OHS Body of Knowledge

Physical Hazards: Electricity

Core Body of Knowledge for the
Generalist OHS Professional

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Physical Hazards: Electricity

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Abstract

Electricity, present in all workplaces, kills a significant number of Australian workers every year. Most of these fatalities occur outside the electrical industry. As a basis for advising on and monitoring controls, the generalist Occupational Health and Safety (OHS) professional should understand the basic physics of electricity and how electricity causes death and injury, as well as the regulatory framework. This chapter presents fundamental information about electricity, its physiological effects on the body, and factors that increase and decrease the risk of injury. Methods of controlling electrical risk are presented, along with details of relevant legislation and standards, and the implications for OHS practice.

Keywords

electricity, legislation, hazards, control

Contents

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. Furthermore, efforts to generate more electricity are having significant impacts on the environment and these, in turn, are driving technological innovations seeking cost-effective non-fossil energy sources that can be converted into electricity. Electricity is a technological leg for the developed world's high standard of living that the developing world is seeking to emulate. Although it can be a powerful servant, it is one that must be tightly controlled.

This chapter presents information to assist the generalist Occupational Health and Safety (OHS) professional in understanding the nature of electricity, how it can harm the human body, legislation and standards relevant to electrical safety, and standard control measures. This chapter does not encompass specialist knowledge required by OHS professionals working in the electrical distribution industry.

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. Thomas Edison is thought to have developed the 'fuse' as the first electrical safety device when, in the 1860s, he used a wire between two terminals that melted when too much current flowed through it (Littelfuse, 2005). While Edison and George Westinghouse argued the relative safety benefits of direct current and alternating current, it was the transmission of electricity at high voltages and then transforming it to lower usable voltages that heralded the need for construction and safety standards. The development of electrical standards was driven by an insurance industry concern about fire hazards. The 1890s saw the advent of the first crude circuit breakers, and in the 1940s the first current-limiting fuses (precursors of the 'safety switch') and a voltage-presence testing device were developed. 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 the 1930s (Littelfuse, 2005). Despite the existence of such controls, the 1942 version of the *American Electricians' Handbook* advised:

> Electricians often test for the presence of voltage by touching the conductors with the fingers. This method is safe where the voltage does not exceed 250…[and] the presence of low voltages can be determined by tasting. The method is feasible only where the pressure is but a few volts…(as cited in Littelfuse, 2005, p. 17).

3 Extent of the problem

Analysis of 2006–7[1] workers' compensation data reveals five fatal contacts with electricity and a further 185 claims related to contact with electricity; 70% of the latter resulted in at least two weeks' absence from work (Safe Work Australia, 2006–7). Other Australian databases indicate a more serious situation: 71 people fatally contacted electricity in the workplace between 2003 and 2008 (i.e. about 15 per year) (Safe Work Australia, 2010a), and 91 people presented to hospital emergency departments with work-related electricity injuries between July 2002 and June 2004 (i.e. about 45 per year) (ASCC, 2007).[2] While less than 3% of the compensation claims for electrical injuries occur in the electricity, gas and water industry, 47% of claims occur in manufacturing, construction and retail trade (Safe Work Australia, 2006–7).

4 Understanding electricity

Handling electricity safely requires a basic understanding of the underlying physics, how electricity is distributed to the workplace, the physiological impact of electricity on the human body, and the nature of electrical injuries.

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; an example is 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 insulators (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 $1.68 \times 10^{-4}\Omega$).

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[1] The most up-to-date and complete data available at the time of writing.

[2] The variation in numbers occurs because workers' compensation data mainly covers employees; hence fatalities to self-employed workers are generally not included. The *Work-related Traumatic Injury Fatalities, Australia* (Safe Work Australia, 2010a) also includes the Notified Fatalities collection and the National Coroners' Information System.

