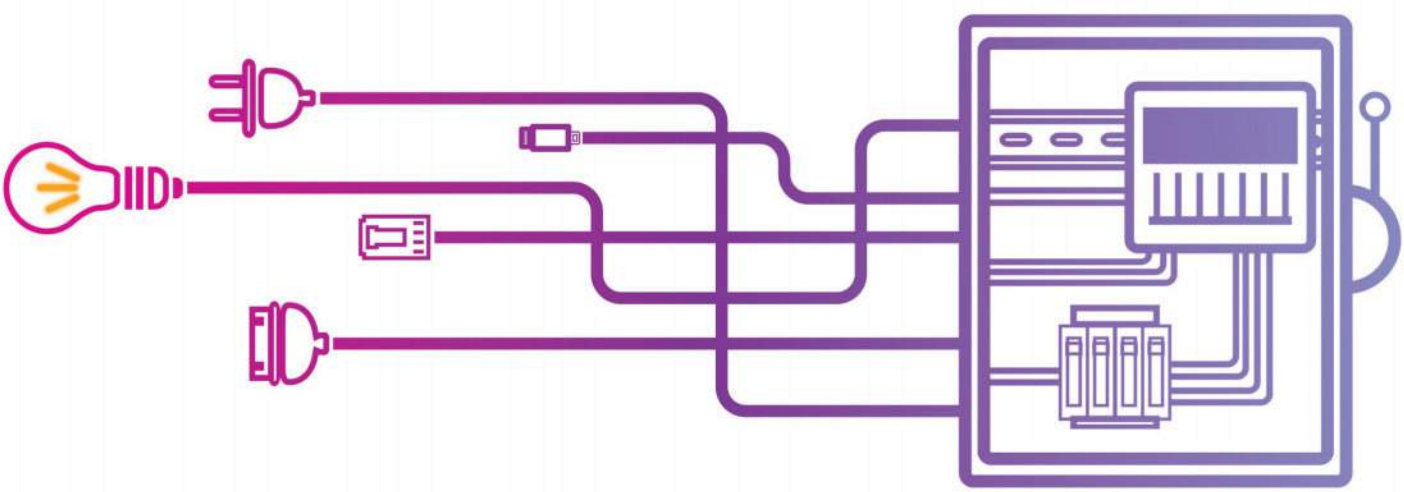
8TH EDITION

ELECTROTECHNOLOGY SERIES

Electrical Wiring Practice

A blended learning package



McGraw Hill Education

Keith Pethebridge • Ian Neeson • Paul Lowe

ELECTRICAL WIRING PRACTICE

AS/NZS 3000:2018

ELECTRICAL WIRING PRACTICE

AS/NZS 3000:2018

KEITH PETHEBRIDGE
IAN NEESON
PAUL LOWE

8th EDITION

McGraw Hill Education

National Library of Australia Cataloguing-in-Publication entry
Author: Pethebridge, K (Keith)
Title: Electrical wiring practice
Edition: 8e
ISBN: 9781760421069 (pbk.)

A catalogue record for this book is available from the National Library of Australia

---

Author: Pethebridge, K (Keith)
Title: Electrical wiring practice
Edition: 8e
ISBN: 9781760421069 (pbk.)
Published in Australia by
McGraw-Hill Australia Pty Ltd
Level 33, 680 George St, Sydney, NSW 2000
Publisher: Norma Angeloni-Tomaras
Content developer: Apeksha Rao
Senior production editor: Daisy Patiag
Editor: Mary-Jo O'Rourke AE
Cover design: Simon Rattray
Illustrator: Ian Neeson, Antony Neeson
Proofreader: Annabel Adair
Typeset in STIXMathJaxMain-Regular 10.5/14 pt by SPi Global
Printed in Singapore by Markono Print Media Pte Ltd on 80gsm matt art

Preface

Approach

The 8th edition of *Electrical Wiring Practice* continues with the visual format of the 7th edition, with revisions covering:

- the knowledge and skills specified in units of competency in national training packages for an electrical trade qualification and advanced trade competencies
- the Essential Capabilities of the Electrical Regulatory Authorities Council (ERAC) for an electrical licence relevant to electrical installations and safety
- extensive referencing to the *AS/NZS 3000:2018 Wiring Rules* and related Standards.

Features of this new edition include:

- practical applications of the *Wiring Rules* and related Standards
- greater use of visual elements that integrate text and graphics to aid learning and teaching
- expansion of review questions and answers for each chapter.

Electrical Wiring Practice employs clear visual elements to illustrate the practices and understanding required for working with electrical equipment and Standards.

Although the text is primarily written for students and teachers of electrical trades, it provides up-to-date reference material that will be helpful to many trade professionals.

Because so much modern human activity and the goods we produce incorporate electrotechnology, Standards for its safety and functionality have become a worldwide concern.

The trend towards the development of internationally aligned Standards and the adoption of new methods and materials means that compliance Standards are constantly changing.

Readers need to be aware that the references to 'Standards' in this book are given as guides, with examples of their application, but are in no way intended to replace them.

Features

- **Figures**—There are new and revised figures throughout, with text callouts to provide visual learning aids for practice and theory.
- **New Standards**—The chapters have been thoroughly reviewed to incorporate the latest Wiring Rules and compliance Standards, and current work practices.
- **Learning objectives**—Each chapter begins with a list of learning objectives, giving a summary of projected learning outcomes.
- **Introductions**—Each chapter begins with a chapter outline.
- **Chapter summaries**—Summaries list each chapter's key points.
- **Review questions**—In addition to being useful revision tools for students, these questions can also be used as sources for assignments and test questions for teachers and trainers. The solutions to these questions can be found on the Connect website.

Brief contents

Contents

About the authors

Keith Pethebridge

Keith Pethebridge, a passionate teacher and mentor, sadly passed away in March 2010. However, his insight and commitment, going as far back as the 1970s, to creating a text devoted to electrical wiring lives on. Now in its eighth edition, *Electrical Wiring Practice* can be regarded as Keith's legacy to the electrical industry. Thanks, Keith.

Ian Neeson

Ian Neeson is a vocational education and training consultant specialising in electrotechnology. He was involved in the development of the National Competency Standards for Electrotechnology and continues to provide assistance to the National ElectroComms and Energy Utilities Skills Council (EE-Oz Training Standards) in its program of continuous improvement.

Ian also represents the National Skills Council on the *Wiring Rules* Committee (EL-001) and Hazardous Areas Competency Standards Committee (P-12). He is a member of an IECEx Working Group for Personnel Competencies. For the past few years, Ian has also been a member of the judging team for the National Electrical and Communications Association (NECA) NSW Excellence Awards.

Paul Lowe

Paul Lowe has been involved in the electrotechnology field for over 35 years. During the past 14 years Paul has worked for TAFE NSW as a teacher, head teacher and, more recently, as Industry Liaison Manager responsible for electrotechnology across NSW.

He has been an active participant in the development of training package qualifications and units for the last six years and is a member of several technical advisory committees, representing NSW in the National Technical Advisory Group. He is currently part of the Commonwealth Industry Skills Committee as a technical expert, representing the Electrotechnology Training Package.

Acknowledgments

The production of a book covering such a wide range of topics would not be possible but for the contributions made by members of the electrotechnology industry in Australia and New Zealand. Our thanks go to these groups and organisations, who are listed below and cited throughout the text:

- ABB Robotics
- Boutique Power
- Clipsal, Schneider Electric
- EDMI
- Emona Instruments
- Fuji SMBE Harwal
- Heyday Group
- National Electrical and Communications Association (NECA)
- NATSPEC
- Olex Cables
- Philips
- PowerGen Australia
- Redflow
- SAI Global Ltd
- Selectronic
- Stand Alone Power Systems
- Standards Australia
- Tesla

Permission to reproduce the cover of *AS/NZS 3000:2018* given by SAI Global Ltd. This Standard can be purchased online at www.saiglobal.com.

The development of this edition would not have been possible without the help and encouragement of our colleagues in vocational education and training and in industry. Particular thanks go to Antony Neeson for his artistic prowess.

