OHS Body of Knowledge

Electricity

Appendix - Arc Flash

Core Body of Knowledge for the
Generalist OHS Professional

Second Edition, 2019

23.2

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Electricity

Appendix - Arc Flash

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Since starting as a cadet with BHP in 1993, Brett has worked in steel mills, mines and electrical utilities, executing a range of duties in maintenance, engineering, governance, production and project management. He developed a strong commitment to electrical safety, and received BlueScope awards for leadership and engagement. In 2013, Brett established Engineering Safety through which he provides project management services for a range of electrical companies together with general advice on electrical safety to industry. At the leading edge of hazard identification, assessment and control for arc flash in Australia, Brett is a strong advocate for the need for knowledge of arc flash to evolve to provide clarity on the most appropriate practices and controls.

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Core Body of Knowledge for the Generalist OHS Professional

Electricity

Appendix – Arc Flash

Abstract
This appendix to the *OHS Body of Knowledge* Chapter 'Physical Hazards: Electricity' focuses on the electrical hazard of arc flash from the perspective of the generalist OHS professional. After defining relevant terms, examining the incidence of arc flash injuries and reviewing relevant legislation and standards, it considers options for control of arc flash and implications for OHS practice.

Keywords
electricity, arc flash, arc blast, arc flash, risk,

Contextual reading
This Appendix should be read in conjunction with *OHS Body of Knowledge* Chapter 23 'Physical Hazards: Electricity.' Readers should also refer to 1 'Preliminaries' for a full list of chapters and authors and a synopsis of the *OHS Body of Knowledge*. Chapter 2 'Introduction' describes the background and development process, and Chapter 3 'The OHS Professional' provides context by describing the generalist OHS professional role and professional environment.

Terminology
Depending on the jurisdiction and the organisation, Australian terminology refers to 'Occupational Health and Safety' (OHS), 'Occupational Safety and Health (OSH) or 'Work Health and Safety' (WHS). In line with international practice this publication uses OHS, with the exception of specific references to the Work Health and Safety (WHS) Act and related legislation.

Jurisdictional application
This appendix includes a short section referring to the Australian model work health and safety legislation. This is in line with the Australian national application of the *OHS Body of Knowledge*. Readers working in other legal jurisdictions should consider these references as examples and refer to the relevant legislation in their jurisdiction of operation

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Industry comment

Vanessa Garbett, Team Leader, Electrical Installation Safety, Energy Safe Victoria

It is very positive to see this publication. It is long overdue in my opinion. Too little is available with Australian content in this important and little understood area of risk.

It is acknowledged across industry that not enough is being done in this space and that there is a lack of guidance or standard information. Whatever can be done to inform operators of installations of the risks and how to treat them is an improvement. It is a good starting point for OHS professionals.

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A1 Introduction

The *OHS Body of Knowledge* chapter Physical Hazards: Electricity presents information required by generalist OHS professionals to enable them to better understand the nature of electricity as a hazard, how it can harm the human body and the standard control measures. The chapter emphasises the severity of potential consequences of an electrical incident, noting that several deaths by electrocution occur in workplaces across Australia every year.

This appendix focuses on one particularly dangerous type of electrical hazard – arc flash – the consequences of which can range from inconsequential to severe burns and death as well as power outages, fire and significant property damage.

While arc flash is associated with electrical work, and may be considered a specialist topic, all workplaces have electricity and so arc flash hazards are of pervasive relevance. With the introduction of metal clad switchboards from the mid-20th century came the practice of switchboard arc flash containment and testing, and it was not until the 1980s that arc flash hazards were first quantified. Consequently, knowledge of arc flash hazards, the risk factors and the mechanism of injury causation is still evolving. The dynamic nature of this knowledge is reflected in the existence and use of different standards and terminology across countries and organisations; this inconsistency can present problems for generalist OHS professionals working with electrical personnel to implement a risk management approach to minimising arc flash.

Arc flash is sometimes referred to as arc fault and vice versa.

> Arc faults arise when current flows through the air between phase conductors or between phase conductors and neutral or ground. Put simply, an arc fault could be described as an unexpected, violent, electrical short circuit in the air that produces an arc and associated by-products…
>
> The term Arc Flash comes from an earlier understanding that the burns from an arc fault were similar to the flash burns from a welding arc. That is, the heat was transferred to the individual by the radiant heat and light (infrared – ultraviolet) from the arc.
>
> Recent research has shown that, although the radiant energy from an electrical arc contributes to the energy received, the major hazard to an individual comes from the plasma ejected by an arc. (AEC, 2019, p. 13)

Thus improved understanding of the mechanism of injury causation from arc flash has directed attention away from the heat and light component of the ‘flash’ to a plasma cloud as the major factor in the causation of burns (see section A3). In line with current usage, this document uses the term *arc fault* to describe the causative event and *arc flash* as the outcome.

This appendix addresses arc flash from the perspective of the generalist OHS professional and so forms an important part of the safety literature. After defining some electrical terms relevant to arc flash and examining the incidence of arc flash injuries, it briefly reviews relevant legislation and standards. Options for control of arc flash are examined and implications for OHS practice are considered. This document is not a comprehensive guide to arc flash hazard assessment and control; those who require definitive information on arc flash hazards and controls should refer to relevant Australian regulations, codes of practice, standards and guidelines (see section A5).[1]

A1.1 Some electrical terms

An understanding of arc flash requires familiarisation with the following terms.[2]

Arc flash current
The amount of current the electrical system can deliver to an arcing fault; similar to a short-circuit fault current, but with current flow being restricted by the impedance of the arc between the conductors and/or earth.

Arc flash protection boundary

An approach limit set at a distance from exposed live parts where the prospective incident energy from an arcing fault has dropped to 1.2 cal/cm^2.

Arc thermal performance value (ATPV)
The protective value of arc-rated PPE expressed in calories per centimeter squared (cal/cm^2). When the incident energy of an arcing fault has the same value as the ATPV of a worker's personal protective equipment (PPE), the bulk of a worker has a 50% likelihood of receiving second-degree burns.

Busbar/busway
Fixed bare or insulated conductors (copper or aluminium) inside a switchboard that are used to connect switchboard devices such as switches and circuit breakers. Busways are dedicated enclosures for busbars within or between switchboards.

Circuit breaker
An automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit.

Impedance
A measure of the complex resistance a conductor has to electrical current flowing through it. Impedance can change with any change to the state of a conductor. The high

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1 For a description of arc flash and the management of arc flash hazards written for electrical specialists, see AEC (2019).

2 The generalist OHS professional should also be familiar with the content of the core chapter, Physical Hazards: Electricity.

impedance of air, which is generally a good insulator, is dramatically reduced when the air is ionised through exposure to excess voltage.

Incident energy
The prospective amount of energy that the bulk of a person may be exposed to during an arcing fault. Incident energy is in units of calories per centimeter squared (cal/cm^2), with 1.2 cal/cm^2 accepted as the threshold for the onset of second-degree burns to skin.

Insulator
A material that is a poor conductor, and not intended to carry electrical current.

Motor control centre (MCC)
Switchgear that is primarily designed to distribute power to multiple motor loads whereas a common busbar typically supplies multiple separate motor control starter units within the same switchgear.

Short circuit
An electrical circuit that allows a current to travel along an unintended path with no or very low electrical impedance, often as the result of a problem in the electrical circuit; can result in an excessive amount of current flowing into the circuit.

Short-circuit fault current
The maximum amount of current that the system can deliver through a zero impedance short circuit between two or more conductors and/or earth.

Switching
Switching in electrical power systems reconfigures the electrical network; it involves the making and breaking of circuits and causes a disturbance in the steady energy flow.