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 then 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:

$$V \text{ (voltage in volts)} = I \text{ (current in amps)} \times R \text{ (resistance in ohms)}$$

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):

$$P \text{ (power in watts)} = V \text{ (volts)} \times I \text{ (amps)}$$

AS/NZS 3000:2007 (SA/SNZ, 2007) defines types of voltage as:

- Extra low voltage: <50V AC or <120V DC
- Low voltage: between extra low- and high-voltage ranges
- High voltage: >1000V AC or >1500V DC

Domestic and industrial voltages (AC) are defined in *AS/NZS 3000:2007* as:

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

In most domestic electrical circuits there are 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 occurs (the ground provides an alternative path for the electric current to return to the power source). A similar situation applies to industrial three-phase circuits, except that there are three actives (red, white and blue phases). Safety is compromised if active and neutral wires are inappropriately wired (reversed polarity) or if the earth is inappropriately wired to the neutral connection. It should be noted that within the electricity industry (i.e. generation, transmission and distribution) and within organisations that are users of high-voltage electricity, there is additional complexity in controlling electrical safety that is beyond the scope of this chapter.

Electricity produces an electromagnetic 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. Health-effect concerns about the radiation from fields around high-voltage power lines relate to the magnetic field.[3]

Static electricity refers to the build-up of electrical charge on the surface of objects, where it can remain if the object is an insulator, 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, a discharge in the form of a spark can provide enough energy to initiate an explosion or fire.

4.2 The electricity distribution system

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). 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 starts to exceed generating capacity, the system initially tries to compensate by reducing the voltage (brown-out); if this is not sufficient to balance supply and demand, then supply is suspended temporarily from particular regions (black-out).

4.3 Physiological effects of associated injuries

Electric shock and burns may occur as a result of contact with electricity. Also, as electricity is a form of energy, injury can result from being in the proximity of electrical equipment when there is a loss of control of the energy. There may be further injury as a consequence of the impact of electricity.

4.3.1 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 that the resistance of the circuit contacted, then the electrical current will preferentially flow through the human body. There are three main types of direct electrical injuries:

- Electrocution, which occurs when the electrical contact results in death
- Electric shock, which occurs when there is any contact with electricity ranging from a minor 'zap' to non-fatal fibrillation and/or burns

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[3] *See BoK* Physical Hazards: Radiation

- Burns, which may be either internal or external and depend on voltage, current and duration of contact.

The degree 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. The resistance of human skin varies between individuals and the environment or circumstances they are in. 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 effects of various current strengths on the human body are indicated in Table 1.

Table 1: Approximate effects of AC current (NIOSH, 1998)

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

Burns usually occur at the points of entry and exit of the electric current. Internal burns on the path that the current takes through the body also can occur, particularly with high voltage. Currents greater than 16mA stimulate involuntary contraction of the flexor and extensor muscles. If the flexor muscles predominate, the person will be unable to release their grip on the conductor until the current stops, thus increasing the degree of injury. Currents exceeding 20mA passing through the chest can cause ventricular fibrillation, potentially resulting in death from electric shock.

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 thorough the person. Factors affecting the strength of current, and therefore severity of potential injury, are those that decrease body resistance:

- Presence of moisture, including perspiration, wet clothing, standing in water or high humidity
- Metal objects worn, e.g. jewellery, watches, eyeglasses.

An example of decreased resistance is provided by the Federal Government's 2009–10 Home Insulation Program where aluminised batts and sweating workers in hot ceilings interacted fatally with electric wiring (Hawke, 2010). Conversely, factors which increase resistance include: appropriate protective equipment such as insulating rubber mats; and appropriate protective clothing covering the body including arms and legs, special insulating gloves, and safety shoes.

If a person contacts electricity, every effort must be made to turn off the current or remove the contact. In the latter case, it is important that an insulating tool (e.g. dry wood) is used to remove the contact 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). The person should then be treated promptly by appropriate medical staff. As symptoms may take up to 48 hours to appear, assessment and treatment should still be undertaken when there appears to be little immediate effect from the electric shock.

4.3.2 Injuries when working in the proximity of electrical apparatus

Arc flash and blast

Arc flashes or blasts may occur when the insulating material surrounding an energised conductor becomes damaged to the extent that there is a sudden release of intense energy in the form of an arc. These currents can be high enough to immediately vaporise the conducting metal, causing an explosion. If people are in close proximity and exposed to such an event it is very likely that they will suffer arc blast or flash burns. Sparks or arcs also may ignite environments containing flammable substances.

Capacitor discharge

Capacitors are used to store charge in electrical circuits. If the electrical charge is not drained after isolation, they have the potential to cause serious injury when the apparatus is worked on and then discharges through the person. Where applicable, capacitor discharge should be part of an isolation procedure.

