Electricity

Core Body of Knowledge for the Generalist OHS Professional

Second Edition, 2019

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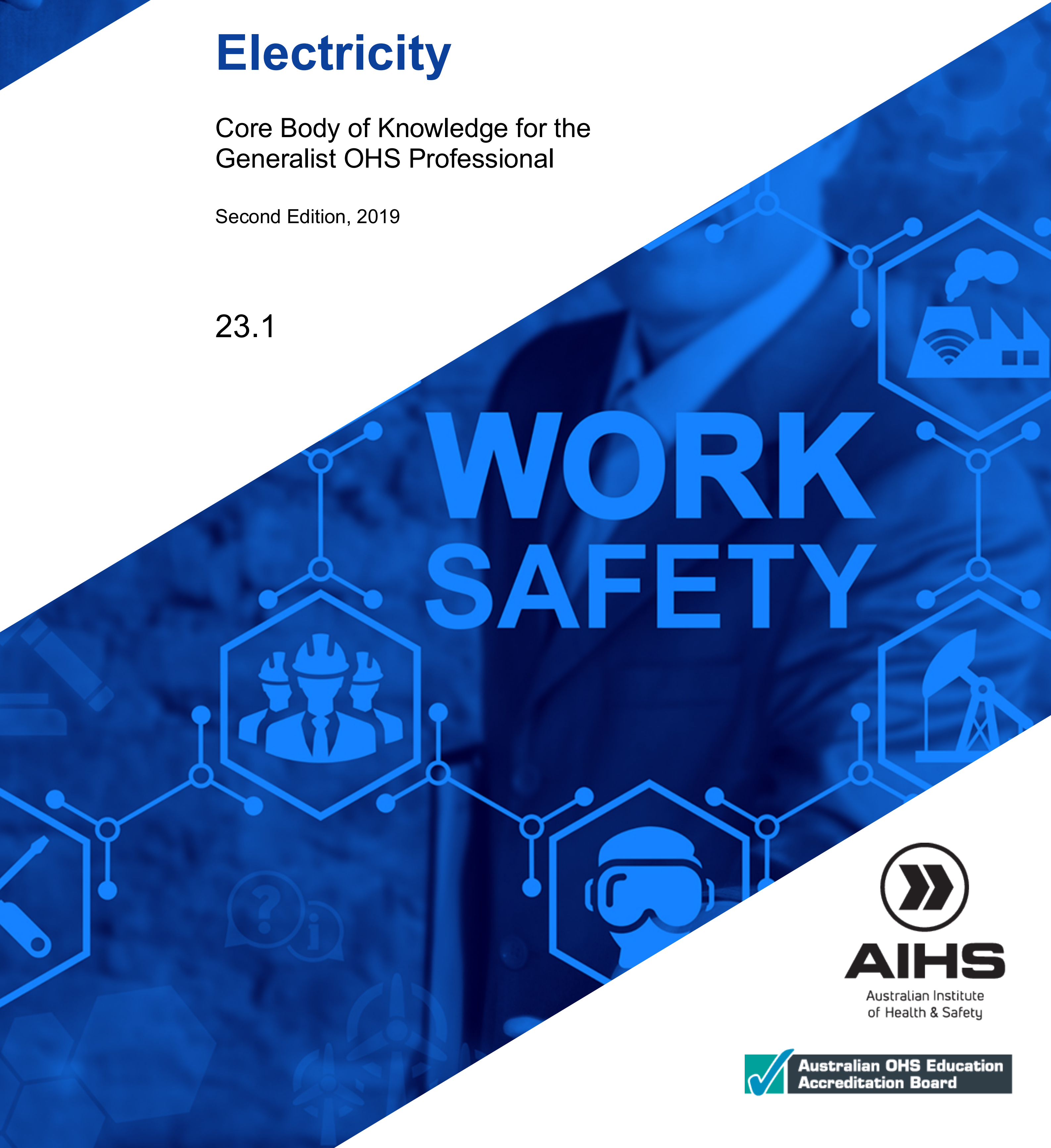

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The Manager, OHS Body of Knowledge
Australian Institute of Health and Safety, PO Box 2078, Gladstone Park, Victoria, Australia, 3043
Manager@ohsbok.org.au

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Author
Leo Ruschena, Senior Lecturer, RMIT University

Peer reviewers

Stephen Kuehn, Principle Engineer, Escape Technologies

Steve Gambrill, OHS Manager, Eraring Energy

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Author
Leo Ruschena, Chair of the Australian Institute of Health and Safety (AIHS) College of Fellows Policy Committee

Peer reviewer

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

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Electricity

Leo Ruschena MSc, MIER, BEng, BEcon, GradDip OrgBeh, ChOHSP

Leo retired as a Senior Lecturer in OHS from RMIT University (2003 – 2018). He is currently Chair of the Australian Institute of Health and Safety (AIHS) College of Fellows Policy Committee, and on the OHS Body of Knowledge Advisory Panel. Prior to his tenure at RMIT, Leo held executive HR/OHS roles in WorkSafe Victoria and in the electricity industry in Victoria and the ACT. He has a particular interest in the strategic involvement of health and safety to improve organisational effectiveness.

Content Editor

Pam Pryor AO BSc, BEd, GDOHM, MAppSci, ChOHSP, CFSIA

Manager, *OHS Body of Knowledge* Development

Email: manager@ohsbok.org.au'

Topic Specific Technical Panel

Pam Pryor	Manager *OHS Body of Knowledge* Development
Effie Eleftheriadis	OHS Manager, CYP Design & Construction Joint Venture
Scott Fisher	Group Manager, Zero Harm Risk
Kelly Lovely	Program Manager, AGL
Chad Pettitt	Lead Consultant, Aussafe
Mitch Pritchard	Electrician Ash & Dust L Shift, Vice Chair Person WHSE Committee – Liddell Power Station, AGL Macquarie
Leo Ruschena	Author
Dev Sharma	Electrical Engineer, AGL

Consultative Focus Group

Sydney, 4th May, 2019

Joe Borg	HSE Manager	Optus
Mathew Lean	Assistant State Inspector	SafeWork NSW
Darren Jenkins	Senior Electrical Safety Specialist	Ausgrid
Michael Johansen	Work Practice Analyst	Endeavour Energy
Brett Cleaves	Director	Engineering Safety
Anthony Baerwinkel	Electrical Safety Manager	Endeavour Energy
Daniel Daoud	State Inspector Electrical	SafeWork NSW
Jim Tzakos	Inspector	SafeWork NSW
Cameron Stevens	Head of Safety	Oil Search Limited
Simon Lyster	Regional Risk Manager	Scentre Group
Bill Manns	Group Manager Health & Safety	Zinfra
Peter Mc Intyre	GM EHS & Q	
Roger Fairfax	WHS Coordinator	Seventh Day Adventist Church
Barry Silburn	Consultant	

Peer reviewer

Vanessa Garbett	Team Leader, Electrical Installation Safety	Energy Safe Victoria

Electricity

Abstract

Electricity, present in all workplaces, kills a significant number of workers every year. Most of these fatalities occur outside the electricity supply industry. Effective control of electrical hazards needs to consider the nature of the work and the exposure, and include appropriate controls for electrical workers outside the electricity supply industry and for non-electrical workers. While control of electrical hazards requires specialist knowledge, the generalist Occupational Health and Safety (OHS) professional has a vital role in stimulating critical analysis to ensure electrical safety is effectively integrated into an organisation's OHS management system and risk management processes for both electrical and non-electrical workers. To deliver on this role, the OHS professional should understand the basic physics of electricity and how electricity causes injury and death, the regulatory framework, standard controls for both electrical and non-electrical work, and how the controls might fail. This chapter and an appendix addressing the high-risk event of arc flash present this information from the perspective of the generalist OHS professional.

Keywords

electricity, electrocution, voltage, burns, induction, arc flash, safety, control

Contextual reading

Readers should 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 while Chapter 3, *The OHS Professional* provides a context by describing the role and professional environment.

Terminology

Depending on the jurisdiction and the organisation, 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 reference to the Work Health and Safety (WHS) Act and related legislation.

Jurisdictional application

This chapter 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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1 Introduction

The paradox of electricity is that modern civilisation has become totally dependent on the continuous and increasing availability of one of the most lethal physical agents that a human can contact. Industry and community demands for higher levels of power and consistency of supply are increasing the exposure of workers to electrical hazards and the potential severity of consequences of an incident. Although it can be a powerful servant, electricity must be tightly controlled as a critical risk.

Safe Work Australia has published a model code of practice for managing electrical risks in the workplace (SWA, 2018) and specific guidance (e.g. SWA, 2014a, 2014b, 2016a). This chapter presents information specifically targeted at generalist Occupational Health and Safety (OHS) professionals to enable them to better understand the nature of electricity and how it can harm the human body, and the legislation and standards relevant to electrical safety. It considers the different work roles, exposures and controls for non-electrical workers and for electrical workers working outside the electricity supply industry. This knowledge will enable OHS professionals to assist line personnel in managing risks associated with electrical plant and working in proximity to such installations, and others who may inadvertently interact with electricity. The chapter does not encompass specialist knowledge required by OHS professionals working in electricity supply, including generation, transmission and distribution.

The relevance and importance of electrical safety to generalist OHS professionals is supported by electrical incident data. In the ten years, 2008-09 to 2017-18, 156 people across Australia and New Zealand died as a result of electrical incidents (ERAC, 2018). Eighty percent of these fatalities were work-related; of these, 19% were non-electrical workers and 50% were electrical workers (excluding electrical supply industry workers), with less than 1% electrical workers in the supply industry (ERAC, 2018).

2 Historical perspective

With the advent of the electric light bulb and electric motors in the late-18th and early-19th centuries came the realisation that electricity can cause fires and kill people (Littelfuse, 2005). The history of electrical safety devices includes: attribution of the first ‘fuse’ to Thomas Edison “using a wire between two terminals that would melt if too much current flowed through it;” Edison and George Westinghouse arguing over “the relative benefits and dangers” of direct current and alternating current; and Westinghouse’s “better plan for generating and distributing electrical energy over long distances at higher voltages and then transforming it to lower usable voltages [that] began the need for increased electrical construction and safety standards” (Littelfuse, 2005, p. 16).

The development of electrical standards was driven by an insurance industry concern about fire hazards (Littelfuse, 2005). The 1890s saw the advent of the first crude circuit breakers, and, in the 1940s, current-limiting fuses (precursors of the 'safety switch') and a voltage-presence testing device were developed (Littelfuse, 2005). These 'engineering' controls were supported by the development of procedures and codes; the first National Electrical Code was established in 1897 in the US, and the *American Electricians' Handbook* was published in 1913 (Littelfuse, 2005).

Despite the existence of such controls and guidance material there was little improvement in electrical safety until the concept of a 'safety switch' evolved in the 1950s and the differential current-operated earth leakage circuit breaker (ELCB) was developed. As there was often confusion between voltage ELCBs (which did not protect the user) and differential current-operated ELCBs, the International Electrotechnical Commission renamed the latter Residual Current Devices (RCDs). RCDs have been mandatory on all power and lighting circuits in new houses in Australia since 1991 and are required by legislation for some types of work sites.

3 Extent of the problem

Collating Australian accident statistics on electrical incidents is difficult as data collection is often inconsistent across jurisdictions. Based on data collected by the Electrical Regulatory Authorities Council for Australia and New Zealand (ERAC):

- In the ten years 2008-09 to 2017-18, 124 workers died in electrical incidents in the workplace (excluding electrical supply workers) (ERAC, 2018; Table 1)
- Since 2001, electrical deaths have trended downward in Australia, both in absolute numbers and in the three-year moving average per million population (ERAC, 2018)
- Of six deaths involving consumer installations or equipment in 2016-17:
    - two related to misuse/interference with equipment or wiring
    - two related to failure or deterioration of equipment or wiring
    - one related to work practice (ERAC, 2017).