Switch/control gear
Switchgear is the combination of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment.

Switchboard
An enclosure designed and installed to allow for the distribution of electricity to various circuits via switches, fuses and/or circuit breakers.

A2 The extent of the problem

In Australia, inadequate data on electrical incidents and injuries makes it difficult to provide definitive statements about the occurrence of arc flash incidents. However, inferences can be drawn from individual reports and information provided by regulators and industry bodies.

- "Over the five years from 2011 to 2015, 13 workers on Western Australia mine operations received injuries from arc flash incidents that required medical attention and were placed on restricted duties or lost time" (DMPRS, 2016a, p. 1).

- In November 2018, WorkCover Queensland reported that “Since 2013 there have been 32 incidents involving an arc flash. Of these, 20 resulted in injuries requiring hospitalization” (WorkCover Queensland, 2018).
- An analysis of serious arc flash burns to workers admitted to NSW critical burns units between 2003 and 2016 indicated that injuries requiring specialist burns treatment were occurring at a frequency of approximately one per month. Observations from the data include:
    - The majority of injuries (63%) were associated with working on switchboards
    - The second and third most frequent sources of energy were live cables and overhead power lines
    - The average size of the burn injury was 6.4% of the body (the hand represents roughly 2.5% of body area)
    - 66% of all injuries involved burns to the hand with 40% of all patients receiving burns to both hands
    - 80% of hand burns were second-degree burns or worse
    - 54% of patients had facial burns, with half of the facial burns being second-degree burns (Cleaves, 2016).

  The high incident of hand injuries is consistent with the worker performing tasks on energised equipment.
- An internet search revealed that, during 2018, six incidents involving arc flash resulted in six workers receiving serious burns and the death of one worker (Table A1).

Table A1: Arc flash incidents in 2018

Month & Source	State	Industry	Reported activity	Injury
February (Chiat, 2018)	WA	Mining	Connecting a cable to a low-voltage circuit breaker board	Burns to face and hands
July (SafeWork NSW, 2018)	NSW	Excavation	Electrical hammer drill used to break up concrete struck live UG cables	Burns to upper body and face
September (WorkCover Queensland, 2018)	QLD	-	Pliers shorted two phases	Burns to hands
October (WorkCover Queensland, 2018)	QLD	-	Terminating cables to switchboard	Burns to hands, neck and face
November (NECA, 2018)	NSW	-	Switchboard explosion in apartment block	Two workers Burns
November (NECA, 2018)	VIC	Power generation	Operating switch gear	Death

The incidence of arc faults and arc flash injuries may increase due to changes in work practices such as:

- Decreasing tolerance for power outages and their impact on production, resulting in pressure to work on energised equipment (with the associated risk of arc flash)
- Increasing power demands on electrical installations in larger factories and mines
- Changes in isolation and switching practices, requiring more frequent maintenance of circuit breakers to prevent faults.

A3 Understanding arc flash

A3.1 Electrical arcs

Electrical arcs occur when a gas is exposed to a voltage greater than its insulative properties. The arc initiates when the voltage is sufficient to ionise the gas (usually air) across the gap between conductors. Once ionised, the gas becomes a good conductor, allowing current to flow.

The amount of current is limited by the capacity of the power supply and the characteristics of the arc itself. The arc will sustain until it is quenched, suppressed or extinguished. In air, the current flow generates heat and bright visible light. The heat from the electrical current causes the ionised gas to rise, resulting in the arched shape of the current that gives the phenomenon its name.

An arc in air can generate temperatures above 20,000°C (Das, 2012). The arc produces a plasma cloud of approximately 5000°C (ENA, 2014). Arcs in other insulating mediums such as insulating oil (used in some circuit breakers and transformers), specialised insulating gases such as sulphur hexafluoride (SF6), and arcs in vacuums have their own unique safety, environmental, maintenance and operational requirements in addition to those for arcs in air and are not covered in this document.

A3.2 Arc faults, arc flash and arc blast

Controlled arcs can be used in steelmaking, cutting and welding but when uncontrolled, they present significant risk to people and property. Uncontrolled arcs occur in arc faults.

As indicated in section A1, the terms arc fault and arc flash are often used interchangeably. This appendix uses the term arc fault to describe the event leading to the outcome of an arc flash.

Arc faults are the unintended discharge of electrical energy and are typically caused by:

- The breakdown or compromise of insulation through equipment damage, contamination or work practice
- A failure during switching
- Contact resistance and loose connections forming hot joints and thermal runaway.

Arc faults can result in:

- A plasma cloud appearing as a fireball at 5000°C
- Arc temperatures above 20,000°C
- Blinding light
- Deafening noise
- Explosive pressure wave
- Ejected molten metal and other shrapnel
- Toxic smoke.[3]

The radiated heat and light is the arc flash and the pressure wave and ejected material is the arc blast.

[3] For details of the impact of arc flash, see IEEE (2018).

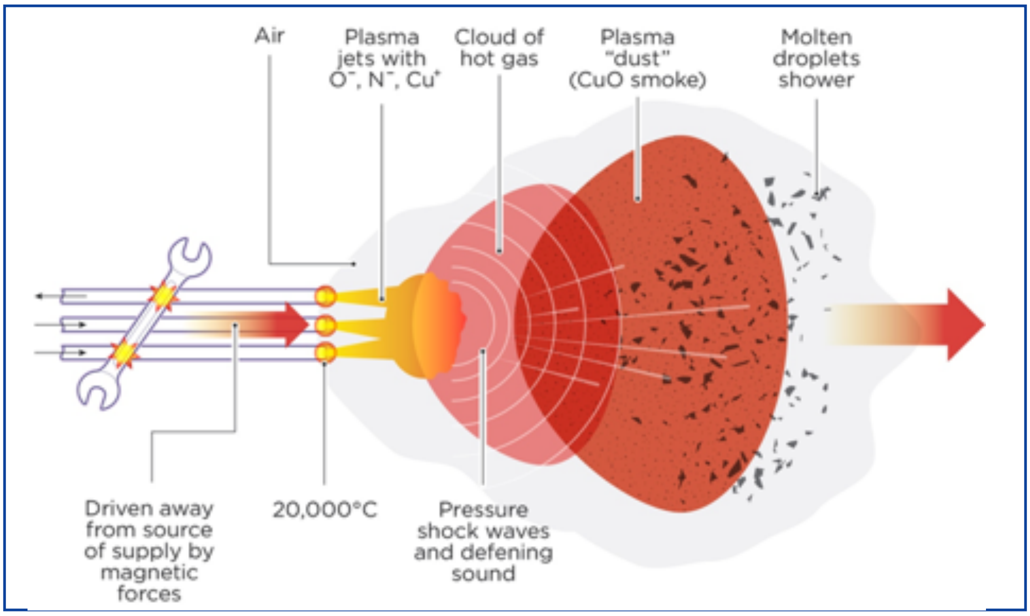


Figure A1: Arc flash and arc blast (AEC, 2019, p. 13)

A3.3 Impact of arc flash

The intense heat of an arc flash can melt cables, busbars and metal switchboards.

In humans, the main mechanism for injury is burns through exposure to the plasma cloud (ENA, 2014). Plasma is often referred to as the fourth state of matter beyond solid, liquid and gas, and is best described as superheated ionisied gas. Burns can be exacerbated by the ignition or melting of synthetic clothing or traditional cotton drill workwear. At high voltages, electricity can also arc over the surface of the skin, causing burns without the skin becoming part of the circuit and not resulting in an electric shock.