Induction

Electrical induction can cause circuits to become energised even without physical contact to a live circuit. Alternating currents produce an alternating magnetic field, which can then induce current in a stationary wire loop not directly connected. This effect can occur on the ground underneath a high-voltage power line and may create electrical hazards for people in the area.

Down power lines

When a live wire touches the ground, the voltage on the ground fans out in concentric circles, decreasing with increasing distance from the point of contact. This provides the potential for a person standing on a line radial from the point of contact to have a voltage difference between their feet ('step potential') causing current to flow through the person and hence an electrical shock. If caught in such a situation, a person should keep their feet together and hop out of the area.

Plant contacting power lines

Mobile plant such as cranes or forklifts with tines extended can contact overhead cables. An arc can form when earthed metal objects approach power lines without contacting them. When such plant becomes electrified, persons in contact with the plant may receive a fatal electric shock. Persons inside such plant should stay inside and avoid contacting any metal surface.

4.3.3 Static electricity

Static electricity produces effects that can vary in severity from explosions within flammable environments, as noted above, to discomfort associated with static discharges within an office where the humidity is low, and where carpets and other furnishings cause charge build-up.

4.3.4 Other hazards associated with electricity

Other possible consequences that may result from working on or near electrical equipment include *falls,* which can occur while working at heights after a mild electric shock causing a loss of equilibrium, or by a throw from electrical contraction of the extensor muscles. Also, there may be *legacy safety issues,* such as those 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.

5 Legislation and standards

Historically in some jurisdictions, electrical safety has had legislation and specialist regulators separate from mainstream OHS. However, the draft national *Work Health and Safety Regulations* (Safe Work Australia, 2010b) now cover electrical work (*WHSR* Part 4.7), and the national *Model Work Health & Safety Act* (Safe Work Australia, 2011) makes electric shock a notifiable incident (WHSA ss 34c, 36e). 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, e.g. the regulations under the *Electrical Safety Act 1998* (Vic), which also govern licensing of electricians within Victoria.

Each Australian jurisdiction has developed relevant codes of practice for low-voltage and high-voltage work with the relevant Australian Standard being *AS/NZS 3000:2007 Electrical Installations* (known as the *Wiring Rules)* (SA/SNZ, 2007). Two standards of importance for the OHS professional are *AS/NZS 3760:2010 In-service Safety Inspection and Testing of Electrical Equipment* (SA/SNZ, 2010) and *AS/NZS 4836:2011 Safe Working On or Near Low-voltage Electrical Installations and Equipment* (SA/SNZ, 2011).

6 Control of electrical risk

Although specific controls for electrical hazards are discussed below, a systems approach[4] with multiple layers of defences is particularly important for electrical hazards. Certain aspects of electrical safety require specialist expertise (e.g. relating to design and to high-voltage work). However, the generalist OHS professional should be aware of the following control measures, normal risk-management processes and the hierarchy of control in managing electrical hazards.

Control measures put in place in any situation depend on a range of factors, and organisations may manage the risks in different ways. The controls discussed below are not exhaustive.

6.1 Elimination

The draft national *Work Health and Safety Regulations* (Safe Work Australia, 2010b) prohibit work on electrical apparatus while the equipment is energised except in specified circumstances (*WHSR* s 4.7.13). All electrical apparatus should be considered energised unless it is specifically tested to show that it is de-energised. Testing should be done by authorised persons. Lock-out/tag-out procedures should be employed to ensure that the apparatus remains de-energised while being worked on.

6.2 Engineering controls

Safe design is generally the primary mode of ensuring safety of electrical apparatus. In the first instance, this requires that electrical circuits are not readily accessible through location (e.g. power lines are above normal reach) or through the use of barriers (e.g. insulation or enclosed ‘fixed guards’ on electric motors conforming to *AS 4024.1601–2006* (SA, 2006)).

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[4] See *OHS BoK* Systems

Elevating work platforms required for work on energised apparatus (e.g. powerlines) need to be insulated so no electrical path to earth exists.

Engineering controls that protect against fault conditions need to be included as part of all electrical circuits. These include circuit breakers and residual current devices (RCDs). 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 structures. RCDs detect any misbalance 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 of 5mA and cut supply within 25–40 milliseconds. Since 1991 in Australia, RCDs have been mandatory on all power and lighting circuits in new houses. The draft *Work Heath and Safety Regulations* (Safe Work Australia, 2010b) require the use of RCDs on all electrical circuits at construction sites (*WHSR* s 4.7.21). Several jurisdictions also require RCDs in all workplaces and this could be considered best practice.