Table 1: Workplace electrical fatalities, Australia and New Zealand 2008-09 to 2017-2018 (ERAC, 2018, p. 8)

	Non-electrical workers	Electrical workers	Electrical supply workers
2008-09	8	5	1
2009-10	12	15	0
2010-11	5	17	1
2011-12	5	8	0
2012-13	1	8	1
2013-14	4	5	1
2014-15	0	8	0
2015-16	5	7	0
2016-17	5	4	0
2017-18	1	1	0
Total for category of worker	46 (36%)	78 (61%)	4 (3%)
Total workplace		**128**	

The ERAC dataset emphasises electricity as a hazard with potentially fatal outcomes, however it does not include workers who receive non-fatal injuries in an electrical incident. While there is no standardised national data collection for non-fatal electrical incidents, Western Australian data give an indication of the prevalence. In Western Australian workplaces during the ten-year period 2007-08 to 2016-17, there were:

- 7 workplace-related electrical fatalities
- 104 non-fatal electrical accidents where the worker required hospitalisation or medical treatment
- 5275 reported workplace electric shocks not requiring treatment (DMIRS, 2017).

4 Understanding electricity

Working safely with electricity requires a basic understanding of the underlying physics, how electricity is distributed, the physiological impact of electricity on the human body, and the nature of electrical injuries. This section reviews the nature of electricity and the electricity distribution system while section 5 briefly addresses health and injury outcomes associated with electricity.

4.1 The nature of electricity

Electricity involves the flow of electrons through a conductor caused by an electromotive force (EMF). The movement of electric charge is known as an electric current and the intensity of the current is measured in amperes (or amps). The symbol for current is I (for 'intensity'). Current can be either direct current (DC) or alternating current (AC). Direct current flows in one direction only (e.g. the flow of current from the negative to positive terminal of a battery). Alternating current reverses direction generally in a sinusoidal form, with a specific frequency. In Australia, distributed AC oscillates at a frequency of 50 hertz.

The movement of current through a medium depends on the resistance of the medium to the flow of current and the electrical force or potential across the medium. Electrical resistance of a material is measured in ohms (Ω). Materials that have a high resistance are termed non-conductive or insulative (e.g. glass of 1 cm^2 cross section and 1 m length has a resistance $>10^{14}\Omega$), and those that have a low resistance are termed conductors (e.g. copper of 1 cm^2 cross section and 1 m length has a resistance of $1.68 \times 10^{-4}\Omega$). All materials conduct electricity to some extent. Table 2 lists some common conductive and generally non-conductive materials.

Table 2: Examples of conductive and non-conductive materials

Conductive materials	Non-conductive materials
Metals such as copper, aluminum, steel Steel poles Concrete reinforced poles (through the metal reinforcing) Ladders with metal reinforcing Metal fences Water Green timber Fire, smoke, flame Polluted air People	Glass Porcelain Very dry timber Plastic Polycarbonate Rubber Clean, dry air Some non-conducting materials such as wood and rubber can become conductors when wet.

The electromotive force, or electrical potential measured in volts across the medium, causes the current to flow. For a given conductor (material, cross section and length), the higher the voltage, the higher the current flow. If the potential is high enough, an insulating medium (e.g. air) can break down to allow current to flow, as in an electrical arc.

Current, voltage and resistance are connected through Ohm's Law as follows:

V (voltage in volts) = I (current in amps) x R (resistance in ohms)

Power (measured in watts) is the product of voltage and current; it is used to rate the capacity of a circuit (e.g. wires, fuses):

P (power in watts) = V (volts) x I (amps)

Voltage is usually described as extra low, low, high or extra high (Table 3). Recognition of the voltage type is important as there are different risks with different potential outcomes.

Table 3: Types of voltages (SA/SNZ, 2018, p. 53))

Type	Range	Examples
Extra-low voltage	<50V AC or <120V DC	Control circuits, instrumentation
Low voltage	50V – 1000V AC	Domestic and normal commercial/industrial power
High voltage	>1000V AC >1500V DC	Distribution and transmission lines – up to 500,000V AC in Australia Electric trains Bass Strait link 400,000V DC

An electric current is produced when a wire is moved in a magnetic field (as in a generator). Electricity produces an electromagnetic (EM) field, composed of an electric field and an orthogonal magnetic field. The strength of the electric field is proportional to the voltage, and is present even when no current is flowing but the circuit is energised. The magnetic-field strength is proportional to the current flowing and is zero when no current is flowing

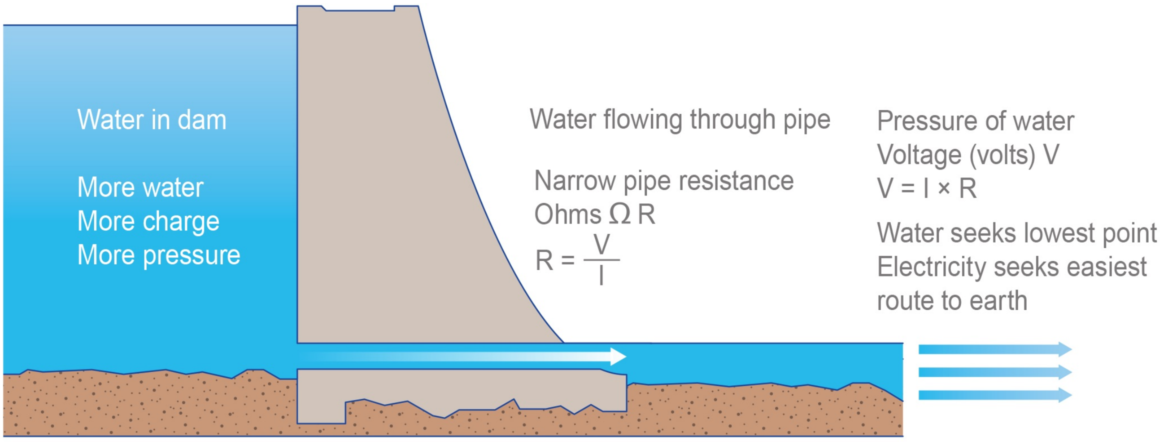
The electromagnetic field from a power line can induce currents in nearby circuits. The strength of the current will depend on the voltage and distance from the original circuit, but there have been instances where the current was sufficient to be fatal.

Electricity water analogy

The analogy of the flow of water is often used to explain electricity (e.g. Schmidt-Jones & Jones, 2009).

Think of water in a dam:

- The water in the dam can be considered a battery (the more water in the dam, the more charge in the battery)
- The pressure created by the depth of the water represents electric potential or voltage
- The dam wall and any pipes flowing out of the dam are the same as electrical insulation of conductors. Due to water pressure, dam walls need to be thicker at the base, likewise insulation needs to be greater when voltages are higher
- When water is released from the dam, the amount of water flowing through the pipe models current (amps)
- The width of the pipe is the resistance (ohms); the narrower the pipe, the more resistance. All pipes (and all cables) have some resistance to flow
- In direct current (DC), the water will consistently flow in the same direction; in alternating current (AC), the water will continually change directions (slosh back and forth).



All analogies have limitations. One significant limitation of the water/electricity analogy is that it fails to take into account the magnetic field produced around all current carrying wires and cables.

4.2 Generation, transmission and distribution

Electrical energy is produced by conversion from other energy sources – chemical (coal, oil, gas, diesel), radiation (nuclear, solar), potential (hydro), geothermal and momentum (wind, wave). Traditionally, generators have been built in the vicinity of the energy source (e.g. coal field, dam, geography with high winds or sunshine). Often these locations are distant from cities or centres where the electricity is utilised and, traditionally, high-voltage transmission lines carry power from the generators to the users (ESV, 2017a).

As high losses can occur during transmission, electricity is usually transmitted from the power station to main population centres at high voltage (up to 500,000V in Australia). Voltage is then transformed down and distributed to domestic and industrial users for consumption. The electrical distribution system is normally in a state of equilibrium, with generated supply being equal to electrical demand. If demand increases to the point where it starts to exceed generating capacity, the control system initially tries to compensate by reducing the voltage (brown-out); if this is not sufficient to balance supply and demand, then supply may be suspended temporarily for particular regions (black-out).

With the reduced costs of renewable power sources, there is a move away from centralisation of power generation, particularly with domestic and industrial roof-top solar (EEC, 2018). Clearly, solar and wind generation are dependent on the sun shining and wind blowing. Base-load generation (coal, gas) will, for the near future, still be required to make up the shortfall when the renewables are not generating, although battery and hydro storage capacity are ramping up nationally and internationally (EEC, 2018). Fixed or portable generators are a feature of many worksites, and electrical hazards discussed in this chapter also apply to such local generation. The decentralisation of the energy grid increases the complexity of the grid with each mode of generation having other hazards to be managed (Figure 1). From an OHS perspective, when managing electrical hazards the mode of generation is irrelevant; electricity remains the core hazard.

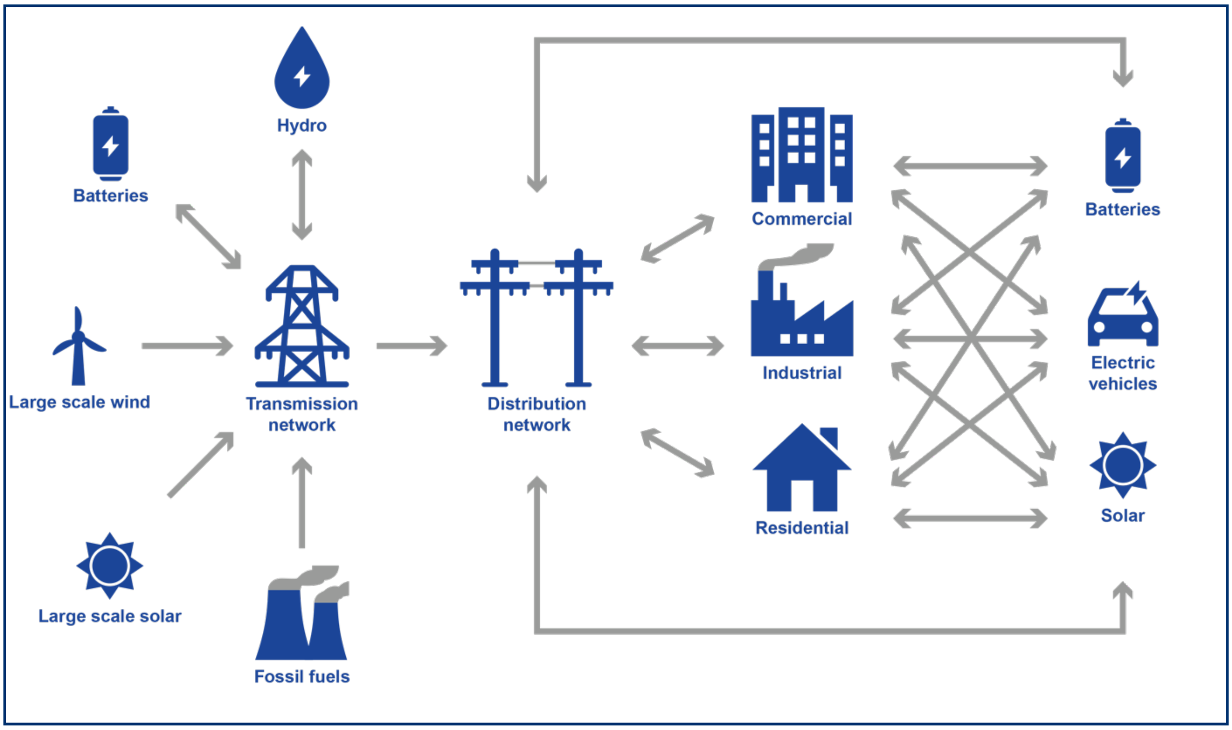


Figure 1: The energy grid in the 21st century (EEC, 2018, p. 14)

Electricity is present in all workplaces and there are a range of controls in place to separate workers from electricity. It is when workers interface with electricity that they are at risk. This section considers how workers interface with electricity, introducing circuits, fault current, and step and touch potential.