The intense light from an arc can damage eyes and cause temporary or permanent blindness. The noise of the arc can exceed that of a jet engine and damage hearing. The gases and fumes generated are also typically toxic. It is important to note that time and motion studies show that human reaction time to sense, judge and run away typically is 0.4 second (Das, 2012). This reaction time is too long for a worker to move away and shelter themselves from an arc flash and the consequences.[4]

[4] For a demonstration of the impact of an arc flash, see the video posted by Arc Flash Consultants (2015).

As an arc flash forms, the almost instantaneous conversion of the conductors from solid to gas and ionised plasma, and the superheating of the surrounding air, can combine to produce a rapid increase in pressure, especially if the arc flash occurs within an enclosed switchboard or switch room. This pressure is capable of direct injury, indirect injury from falls, or workers being struck by covers and doors, as well as damage to switchboards and the switch room building. (Figure 2A) The arc blast component, while important, is secondary in terms of protecting life (ENA, 2014).

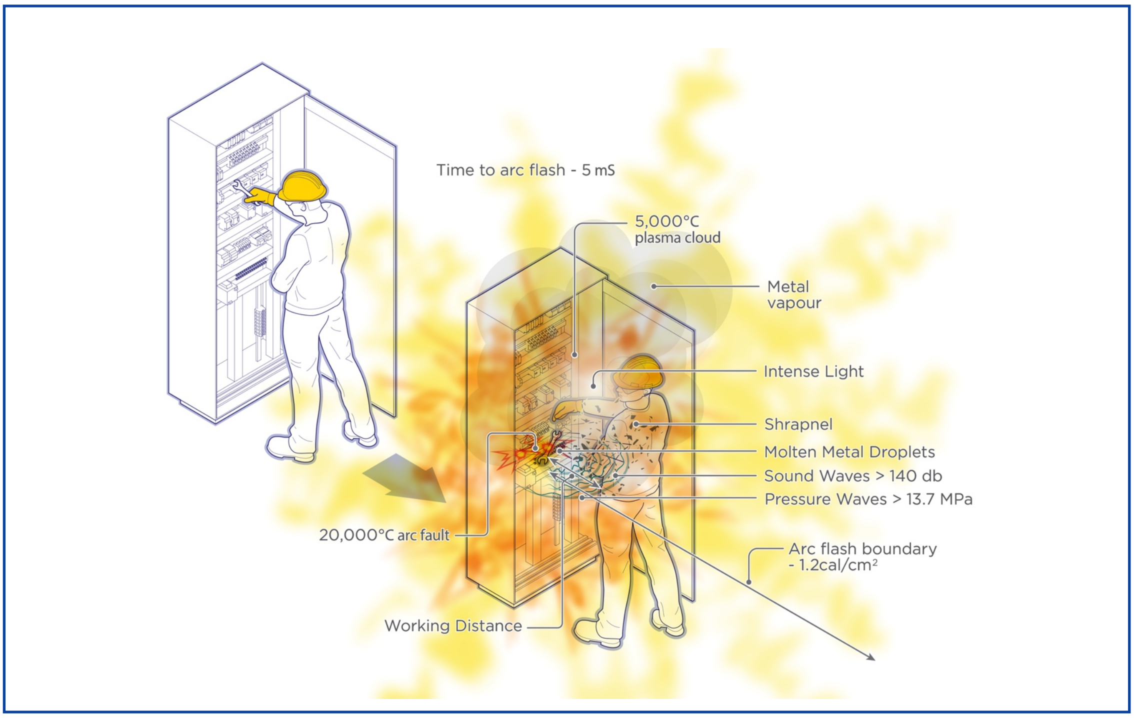


Figure: A2: Electrical work and arc flash (Modified from AEC, 2019; p. 5)

Arc flash water analogy

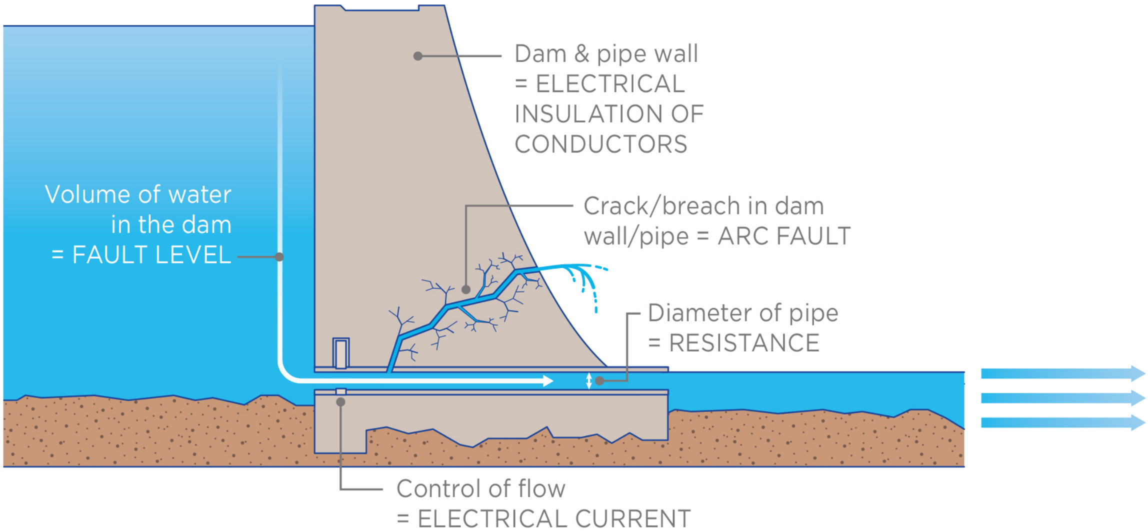
In the core chapter, Physical Hazards: Electricity, water was used as analogy to explain current, voltage and resistance. The dam of water analogy can be expanded for a basic description of arc flash. The depth of the water in the dam and the potential for it to push water through a pipe at the bottom of the dam wall was likened to voltage, the controlled flow of water out of the dam to electrical current, and the diameter of the pipe to electrical resistance.

The dam wall, and the walls of any pipes flowing out of the dam can be likened to the electrical insulation of conductors. Due to water pressure, dam walls need to be thicker towards the bottom; likewise, insulation needs to be greater for higher voltages.

If the pressure of the water in a pipe exceeds the pipe's strength, or if the pipe is weakened by damage, then the pipe might burst; it is even worse if this happens in the dam wall. The amount of water or electrical current flowing through the hole will depend on the size of the hole and the capacity of the dam. Likewise, the amount of current that flows in an electrical arc flash will depend on the capacity of the electrical system and any resistance to the flow of electricity.

Low dam walls or levies can contain much more water than tall tanks or deep walled dams in a narrow canyon. Likewise, low-voltage systems can have much higher potential fault currents than high-voltage systems.

In an arc flash, the air becomes ionised and changes from being a high-resistance insulator to a conductor with low resistance. This is the same as if a small hole causes the dam wall to burst. Quantifying how wet the village near the dam will get in the event of a wall failure is about as difficult as predicting how burnt a worker might get if exposed to an arc flash. Regardless, neither position is one that anyone wants to be in.



A3.4 Arc flash and nature of work

Arc flash can occur at most industrial workplaces but is commonly associated with electrical work. The model code of practice – *Managing Electrical Risks in the Workplace* (SWA, 2018) – defines electrical work as:

- connecting electricity supply wiring to electrical equipment or disconnecting electricity supply wiring from electrical equipment
- installing, removing, adding, testing, replacing, repairing, altering or maintaining electrical equipment or an electrical installation (p. 7).

