owner to know if it works, or not. The bathtub curve model, widely used in reliability engineering, shows that the failure rate is significantly higher at the beginning and end of life.

Passive arc fault containment protection is always there to mitigate risk. Ideally that protection operates at escutcheon level so that operators (and public) are kept safe during maintenance. The risk is heavily mitigated, even when good people make mistakes.

*When long-term safety relies on actions of smart aging equipment or people, risks are elevated.*

## A 25- year Asset Decision

- *Short-term gain exposes lifetime risk*

Arc Faults hazards cannot be eliminated within electrical switchboards and everyone in the process has a duty of care in minimising the risk to themselves and others. Accepting 2$^{nd}$ degree burns as OK by today's standards, is unlikely in the future.

Industry innovation have proven that hazards can be engineered out during normal operation of a switchboard through the use of passive arc fault contained switchboards. Far superior protection at low or no cost.

Arc flash assessments are still a vital piece to workplace safety to determine a level of PPE to be worn when switchboard maintenance is undertaken. Administrative controls remain, however higher order engineering controls is both cost effective and desirable.

Designing safer equipment also reduces cost of ownership, makes employees more productive because equipment can be operated easily without reliance on properly worn bulky PPE, additional staffing or onerous administrative controls.

The challenge for engineers, specifiers and executive decision makers comes down to long-term cost-effective risk mitigation. No-one wants to reflect on decisions that have little or no commercial impact on current projects, yet accepted a lower safety benchmark, which in the life of the asset has led to maiming of personnel, or a fatality.

The 'state of the art' is generally advanced on the 'technical standards'. With courts in many jurisdictions (11) now viewing work injury culpability as (intentional or negligent) behaviour of the employer. It is particularly important that the 'state of the art' in the sense of regulations for employee safety is not mistaken for the 'state of technical standards'.

While arc flash incidents are relatively rare their long-term cost to an organisation is very high. The risk is avoidable. Prudent decision-making by responsible engineers and leaders ultimately demonstrates good corporate governance.

*Well-engineered designs, like PTAS innovative ABCD arc-flash containment modular outdoor switchboard, are essential for organisations that understand their duty of care for the safety of employees and the general public.*

## References

1: https://standards.ieee.org/standard/1584-2018.html IEEE 1584-2018 - IEEE Guide for Performing Arc-Flash Hazard Calculations. “This guide provides mathematical models for designers and facility operators to apply in determining the arc-flash hazard distance and the incident energy to which workers could be exposed during their work on or near electrical equipment.”

2: https://www.leafelectricalsafety.com/blog/ieee-1584-changes-the-end-of-arc-flash-calculations-as-we-know-them “When IEEE first did the tests to determine arc flash incident energy levels they used "vertical electrodes…That incident energy levels on the horizontal plane can be up to 330% greater than what they were originally thought using the calculations from the vertical”.

3: AS/NZS 61439.1:2016 Appendix ZD cl.ZD1 “…The requirement for internal arcing fault tests is subject to agreement (refer to Annex C) but if agreed shall be tested to this Appendix ZD or IEC TR 61641. This Appendix specifies tests for the verification of any increased security provided by the design of the ASSEMBLY against the effects of internal arcing which may occur in service with all doors closed and all covers and internal barriers in place. …”

4: http://arcadvisor.com/faq/threshold-incident-energy-second-degree-burn “IEEE P1584 refers to an example of a butane lighter. Quote: "if a butane lighter is held 1 cm away from a person's finger for one second and the finger is in the blue flame, a square centimeter area of the finger will be exposed to about 5.0 J/cm$^2$ or 1.2 cal/cm$^2$".

5. Queensland Work Health and Safety Act 2011 https://www.legislation.qld.gov.au/view/pdf/inforce/current/act-2011-018 Clause 18 “In this Act, reasonably practicable, in relation to a duty to ensure health and safety, means that which is, or was at a particular time, reasonably able to be done in relation to ensuring health and safety, taking into account and weighing up all relevant matters including…”

6. Australia Institute of Company Directors – Risk Management https://aicd.companydirectors.com.au/~/media/cd2/resources/director-resources/director-tools/pdf/05446-5-12-mem-director-rob-risk-management_a4-web.ashx

7: Workplace Health and Safety Queensland – eSafe Incident Alert https://www.vision6.com.au/v/15149/1808572364/email.html?k=8TptmsdfdXOY2qgZLHtc7_tyXaVRnpYMZpj2nqHTsgs

8: http://www.engineeringsafety.com.au / 5 Arc Incidents in Australia UPDATED - T&D Oct_Nov 2016, by Brett Cleaves, Engineering Safety

9: Johnson, Dave, Arc Flash Statistics, ISHN, May 31, 2013 https://www.ishn.com/articles/96001-arc-flash-statistics

10: SafeWork Australia Guide to the Model Work Health and Safety Act https://www.safeworkaustralia.gov.au/system/files/documents/1702/guide-to-the-whs-act-at-21-march-2016.pdf

11: Alfred Mörx, Eur.-Phys. Dipl.-Ing. Dave, Safety and risk in electrical low-voltage installations https://www.ishn.com/articles/96001-arc-flash-statistics

## *Arc Flash Hazards and Arc Faults

An arc flash is the light and heat energy produced by an arc fault. An arc fault is usually initiated by either a breakdown of insulation or a foreign object (such as a hand tool) causing a conduction path through an air gap.

For arc faults, including in those installations that comply with the minimum requirements pursuant to IEC 61439 series the following can cause ignition:

- Condensation (humidity in the switchgear assembly)
- Pollution in the form of foreign deposits (dust, salt) on busbars and parts of switchgear
- Entry of wildlife and their residue
- Transient over voltages following storm and/or switching surges
- Premature (unnoticed) ageing of insulating materials and protection devices following sporadic or thermal overload
- Loose or slack connections, defective contact points
- Working on or operating parts of the switchgear

The consequences of an arc fault include significant damage to assets and disruption to operations and production. However, the biggest consequence is the injury, permanent maiming or death of operators or persons in the area.
Protection against the effects of arc faults serves both employee protection, the reduction of asset and consequential business damages.

## About the Authors

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Roland is a highly regarded, well-qualified Electrical Design and Project Engineer grounded on an electrical fitter mechanic trade background. His trade background provides unique viewpoint to ensure solutions are practical and readily delivered by construction teams. He’s worked closely with PTAS on many projects over the past few years, notably on the R&D of our unique and award winning ‘ABCD’ Arc Fault Containment modular outdoor switchboard.

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