4.3.1 Circuits

Domestic and industrial voltages (AC) are defined in *AS/NZS 3000:2018 Electrical Installations ("Wiring Rules")* (SA/SNZ, 2018) as:

- Single phase (generally domestic) – 230V (with an acceptable range 216V – 253V)
- Three phase (industrial) – 400V (with an acceptable range 376V – 440V).

Most domestic electrical circuits are single phase with three wires: the active (where the electrical current flows to reach the appliance); the neutral (where the electrical current returns to the power source after operating the appliance); and the earth, which is generally attached to a spike inserted into the ground and provides a path to the ground if a short circuit or a fault current occurs (the ground provides an alternative path for the electric current to dissipate) (Figure 2).

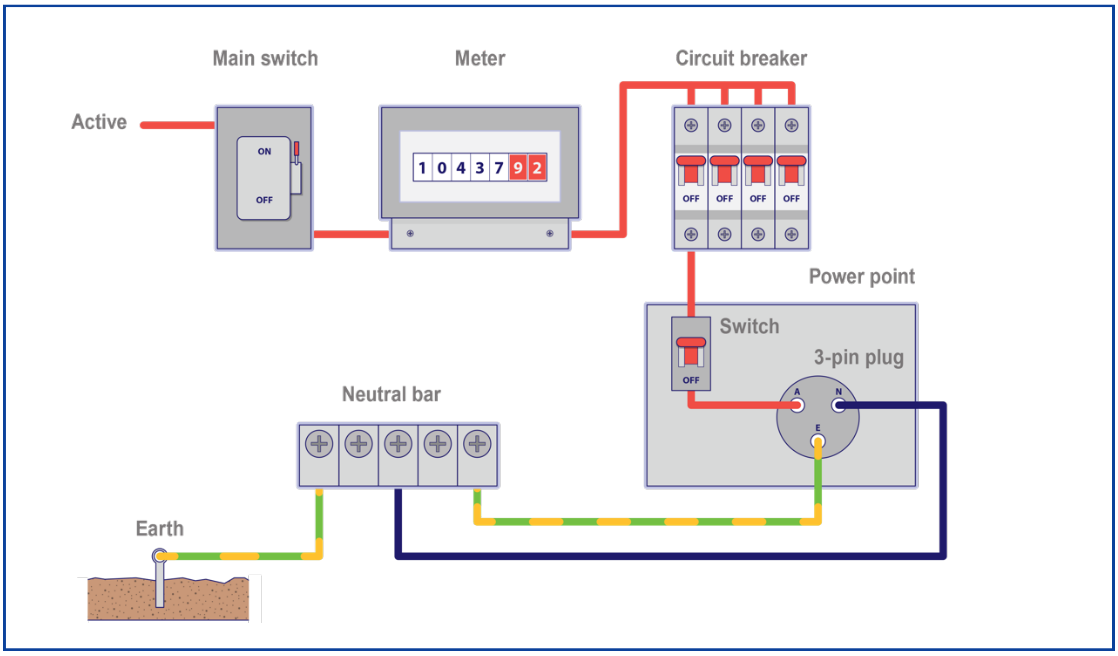


Figure 2: Electrical wiring of a premises showing active, neutral and earth

Industrial sites are wired with three-phase power at 415 volts, which provides more power than a single-phase system as is required to run workshop and other machinery (Build, 2019). Increasingly, three-phase power is being installed for domestic purposes such as induction appliances, air conditioning and electric car charging. Three-phase circuits have three actives (red, white and blue phases) plus a neutral (black) (Figure 3).

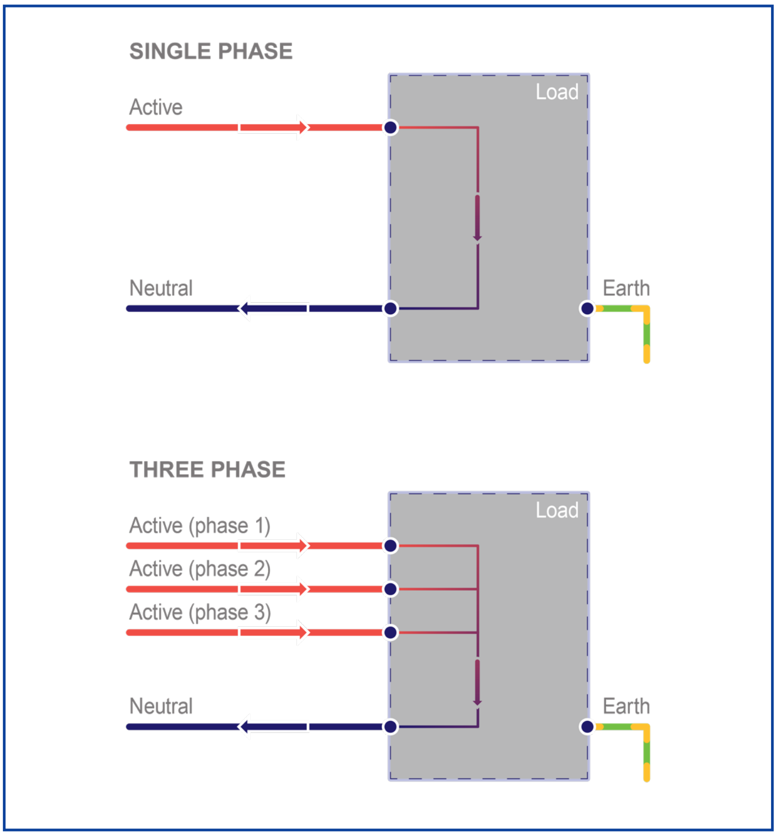


Figure 3: Single-phase and three-phase power (modified from Build, 2019)

4.3.2 Fault current and earthing

"A fault condition occurs when one or more electrical conductors short to each other or to the ground…A fault current is usually several times larger in magnitude than the current which normally flows through the circuit in a non-fault condition" (Eland Cables, n.d). If a person becomes part of the electrical circuit, and the resistance of the person is less than that of other available routes, then the electricity will flow through the human with potentially fatal outcomes (Figure 4). Electricity has a tendency to leak to earth and, where the electrical system is earthed, earthing provides the easiest path for the fault current and so protects people voltage surges and lightning discharges. Should there be damage to the earth wire, there is potential for the earth leakage current to be diverted through a person to earth. Safety is also compromised in circuits if active and neutral wires are inappropriately wired (reversed polarity) or if the earth is inappropriately wired to the neutral connection.

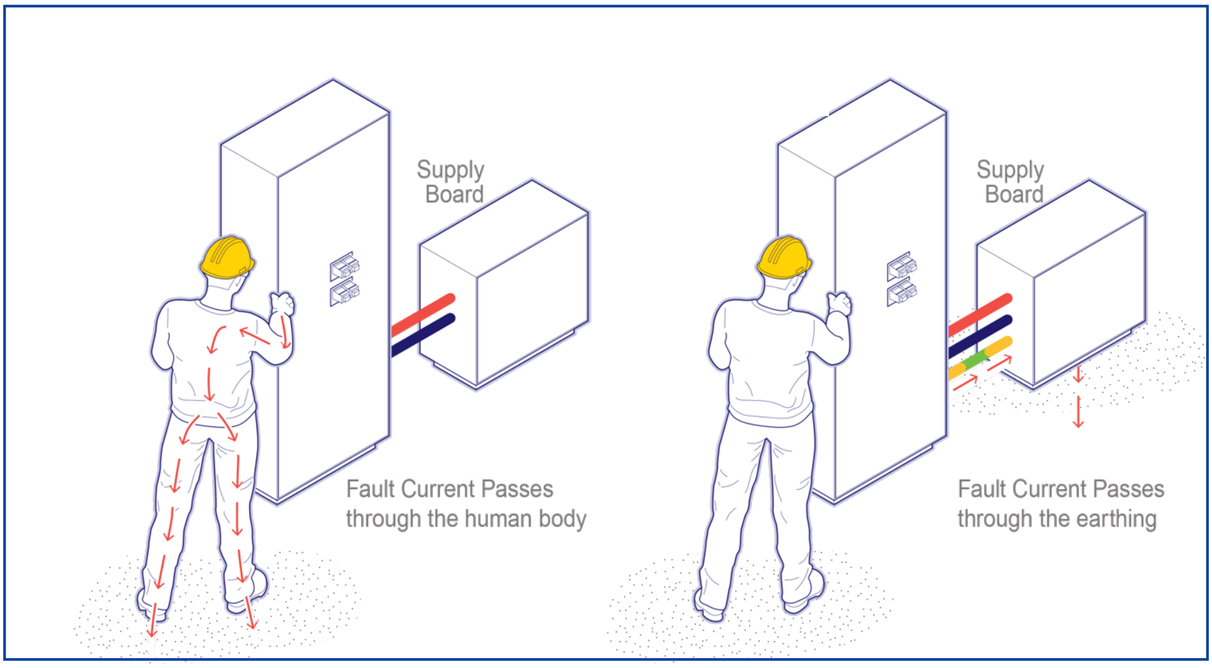


Figure 4: Effect of earthing on fault current and protection of personnel

4.3.3 Step and touch potential

As noted in the previous section, electricity has a tendency to flow to the earth. Voltage in the ground creates a 'step potential,' while a 'touch potential' is created when a person contacts a live conductor while standing on the ground (e.g. ESV, 2017a).

A step potential can occur with a downed power line or when a fault current flows through a structure to the ground (ESV, 2017a). The voltage diminishes with distance from where the energy contacts the ground, creating a voltage difference. When a person is in the area, the voltage difference between their feet can cause a current to flow through the person and an electric shock occurs (ESV, 2017a). If caught in such a situation, a person should keep their feet together and shuffle out of the area (Figure 5).

Touching a live conductor with any part of the body while the feet are in contact with the ground allows electric current to flow through the body to ground due to the difference in potential between the person's hand and their feet on the ground (Figure 5). Water and conductive objects can extend the step and touch potential hazard areas.