If all electrical and other maintenance work could be carried out in a de-energised state, short circuits could not occur and therefore there would be no risk of arc flash as part of work. At times it may not considered practicable to de-energise equipment to carry out simple operations such as racking out circuit breakers or switching/operating equipment. Also, switching and proving that a part is de-energised exposes workers to arc flash hazards, as does other testing and fault-finding tasks (see section 5).

Electrical work typically involves three stages:

Stage 1: *Creating a safe work situation*

- Operating work for electrical isolation/de-energising, which includes switching and potentially racking circuit breakers in and out of service
- Verification of isolation
- Lockout/tagout

Stage 2: *Carrying out the work activity*

- Test-before-touch
- Electrical work tasks
- Pre-commissioning

Stage 3: *Restoration of equipment to operational status*

- Commissioning
- Operating/switching to re-energise equipment.

Arc flash may occur in stage 1 – during operating and switching and when verifying isolation; in stage 2 – during testing if the equipment has been re-energised; and in stage 3 – during operating and switching to re-energise the equipment. As contact is not necessary for injury to occur, any workers in the vicinity of live conductors/parts (and electrical installations generally) are at risk of exposure to arc flash. Arc flash risk also occurs in work where plant and lifting equipment are being operated near power lines.

Depending on the work task being undertaken, there is also the risk that an arc flash may occur beyond the normal boundaries of de-energisation. The tasks listed below are examples of higher-risk tasks that would generally require the entire switchboard, motor control center (MCC) or panel to be de-energised:

- The removal of fixed covers in electrical installations
- The removal or insertion of bolts or screws that enter blind holes in backplates or equipment-mounting plates
- Any drilling and metal work in electrical cabinets (except that on an open door where both sides can be seen)
- Disconnecting, pulling-in, terminating cables in compartments with exposed conductors or terminals
- Blowing out any of this equipment
- Any activity (except operating work) on any isolating device where the incoming side is still live
- Working on top of or above switchgear (from personal records of the author).

Electrician injured by arc flash in low voltage switchboard
In February 2018, an electrician went to install a new power supply in a wall-mounted, low voltage (415 V) switchboard to provide three-phase power for an electric motor. He removed the escutcheon panel from the front of the switchboard (which was still live) and, as he tried to remove an existing circuit breaker with a screwdriver, there was an arc flash.

The electrician received thermal burns to his face, upper body and hands. His assistant also received burn injuries and both workers were temporarily blinded. Both the electrician and his assistant required hospital treatment for their injuries.

DMIRS, 2018

Arc flash damage to the low voltage switchboard showing the isolator in the "On" position (A) and the circuit breaker that was to be removed (B).

It should also be recognised that arc flash hazards can occur when no work is being carried out on electrical equipment. Just the presence of a worker (e.g cleaner) in a switch room exposes the worker to risk of arc flash.

A4 Risk assessment

Risk assessments are usually undertaken by those doing the work, and arc flash risk assessment is a specialist activity requiring in-depth knowledge of the functioning of the equipment.[5] However, as with all risk assessments, arc flash risk assessment is best undertaken as a multidisciplinary activity involving specialist input, consultation with workers and contributions from other stakeholders to ensure that an understanding of the work, the workers and the context within which the work is occurring interfaces with other operations.

The generalist OHS professional has a role in ensuring that an arc flash hazard analysis and risk assessment is performed by competent persons (typically an electrical engineer or specialist electrician) and that it is performed according to recognised standards and

[5] For information on the technical approach to arc flash risk assessment, see 'Annex A: Arc Flash Risk Assessment and Control' in AEC (2019).

industry practice. In addition, a generalist OHS professional can add value and balance to the hazard analysis in an arc flash risk assessment, ensuring appropriate inquiry and clarification, particularly in the context of the hierarchy of controls. Consideration of how controls may fail and additional redundancy or layers of protection needed should be part of any risk assessment and to determine whether the risk has been eliminated or otherwise minimised So Far As Is Reasonably Practicable (SFAIRP).

The OHS professional should bring a critical analysis approach to the risk assessment, and ensure that 'people,' 'processes,' 'plant' and 'system' aspects are considered along with the technical aspects. Also, the OHS professional should ensure that arc flash risk is adequately considered in common risk assessment processes, including activity/task-based, project, site/operational and plant risk assessments.

Table A2 provides a brief summary of risk factors for arc flash categorised by occurrence and severity.

Table A2: Risk factors for arc flash

Occurrence	
Nature of work	• Most frequently associated with opening compartment doors on energised switchboards, fault finding and maintenance (Kowalski-Trakofler & Barrett, 2007) • Probability of occurrence higher in high-voltage work • Frequency of exposure higher for low-voltage work
Condition of equipment	Breakdown of insulation due to: • Aging of equipment • Electrical processes • Incorrect, or lack of, maintenance • Presence of foreign bodies such as tools or equipment • Environmental impact • Damage due to rodents or reptiles • Explosion or fire
Severity	

Energy	• Incident energy
	    ○ Low voltage often related to higher incident energy in the working position
	    ○ System configuration and equipment characteristics
	• Distance of worker from arc
	• Ignition of traditional cotton PPE

Duration of arc	• Often longer for low voltage than high voltage • Function of circuit breaker or fuse fault detection, and clearing time

Arc flash from foreign body (nut) creating circuit

A team of electricians was removing redundant electrical cables from a 440 volt switchboard at a Pilbara iron ore mine.

The task was to remove 'dead – non-energised' redundant electrical cables from the switchboard by externally pulling the cable out of the switchboard via the cable gland outlets. No contact or entry was required into the switchboard during this work and the switchboard busbars remained live during the cable pulling.

The switchboard door was opened to enable the apprentice electrician to observe and report on the cable removal and any obvious issues. Whilst the cable was being pulled out there was a loud bang a

The apprentice suffered burns to his face but his eyes were protected by his safety glasses…

A small nut found between two bus bars was the cause of the flash-over. It was determined that the nut had been left sitting free in the cabinet – some time previously (probably during construction) and had been dislodged when the cable was being pulled out of the cabinet [creating a contact across live terminals].

Power, 2106

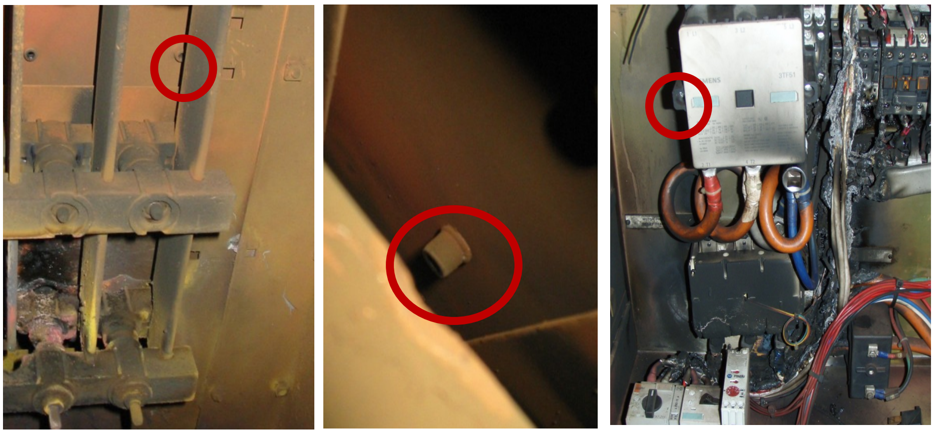
Equipment damage from arc flash in motor control centre

An electrician was changing a motor contactor of a motor starter module in a motor control centre at a raw materials handling facility. The module was isolated, verified and secured prior to opening the door. Test-before-touch was completed before work commenced with no live exposed terminals identified. The motor control centre was still energised, including the tier busbars behind the module being worked on.