We would also like to thank the publishing team at McGraw-Hill for their hard work throughout the production of this book: Norma Tomaras, Apeksha Rao and Daisy Patiag.

Keith's legacy lives on.

Ian Neeson and Paul Lowe

Text at a glance

Learning outcomes

These points orient students to what they can expect to learn from the chapter and aid self-assessment.

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you will be able to:

- explain the principles for producing electricity
- explain the reasons for the adoption of alternating current (a.c.) for the main electricity power supply system
- describe the advantage and applications of modern direct current (d.c.) transmission
- identify the conductors and their purpose in a three-phase distribution system
- illustrate how electricity is transmitted and distributed
- illustrate the different arrangements of distribution to consumers
- describe the arrangements for electricity distribution within an electrical installation
- discuss the processes for the connection of electricity to a consumer's installation and the need for compliance with safety standards.

Chapter introduction

Every chapter commences with an introduction to provide a big picture overview and identify the key concepts to be covered in the text.

Learning how to achieve safety in the workplace is one of the most important aspects of your vocational training and education, and you will continue to put this knowledge into practice throughout your working life. Electricians have multiple roles when it comes to safety.

Firstly, they must carry out their work safely and observe all measures needed to protect themselves and fellow workers against workplace hazards. In addition to common workplace hazards, they must also deal with the dangers of working with electricity. This requires an understanding of the use of work safety practices and how safety is managed in the workplace, including a willingness to cooperate with other workers to recognise and deal with health and safety risks.

Secondly, electricians have a liability to ensure that the electrical systems and equipment they install and maintain are safe and remain safe for all those who use them. This requires a thorough knowledge of electrical principles, the *Wiring Rules* and regulations, and the skills to apply this knowledge.

In addition to this, if an accident does occur, those able to give assistance should know how to rescue a victim safely and how to apply emergency treatment.

Exercises

Throughout the book are a number of exercises for students to test their knowledge.

EXERCISE 3.1

Open the *Wiring Rules* at *Section 4 Selection and installation of appliance and accessories.* Note that all the clauses start with the number of the section, in this case 4, and the main requirements for each aspect of *Selection and installation of appliances and accessories* are listed under clauses numbered 4.1, 4.2, 4.3 and so on.

Now look up *Clause 4.4 Socket-outlets.* As the information about socket-outlets becomes more specific, that part of the clause is given a new heading and an additional point and number. In this case *Clause 4.4.1* covers 'Types' (of socket-outlets), while under the heading 'Types' the more specific requirement for suitability, the clause 'General', is given number *Clause 4.4.1.1.* Clauses like *4.4.1* and *4.4.1.1* are often called *sub-clauses.*

Information boxes

These box features highlight dangers, hazards and information that students should be aware of in the field.

CAUTION

Electrical workers in service or maintenance roles will often find themselves in unfamiliar working environments. Each time electrical workers encounter an unfamiliar workplace, they should request an orientation on the health and safety hazards present, and the procedures for controlling the risk of illness or injury in the unfamiliar environment.

ATTENTION

Don't rely on memory—write it down. Even on small jobs, several weeks can pass between roughing in the wiring and fitting out. If the job is a renovation, the cable routes you would normally use in a new structure may not be accessible, often resulting in convoluted cable runs. A record in a job notebook and on a plan of what you intend to do and what you have done can save a lot of time and prevent costly mistakes.

AS/NZS 3008.1 SERIES

Electrical installations—Selection of cables Part 1: Cables for alternating voltages up to and including 0.6/1 k V

This important Standard gives all the information about cables and, together with the *Wiring Rules*, is used by electricians when planning electrical installation work. It is published as *Part 1.1* for Australian conditions and *Part 1.2* for New Zealand conditions.

SAFETY ALERT

- ▲ Danger tags are for the personal protection of individual employees. No plant, switch, equipment, valve or any other controlling device should ever be operated if a Danger tag is attached.
- ▲ The isolation of any power source should only be conducted by competent and qualified personnel.

DANGER

Test before you touch

Do not rely on cable colours or markings as the only means of identification. Before connecting or disconnecting any cable, always follow safe testing procedures in order to know whether the cable is safe to work on and to confirm its function.

Figures

Extremely detailed and informative illustrations clearly explain key concepts. These figures are valuable visual tools for learning and teaching.

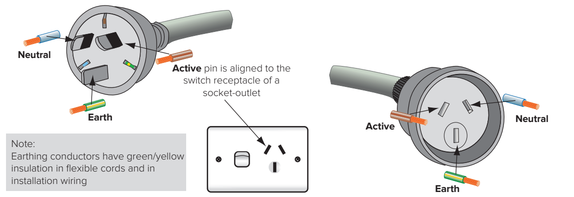


Figure 2.4c Making up a single-phase cord extension lead

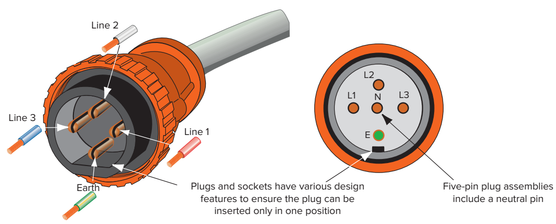


Figure 2.4d Connecting a multi-phase plug and cord

Examples

The text contains a wealth of examples to ensure student understanding and application.

EXAMPLE

In this example, the current through the body as determined by Ohm's Law is:

$$I = \frac{V}{Z}$$

where

I = current in amperes
V = touch in voltage
Z = impedance of current path through the body in ohms.
I = 230/1400

Then:

I = 0.164 A or 164 milliamperes, less than that drawn by a 40 watt lamp.

(Z is made up mainly of resistance in the examples in this text. Where reactance is significant, this will be noted.)

Review questions

At the end of every chapter is a comprehensive list of review questions to ensure students have covered all of the learning outcomes listed at the beginning of the chapter.

Review questions

1 Name the legislation and regulations governing workplace health and safety in your jurisdiction.
2 What is the purpose of codes of practice?
3 What is the purpose of health and safety regulation in the workplace?
4 Who is responsible for safety at work?
5 List four important steps an employer should take to ensure a safe and healthy workplace.
6 Describe, in order of importance, measures for controlling the risk from hazards in the workplace.
7 Describe a specific task or process that improves safety in the workplace.
8 List four ways in which hazards are identified.
9 Give an example of how the level of a risk is assessed.
10 What does risk level 'high' mean?
11 List some of the types of information given in a SWMS.
12 What precautions should an electrician take before entering an unfamiliar workplace?
13 Outline the purpose of WHS orientation and training.

Acronyms

Important acronyms are included in a glossary at the end of the book.

Acronyms

A	amp	JSA	job safety analysis
a.c.	alternating current	LAN	local area network
ACIF	Australian Communications Industry Forum	LOBAC	low-voltage aerial bundled cable
		LPG	liquid petroleum gas
ACMA	Australian Communications and Media Authority	MEN	multiple earthed neutral
		MIMS	mineral-insulated metal-sheathed
ACSR/GZ	aluminium conductor galvanised steel reinforced	MW	megawatt
		MΩ megaohm:	unit of electrical resistance equal to 10^6 ohms
AEMC	Australian Energy Market Commission		

Summary

The chapter summary provides a quick review with section references to ensure students can easily refer back to key material within the chapter.