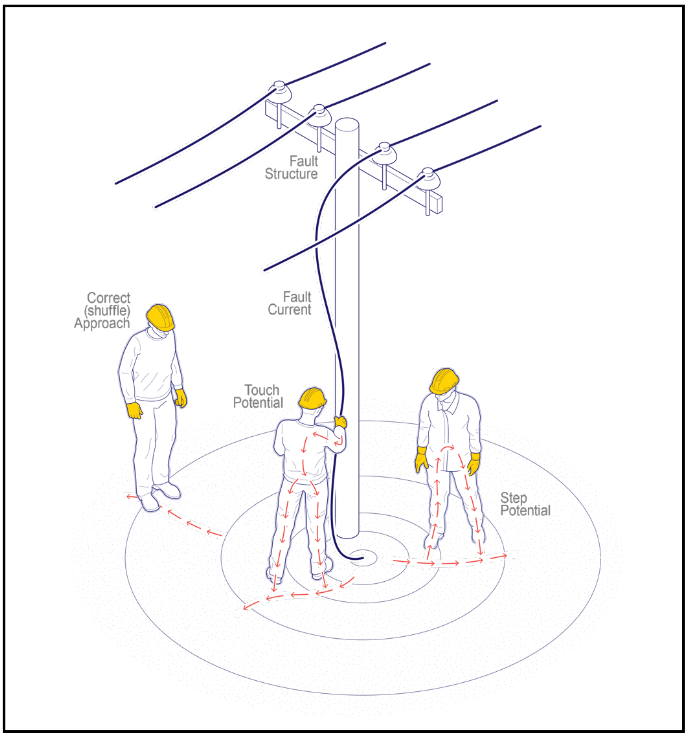


Figure 5: Step and touch potential

4.4 Energy storage

Electrical energy cannot be stored; storage requires conversion to another form of energy. Large-scale energy storage systems are based on:

- *Pumped hydro [potential energy]:* Water is pumped from a lower elevation source during periods with reduced [electricity consumption] to a higher elevation for storage and used to spin generators at higher electric rate periods.
- *Mechanical energy:* [1] Compressed air energy storage (CAES) pumps air into caverns or tanks at high pressures and releases it to spin generators. [2] Flywheels utilise kinetic energy in large mass cylinders and spinning at high RPMs in a vacuum. When power is needed, a motor engages to generate electricity as the wheel spins down.
- *Thermal energy:* Solar radiation is focused on a heat transfer medium, which can be used to generate steam to spin generators for electrical energy production. This heat can also be stored in oils or other fluids, or as molten salt, for use when solar radiation is not available.
- *Electro-chemical energy:* Electrical energy is stored via chemical bonds or via reversible chemical processes requiring an electrolyte and electrodes (cathode and anode) [as in a battery]. (Paiss, 2017, p. 5)

The latter type of energy storage system, electrochemical energy, is a rapidly growing format for both small- and large-scale energy storage (Paiss, 2017). While the technology around this type of storage is developing, the OHS professional should be aware of associated hazards (Table 4).

Uninterruptible power supplies (UPS) are used in computerised operations, data storage and critical systems such as health care and may present unanticipated hazards. A UPS, which may be permanently connected or plugged in, still supplies electricity when the normal supply has been isolated (ESV, 2017a).

Table 4: Hazards associated with electrochemical storage systems (modified from Paiss, 2017, p. 7)

Hazards		Lithium-ion	Lead-acid flooded cell	Sodium sulfur	Vanadium redox flow battery
Arc flash/blast	Occurs as systems cannot be turned off; highest risk in systems >100V, but high fault current can occur in systems at lower voltage	X	X	X	
Toxicity	From off-gassing produced by overheating aqueous or vaporised electrolytes; toxic gases generated through fire	X	X	X	X
Fire	Charging can produce oxygen and water	X	X	X	
Deflagration[1]		X	X		
Stranded energy	Energy remaining in damaged batteries that cannot be discharged	X	X	X	

[1] For a definition of deflagration see *OHS BoK* 17.3 Process Hazards (Chemical).

5 Health and injury outcomes associated with electricity

This section briefly examines potential injury outcomes from direct contact with electricity and potential health effects of working near electricity.

5.1 Electric shock and burns as result of direct contact

Electrical injury occurs when the body becomes part of an electrical circuit. For example, if a person contacts a bare electrical conductor and if the resistance of the body to earth is less than the resistance of the circuit contacted, then the electrical current will preferentially flow through the human body. The flow of electricity impacts the electrical functioning of the body, including the heart and nerve conduction, and has a thermal effect causing burns.[2]

The extent of damage depends on the strength of current flowing through the body and the contact time. For any voltage, the current flowing will depend on the resistance, as noted by Ohm's Law (I = V/R) (section 4.1). The resistance of skin varies among individuals and according to the environment or circumstances. Under dry conditions, the resistance of the body may be as high as 100,000Ω; if wet, the resistance can reduce to 1000Ω (NIOSH, 1998). The electrical resistance for hand-to-hand, dry-skin contact with 220V is estimated at less than 2125Ω for 95% of the population. The electrical effects of various current strengths on the human body are indicated in Table 5.

Table 5: Approximate effects of AC current (NIOSH, 1998, p. 7)

1mA	Barely perceptible
16mA	Maximum 'let go' threshold
20mA	Paralysis of respiratory muscles
100mA	Ventricular fibrillation threshold
2A	Cardiac standstill and internal organ damage

[2] For more information see for example: https://www.aci.health.nsw.gov.au/networks/eci/clinical/clinical-resources/clinical-tools/environmental-health/electrical-injuries

Generally, higher AC voltages will carry higher currents, so will be more dangerous. However, this is not universal as static electricity or DC current in an electric fence will work at thousands of volts, but carry small currents; they will shock, but are unlikely to kill.

There are three main types of direct electrical injuries:

1. Burns, which may be internal or external, with severity depending on voltage, current and duration of contact.
2. Electric shock, which occurs when there is any contact with electricity ranging from a minor ‘zap’ to non-fatal fibrillation and/or burns
3. Electrocution, which occurs when the electrical contact results in death (NIOSH, 1998).

Burns usually occur at the points of entry and exit of the electric current. Also, internal burns on the path that the current takes through the body can occur, particularly with high voltage.

Currents greater than 16mA stimulate involuntary contraction of the flexor and extensor muscles and, “when the stronger flexors dominate, victims may be unable to release the energized object they have grasped as long as the current flows,” thus increasing the degree of injury (NIOSH, 1998, p. 7). Currents exceeding 100mA passing through the chest can cause ventricular fibrillation, potentially resulting in death from electric shock (NIOSH, 1998).

From Ohm’s Law, it can be seen that if domestic voltage (230V) is contacted in wet conditions (1000Ω), a potentially fatal current of 230mA can flow through a person. Factors affecting the strength of current, and therefore severity of potential injury, are those that decrease body resistance (NIOSH, 1998):

- Presence of moisture (e.g. perspiration, wet clothing, standing in water or on damp soil, high humidity)
- Metal objects (e.g. jewelry, watches, eyeglasses, keys).

An example of decreased resistance is provided by the Federal Government’s 2009–2010 Home Insulation Program. During this government-sponsored program, four deaths occurred; workers installing aluminised batts in hot ceiling spaces contacted electricity and the reduced resistance as a result of their sweating increased the risk in an already hazardous work environment (Hawke, 2010). Conversely, increased resistance is provided by appropriate protective equipment such as insulating mats, insulated tools, insulating gloves and safety shoes conforming to AS/NZS 2210 (SA/SNZ, 2010a).

5.2 Health effects of working near electricity

As noted in section 4.1, wherever electricity flows, both electric and magnetic fields occur close to the electrical conductor and any equipment being powered by electricity. These electromagnetic fields occur at extra-low frequency (ELF) (50Hz). Potential health effects of exposure to such electromagnetic fields have been a topic of discussion since 1979 when a US study identified a possible link between homes in proximity to high-voltage power lines and childhood cancer (Wertheimer & Leeper as cited in ANSES, 2017). “In 2002, the International Agency for Research on Cancer (IARC) placed ELF electromagnetic fields in Category 2B (possibly carcinogenic to humans)…However, to date, the studies carried out to determine a biological mechanism have reached no convincing conclusion” (ANSES, 2017). While current recommendations from research relate to children, there is a call for research targeting workers who may be exposed to higher doses of ELF electromagnetic fields (ANSES, 2017).

In Australia, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) advises that:

> The scientific evidence does not establish that exposure to the electric and magnetic fields found around the home, the office or near powerlines causes health effects. … There is no established evidence that the exposure to magnetic fields from powerlines, substations, transformers or other electrical sources, regardless of the proximity, causes any health effects. (ARPANSA, n.d.)

6 Legislation and standards

Historically, in some jurisdictions, electrical safety has had legislation and specialist regulators separate from mainstream OHS. However, the national *Model Work Health and Safety Act* (SWA, 2016b) makes electric shock a notifiable incident (WHSA ss 35c, 37e), and the national *Work Health and Safety Regulations* (SWA, 2019) now cover electrical work (*WHSR* Part 4.7). Key requirements under these regulations address:

- Removal of unsafe electrical equipment
- Inspection and testing of electrical equipment
- Prohibition of work on energised equipment, except under certain specified circumstances
- Conditions under which work may be undertaken on energised equipment and requirements for such work
- Special requirements for construction work
- Working near overhead or underground lines (SWA, 2019).

Organisations involved in the generation, transmission or distribution of electricity are not covered under Part 4.7 of the regulations, but need to comply with specialist regulations in each jurisdiction; for example, the regulations under the *Electrical Safety Act 1998* (Vic), which also govern licensing of electricians within Victoria. This Act also requires that electrical incidents be reported to the state's electrical safety regulator – Energy Safe Victoria. Other jurisdictions have similar requirements.

Safe Work Australia (2018) has provided a model code of practice titled *Managing electrical risks in the workplace*, which has been adopted by those Australian jurisdictions working under the model legislation. Also, jurisdictions have developed relevant codes of practice and guidance material for high-voltage work. An important Australian Standard is *AS/NZS 3000:2018 Electrical Installations* ("*Wiring Rules")* (SA/SNZ, 2018). Three other standards important for the OHS professional are *AS/NZS 3760:2010 In-service Safety Inspection and Testing of Electrical Equipment* (SA/SNZ, 2010b), *AS/NZS 4836:2011 Safe Working On or Near Low-voltage Electrical Installations and Equipment* (SA/SNZ, 2011) and *AS/NZS 3012:2010 Electrical Installations – Construction and Demolition Sites* (SA/SNZ, 2010c).

7 Working near electricity – non-electrical workers

Having discussed the nature of electricity, how it behaves and how it causes injury in sections 4 and 5, it is now important to understand how workers interact with electricity and appropriate controls. From the perspective of the OHS professional, it is necessary to differentiate between workers working with or in the proximity of electricity, and licensed or registered electrical workers working on electrical installations. This section addresses non-electrical workers while section 8 focuses on electrical workers.

As identified in Table 1, 36% of work-related electrical fatalities in the last ten years have involved non-electrical workers. Electricity is in all workplaces and there are many ways that non-electrical workers can come in contact with electricity. Figure 6 gives an indication of the range of situations where non-electrical workers may encounter electrical hazards and a few of these are discussed below.