In the process of changing the contactor, the electrician inserted a screwdriver into a blind threaded hole to check its depth. The screwdriver initiated a phase-to-earth arc flash, which went phase-to-phase across the busbars at the back of the board. The arc travelled down the bars until the ends of the bars. The arc flash continued for a prolonged period, melting the steel work and burning the control wiring inside the starter unit. Two of the 800 amp fuses supplying the motor control centre tripped, but the other fuse did not blow, and the fault continued as a single-phase fault. The fault eventually stopped when another electrician entered the smoke-filled room and opened the upstream combined fuse switch. The electrician was not injured, however the motor control required extensive repairs.

BlueScope Steel, 2008

Isolation for electric shock may not be sufficient to protect against arc flash. Traditional low-voltage protective devices might not detect arcing faults in time to prevent damage to equipment and injury to personnel. The arc travels away from the source of supply and the end of the busbars is where the damage occurs. The initial inspection reported that conductive dust on the busbar support was likely responsible for the flashover.



The red circle identifies where the arc flash initiated with the small scallop out of the busbar. The photos also show the damage, including molten steelwork copper busbars, and burnt control wiring.

A5 Legislation and standards

A5.1 Legislation

Arc flash can only occur in energised electrical equipment. The national *Work Health and Safety Regulations* (SWA, 2019) prohibit work on energised equipment, except under certain specified circumstances (*WHSR* ss 154, 157; SWA, 2019). The exclusions for working live are very limited and any decision to work on energised equipment should be informed by the caution in *Managing Electrical Risks in the Workplace: Code of Practice* (SWA, 2018, p. 42): "Electrical work must not be carried out on electrical equipment while energised for the reason of it being merely more convenient for the electrical equipment to stay energised while the work is being carried out."

The regulations require that processes are in place to ensure equipment is not inadvertently re-energised while the work is being carried out (s 156). Thus, from a legislative perspective, the risk of arc flash should be minimised by work only occurring on de-energised equipment.

However, the regulations (and safe work practice) also require that before electrical work is carried out, the equipment is tested to determine whether or not it is energised (s 155); such testing involves access to potentially energised parts with a risk of arc flash.

A5.2 Standards

There are a number of Australian and other standards that inform electrical work with a risk of arc flash. This range of standards can create confusion in application for electrical specialists and particularly for OHS professionals. The key standards are:

Australian/New Zealand standards:

> *AS/NZS 3000:2018 Electrical Installations* (known as the Australian/New Zealand Wiring Rules) (SA/SNZ, 2018)
> This standard includes direction on engineering controls to help prevent initiation and guidance on engineering mitigating controls to reduce damage from arc flash.
>
> *AS/NZS 4836:2011 Safe Working On or Near Low-voltage Electrical Installations and Equipment* (SA/SNZ, 2011)
> This standard includes basic electrical risk assessment information, electrical isolation methodology, selection of electrical safety tools and equipment, training and task-based PPE levels for different equipment based on the rating of the electrical supply. Since 2001, the standard has specified FR (flame-retardant) clothing for electrical workers.

AS/NZS 3007:2013 Electrical Equipment in Mines and Quarries – Surface Installations and Associated Processing Plant (SA/SNZ, 2013)
While a mining standard, AS/NZS 3007:2013 also references IEEE 1585-2018 and NFPA 70E-2018 for information on arc flash safety.

Australian industry standard:

ENA (Energy Networks Australia) *NENS 09-2014 National Guideline for the Selection, Use and Maintenance of Personal Protective Equipment for Electrical Arc Hazards* (ENA, 2014)
This guideline is referred to in *AS 2067:2016 Substations and High Voltage Installations* (SA, 2016) as a source of information for operational work. The guideline controls are independent of voltage and establish how arc-rated PPE should be constructed, and the minimum requirement for arc-rated clothing with an ATPV of at least 4 cal/cm^2 for all electrical work. The guideline also provides some direction on gloves, glasses, face shields, balaclava and hoods.

North American standards:

IEEE (Institute of Electrical and Electronics Engineers) *1584-2018 – IEEE Guide for Performing Arc-Flash Hazard Calculations* (IEEE, 2018)
Following the initial 2002 standard, this revision of the widely used calculation process for arc flash incident energy has added greater accuracy on the modelling of arc flash. This has come at cost of increased complexity in the calculations and the requirement for increased plant data.

NFPA (National Fire Protection Association) *70E-2018 Standard for Electrical Safety in the Workplace* (NFPA, 2018)
This standard was developed in recognition of the role of electricity in causation of building fires and burns to people. Although routinely updated every three years, it was only in 2015 that the standard referred to the hierarchy of control. The 2018 version aligns more closely with accepted Australian risk assessment processes. The standard introduced Hazard Risk Categories (HRCs) for selection of arc-rated PPE, and PPE is often labelled with these NFPA 70E-2018 Arc Flash PPE categories.

A6 Control of arc flash hazards

Ensuring electrical safety from arc flash requires layers of controls, or defences in depth that reflect the priorities in the hierarchy of control. While it is important to ensure individual arc flash scenarios are subject to expert technical assessment and control, the assessment and control of arc flash should also consider the broader systems, culture and context of an organisation. This section reviews the options for control of arc flash based on the hierarchy of control from the perspective of the OHS professional. It concludes with an overview of the resilience of controls and the role of the broader organisational systems and culture in maintaining the effectiveness of controls. Table A3 lists options for control of arc flash.

A6.1 Elimination

As noted in section A5.1, the national *Work Health and Safety Regulations* (SWA, 2019) prohibit work on electrical apparatus while the equipment is energised except in specified circumstances (*WHSR* ss 154, 157). Arc flash cannot occur in electrically de-energised systems, thus the priority for arc flash prevention must be a focus on working on equipment that is de-energised.

However, as demonstrated in a number of arc flash incidents, electrical systems can inadvertently become re-energised.[6] Thus ‘elimination’ of arc flash hazards through de-energisaton requires rigorous administrative controls, including safe systems of work to ensure maintenance of the de-energised state. There should be an emphasis on substitution to reduce the energy levels and on engineering to minimise the worker’s exposure, supplemented by administrative controls and appropriate PPE. These levels of control are also vital as switching to achieve de-energisation and testing for fault finding is ‘live’ work and so exposes the worker to risk of arc flash.

A6.2 Substitution

There are number of equipment design features available to electrical design engineers to reduce the incident energy in the case of an arc flash. These design features reduce the amount of short-circuit current associated with the electric arc and/or the duration of the arc.

A6.3 Engineering controls

Engineering controls reduce a worker’s exposure to arc flash by reducing the frequency of occurrence of arc faults or by creating a barrier between the electrical system and the worker.[7] Addressing arc flash hazards as a specific step in design reviews and management of change processes can ensure that new and modified plant and equipment is as safe as practicable.

[6] See core chapter, Physical Hazards: Electricity (section 8).

[7] The hierarchy of control category *Isolation* (as in separating the worker from the hazard) is not used in discussing control of electrical hazards as it can be confused with the procedure of electrical isolation.

A6.4 Administrative controls

Administrative controls include hazard awareness, training and competency, and procedures.

Trained, competent and authorised workers are an essential component in minimising arc faults and so managing the risk of arc flash, as is effective and knowledgeable supervision. Personnel working on or near electricity must understand the hazards that may be present around electrically energised equipment, the required controls and the emergency response should an arc flash incident occur. Worker awareness requires hazard warning/labelling to indicate the arc flash boundary and/or a requirement for appropriately rated PPE. There is no Australian standard for signing of arc flash hazards, but guidance is provided in 'Annex C: Do's and Don't's of Arc Flash Labelling' of AEC (2019).