Summary

2.1 Workplace health and safety
2.1.1 Regulations, codes of practice and Standards about work health and safety (WHS), Figure 2.1a
2.1.2 Managing risk, Figure 2.1b

2.2 Instruction, training, information and supervision
Figures 2.2a, 2.2b

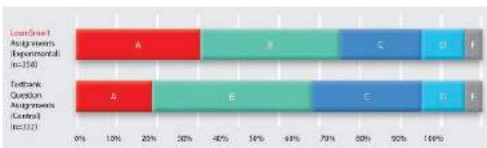
2.3 Workplace hazards and risk control measures
WHS safety practices in electrical work, Table 2.1
2.3.1 Lifesaving rules, Table 2.2
Safe work method statement (SWMS), Figure 2.3a, Table 2.3
2.3.2 Isolating supply—essential points of the safe work method, Table 2.4
2.3.3 Personal protective equipment (PPE) and tools, Table 2.5
2.3.4 Hazardous manual tasks
2.3.5 Workplace safety signs, Table 2.6
Fire safety, Table 2.7
2.3.6 Dealing with harmful substances

2.4 Safety of electrical installations and equipment
Purpose of the *Wiring Rules*, Figure 2.4a
2.4.1 Protective earthing, Figure 2.4b
2.4.2 Flexible cords and extension leads
Making up plug-and-cord sets, Figures 2.4c and 2.4d
2.4.3 Damp areas

LEARNSMART® ADVANTAGE

LEARNING AT THE SPEED OF YOU

LearnSmart Advantage is a series of adaptive learning products fuelled by LearnSmart—the most widely used and adaptive learning resource proven to strengthen memory recall, increase retention and boost grades.



Adaptive learning

No two students are the same, so why should their learning experience be? Adaptive technology uses continual assessment and artificial intelligence to personalise the learning experience for each individual student. As the global leader in adaptive and personalised learning technologies, McGraw-Hill Education is pioneering ways to improve results and retention across all disciplines.

SmartBook

Fuelled by LearnSmart, SmartBook is the first and only adaptive reading experience available today. Starting with an initial preview of each chapter and key learning objectives, students read material and are guided to the topics they most need to practise at that time, based on their responses to a continuously adapting diagnostic. To ensure concept mastery and retention, reading and practice continue until SmartBook directs students to *recharge* and review important material they are most likely to forget.

LearnSmart

LearnSmart maximises learning productivity and efficiency by identifying the most important learning objectives for each student to master at a given point in time. It knows when students are likely to forget specific information and revisits that content to advance knowledge from their short-term to long-term memory. LearnSmart is proven to improve academic performance, ensuring higher retention rates and better grades.

To find out more about **SmartBook** visit
www.mheducation.com.au/student-smartbook

Electrical energy 1

LEARNING OUTCOMES

After you complete this chapter and relevant learning experiences, you will be able to:

- explain the principles for producing electricity
- explain the reasons for the adoption of alternating current (a.c.) for the main electricity power supply system
- describe the advantage and applications of modern direct current (d.c.) transmission
- identify the conductors and their purpose in a three-phase distribution system
- illustrate how electricity is transmitted and distributed
- illustrate the different arrangements of distribution to consumers
- describe the arrangements for electricity distribution within an electrical installation
- discuss the processes for the connection of electricity to a consumer's installation and the need for compliance with safety standards.

1.1 Producing electricity

The bulk of electrical energy produced today is obtained from a rotating turbine attached to an electrical generator that uses electromagnetic induction to produce energy (Figure 1.1a). Energy used to drive turbines is extracted from steam, flowing water, hot gases and wind. In Australia, as in many other countries, the prime source for producing steam to drive turbines is coal. However, this is changing with the adoption of renewable energy sources driven by the need to reduce greenhouse gas emissions from burning fossil fuels. In a number of other countries, nuclear energy is the prime source. Although nuclear power stations are similar in many respects to other thermal power stations, they are identified separately because of the additional equipment required to control the process, the associated risk of a nuclear accident and the problems of nuclear waste containment.

Additionally, there are many small diesel engine-driven generators for electricity supply in areas remote from main power networks. These are becoming more prevalent as standby supply in non-domestic installations. Note that electricity produced for the main power network is alternating current, which has some distinct advantages over direct current.

Table 1.1 Common sources of energy and methods for producing electricity

Energy from materials by extracting thermal energy			
Energy source	**Method for producing electricity**	**Application**	**Figure**
Burning coal, oil or natural gas to produce steam or hot gases	Steam-turbine generator sets	Network base-load power	1.1b and e
Burning gas to produce high pressure combustion gases	Gas-turbine generator sets	Network base-load power	1.1c and e
Nuclear reaction to produce steam	Steam-turbine generator sets	Network base-load power	1.1d and e
Burning renewable organic matter (commonly known as biomass) to produce steam (emerging technology)	Steam-turbine generator sets	Supplementary supply to network and industrial consumers	
Fuels, typically diesel or biofuel, in combustion engine	Combustion engine-generator sets	Standby generation in critical facilities such as hospitals and data centres, and remote areas	
Energy existing in nature			
Energy source by conversion	**Method for producing electricity**	**Application**	**Figure**
Kinetic energy of moving (falling) water	Water-turbine generator set	Renewable base-load power and storage	1.1f and g
Kinetic energy of wind	Wind-turbine generator set	Renewable energy in the supply network	1.1k
Solar energy	Photovoltaic effect in solar cells	Consumer's own energy needs with supplementary power supplied to network	1.1i
Solar energy concentrated to produce steam (emerging technology)	Steam-turbine generator sets	Renewable energy in the supply network	1.1j
Heat energy in geothermal field to produce steam	Steam-turbine generator sets	Renewable base-load power in NZ only	1.1h
Kinetic energy of ocean waves (developing technology)	Hydraulic-turbine generator set	Renewable energy in the supply network (see www.carnegiece.com/wave/what-is-ceto)	

The voltage or pressure at which the current is produced ranges from 11 000 V to 23 000 V. Transformers are used to 'step up' the voltage for transmission and 'step down' for utilisation of the electrical energy. The ease with which voltage can be transformed is one of the main advantages of using a.c.

Hydroelectric power stations, such as those used in the eastern states of Australia and South Island, New Zealand, use the kinetic energy of moving water to drive turbines. Hydroelectric generation is the fastest to respond to increasing power demands, reaching full power in two to three minutes. These plants can provide both base-load and peak-load demands for power at a relatively low cost provided sufficient water is available. Hydroelectricity has the advantage of being able to store electricity. The generators can be used as a motor to pump water from a lower holding dam to the storage dam store. This is done during periods of low demand on the network.