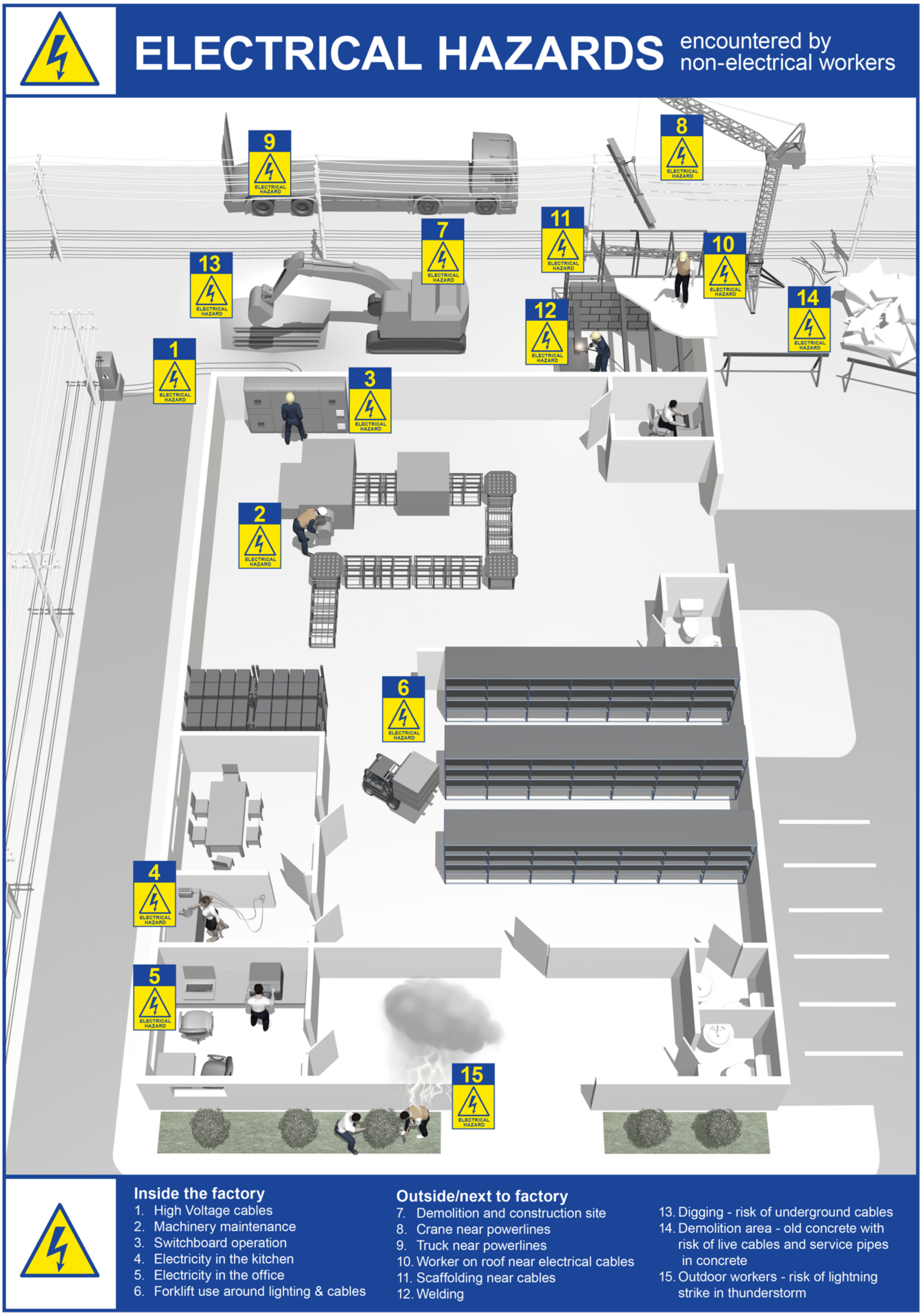


Figure 6: Example electrical hazards encountered by non-electrical workers

7.1 Overhead power lines

7.1.1 People and plant contacting power lines

People working near power lines to carry out tasks not related to electricity are at risk of injury and fatality. 'Look up and live' awareness campaigns (e.g. ESV, 2019) are designed to raise awareness of these hazards.

Working on billboards

WorkCover Queensland (2017a) describes four incidents occurring in Queensland between 2012 and 2017 that were associated with working on billboards, and that resulted in the death of one worker and severe shock and burns to four other workers.

2012: Two workers were removing and installing advertising skins to a billboard from a gantry. One of the workers, using an uninsulated 6.5 metre metal pole to remove the advertising skin, made contact with a live powerline and was electrocuted.

2016: A worker changing a billboard skin suffered an electrical shock and severe burns when an uninsulated metal pole the worker was using contacted a nearly 33kV powerline.

2016: A worker installing a sign from an elevated work platform received an electrical shock and severe burns after manoeuvring a 6m aluminium sail track into nearby powerlines.

2017: Two workers in an uninsulated elevating work platform contacted an 11 kV powerline with the six metre aluminium sail track they were installing on a billboard. Both workers suffered a severe electrical shock and burns from contacting the high voltage lines.

WorkCover Queensland , 2017a

Horticultural worker contacts overhead lines

457 Visa worker aged in his 20s was operating a cherry-picker to trim avocado trees when he died after the pruning tool he was using came too close to the 22,000 volt lines.

WorkCover Queensland , 2018

Mobile plant such as cranes and forklifts can come into contact with overhead conductors. An arc can form when earthed metal objects approach power lines without contacting them. When such plant becomes electrified, any person in contact with the plant may receive a fatal electric shock. Any person inside such plant should stay inside and avoid contacting any metal surface as once outside and clear of the vehicle, there is a risk of step potential.

A phenomenon known as ‘tyre pyrolysis’ may occur:

> …when rubber tyred vehicles come into contact with powerlines…[E]xcessive heat within the tyre causes decomposition of the compounds in the tyre creating flammable gas, vapour and/or oils which can rupture or explode the tyre…The danger area can be up to 300 metres from the tyre… (WorkCover Queensland, 2017a)

There may be no warning signs that a vehicle has contacted power lines. If danger of a tyre explosion is suspected, an isolation area should be established and the fire services notified (WorkCover Queensland, 2017a).

Relocation of grain auger on rural property
In October 2017 two workers on a rural property in the Western Downs region of Queensland received serious burns from an electric shock. The workers were relocating a grain auger when it came into contact with a 12.7kV single wire earth return (SWER) overhead powerline. Both workers were transported to Brisbane for surgery and one was placed into an induced coma.

WorkCover Queensland, 2017b

Crane operating under powerlines
[A construction company] engaged a crane operator to lift a housing display suite approximately the size of a twenty-foot shipping container onto the rear of a flatbed truck…The 20-tonne crane was parked directly under power lines and high voltage tram wires. …

A Yarra Trams employee who saw the crane being moved into position warned the crane operator not to conduct the lift as he believed it would be encroaching the ‘no go’ zone for work near live power lines, but was ignored. The employee videoed the lift on his mobile phone and then reported the matter to WorkSafe. …

The court heard that [the construction company] had no Safe Work Method Statement for the work, nor had it conducted any risk assessment to ascertain the presence, type and operating voltage of overhead cables and tram wires. It had also failed to obtain the permission of the electricity supplier or the tram company before performing the lift. …

[The regulator noted that the construction company] had placed the crane operator's life in danger. “…The risk of electrocution was high if the crane or the load had come into contact with the overhead lines. And, given the incident location on a busy street, the company had also put at risk the lives of road users and pedestrians.” …

[The company] was found guilty of two charges under the 2004 OHS Act for failing to ensure persons other than employees were not exposed to health and safety risks, and failing to ensure the means of entering the workplace were safe and without risks to *health. The company was* [fined $24,000 and] *ordered to pay $6387 in costs.*

WorkSafe Victoria, 2017

7.1.2 Working in proximity to power lines

Air is an effective insulator for power lines; however, if the separation distances are insufficient, a flashover can be generated between a power line and an earthed object such as a person or vehicle or to the ground. The distance will depend on the voltage and atmospheric conditions such as humidity. Safe distances are provided in *ENA NENS 04-2006 National Guidelines for Safe Approach Distances to Electrical and Mechanical Apparatus* (ENA, 2006). Work planned in the vicinity of power lines where the safe working distances could be breached requires information and authorisation from the network operators who will set conditions for approach.[3]

Live work undertaken to avoid delaying a project

In May 2017, construction company WGA Pty Ltd was convicted and fined AUD $1 million…after the NSW District Court found that its director deliberately let a subcontractor work near live high-voltage powerlines in order to avoid delaying a construction project. …

[An] apartment building had been constructed in close proximity to powerlines… [The worker] was standing on a window ledge and installing aluminium angles to the outside of the windows. [He] suffered an electric shock [and extensive burns] when the 2.7m angle he was holding came in contact with (or in close proximity to) the high voltage upper powerlines.

Titterton, Bochenek & Nguyen, 2017

As indicated in section 4.1, an electromagnetic field is created around power lines, with the strength of the field proportional to the voltage (ENA, 2016). This electromagnetic field around high-voltage power lines and other high-voltage energised systems can 'induce' currents in nearby circuits, the strength of which will depend on the voltage and distance from the energised system.[4] The induction can cause circuits to become energised even without physical contact with a live circuit (Figure 7). This effect can occur on the ground beneath a high-voltage power line and may create electrical hazards for people in the area. Maintaining safe working distances in such situations is essential

[3] Safe approach distances for high voltages are provided in Table 1 in *The Blue Book 2017: Code of Practice on Electrical Safety for the Work On or Near High Voltage Electrical Apparatus* (ESV, 2017c).

[4] See, for example, the discussion of induction of current in fluorescent tubes in Schilling (2013).

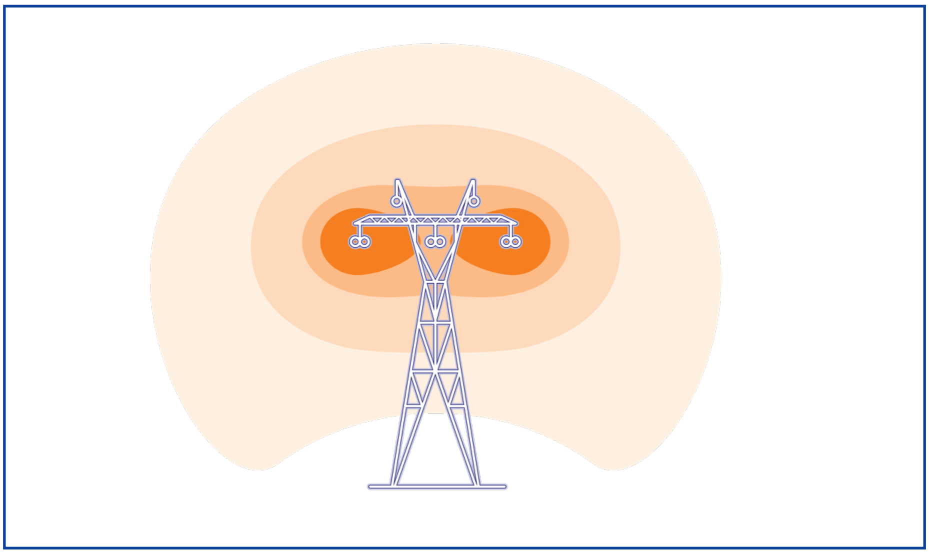


Figure 7: Thermal image representation of induced voltage around high-voltage power lines

7.2 Underground cables

Contact with power lines is also an issue with underground cables. Increasingly, suburban power lines are being installed underground; this provides protection from extra-low frequency radiation and contact with overhead lines, but does create a hazard for persons excavating or digging where there is potential for power lines to exist. 'Dial before you dig'[5] protocols are standard practice before any excavation in areas where underground cables may exist. As with working in locations with the potential for overhead contact, information and authorisation by the relevant network operator is required before digging or excavating

Contact with live underground cable

A contractor was preparing a trench as part of a project to replace underground cabling. During the excavation, the contractor hit a 11kV underground cable while using a hand-held power tool. The worker suffered burns to his arms and face.

Endeavour Energy, 2018

A challenge is that while all planning procedures may be followed, the indicated location of power lines may not include all assets underground (due to drawings not being current). Non-destructive digging (NDD) can be used to locate underground services, using high-pressure water to safely blast through soil to excavate the ground then vacuum to recover

[5] See https://www.1100.com.au

and hold the material, thereby reducing the risk to people and services (see, for example, Pressure Works, 2019).

7.3 Downed cables

Live cables may come in contact with the ground as a result of vehicle accidents or weather events. When a live cable touches the ground, the voltage on the ground fans out in concentric circles, decreasing with increasing distance from the point of contact (step potential). Also, a touch potential may occur if a person touches a live conductor that is in contact with the ground. (See section 4.3.3; ESV, 2017a)

7.4 Lightning

While data are not kept on deaths due to lightning strikes, “it is estimated that there are five to 10 deaths a year from lightning strikes in Australia and more than 100 people are seriously injured annually” (Ceranic, 2018). Outdoor workers are at particular risk of injury due to lightning.

“Lightning is an electrical discharge caused by imbalances between storm clouds and the ground, or within the clouds themselves” (National Geographic, 2019). Lightning can strike objects such as a tree or a ladder and enter the ground, or strike the ground directly. A voltage difference set up in the ground can drive a current connecting to a person who is touching the object, standing near the object or standing on the ground carrying the voltage difference. “People have been injured 15 to 30 metres away from where a lightning strike has hit the ground” (Government of Canada, 2018). The only safe place in a thunderstorm is indoors or inside a vehicle.