Safe work systems include effective permit-to-work systems, lockout/tagout and pre-start briefings. Identification and analysis of safety critical tasks and development of safe working procedures for critical tasks are vital in managing arc flash risk, but should not be a default in lieu of controls higher in the hierarchy of control.

Electrical testing of power board – risk assessment, trained and authorised workers

Campbell v Simec Zen Technologies (Power and Energy) Pty Ltd

South Australian Employment Tribunal, 31 October 2018

Zen Technologies (Power and Energy) Pty Ltd (the defendant) *conducted the business of providing renewable energy solutions.* Two of the defendant's employees, a senior employee and an apprentice, attended at a manufacturing worksite *to measure energy consumption and make an assessment as to a suitable energy storage system with a view to* [the company] *going off grid.*

At this time, one of the employees was working on a Restricted Electrical Workers Registration. Unbeknownst to either employee, *connecting or installing power monitoring equipment to an energised or live electrical board (which is fixed wiring) was clearly outside the scope of the restricted license…The distribution board was alive and power was still connected. Access was constricted and* [the apprentice] *was required to shine his phone torchlight on the area to enable* [the other employee] *to see to connect the power analyser to the distribution board.*

In the process of attaching power analyser test equipment to a live electricity board…an electrical arc occurred and [the senior employee] *was seriously injured. He suffered burns to his hands, arms and superficial burns to his face…He remains in constant pain and has been diagnosed as suffering from post-traumatic stress disorder...Due to the proximity to the incident,* [the apprentice] *was also exposed to a risk of serious injury or death, but was not seriously injured.*

The defendant pleaded guilty to breaching Sections 19 and 32 of the *Work Health and Safety Act 2012* (SA) in exposing workers to the risk of death or serious injury. The defendant failed to ensure, so far as reasonably practicable, the provision and maintenance of safe systems of work, including failure to:

- *undertake adequate hazard identification and risk assessment in relation to measurement of* *electrical consumption by use of a power analyser…*

- *have in place any or adequate documented safe work procedures…*
- [ensure the wearing of] *personal protective clothing (PPE) appropriate for the task.*

SAET Deputy President Magistrate Michael Ardlie accepted the defendant's remorse and corrective actions, as well as its early plea of guilty (entitling it to a reduction in penalty of up to 40%), convicting the defendant and fining it $114,00, plus costs of $1326.

South Australian Employment Tribunal, 2018

A6.5 Personal protective equipment (PPE)

Although the least preferred control for electrical work, PPE is a critical part of the safe system of work, including when performing isolation verification and testing for dead protocols. Appropriate PPE is especially important for arc flash.

Inappropriate PPE can increase the severity and surface area of the burns from arc flash. When exposed to arc flash, synthetic materials can ignite and melt onto the worker. Cotton PPE is also flammable; once cotton PPE starts to burn it will continue until the flames are extinguished or the material is completely burnt.

Materials that have been tested and the arc thermal protective value (ATPV) determined are deemed arc-rated (AR) materials. As the process used to test clothing focuses primarily on radiated heat, the testing does not include the real-life exposure to the plasma cloud from an arc flash. The latest empirical standards, including ENA NENS 09-2014 and IEEE 1584-2018, predict incident energy exposures up to three times higher than the previous radiant-heat-only models.

Flame-retardant (FR) materials are subjected to different testing and, while arc-rated materials are flame retardant, not all FR materials are arc rated. Arc-rated PPE is often described in terms of its PPE category rating.

As indicated in section A5.2, there are three standards that set out PPE requirements related to arc flash, two Australian and one North American:

- *AS/NZS 4836:2011 Safe Working On or Near Low-voltage Electrical Installations and Equipment* (SA/SNZ, 2011)
- *ENA NENS 09-2014 – National Guideline for the Selection, Use and Maintenance of Personal Protective Equipment for Electrical Arc Hazards* (ENA, 2014)

- *NFPA 70E-2018 Standard for Electrical Safety in the Workplace* (NFPA, 2018).

Each standard takes a different approach to specifying PPE requirements, with varying levels of complexity in the assessment underpinning the specification and varying levels of resultant protection. Under NFPA 70E-2018, appropriate PPE for arc flash protection is determined by an arc flash analysis for each installation. These analyses consider the type of equipment and the voltages to define the arc flash protection boundary and the Hazard Risk Category (HRC) that determine the level of PPE required. Arc flash analyses are conducted by electrical specialists with the methodology defined by standards such as NFPA 70E-2018 and IEEE 1584-2018.

Table A3: Control options for arc flash

Control category	Examples of controls
Elimination	Work de-energised (supported by safe systems of work and other controls to ensure maintenance of de-energised state)
Substitution	A comprehensive arc flash hazard analysis can enable protection settings to be set to sense and trip circuit breakers to, in the shortest possible time, dramatically reduce the potential incident energy. Engineered controls to reduce/limit energy levels may include: • Zone-selective interlocking • Differential relaying • Current limiting devices • Energy-reducing switching for maintenance purposes • High-resistance grounding (NFPA, 2018,) • Substituting isolation verification testing on high-fault-level conductors with low-fault-level test points.
Engineering	Engineered controls to protect the worker and/or separate the worker from the energy include: • Remote metering, switching and racking of circuit breakers • Inspection windows for non-contact inspection • Disconnects located within easy sight and access • Finger-safe components, covers and insulating barriers to reduce exposure to energised parts (NFPA, 2018) • Error-tolerant designs (e.g. integral guarding to prevent arc caused by dropped tools) • Use of insulated tools such as screwdrivers • Arc blast containment systems • Enclosure/cabinet design that accommodates arc venting to dissipate a potential arc blast (pressure and heat) away from the worker • Optical sensors for arcing fault detection • System design that facilitates safer maintenance (e.g. withdrawable functional units that can be isolated, removed, maintained and tested away from the switchgear) • Design where cable entries are sealed to prevent pests and dust ingress

Control category	Examples of controls
	• Engineered thermography ports that can be used online without removing switchboard covers instead of fixed panels on switchgear that need to be removed

Administrative controls	• Electrically aware workers
	  ○ Appropriate signage for arc flash hazards including incident energy levels, arc flash protection boundaries and required PPE
	  ○ Training for non-electrical workers on not undertaking work for which they are not authorised
	• Trained, competent and authorised electrical workers[8]
	  ○ Defined performance criteria for competency
	  ○ Assurance systems for monitoring effectiveness and currency of training
	• Knowledgeable, effective supervision with accountability
	• Safe work systems
	  ○ Permit-to-work systems
	  ○ Lockout/tagout
	  ○ Pre-start briefings
	  ○ Identification and analysis of safety critical tasks and development of safe working procedures for critical tasks
	  ○ Access authority systems to ensure only trained, competent and authorised workers access hazardous areas
	• Procedures and instructions for electrical work that:[9]
	  ○ Specifically identify arc flash hazards
	  ○ Minimise exposure by working de-energised where practical
	  ○ Address interactions with other work groups where differing work priorities may increase arc flash hazards.
	Other administrative controls for arc flash include:
	• Rigorous arc flash hazard studies that are maintained, up to date and reflective of system design modifications
	• Preventative maintenance, effective testing, online monitoring, and diagnostics of systems (e.g. temperature monitoring / heat mapping, arc flash vent testing, etc.)
	• Workplace inspections to identify any 'housekeeping' issues that may lead to breakdown of insulation or foreign bodies left in electrical installations
	• Electrical asset design specification and verification processes to optimise inclusion of risk control design features
	• Re-arranging switching operations to allow for racking onto de-energised switchboards.