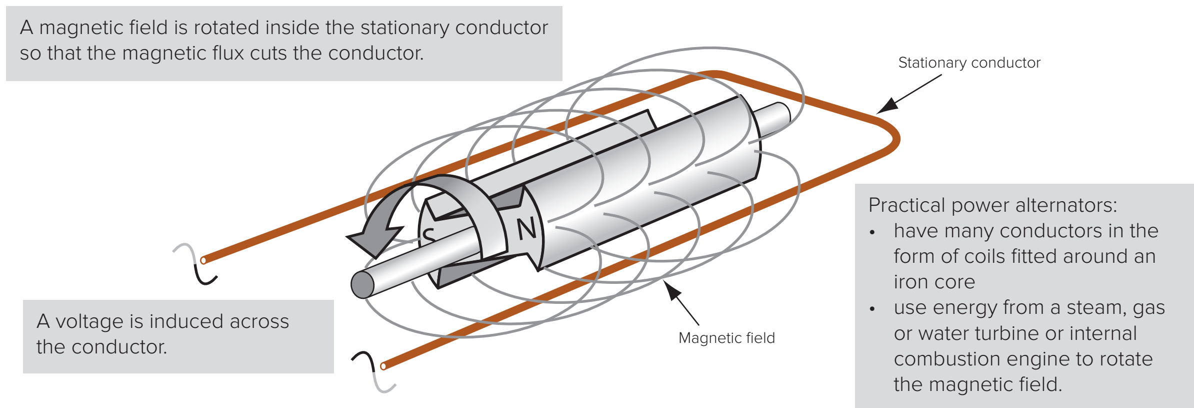


Figure 1.1a The law of electromagnetic induction applied in generators

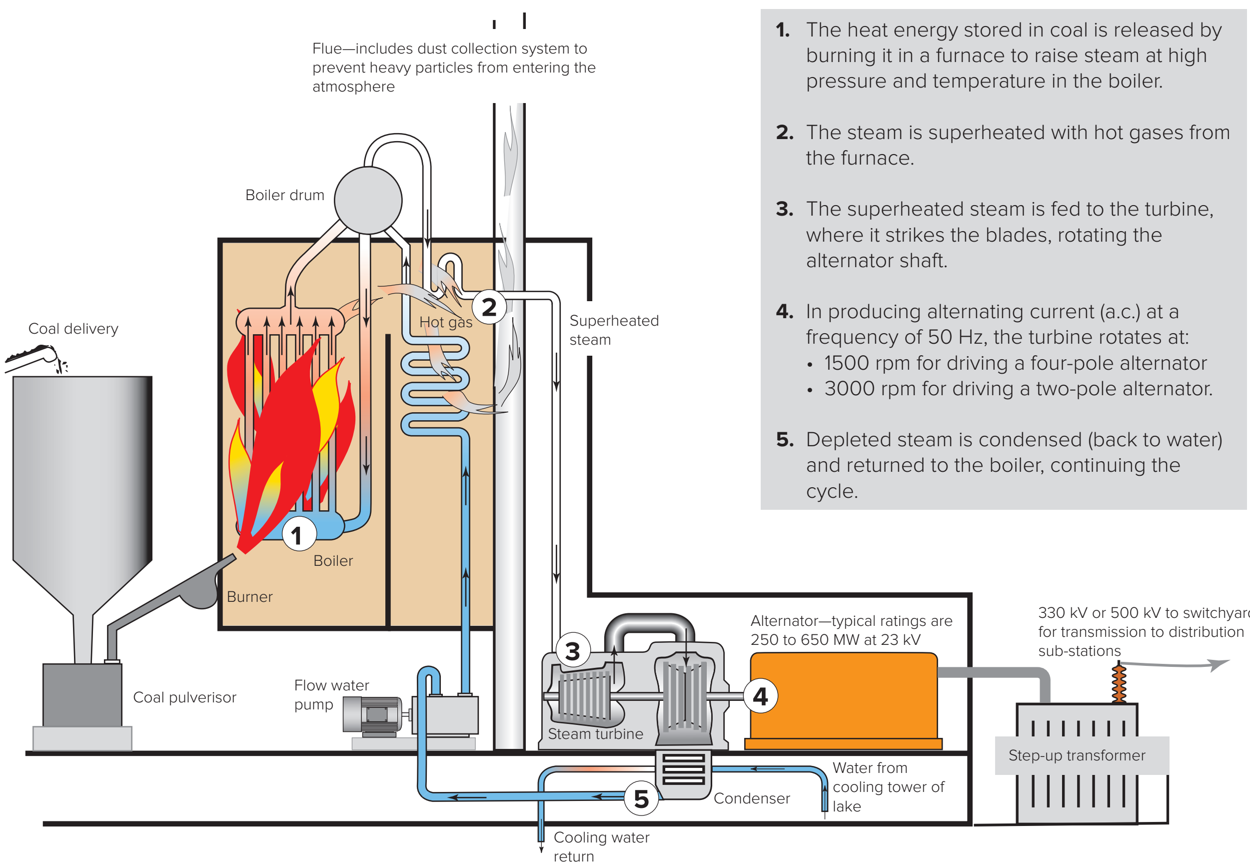


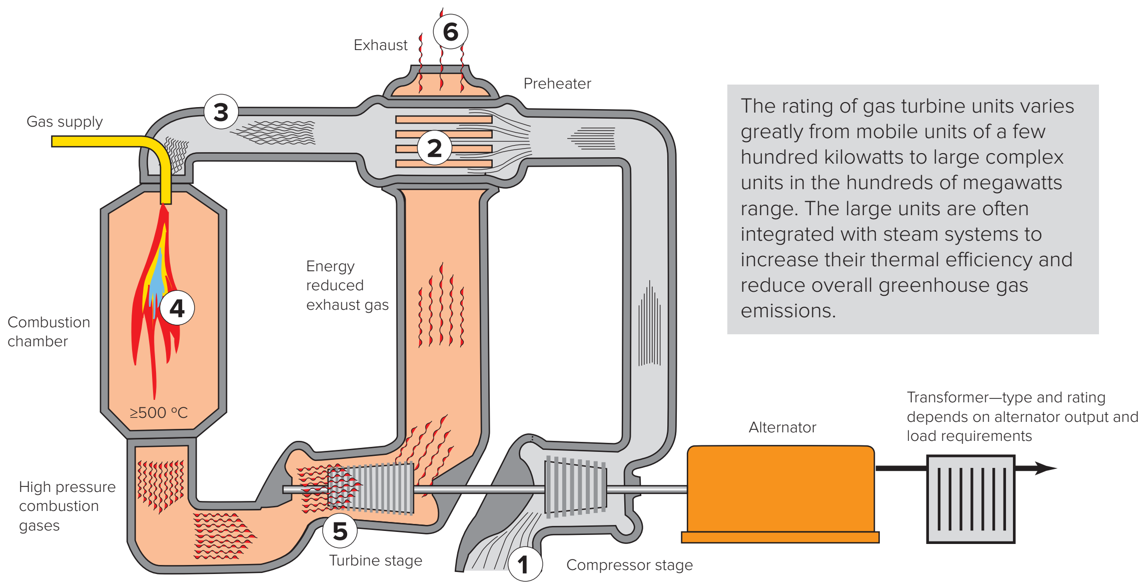
Figure 1.1b Principles of coal-powered thermal power generation

1.1.1 Generating and using energy efficiently

The efficiency of energy use can be increased by utilising the energy lost to the atmosphere through flue and exhaust systems to either generate electricity or provide the thermal energy needed for other processes. For example, a hospital might generate electricity using a gas turbine, and the hot exhaust gases from the turbine could be used to produce hot water and steam for hospital cleaning and sterilising purposes (see Figure 1.1c). Any excess electricity could be fed into a public grid system, resulting in a reduced cost of electrical energy for the hospital. This arrangement is known as co-generation and is being used in manufacturing processes where thermal energy is required.

1. Air is drawn into the compressor and compressed.
2. Exhaust gases heat the compressed air in the preheater.
3. Heated compressed air is fed to the combustion chamber.
4. Gas is burnt in heated compressed air in the combustion chamber producing high pressure combustion gases.
5. Combustion gases are fed to the turbine, where they strike the blades, rotating the alternator shaft.
6. Energy reduced combustion gases are emitted as exhaust.

In co-generation systems the exhaust gas is used in space, water or process heating increasing the thermal efficiency of the system to as much as 90 per cent.



The rating of gas turbine units varies greatly from mobile units of a few hundred kilowatts to large complex units in the hundreds of megawatts range. The large units are often integrated with steam systems to increase their thermal efficiency and reduce overall greenhouse gas emissions.

Figure 1.1c Principles of gas-powered thermal power generation

1. Reactor vessel contains a water coolant. Uranium fuel is immersed in the coolant.
2. Energy released in the nuclear fission process heats the coolant water in the reactor. The process is controlled by the lowering and lifting of neutron-absorbing control rods.
3. The heated coolant is circulated through the steam generator where it gives up heat and returns, cooled, to the reactor.
4. The heat from the reactor coolant heats water in the steam generators producing high pressure steam. This process isolates the energy produced in the reactor from the steam used to drive the alternators.
5. The steam is fed to the turbine, where it strikes the blades, rotating the alternator shaft.
6. Alternators are similar to the types used in coal-powered thermal power generation.
7. Depleted steam is condensed (back to water) and returned to the steam generator, continuing the cycle.