7.5 Static electricity

As explained in the *OHS Body of Knowledge* chapter 17.3 Process Hazards (Chemical), static electricity refers to the build-up of electrical charge on the surface of objects, where it can remain if the object is an insulating material, or discharge to earth if a conductor. Discharge can occur through a person (static shock) or through slow-charge bleeding in a humid environment. Static charge can build up whenever any fluid (powder, liquid, gas) is transferred through a pipe or other conduit. In a flammable environment,[6] a discharge in the

[6] A flammable environment is one where the concentration of flammable gas in air is between the Lower Flammable Limit (LFL) and the Upper Flammable Limit (UFL). Concentrations outside these

form of a spark can provide enough energy to initiate an explosion or fire. Discomfort associated with static discharges may occur within an office where the humidity is low, and where carpets and other furnishings cause charge build-up.

Most people will be familiar with the effect of static electricity when exiting a motor vehicle:

> The static shock which motorists experience when exiting a car is predominantly caused by friction between the motorist and the seat. The static electricity that has been generated usually discharges when the motorist touches the metal car door on exiting. However, if the first point of contact with the metal happens to be the fill point of the fuel dispenser nozzle, the spark can ignite the petrol vapours and cause a brief flash fire. The likelihood of this occurring is higher when the person re-enters their vehicle during refuelling [as the friction builds up the static charge which is not discharged as the door is usually open]. (ATSB, 2005, p. 4)

For this reason, Australian motorists are not permitted to leave the pump unattended when fueling their vehicle.

> In contrast to refuelling a vehicle, the risk of fire igniting from a static charge is higher when an unearthed container is being filled with fuel. The risk is particularly high when the fuel is spilt or being 'splash filled.' Evidence suggests that refilling containers (either metal or plastic) on the back of a pick-up truck is especially hazardous. This is because the friction between the surfaces of the moving vehicle and the container can build up sufficient energy to cause a spark between the container and the dispenser nozzle, resulting in ignition of the fuel vapours in the air. (ATSB, 2005, p. 4)

Thus, the requirement for fuel containers to be removed from vehicles before filling.

7.6 Other hazards associated with electricity

While electricity is a high-risk hazard, in combination with other hazards such as flammable gases and gravity it presents more complex situations that should be considered in risk assessments.

7.6.1 Gaseous environments

In addition to static electricity noted above, electrical circuits can provide other sources of ignition. The opening or closing of an electrical contact often results in a spark or arc that could ignite a flammable atmosphere. Figure 8 illustrates the impact of static electricity – a spark and a flammable atmosphere. In this instance, combustible gas leaked from a cylinder and accumulated in the rear of an enclosed utility parked outside a supermarket. When the driver returned to the vehicle and unlocked it with a remote control, the spark generated from

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limits mean that the mixture is too lean (<LFL) or too rich (>UFL) for ignition. See *OHS BoK* 17.3 Process Hazards (Chemical).

the locking mechanism releasing in the back of the utility caused a spontaneous combustion of the gas.

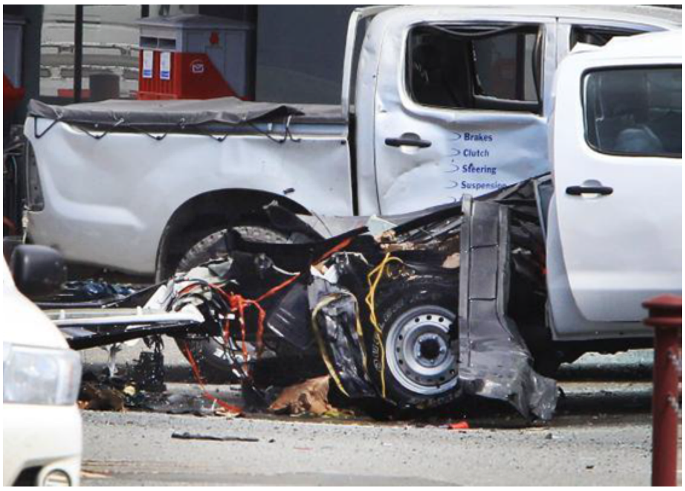


Figure 8: Impact of explosion caused by build-up of flammable gas ignited by spark from remote locking mechanism

Electrical apparatus for application in flammable environments needs to be intrinsically safe; that is, no spark or similar can reach the environment surrounding it during its operation.

In fire situations burning insulation in electric cabling can give off toxic gases creating a hazardous environment.

7.6.2 Falls

If a person working on or near electrical equipment at a height suffers even a mild electric shock, a loss of equilibrium, or involuntary muscle contraction, it may cause them to fall. Depending on the height, the fall may cause more serious injuries than the electric shock.

7.6.3 Legacy issues

There may be legacy safety issues associated with electricity such as problems associated with asbestos insulation used in older electrical installations. Because of its excellent insulation properties, asbestos was extensively used for circuit boards containing switches, meters and other electrical apparatus, and as insulation on some electrical equipment, such as heat banks and electrical cables.

8 Working on electrical installations: electrical workers

The Electrical Regulatory Authorities Council (ERAC) defines an electrical worker as "a person who carries out electrical work and is licensed or authorised to do so" and a supply worker as "a person who is employed by an electrical network operator" (ERAC, 2018, p. 1). In the model code of practice for *Managing Electrical Risks in the Workplace*, electrical work is defined 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 (SWA, 2018, p. 7).

Such work may include:

- Installation of electrical infrastructure
- Working on switch boards
- Working on or near live electrical equipment (opening machinery to test cover plate on terminal)
- Commission and testing
- Metering and servicing
- Fault response
- Working in a high-risk induction environment.

The remainder of this section considers the work of electrical workers from the perspective of the OHS professional and expands on three key principles for electrical work:

- Electrical work is only carried out by workers appropriately authorised to undertake electrical work
- Except in certain specified circumstances, work must only be carried out on de-energised equipment
- A clear understanding of what constitutes 'live' or energised work is required.

8.1 Licensed/registered electrical workers

Arrangements for licensing or registering electrical workers varies across Australian states and territories; some states have purpose-specific electricity or energy licensing bodies while in others the licensing authority resides with the OHS regulator. In some industries and organisations there are also arrangements for 'authorised persons' where a person with specific technical knowledge and appropriate experience is approved by the organisation to perform a specific duty or task.

Although the requirement for electrical work to be undertaken only by appropriately licensed/registered personnel is well recognised, a significant number of non-electrical workers have died while undertaking electrical tasks. Lack of awareness or pressure to continue work do not constitute a rationale for such personnel to undertake restricted tasks.

Drill operator in underground mine
In 2002, a Drill Jumbo operator sustained a fatal electric shock in an underground mine after contacting 415 volt terminals inside an electrical control box. … [The operator was] installing a pumping line from the surface to the main decline in the mine [which required relocating] the pump starter to reset the pump (as the pump starter kept tripping out). [The] operator's hand touched the live [415 volt terminals] inside the electrical control box. He was standing in water at the time. … The operator had opened the control box using a special unlocking tool that was available to him. The deceased was not a licensed electrician and clearly should not have accessed the control box.

DIR, 2002; DMIRS, 2018, 2018

8.2 Working on de-energised equipment

Working on energised electrical equipment is prohibited, except under certain specified circumstances, under the national *Work Health and Safety Regulations* (*WHSR* ss 154, 157; SWA, 2019). The model code of practice (SWA, 2018, p. 34) specifies that:

> 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 (SWA, 2018; p. 42).

Ensuring work is only done on de-energised equipment requires:

- Effective work planning
- A rigorous electrical testing regime
- Effective isolation and lockout/tagging procedures.[7]

Electrical testing is based on the principle of 'test for dead before you touch.'

- All electrical conductors and components must be assumed to be energised unless proven to be de-energised
- Testing is undertaken prior to any work, prior to touching any item of electrical equipment, after any changes to equipment or if the equipment or area has been left unattended for any period
- Testing includes testing the test equipment
- Electrical testing can only be undertaken by licensed/registered electrical workers (SWA, 2018).

[7] Requirements for lockout/tagout systems are discussed in *OHS BoK* 28 Mechanical Plant.

Isolation of electrical equipment ensures that the equipment cannot be inadvertently re-energised. As specified in the model code of practice (SWA, 2018), isolation includes:

- Identifying the circuit(s) requiring isolation, including multiple sources such as standby systems, generators, batteries, photovoltaic systems, auxiliary supplies from other boards and sources of induction
- Disconnecting the electricity supplies, including ensuring discharge of any stored energy
- Securing the isolation by locking isolating switches where practicable or removing conductors
- Tagging switching points to ensure people are aware of the lock out
- Earthing all potentially inducted equipment when the source of the induction cannot be de-energised
- Testing to confirm all circuits and conductors have been de-energised
- Re-testing should the worker leave the area temporarily or following any change to equipment or change in personnel.

8.3 'Live' work

'Live' or energised electrical work is "electrical work carried out in circumstances where the part of the electrical equipment being worked on is connected to electricity or 'energised'" (SWA, 2018; p. 42). Energised electrical work involves strict procedures addressing: job planning, risk assessments, safe work method statements, specified equipment (including personal protective equipment), licensed and competent workers (including safety observers) and record keeping. The challenge and risk occurs when lack of awareness and modification to a task to address contingencies change working 'dead' to 'working live' without the appropriate planning and controls.

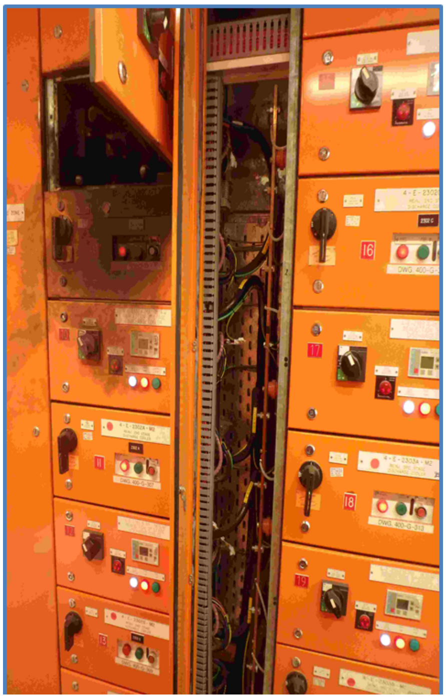
Moving from working de-energised to energised

An electrical technician was replacing a starter module. Installing the starter feeder assembly was a relatively straightforward task and the appropriate permits and authorisations were in place. Eight installations had been successfully completed.

On installing the ninth unit a live line indication was not obtained. The starter feeder assembly was incomplete when received on site, the main isolator contacts were not tightened with the incoming power supply leads, resulting in no power availability shown on the Live Line Indicator (LLI) after it was switched on.

In attempting to correct the alignment of the contacts, the electrical technician removed the protective shroud with the module in-situ within the panel housing. A screw driver he was using touched live contacts, causing an earth fault / short circuit. An arc flash occurred and the technician received burn injuries to his left hand, right side of upper body and face, requiring medical treatment and hospitalisation.

The initial eight installations were planned as per work arrangements for de-energised equipment. Once the protective shroud was removed while the module was in-situ the work became 'live,' requiring a different set of permits, authorisations, work procedures and PPE. This was not recognised nor acted on by the technician.



Case study provided in confidence

9 Control of electrical risk

Although specific controls for electrical hazards are discussed below, a systems approach[8] with multiple layers of defences is particularly important for electrical hazards. From the generalist OHS professional perspective, it is useful to consider the controls for electrical hazards under two headings: all workers and additional controls for electrical workers.

9.1 All workers

In general, the principles behind electrical safety involve eliminating or minimising the possibility of leaking current to the ground via routes other than the neutral wire. Faults in the protection include damaged or failed insulation or barriers, breaches of safe working distances, and the failure of personal protective equipment (PPE) or procedures.