PPE	• For all electrical workers, minimum PPE that provides:
	  ○ Full-body coverage for a range of user body positions (e.g. bending, reaching up, arms out stretched, or squatting)
	  ○ Protection for the torso, neck, arms to the wrist, and legs to the ankles.
	• For work with risk of arc flash:

[8] See AEC (2019) section 6 for discussion of competency requirements for working on/around electrical arc flash hazards.
[9] See *OHS BoK* 11.4 Rules, Procedures and Documentation.

Control category	Examples of controls
	○ Arc-rated protective clothing ○ Rated protective gloves/gauntlets ○ Head, face and eye protection ○ Hearing protection.

A6.6 Resilience of controls

The preceding discussion of controls demonstrates a number of options at each level of the hierarchy of control. However, each arc flash incident is an example of a failure in one or more controls, often with serious consequences. Such failures may occur for a range of reasons, including technical hardware failure, procedural or human error, or deeper system-level or organisational factors. Resilience of controls requires an environment that actively supports the controls together with an assurance process that not only provides information on the effectiveness of the controls, but also a framework for ensuring their implementation.

While the following discussion of the organisational context and critical control management can apply to most critical risks, it is important that it is part of the discussion on the management of arc flash risk.

A6.6.1 Organisational context

The organisational context will impact the extent to which the controls for arc flash are implemented and maintained. The organisational context includes:

- Organisational culture (what managers pay attention to)
- Organisational financial and business priorities
- Management structures and systems
- Local work-group culture (personal relationships and support processes).

Examples of the impact of organisational context on implementation of arc flash controls are listed below.

Table A4: Examples of impact of organisational context on implementation of arc flash controls

Control category	Examples of organisational impact
Electrical design and engineering controls	• Awareness of importance of engineering controls by decision-makers • Preparedness to invest in new/upgraded equipment
Trained and competent workers	• Selection and recruitment priorities • Apprentice management and mentoring processes • In-house training and competency-assurance processes
Supervision	• Selection, training and support for supervisors
Procedures	• Development process and authority, based on work-as-done (WAD) rather than work-as-imagined (WAS) • Worker awareness and understanding of procedures • Recognition of potential for normalisation or drift (into failure) of non-compliance • Proliferation of procedures inhibiting recognition of critical actions and situational awareness in changing circumstances • Workplace culture related to compliance based on learning rather than blame • Management of work pressure and work relationships • Fatigue management
PPE	• Awareness of required and appropriate PPE • Availability of required PPE • Maintenance arrangements for PPE • Promotion and support creating a culture of wearing required PPE

A6.6.2 Critical control management

A reliance on procedural controls creates a high residual risk in many arc flash management processes. Given the severity of potential consequences of arc flash incidents, lessons learned from the mining and chemical industries on critical controls could be applied to increase resilience of arc flash risk controls.

A *critical control* is one “that is crucial to preventing the event or mitigating the consequences of the event” (ICMM, 2015, p. 5). A key component of critical controls is the critical control management process (CCM) to ensure their integrity. A CCM includes:

- Defined performance criteria for the controls
- Assigned accountability/ownership of the controls
- Verification and reporting on critical control implementation and ongoing status (ICMM, 2015).[10]

[10] See ICMM (2015) for more information on critical control management.

With these three elements, CCM goes beyond the concept of auditing to create a rigorous framework for ensuring the integrity of controls for critical risks such as arc flash.[11]

A7 Implications for OHS practice

As noted in several sections of the core chapter Physical Hazards: Electricity and in this appendix, electrical work and particularly the management of arc flash, is a specialist area. Arc flash specialists (mainly electrical engineers and electricians) have specialist knowledge of the technical characteristics of electrical installations, the assessment of such installations, and the arc flash risks present. Such specialists have the major responsibility for understanding and defining the magnitude of the arc flash risk and the measures required to mitigate the risk.

Generalist OHS professionals have an important complementary role in bringing a broader systems approach to the control of arc flash that takes account of the overall OHS management system, the organisational culture and the implications for how the work is performed. They should be mentoring supervisors and managers on their role in implementing and maintaining rigorous controls for arc flash. The chapter Physical Hazards: Electricity referred to this role as the 'black hat' or the devil's advocate, involving asking questions to ensure a critical analysis approach to arc flash risk assessment and control.

To fulfill this role, generalist OHS professionals require a basic understanding of the causation and standard controls for arc flash, including an awareness of the heavy dependency on the human element/factors involved in many electrical testing and commissioning environments within industry, in particular those with ageing electrical installations. Also, OHS professionals need to contribute their broader knowledge of systems,[12] and specifically OHS management systems,[13] and the impact of organisational culture[14] to the development of risk controls and the monitoring of their effectiveness. Knowledge of current research and thinking relevant to the role and use of rules and procedures as controls in high-risk environments is important here.[15] Where the OHS professional has an opportunity to contribute at the design phase, knowledge of the role of the OHS professional in supporting design specialists is important.[16]

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[11] See also *OHS BoK* 34 Prevention and Intervention (section 3.7).

[12] See *OHS BoK* 11.1 Systems.

[13] See *OHS BoK* 11.2 OHS Management Systems.

[14] See *OHS BoK* 10.2 Organisational Culture.

[15] See *OHS BoK* 11.4 Rules, and Procedures.

[16] See *OHS BoK* 34.3 Health and Safety in Design.

In the chapter Physical Hazards: Electricity, Figure 9 is a tool designed to support OHS professionals in their role related to job planning and in mentoring supervisors and managers. The system factors listed in section 10 of the core chapter also apply to arc flash.

The OHS professional should have sufficient knowledge to be mindful of the risk of arc flash in situations where electrical specialists may not be available, where arc flash hazard analysis has not been performed, and where the characteristics and/or electrical design of the system may not be well known or documentation and data not readily accessible. In such cases, the OHS professional should have the authority and capability to identify and engage appropriate specialists.

An animated video of a high-voltage flashover (AngloAmerican, 2012) provides an interesting example of the broader organisational and system factors for arc flash risk when viewed from the perspective of the generalist OHS professional. Based on this video, a generalist OHS professional drafted the scenario below then developed a list of factors that may have impacted on the decision-making leading up to the event. While this analysis could be open to discussion, it shows the broader perspective that can be brought by the generalist OHS professional to prevention of arc flash and reduction of arc flash risk.

Scenario summary – arc flash incident

Two electricians were doing routine maintenance on coal mine equipment powered from a 22,000 volt system. They obtained the required permits and followed procedures for the work. On completion of the scheduled work, they were unable to close the isolator. After several unsuccessful attempts, they advised the supervisor and went home. They were called in during the night, but could not close the isolator.

The next day, further attempts to close the isolator revealed that the switch mechanism in the isolator was faulty, but there was no replacement switching mechanism in the store. The supervisor instructed the electricians to remove the switching mechanism in the hope that it could be repaired. However, there was no procedure for removing the switching mechanism; the manufacturer's manual did not refer to removing the switching mechanism and a telephone call to the manufacturer's agent did not result in any relevant information. An internet search also failed to locate any relevant procedural information.

Eventually the switching mechanism was removed and it was found that an actuating spring was damaged and could not be repaired. The supervisor then instructed the electricians to remove an isolator from another part of the plant. However, in removing the second isolator, the actuating springs lost tension, making the isolator unusable. It was then decided to remove an isolator from a third unit. This time they used an improvised method of drilling and tapping to hold the springs in place during removal. They then did a verbal Take 5 and decided not to apply for an HV access permit as they would not be entering an HV cabinet.