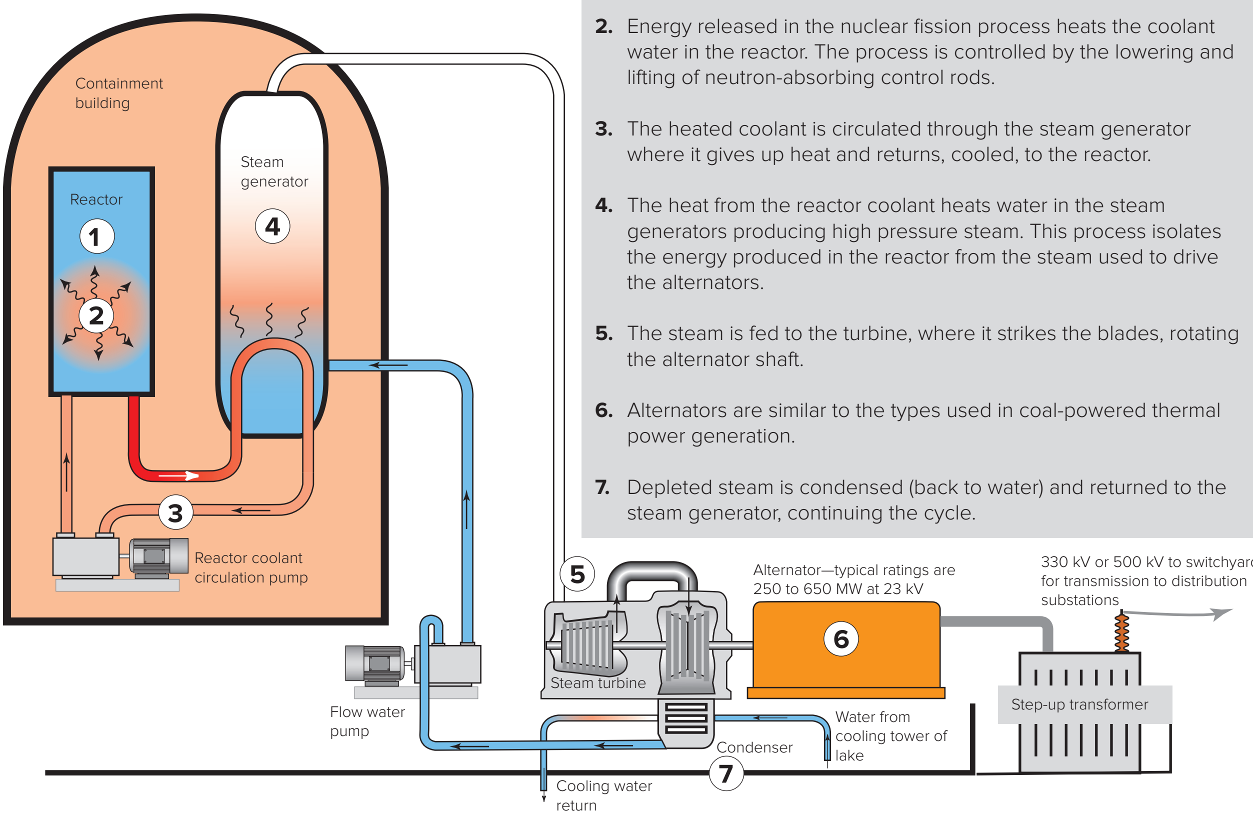


Figure 1.1d Principles of nuclear-powered thermal power generation

Steam and gas driven generators
Steam and gas turbine driven generators are typically designed with 2 or 4 poles because of high optimum turbine speed. (Generating at the standard frequency of 50 Hz a 2-pole machine spins at 3000 rpm.) These generators are designed with relatively small diameter rotors and long axial length. Steam turbine generators are the main source of base-load supply in Australia with machines rated up to 660 MW.

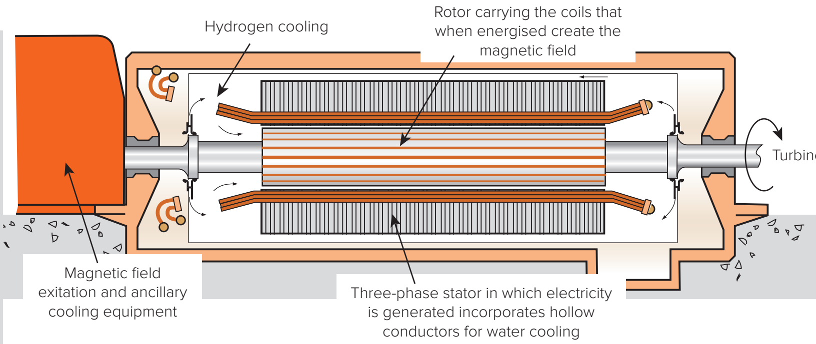
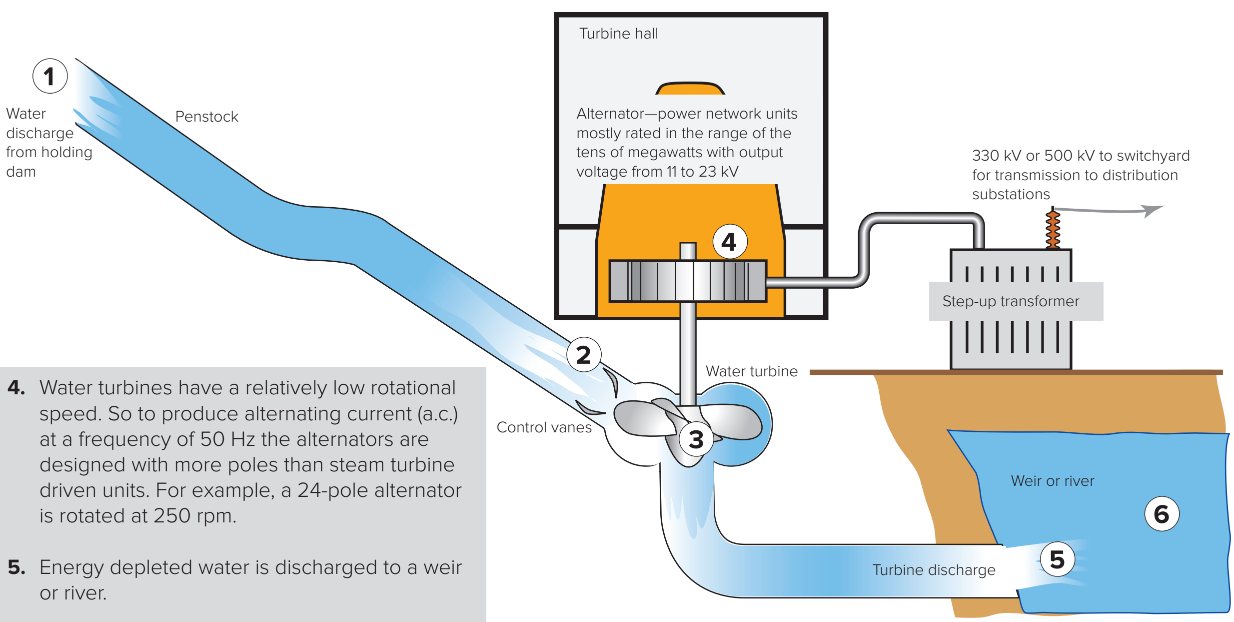


Figure 1.1e Features of steam turbine generators

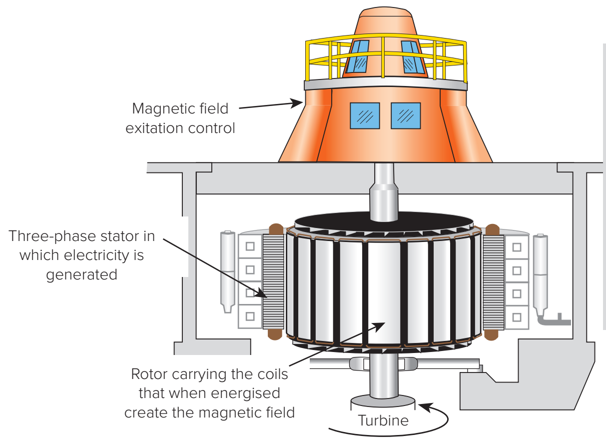
1. The water stored behind a dam is released through huge pipes known as penstocks.
2. Inlet guide vanes direct the water through the water turbine.
3. The kinetic energy in the falling water is transferred to the turbine blades rotating the turbine and the attached generator. The guide vanes allow the shaft to spin at a controlled speed and regulate energy output.