6.3 Administrative controls

Regardless of specific engineering controls in place, it is normal to apply appropriate procedural controls when working with electricity. The over-arching procedural control is that no work should be conducted on or near live conductors, but work may be undertaken on energised circuits under controlled conditions (e.g. for testing purposes). The procedures used to control work on or near electrical apparatus include individual locks and/or Permits to Work. The permit should cover the relevant safety precautions required that could include the use of authorisations or licensed operators, testing and bonding, barriers, safety observers and personal protective equipment. For example, work near NO GO zones around powerlines requires written authorisations from the electrical authority before any work commences. If conditions are unable to be met, then work must not proceed. Also, training and authorisation of workers for specific tasks are important administrative controls.

Plant and equipment records, including design diagrams and maintenance records, provide important information on electrical hazards associated with the equipment and should be kept up to date. Other administrative controls include inspection, testing and tagging of electrical equipment to ensure that it is in good condition, and signage to indicate the presence of electrical hazards.

6.4 Personal protective equipment (PPE)

Work clothing should always be made of natural fibres such as cotton or wool, or specially formulated or chemically treated synthetics (e.g. Nomex).[5] Common synthetics (e.g.

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

polyester) can melt onto the skin in an arc or high-current flow and exacerbate the burn injury. Safety footwear conforming to *AS/NZS 2210.1:2010* (SA/SNZ, 2010) and marked with "I" has electrical insulating properties. Insulated gloves conforming to *AS 2225–1994* (SA, 1994) are available for use with low-voltage apparatus, and generally are used together with insulating rubber mats. Faraday suits are used in the vicinity of high-voltage apparatus to protect against magnetic fields.

6.5 Control of static electricity

Process safety requires elimination of sparks from static charge build-up that might initiate an explosion. The primary control is to earth all relevant machinery 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.

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.

7 Implications for OHS practice

In a normal industrial situation, it is likely that the generalist OHS professional will deal with electrical matters only when purchasing electrical plant, through maintenance of existing electrical plant, or where workers are using electrically powered equipment or working near electrical apparatus.

Purchasing of plant other than portable electrical tools and equipment is a specialised field and the advice of an electrical engineer should be sought. Power tools and similar electrical equipment is normally approved by the jurisdiction testing authorities to *AS/NZS 3100:2009* (SA/SNZ, 2009) or similar.

Electrical safety within a maintenance situation requires inclusion of electrical matters in an organisation's safety management system. This may involve a general Safe Work Procedure covering all electrical work to be carried out, either by internal maintenance personnel or through contractors. The Safe Work Procedure should be consistent with *AS/NZS 4836:2011* (SA/SNZ, 2011) and could cover the information discussed above, for example:

- All electrical circuits must be covered by residual current devices (RCDs)
- All maintenance work on electrical plant should be carried out on de-energised plant, unless required to be testing in energised format

- Maintenance on de-energised plant must be carried out under lock-out/tag-out conditions
- All work on electrical plant must be carried out by licensed and authorised personnel
- Work on fixed electrical plant should be covered by the organisation's Permit to Work system
- Portable electric tools and equipment should be routinely tested and tagged in conformance with *AS/NZS 3760:2010* (SA/SNZ, 2010)
- First aid processes should include cognisance of the possibility of electrical incidents
- Reporting processes should include provision for electrical incidents, particularly in relation to mandatory reporting to the jurisdiction regulator
- Routine audit processes should include examination of electrical safety matters.

8 Summary

The fatal interaction between aluminised insulation batts and electric cables in ceilings in the 2009–10 Home Insulation Program (Hawke, 2010) suggested that understanding of electricity fundamentals is poor within the community. Nevertheless, the regulatory regimen generally ensures that safe design equipment is purchased, and safe work procedures are operating in Australian workplaces.

After brief consideration of the history of electrical safety and the incidence of electrical injury and mortality in the workplace, this 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 physiological effects of injury; relevant legislation and standards; and methods of controlling electrical risk. Finally, it considered the implications for OHS practice.

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

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