Having turned the crank lever to isolate the system, the springs were drilled and tapped to hold them in place. However, the electricians were prevented from removing the switching mechanism by a mechanical interlock on the inside of the cabinet. They removed the cover to get at the interlock and used an improvised non-contact testing technique to check for HV; this indicated no HV present, but a hand-held digital multimeter revealed 20 volts, which they assumed was residual voltage and no threat. Assuming it safe to proceed, they defeated the mechanical interlock and removed the switching mechanism.

In reassembling the isolator, the electrician reached into the cabinet to reassemble the interlock and his sleeve brushed a live HV contact (which had been assumed dead), creating a phase-to-phase contact; this resulted in an arc flash that caused serious injury to both electricians.

On investigation, it was found that turning the crank lever separated the contacts, but when the switching mechanism was removed the contacts descended with gravity to close the circuit and the system became live.

AngloAmerian, 2012

Possible contributing factors to the AngloAmerican (2012) arc flash incident:

- The equipment was not designed to be fail-safe
- The overriding of a protective interlock indicated a lack of awareness of the importance of such devices or a work culture that allowed such action
- The electricians did not appear to understand how the equipment operated and so when they improvised in the absence of procedures they did so without understanding the implications of their actions
- Their decision to use an improvised procedure may have been influenced by their lack of sleep (they were called into work during the night)
- There may have been pressure to get the isolator fixed so the production unit could come back on line
- The electrical supervisor also appears to have not understood the implications of the improvisation and may have been under similar pressure from production.

A8 Summary

This appendix to the chapter Physical Hazards: Electricity addresses the specific electrical hazard of arc flash. While statistics on injuries from arc flash are patchy, it is known that in 2018, six separate arc flash incidents resulted in the hospitalisation of six workers and the death of a man. While commonly associated with electrical work, arc flash risks are present in all workplaces.

Electrical arcs occur when a gas is exposed to a voltage greater than its insulative properties. The arc initiates when the voltage is sufficient to ionise the air across the gap between conductors. Once ionised, the gas becomes a good conductor, allowing current to flow. The heat from the electrical current causes the ionised air to rise, resulting in the arched shape of the current giving the phenomenon its name. Arc fault is the unintended discharge of electrical energy which can result in:

- An arc flash with high temperatures, blinding light and deafening noise
- Arc blast, which is a high-pressure wave that can eject molten metal and shrapnel
- Toxic smoke.

Arc faults are caused by inadvertent contact or failure of insulation, and can occur in both low-voltage and high-voltage systems. Risk factors derive from the nature of the work, the condition of the electrical equipment/installation, the amount of energy created by the short circuit and the duration of the short circuit.

The controls for arc flash must address the hierarchy of control and specifically focus on arc flash as controls for electric shock do not always provide protection for arc flash. Working on equipment that is de-energised must be the highest priority, however layers of control are essential as fault-finding as well as isolation procedures to achieve de-energisation require working on live equipment. Also, safe systems of work are required to ensure maintenance of a de-energised state throughout the work.

Design of equipment is increasingly important, including energy-limiting features (substitution) and engineering controls to create barriers between the worker and the energy as well as error-tolerant designs. In practice, arc flash risk control tends to place a heavy emphasis on work procedures and PPE. All electrical workers should wear, as a minimum, full-body covering, with workers potentially exposed to arc flash wearing arc-rated clothing, gloves/gauntlets and head, face, eye and hearing protection. Considering the potential severity of the consequences of arc flash, a critical control management approach should be applied to optimise the resilience of the controls.

While arc flash risk assessment and risk control is a specialist function, the generalist OHS professional has an important role in bringing a broader systems approach that considers the organisational and operational context in which the work is being done. Figure A3 summarises the work situations, consequences and range of controls for arc flash.

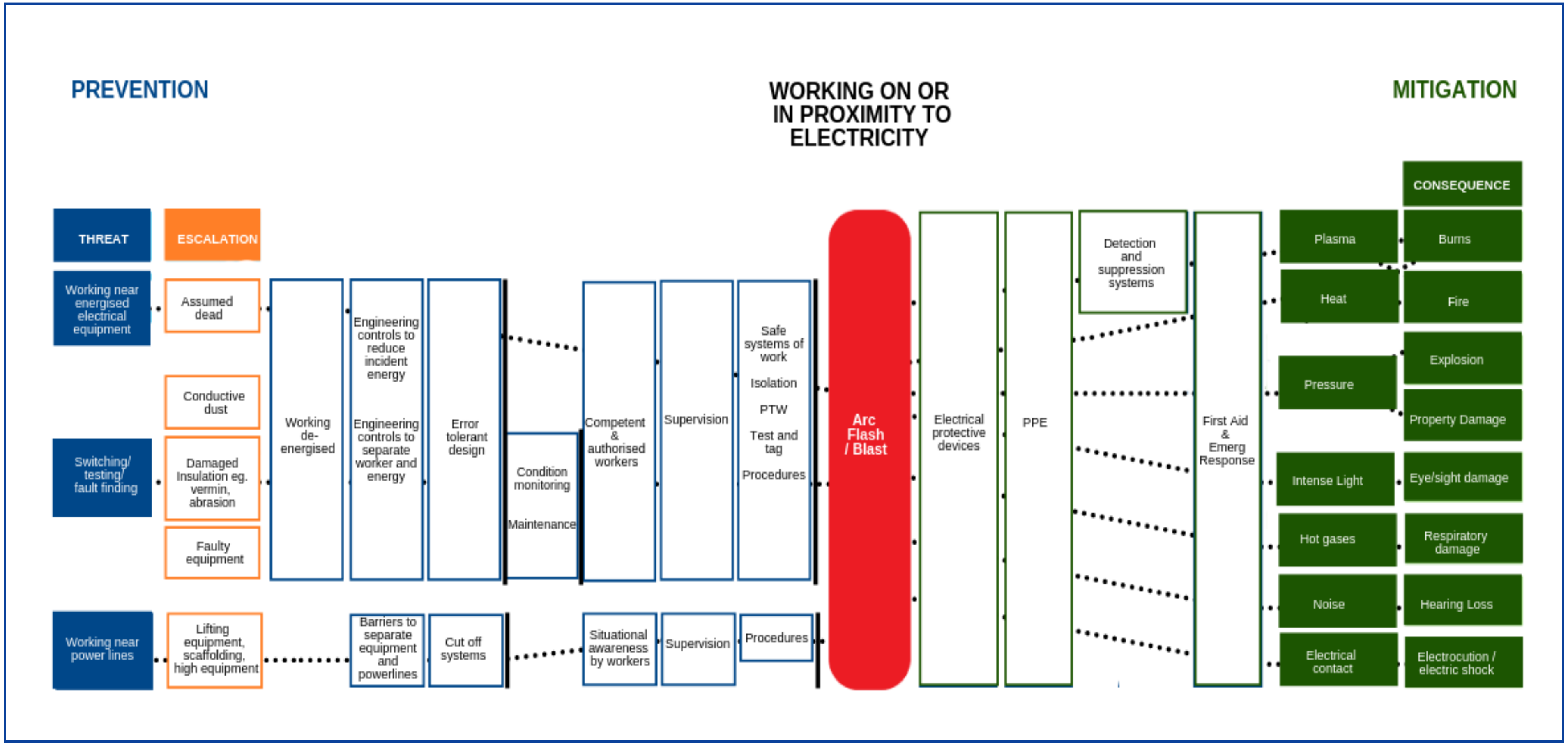

Figure A3: Prevention and mitigation of arc flash hazards

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