6. Discharge water is typically used for irrigation. Some turbine designs (e.g. Francis Turbine) can be used to pump water back to the holding dam.
In this system the alternator is used as a sychronous motor, taking power from the network during the off-peak periods to drive the turbine as a pump.



4. Water turbines have a relatively low rotational speed. So to produce alternating current (a.c.) at a frequency of 50 Hz the alternators are designed with more poles than steam turbine driven units. For example, a 24-pole alternator is rotated at 250 rpm.
5. Energy depleted water is discharged to a weir or river.

Figure 1.1f Principles of hydro power generation



Hydro generators
The spinning speed of water turbines is relatively low compared with steam and gas turbines. Therefore to generate the standard frequency of 50 Hz hydro generators are designed with as many as 24 poles resulting in a machine of large rotor diameter and short axial length. Hydro generators have lower outputs than steam turbine machines; however, they provide the largest amount of 'clean energy' base-load supply in Australia with machines rated up to 250 MW.

Figure 1.1g Features of water turbine generators

1. Water is injected deep into heat-bearing rocks.
2. The heat from the deep rocks is captured as steam and brought to the surface.
3. The steam gives up heat to a secondary (drive) fluid, which boils to become a high pressure vapour.
4. The high pressure vapour is fed to the turbine, where it strikes the blades and rotates the alternator shaft.
5. Depleted vapour is condensed (back to a fluid) and returned to the heat exchanger, continuing the cycle.

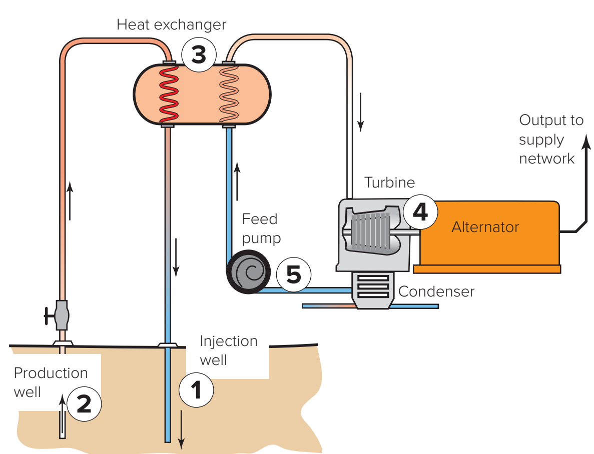
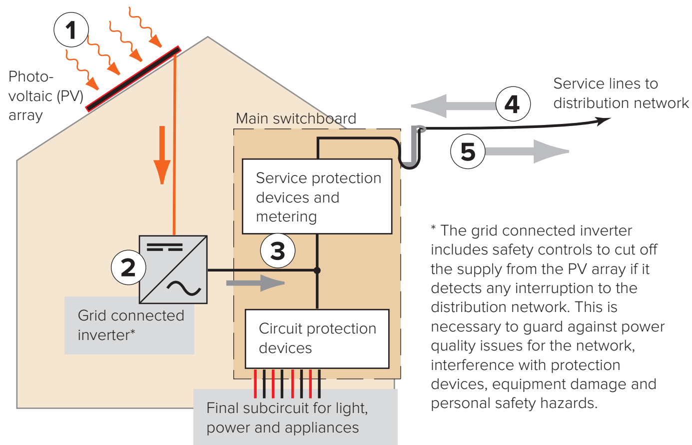


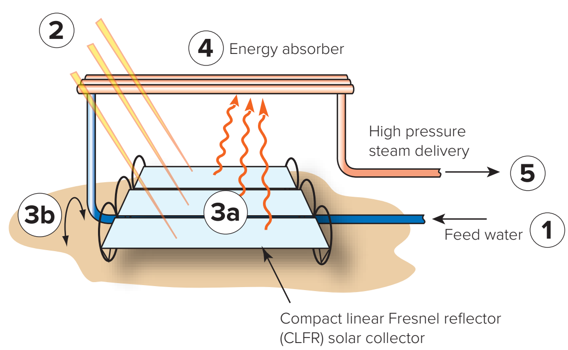
Figure 1.1h Principles of geothermal power generation

The National Construction Code (NCC) in Australia and the Building Code in New Zealand (NZBC) include requirements for buildings to be more energy efficient in which the electrical installation has a part to play. You will learn more about this and sustainable work practices in following chapters and as you progress through your training.



1. Energy from sunlight falling on the array of photo-voltaic cells is converted to d.c. electrical energy.
2. The d.c. from the PV array is fed into the grid connected inverter, which 'inverts' the d.c. to 230 V a.c.
3. Supply from the inverter is fed to supply loads to the consumer's installation or to the distribution network.
4. When the consumer's demand is greater than the energy generated by the PV array, energy is supplied from the distribution network.
5. When the consumer's demand is less than generated by the PV array, energy is supplied to the distribution network. In this way the consumer gains credits for the energy supplied.

Figure 1.1i Application of direct solar power generation



1. Water is fed to pipes in the energy absorber.
2. Sunlight strikes the CLFR collectors.

3a. CLFR collectors are focused on the energy absorber, reflecting the sunlight to roughly 30 times the intensity of sunlight at Earth's surface.

3b. CLFR solar collectors track sun for optimum energy capture.

4. Solar energy focused on the energy absorber is converted to thermal energy in the form of high pressure steam (285°C).
5. Steam is fed to turbines similar to conventional steam generation plants.

Figure 1.1j Principles of concentrated solar thermal power generation

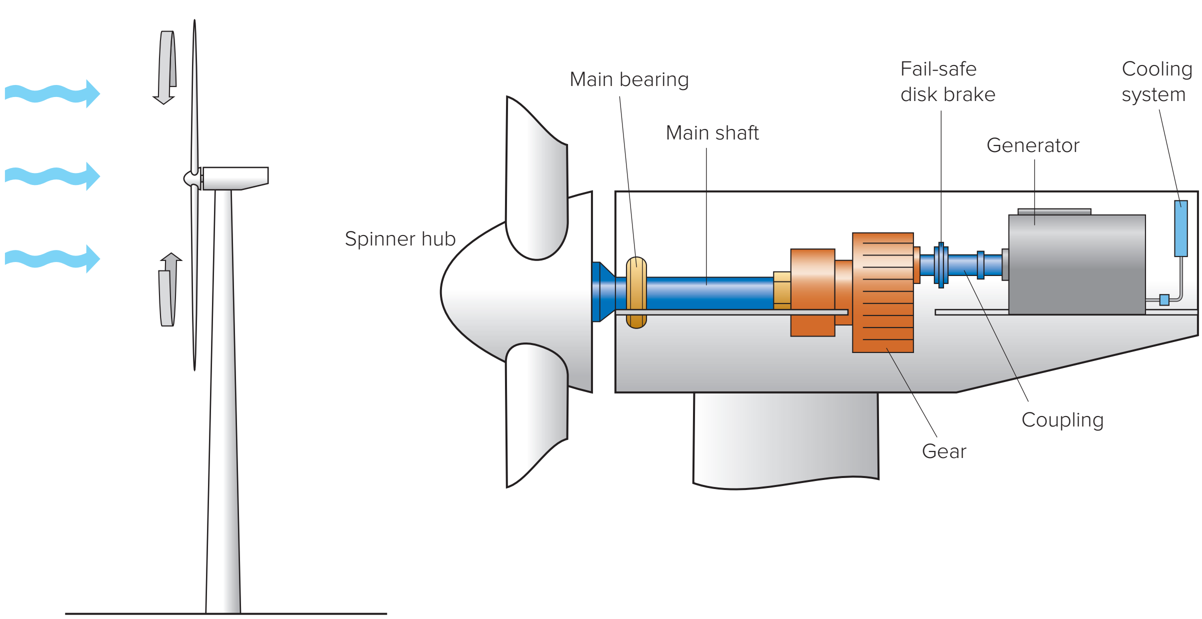


Figure 1.1k Principles of wind power generation

1.2 Electrical energy transmission and distribution

The main source of electrical energy is large power stations located on fuel reserves such as coal fields, producing alternating current which has some efficiency advantages over direct current as shown in Figure 1.2a. This electricity is made available to consumers through a national grid system of transmission and distribution lines. Some of the advantages of this include:

- larger generating units are more efficient in operation than smaller ones
- less reserve plant is required to supply 'peaks' of supply demand or in an emergency
- remote places, such as rural areas that would be considered inaccessible to a normal supply system, may be supplied by 'tapping off' the state grid
- the interchange of power is possible both within the grid system and interstate; the eastern grid scheme interconnects the power systems of Queensland, New South Wales, Victoria, South Australia, Tasmania and Snowy Hydro Limited; the New Zealand grid interconnects power systems of the North and South Islands; the interconnection of different grid systems is made possible by development of high-voltage direct current (HVDC) transmission (Figure 1.2b)
- centralised control is economic in both generation and operation.