[8] See *OHS BoK* 11.1 Systems, 11.2 OHS Management Systems and 34.1 Prevention and Intervention.

9.1.1 Elimination

The national *Work Health and Safety Regulations* (SWA, 2019) prohibit work on electrical apparatus while the equipment is energised except in specified circumstances (*WHSR* s 157). All electrical apparatus should be considered energised unless specifically tested and verified to show that it is de-energised. Testing should be done by authorised persons. Lockout/tagout procedures should be employed to ensure that the apparatus remains de-energised while being worked on. Because such procedural controls do not 'eliminate' the hazard of electricity, there is a reliance on other controls – especially substitution and engineering supplemented by administrative controls and appropriate PPE.

9.1.2 Substitution

While reducing the voltage is usually not an option on existing installations, it should be considered for new installations or when equipment is being modified or upgraded.

9.1.3 Engineering controls

Safe design is generally the primary mode of ensuring safety of electrical apparatus with there being two key elements – limiting accessibility to live electrical circuits, and fuses and circuit breakers.

Accessibility to electrical circuits

Access to electrical circuits can be limited through:

- Location (e.g. power lines above normal reach or buried under ground)
- Use of barriers
  - Enclosed 'fixed guards' (e.g. on electric motors conforming to *AS/NZS 4024.1601:2014* (SA/SNZ, 2014)
  - Temporary barriers when working near energised electrical equipment (e.g. on scaffolding near power lines)
  - Insulation preventing an electrical path to earth (e.g. elevating work platforms required for work on power lines have the boom and bucket fully insulated)
  - Double insulation (e.g. of power tools connected to mains electricity)
- Use of batteries (e.g. for power tools instead of mains current).

Fuses and circuit breakers

Excessive current flow caused by equipment fault, insulation failure or circuit overload can pose a risk to personnel and a risk of fire and property damage. Engineering controls, designed to interrupt the power supply in such circumstances, include fuses and circuit breakers.

Generally, circuit breakers have replaced fuses in circuits; they protect against large current flows (e.g. >10 amps) that could cause fires if contacting wooden or other flammable structures. Fuses and circuit breakers rely on an intact earth and require a fault current higher than that which will cause electrocution so, while they protect the electrical system from damage and fire, they do not protect people.

Conversely, residual current devices (RCDs) detect any imbalance between the magnetic fields of the active and neutral wires that could be caused by a fault or an earth leakage (e.g. through a person). They can detect earth leakages as low as 5mA and cut supply within 25-40 milliseconds, thus protecting from electric shock (see Table 5). As noted in section 2, since 1991 RCDs have been mandatory on all power and lighting circuits in new houses in Australia. The *Model Work Health and Safety Regulations* (SWA, 2019) require the use of RCDs on all electrical circuits at construction sites (*WHSR* s 164). Several jurisdictions require RCDs in all workplaces and this could be considered best practice.

Electrocution of construction worker

A young worker died when a switchboard he was carrying came *into contact with live electrical wires during heavy rain at a construction site.* The electrical contractor – who *didn't install safety switches which were designed to prevent electrocution,…had no experience of a project that size*, and compounded his actions by claiming safety switches were installed – was held responsible and jailed for manslaughter and perjury.

Sibson, 2018

9.1.4 Administrative controls

For any hazard, administrative controls are low on the hierarchy and so considered less reliable than higher-level controls (section 9.4).

Procedural controls

Regardless of specific engineering controls in place, it is normal to also apply appropriate procedural controls when working with electricity. The overarching procedural control for non-electrical workers is that they do not undertake any work that comes under the definition of 'electrical work' (section 8).

Specific procedures relevant to non-electrical workers may include:

- Service checks before digging ('Dial before you dig')
- Compliance with 'No Go' zones for work near overhead cables (e.g. ESV, 2017b)
- Permit-to-work and lockout/tagout systems for maintenance workers working on electrical powered plant

- Inspection, testing and tagging of electrical equipment
- Up-to-date plant and equipment records, including design diagrams and maintenance records that provide important information on electrical hazards associated with the equipment
- Signage to indicate the presence of electrical hazards.

It is worth noting that, while the overall numbers are low, there were electrical fatalities involving consumer installations (non-supply) attributed to "failure [or] deterioration of equipment or wiring" (ERAC, 2017, p. 14). Thus, ensuring equipment is in good working order is vital. For portable equipment this is usually achieved though inspection, testing and tagging of electrical equipment, consistent with the requirements of *AS/NZS 3100:2017* (SA/SNZ, 2017) and/or *AS/NZS 3760:2010* (SA/SNZ, 2010b).

Increased risk in working with electrical apparatus and similar equipment is associated with the commissioning and decommissioning phases. As these events generally occur less frequently than in normal operations, special care needs to be undertaken by the organisation, and particularly local supervisors, to ensure that all workers understand the increased risks and any changes in work procedures that differ from those that apply during normal operations.

Competent personnel and supervision

"Provision of any information, training, instruction or supervision that is necessary to protect all persons from risks to their health and safety arising from work carried out" is stipulated as part of the primary duty of care of persons conducting a business or undertaking (PCBU) (WHSA s 19; SWA, 2016b). This requirement is particularly important in the control of electrical hazards.

While new workers may have documentation showing formal training completed, it is prudent for the employing agency to test their knowledge and practical skills, and to provide additional induction and training to address any identified shortcomings relevant to specific plant that they may be required to work on and for any circumstances specific to the worksite. This includes awareness of electrical hazards and control strategies, including procedures.

9.1.5 Personal protective equipment (PPE)

While there are specific requirements regarding PPE for electrical workers, standard PPE requirements such as suitably rated safety footwear can assist in minimising consequences of an electrical incident for non-electrical workers.

9.1.6 Summary

Threats, consequences and a range of controls for non-electrical workers working in proximity to electricity are summarised in Figure 9. While such a diagram cannot address all relevant threats and controls, it provides a basis for further discussion.

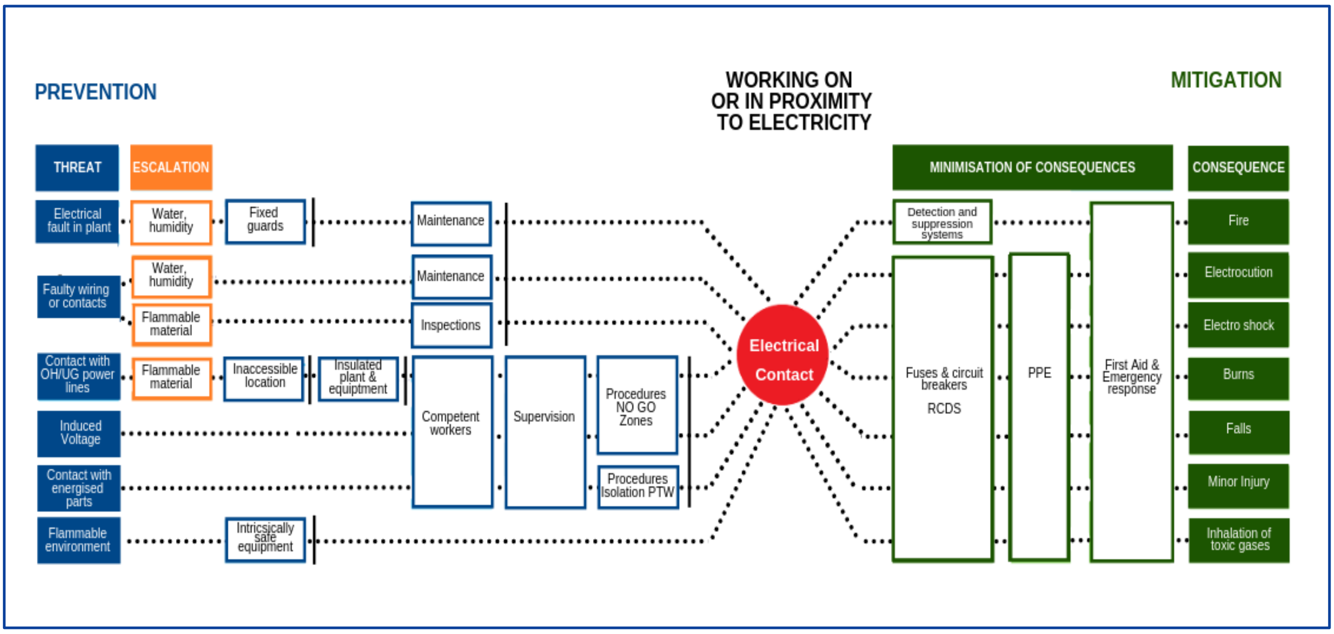


Figure 9: Prevention and mitigation of electrical hazards for non-electrical workers

9.2 Electrical workers

Along with the controls for all workers, there are additional controls that should be in place for electrical work. While the development and implementation of such controls requires specialist expertise, the OHS professional should be familiar with the required controls and the integration of them in OHS and other management systems.

The control measures put in place in any situation will depend on a range of factors, and the controls discussed below are not exhaustive. They do not address work on energised equipment and are outside the electricity generation and transmission industry.

9.2.1 Elimination

As discussed in section 8.2, the national *Work Health and Safety Regulations* (SWA, 2019) prohibit work on energised electrical apparatus except in some limited specified circumstances. Work must not be carried on energised equipment just because it is more convenient (SWA, 2018: p. 42). However, as shown in section 8.3, modification to a task to address contingencies may change working ‘dead’ to ‘working live’, also testing and isolation to place equipment in a de-energised state requires testing and isolation which expose a worker to energised equipment. Thus, engineering, administrative controls supported by appropriate PPE are all important in controlling the risk of injury for electrical workers.

9.2.3 Engineering controls

In some circumstances, it may be possible to use automation or remote energising/de-energising to remove operator contact with live circuits. This will depend on the context and design criteria, and no generalised direction can be given. Regardless of the design, the final electrical apparatus has to be fit for purpose.

Earthing and bonding are applicable controls in some circumstances (e.g. substation maintenance). Bonding utilises a metallic conducting pathway to earth placed on the electrical apparatus so that a fault current follows this pathway in preference to going through a person.

9.2.4 Administrative controls

For any hazard, administrative controls are low on the hierarchy and so considered less reliable than higher-level controls (section 9.4). However, administrative controls are important in electrical work for two main reasons:

- Isolation requires a series of procedures
- Testing for ‘dead’ is a procedural administrative control.

Procedural controls

Regardless of specific engineering controls in place, it is normal to also apply appropriate procedural controls when working with electricity. The procedures used to control work on or near electrical apparatus include isolation of the electricity, licensed electrical workers, individual locks for lockout/tagout and/or permits to work. The permit should cover the relevant safety precautions required; these could include the use of authorisations or licensed operators, testing and bonding, barriers, discharge of capacitors, safety observers and PPE.

Competent personnel and supervision

By definition, those undertaking electrical work must be registered/licensed. However, as stated in section 9.1.4, a person conducting a business or undertaking (PCBU) is required to ensure “the provision of any information, training, instruction or supervision that is necessary to protect all persons from risks to their health and safety” (WHSA, s 19; SWA, 2016b). Thus, the organisation is required to implement processes to evaluate the knowledge and skills of licensed electrical workers to identify the need for further training or instruction and appropriate levels of supervision.