A disruption to this arrangement is the adoption of renewable energy systems in recent years, in particular the installation of photovoltaic arrays by individual consumers who feed electricity excess to their needs to the energy network. This equates to adding many small 'power stations' and has caused some stability problems for energy networks. This will be discussed in more detail in Chapter 12 Renewable energy and other alternative supply installations.

The eastern grid scheme of transmission requires thousands of kilometres of high-voltage transmission lines. A small percentage of these lines might be underground where a concentrated load occurs in large cities, but the major grid system is overhead as aerial lines. Western Australia maintains generation, transmission and distribution systems separate from the eastern grid scheme. The main system services the metropolitan and south west areas while the more remote areas are serviced by smaller local networks. For complete reliability and service, the design of the transmission system must provide for the:

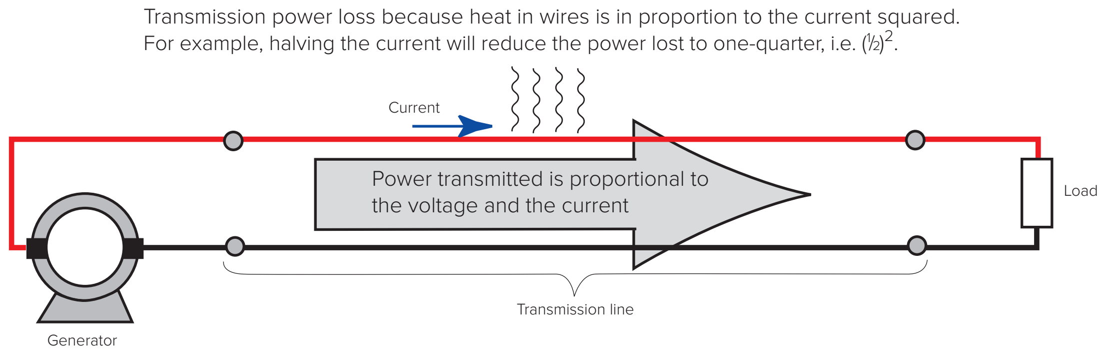
- continuity of supply under any conditions of breakdown, overload or emergency
- full protection of the system from external or internal hazards
- complete flexibility of the system for maintenance, power interchange or switching purposes.

Note: The circuit diagrams in this chapter do not show mandatory protection and control devices as the diagrams are intended to convey general concepts of transmission and distribution.

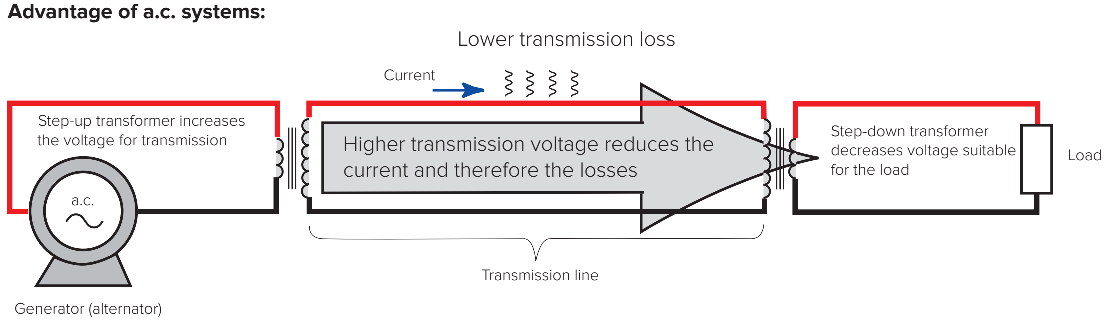
Both thermal and hydroelectric power stations generate three-phase power at voltages dependent on the generator's specifications. Typical generation voltages are 11 kV, 17 kV, 22 kV and 23 kV for thermal stations; and 6.6 kV, 11 kV and 22 kV for hydroelectric generation. The generation voltage is usually too low for long-distance transmission and must be 'stepped up' by transformers to transmission voltages having typical values of 66 kV, 132 kV and 330 kV. Primary grid transmission is usually at 330 kV. Victoria, New South Wales and South Australia have grid sections at 500 kV. At these high transmission voltages, less current is required to transmit a given amount of power, allowing economies to be effected in both the installation and utilisation of the power line. An overview of the whole system is shown in Figure 1.2c.

Control of the power system is effected by transmission network operator control centres in each state in which computer-based facilities continuously monitor energy needs and system stability in communication with distributor and generator control centres. As consumers switch on electrical loads such as lighting or electrical machines, more energy is drawn from the system, and likewise less energy is needed as electrical loads are switched off. In this way the consumer determines the amount of energy the system needs to supply at any point in time. These changes in energy demand cause instability in the system and any change in phase relationship or fluctuation in voltage

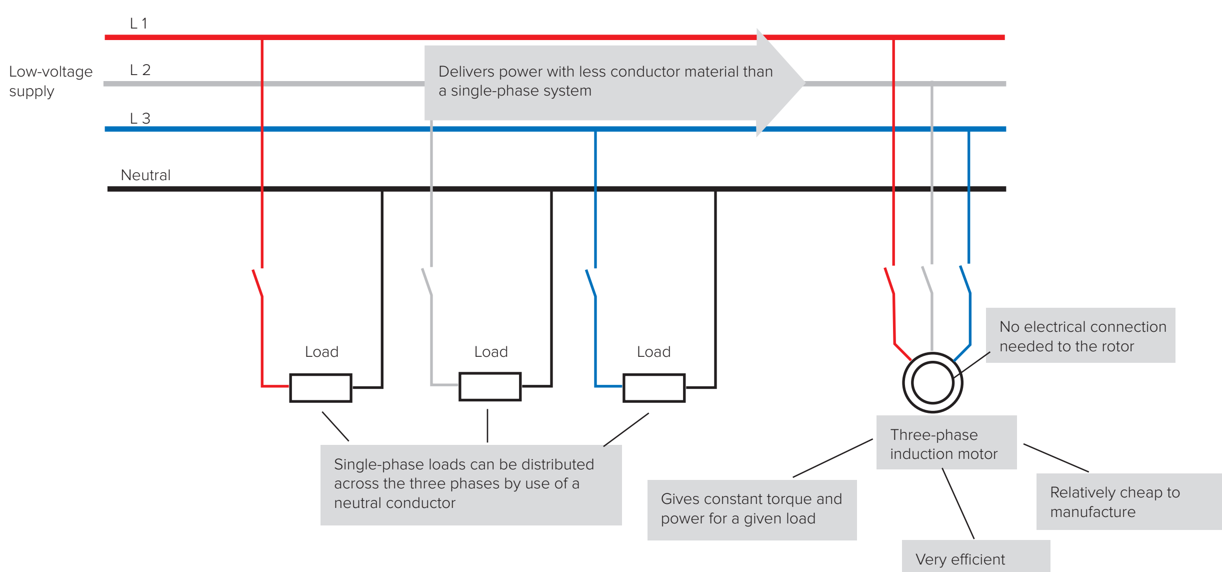
Disadvantage of early d.c. systems:



Advantage of a.c. systems:

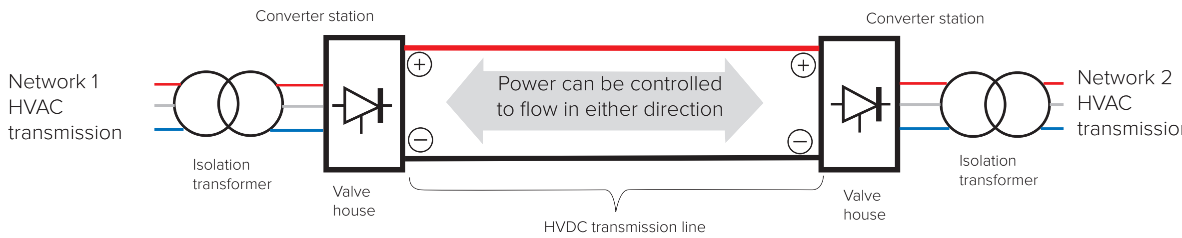


Some advantages of three-phase a.c. systems:



Designation of a.c. conductors:
The three-phase system has three active conductors, each known as a phase or line. They are most commonly designated by line numbers L1, L2 and L3; by their colour code (*Clause 3.8*), Red Active, White Active and Blue Active; as Phase 1, Phase 2 and Phase 3; or as A Phase, B Phase and C Phase.
While the terms line and phase are, strictly speaking, not synonymous, in practice a load is more often referred to as being connected, say, between phase and neutral rather than between line and neutral, or between phases rather than between lines.

Figure 1.2a Direct current and alternating current systems



Some advantages of HVDC transmission:

- It has the ability to transmit large amounts of power over long distances at less capital cost and lower losses than HVAC transmission.
- The high capacitance of under-sea or underground cables has minimal effect compared with the additional losses in a.c. cable caused by current required to charge and discharge capacitance of the cable.
- It can carry more power per conductor.
- It provides increased stability and can interconnect unsynchronised networks, even those operating at different frequencies, e.g. interconnection between 50 Hz and 60 Hz systems.

The main disadvantage of HVDC transmission is cost and it is said to be only economically viable for transmissions over 50 km.

Examples of local HVDC transmission:

- Cook Strait, 40 km, 1200 MW interconnecting the South and North Islands, NZ.
- BassLink, 290 km, 400 MW interconnecting the Tasmanian network to Victoria.
- DirectLink, 65 km, 180 MW interconnecting New South Wales with Southern Queensland.
- MurryLink, 176 km, 220 MW interconnecting Victoria with South Australia.

Figure 1.2b Modern d.c. transmission

and frequency must be controlled by the network operators within the limits set down by the Australian Energy Regulator. Voltages above or below limits specified by the Energy Regulator can cause damage to electrical devices.

1.3 Distribution of electricity to consumers

The generation and transmission system brings electricity supply to the point of final distribution. The low-voltage distribution system is the second-last link in the chain joining the power station generator to the consuming device on the consumer's premises, the last link being wiring within the premises. The final distribution of power is accomplished by high-voltage feeders to bulk supply consumers and a low-voltage network to other industrial, commercial and domestic consumers as shown in Figures 1.3a and 1.3b.

1.4 Distribution of electricity in the consumer's installation

Safety and efficiency are the prime considerations in the electrical generation, transmission and distribution systems discussed in this chapter. In the final step of delivering electricity for use in lighting and appliances, that is, the consumer's own electrical installation, safety is paramount. All electrical installations must comply with the fundamental safety requirements of the *Wiring Rules*. Electricity safety regulations in all jurisdictions require a process to be followed for obtaining connection of supply to a consumer installation and verification that the installation complies with all safety requirements of the *Wiring Rules* and any additional local service and installation rules. You will learn more about the safety aspects of electrical installations in subsequent chapters and as you progress in your training. For now the focus is on the basic concepts of how electricity is distributed within an electrical installation.

The *Wiring Rules* require that an electrical installation be divided into circuits with devices for control and protection against faults and overcurrent. Basic arrangements for a small and larger installation are shown in

The transmission grid lines are interconnected for control, switching, protection and transformation purposes at regional and zone substations. Another function of these substations is the supply of secondary transmission systems at lower voltages, and local distributors 'tap off' this secondary system for supply and distribution within their own franchise area.

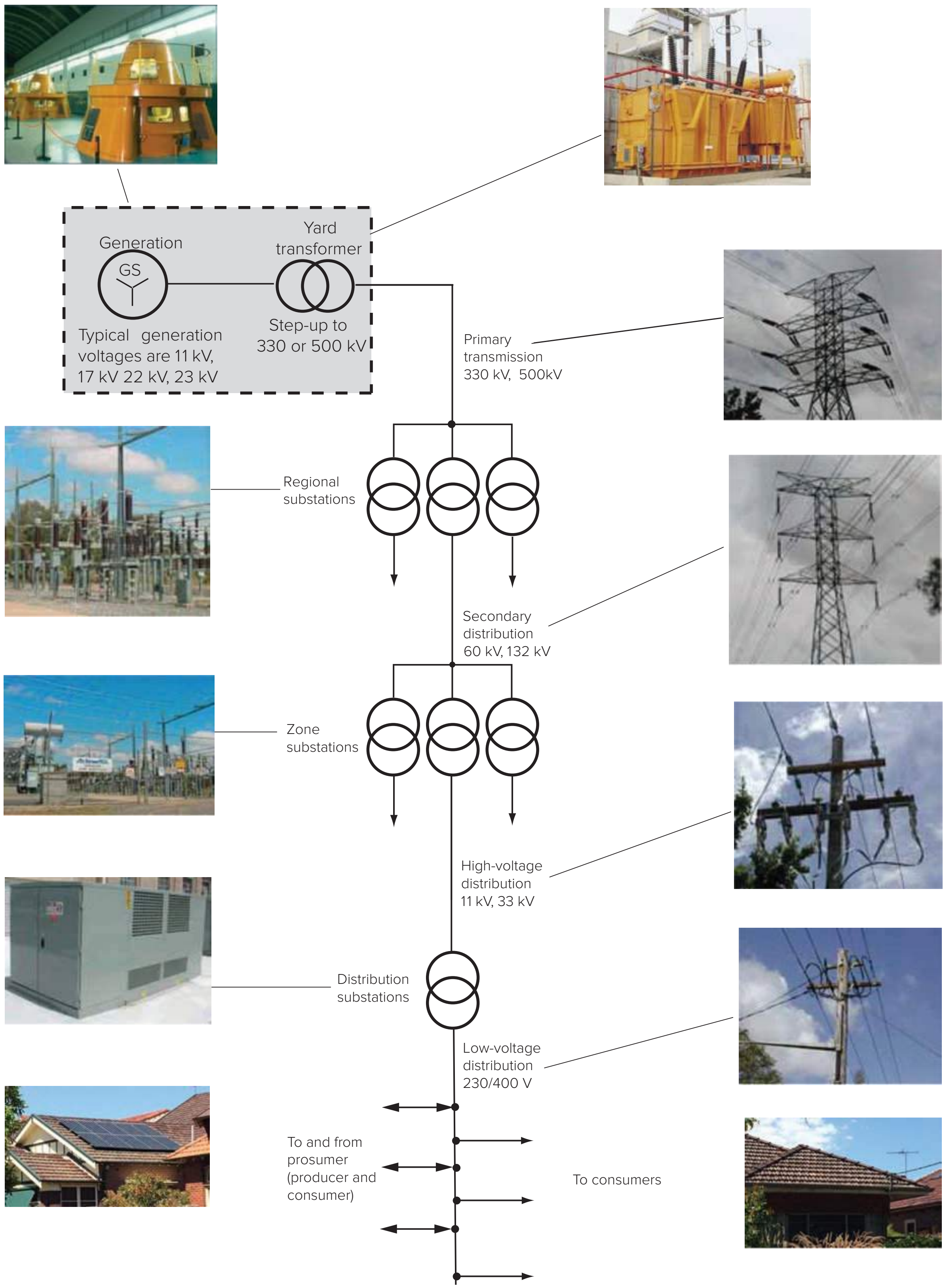


Figure 1.2c From power station to consumer