9.2.5 Personal protective equipment (PPE)

Work clothing for those working in or near electricity should always be made of natural fibres such as cotton or wool, or specially formulated or chemically treated synthetics (e.g. Nomex).[9] Common synthetics (e.g. polyester) can melt onto the skin in an arc or high-current flow and exacerbate a burn injury. Safety footwear conforming to *AS/NZS 2210.1:2010* (SA/SNZ, 2010a) and marked with "I" has electrical insulating properties. Insulated gloves conforming to *AS 2225–1994* (SA, 1994) should be used when working on low-voltage apparatus, and generally are used with insulating rubber mats. Faraday suits are used in the vicinity of high-voltage apparatus to protect against magnetic fields. When working in the vicinity of apparatus where there is potential for arc flash, clothing conforming to the *ENA NENS 09-2014 National Guideline for the Selection, Use and Maintenance of Personal Protective Equipment for Electrical Arc Hazards* (ENA, 2014) needs to be worn (Appendix 1).

9.3 Control of static electricity

Chemical and other high-risk explosive environments require elimination of sparks from static charge build-up that might initiate an explosion. The primary control is to earth all relevant plant so that any charge build-up is prevented. This includes bonding conductors to all separate parts of pipes, loading and discharge points, hoppers, tanks, etc., to earth. All parts should be at the same potential and earthed. Inherently safe equipment and appropriate procedures should be employed where there is a potential for static electricity to build up in a flammable environment.

Where static build-up can occur within offices, the best approach is to review the air conditioning so that humidity is in the higher end of the comfort range of 30-70% to allow static charge to bleed away naturally. Changes to floor coverings may be required in certain cases.

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[9] Although specially treated PPE is increasingly being used in the electrical industry, it is less common in general industry.

9.4 Failures in control

Electricity is in all workplaces and all homes. Australians are familiar with electricity and the standard controls; however, as noted in section 3, these controls are often breached or break down, resulting in injury and death. The most common reasons for failure in controls is the condition of equipment and unsafe work practices due to time and cost pressures. Two decades ago, Williamson and Feyer (1998) found that:

- A number of factors distinguished electrical fatalities from work-related fatal accidents in general
- Poor upkeep of equipment was a common factor
- Behavioural-based events mostly occurred early in the accident sequence rather than immediately before the fatality
- Unsafe work procedures endorsed by management were the largest single contributing work practice.

Regarding procedures, Williamson and Feyer (1998) observed that omissions (things not done) were more common in electrical fatalities than commissions (things done incorrectly), and that the most common type of error was a 'slip' or skill-based error when carrying out a routine activity. A more recent study (White et al., 2016) provided insight into the failure in procedures as a risk control for electrical hazards. Interviews with electrical workers revealed that barriers to safe working included:

> - Insufficient time to conduct risk assessments for every job …
> - Insufficient time to complete a job if an employee acts as a safety observer instead of working on other tasks
> - Insufficient time to regularly read codes of practice and other guiding documents …
> - Cost implications of performing all the safe working practices discussed, and the potential to lose work to other contractors if these costs were passed on to clients …
> - Training [of] new electrical workers, such as apprentices …
> - Discomfort associated with PPE and the possibility that the use of PPE could restrict the workers' movement and increase their risk… (White et al., 2016, pp. 25-26).

Some of the interviewed workers also indicated that a barrier to use of codes of practice related to a perception that these and other guiding documents were "too long and difficult to understand [and] not specific enough to be relevant to their work" (White et al., 2016, p. 26).[10]

Anedoctal reporting indicates that maintenance work is often done on partially de-energised systems because full shutdowns have significant cost impositions. Lockout/tagout and associated permit-to-work processes are vital components of safe systems of working with electricity. However, audit processes and incident investigations often document issues with

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[10] See also *OHS BoK* 11.4 Rules and Procedures.

the integrity of such systems, highlighting their weakness as a risk control strategy. Weaknesses in the permit-to-work system are often exposed by:

- Production pressures
- Unavailability of equipment
- Work extending across more than one shift
- Lack of role clarity, including lack of understanding of the responsibilities of each role in the permit process.

9.5 Post-incident management

As with all emergency situations, the first step in managing an electrical incident is to assess the dangers in the area. This requires identifying any energised equipment, including any fault current in items such as ladders or metal components and any step potential (section 4.4.3), and where possible removing the electrical current. In the case of an incident involving HV electricity where the victim remains in contact with the electricity, rescue is not possible. Action can be taken only when the network operator has de-energised the system.

When safe, every effort must be made to remove the person from contact with the electricity. This should be done using a non-conducting tool or even dry wood to ensure that the would-be rescuer does not fall victim. After contact with electricity, speed of resuscitative measures is critical. Cardiopulmonary resuscitation (CPR) should be initiated immediately and advanced life support (e.g. defibrillation) should occur within eight minutes (NIOSH, 1998). Any person who has received an electrical shock should receive medical assessment and treatment even when there appears to be little immediate effect from the electric shock as symptoms may take up to 48 hours to appear.

10 Implications for OHS practice

Working on or near electrical equipment presents critical risks with a potential for fatality. While electrical work is a specialist activity, the OHS professional has an important role in stimulating critical analysis to inform hazard identification and risk assessment, and in ensuring that a systems approach is applied to both the implementation of controls and the monitoring strategies for assuring their integrity. The OHS professional should bring to the discussion information on the ways in which controls for electrical hazards commonly fail, and challenge those in the workplace to consider how the controls might fail in their specific situation.

While there may be a focus on administrative controls for electrical hazards, the OHS professional has an important role in promoting the prioritisation of controls at the top of the hierarchy of control.[11] When administrative controls are being considered the OHS professional should contribute information about the impact of organisational culture on work practices, including the concept of work-as-imagined compared with work-as-done, and other factors such as time and cost pressures, training and supervision.

To fulfill this role, the OHS professional requires knowledge of:

- Electricity as a hazard
- Injury outcomes associated with electricity
- Standard controls
- How controls might fail.

This knowledge will enable the OHS professional to ask challenging questions such as those below (but not necessarily know the answers).

For the management system:

- What design controls are in place for electrical hazards? Are all electrical circuits protected by residual current devices (RCDs)?
- How is electrical safety integrated into the organisation's OHS management system[12] and risk management processes?[13]
- Do the routine audit processes include examination of integrity of permit-to-work systems, the suitability of labels, the effectiveness of training and other critical controls?
- Are training and experience requirements set for authorisation of electrical workers? What processes are in place for monitoring the currency and effectiveness of training for electrical workers?
- Are processes in place for monitoring reporting electrical incidents?
- Are processes in place for thorough investigation of electrical incidents?
- What processes are in place for monitoring compliance with controls for electrical hazards, including administrative controls?
- How is the impact of work pressure, fatigue and supervision on work practices being monitored?
- Are subcontractors integrated into and working under the OHS management system?

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[11] See *OHS BoK* 34.1 Prevention and Intervention.

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

[13] See *OHS BoK* 31.1 Risk.

For individual tasks:

- Where electrical work is undertaken on behalf of a client and there is a potential for client to pressure minimise disruption (i.e work energised), are processes in place to advise/educate the client of the dangers in working 'live'? Are shutdowns planned and scheduled with the clients knowledge that the alternative can result in much greater disruptions if things go wrong in terms of injury, fatality and the implications for having to replace expensive equipment and having plant shut down for the time required to carry out repairs?
- Has a risk assessment been done? Who was involved in the risk assessment? What experience and authorisations do they have?
- Has a Job Safety Analysis (JSA) (or similar) been done? Who was involved? What experience and authorisations do they have?
- Are Safe Work Method Statements (SWMS) required? Available? Understood?
- Are minimum clearances applicable and known?
- What is the minimum required PPE for the job? Is the PPE compliant with the relevant standard?

For electrical tasks

Figure 11 is a tool to support OHS professionals in job planning and mentoring supervisors and managers. Developed from the sample job briefing and planning checklist in *NFPA 70E: Standard for Electrical Safety in the Workplace* (NFPA, 2018), it includes pre-job checks for arc flash hazards, which are discussed in Appendix 1.

Identify ❑ Hazards ❑ Voltage levels involved ❑ Skills/authorisation levels required ❑ Any 'foreign' (secondary) voltage source ❑ Any unusual work conditions ❑ Number of people needed to do the job, including any safety observer ❑ Shock protection boundaries ❑ Available incident energy	❑ Potential for arc flash (has an arc flask risk assessment been done?) ❑ Arc flash boundary ❑ Evidence of impending failure (e.g. deterioration of insulation, rodent or dust incursion) ❑ Controls in place to prevent/reduce impact of arc flash (and level on the hierarchy of control) ❑ PPE required for task
Ask ❑ Can the equipment be de-energised? ❑ How will the isolation be achieved? Are there risks in carrying out the testing? Can the equipment be effectively locked out? ❑ Has the test equipment been checked? ❑ Who will sign onto the work permit? ❑ Who will authorise the work permit? ❑ Will the job be completed within the shift? What arrangements are in place if the job is not completed within the shift? ❑ Are backfeeds possible in the circuits to be worked on?	❑ Is an energised electrical work permit required? ❑ Is a safety observer required? ❑ Is a SWMS required? Is it available and known by workers? ❑ Are there any maintenance issues with the equipment? ❑ Are there any external factors likely to affect the job (time pressure, weather, …)? ❑ Are there any barriers to getting the job done safely? How might the barriers be addressed?
Check ❑ Job plans ❑ Single-line diagrams and vendor prints ❑ Status board ❑ Permit documentation and process **Know** ❑ Who is in charge (supervisor)? Are they familiar with the job requirements? Will they be at the work site? ❑ Details of job requirements	❑ The work procedure (Are there any barriers to implementing the work procedures?) ❑ Currency/reliability of information on plant and vendor resources ❑ Safety procedures ❑ Worker familiarity with equipment and task ❑ Who else needs to know about the job and/or may impact or be affected by the job)? ❑ How have the details of the job been communicated to those who need to know?
Think ❑ Unexpected events … What if? ❑ Lock – Tag – Test – Try ❑ Test for voltage – First ❑ The right tools for the job; are they available?	❑ Temporary protective grounding or personal bonding ❑ Barriers and barricades ❑ What else … ?
Prepare for an emergency ❑ Is an automated external defibrillator (AED) available? ❑ Is the safety observer CPR/EAD trained? ❑ Is the required emergency equipment available? Where is it? ❑ Where is the fire alarm?	❑ Where is the fire extinguisher? ❑ Where is the nearest telephone? What is the emergency phone number? ❑ What is the exact work location? ❑ How is the equipment isolated in an emergency?

Figure 11: Job planning prompts for electrical tasks (modified from NFPA, 2018, p. 92)

11 Summary

People have lived and worked with electricity since the early 19th century, but the statistics and case studies presented in this chapter show that worker deaths and injuries as a result of electrical incidents are still occurring.

OHS professionals have long considered working with electricity as a specialist activity. While this is certainly the case, this chapter has highlighted a greater role for generalist OHS professionals to work alongside electrical specialists to ensure a systems approach to risk assessment and risk control for electrical hazards. The OHS professional can increase resilience of systems and controls by taking the role of the 'black hat' (or devil's advocate) as described in Edward de Bono's 'six thinking hats' model to "spot difficulties and dangers; where things might go wrong" (The de Bono Group, n.d.).

This chapter provides the knowledge base to enable the OHS professional to take on this role of challenging thinking and practice around the control of electrical hazards for both non-electrical and electrical workers. After a brief consideration of the history of electrical safety and the incidence of electrical injury and mortality in the workplace, the chapter focused on provision of information about electricity that is likely to be relevant to the generalist OHS professional role. It elucidated the nature of electricity, the electrical distribution system and the nature of the electricity/user interface. It then considered the potential injury and health impacts associated with electricity and the relevant legislation and standards. A feature of the chapter is the differentiation between electrical hazards and associated controls for non-electrical work and for electrical work, with the risks to electrical workers for arc flash further explored in the Appendix. Finally, the chapter considered the implications for OHS practice, providing system and individual-job level prompts for the generalist OHS professional.

Sources of information

The electrical safety regulator in each state is a good source of information.

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