1

electrical energy—past, present and future

Learning outcomes

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

- relate the historical development of electricity as our major energy source
- describe the modern methods of electrical generation
- explain the principles for generating electricity from renewable energy sources
- explain the reasons for the adoption of alternating current (a.c.) for the main electricity power supply system
- describe the advantages and applications of modern direct current (d.c.) transmission
- identify the conductors and their purpose in a three-phase distribution system
- illustrate the stages of transmission and distribution of electricity from generation to consumers
- 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.

Electricity was first sold to consumers about 130 years ago and since then the electrical industry has reached a stage where it encompasses so many branches and specialties that the range of career opportunities seems limitless.

The technological advancement of a community can be fairly accurately assessed by the amount of electrical energy it uses. For example, the consumption per person in South-East Asia is considerably less than that of the United States (US). The role of the electrical industry and the electrician in high-technology societies is a vital one.

Regardless of the electrical worker's particular field of activity within the industry, a sound technical knowledge is necessary for work competence and efficiency. When carrying out installation work, theory must be applied to wiring circuits, electrical machine operation and control. Technical knowledge is also necessary for a full understanding of the many rules and regulations governing the installation, repair and maintenance of wiring and equipment.

There are a number of ways in which a person can qualify for an electrician's licence. However, the most common way is to undertake a training program, usually through an apprenticeship, which incorporates prescribed off-the-job and on-the-job training standards. Before a licence is issued, an applicant must demonstrate competence in ensuring their work complies with all safety standards, including demonstration of a sound knowledge of regulations, in particular the *Wiring Rules* (Australian/New Zealand Standard AS/NZS 3000).

However, for those embarking on the electrical trade, it is well worth starting with a look at the fascinating story of the development of electricity.

1.1 A brief history of electrical energy production and supply

Discoveries and development of electrical energy

Electrical and magnetic phenomena have been known and observed in the past as natural occurrences. Over several millennia of human curiosity and enquiry, these phenomena have been applied practically, developing the electrotechnology industry we have today. A summary of this development is given in Table 1.1 and Table 1.2.

Brief history of the electricity supply industry

Electrical energy cannot be stored in large quantities. Therefore bulk supplies of electrical energy must be fed directly from the generating station through a transmission and distribution system to the consumer. This need led to the development of the electricity supply industry.

Immediately following the publication of the results of Faraday's famous 1831 experiments, many practical **generators** were constructed by inventors. Their aim was to produce a supply of direct current that would take the place of the battery as a source of electrical energy.

The first d.c. generators, also known as dynamos, were produced for experimental purposes. Later, dynamos were produced for electroplating and for supplying the arc lamp. Used for lighting, the arc lamp produces an intense light from an arc created between two carbon electrodes. Some of the first machines in Britain were specifically designed to supply the energy required for the arc lamps used in lighthouses, but it was not long before the arc lamp was being used for lighting public places.

The design of larger, more efficient dynamos continued. To give some indication of size, Edison's famous Jumbo dynamo of 1881 was rated at 1500 light 110 volt and was driven by a 150 horsepower engine, equivalent to about 112 kW. By contrast, the larger generators in a base-load power station today are rated up to 650 000 kW.

Before 1880, the primary purpose of most electrical sources was to supply the electrical energy for arc lamps. However, the open arc of these lamps produced gases that were a fire hazard, and the arc carbons and control gear required constant maintenance. They were made only in high ratings; accordingly, when the enclosed, small and low-rated incandescent electric lamp became a practical proposition, it quickly replaced the arc lamp in most lighting applications.

The invention of the incandescent lamp heralded the growth of public supply, but the early public supply systems were nearly all direct current, were small and were often owned by private companies. Municipal councils became involved mainly because of their interest in public street lighting, and they absorbed many private supply companies. In later years, large supply areas came under the control of electricity enterprises, such as county councils in some jurisdictions, that were formed for the sole purpose of distributing electricity.

Table 1.1 Historical discoveries of electrical phenomena

2000 BCE	Hoang-ti	Chinese emperor	Used a form of the magnetic compass to steer war chariots across the plains of Tartary.
750–700 BCE	Homer	Greek epic poet	The lodestone, a natural magnet, is referred to in Homer's *Odyssey*.
1600	Dr William Gilbert	Physician	Published the first major work in English attempting to describe electric forces and magnetic forces, providing the impetus for study and experiment by many philosophers.
1706–1790	Benjamin Franklin	Statesman and scientist	Demonstrated that lightning is a form of electricity, with his kite experiment, and produced an explanation for the differences between positive and negative charge.
1736–1806	Charles Coulomb	Physicist	Proved the force of attraction between two electric charges is inversely proportional to the square of their distance, known as Coulombs Law. The standard unit for the quantity of electricity is named after him, i.e. a coulomb is a current of one ampere per second.
1745–1827	Alessandro Volta	Physicist	Developed the 'pile', consisting of a series of plates of silver and zinc interleaved by spongy matter soaked with a saline solution. The voltaic pile was the forerunner of the modern dry cell and was used by scientists in experiments for the next 25 years. The unit of electromotive force, the volt (V), is named after him.
1775–1836	André Ampère	Physicist	Said to be the founder of electrodynamism (electromagnetism) and proposed Ampère's Law, relating the circulating magnetic field in a closed loop to the electric current passing through the loop. He is remembered in the name of the unit of electric current, the ampere (A).
1777–1851	Hans Christian Oersted	Chemist and physicist	Discovered that a conductor carrying electric current produces a magnetic field.
1787–1854	Georg Ohm	Physicist	Formulated Ohm's Law which states the relationship between current in a circuit and the voltage applied to the circuit. The unit of resistance, the ohm (Ω), is named after him.
1791–1867	Michael Faraday	Chemist and physicist	Discovered electromagnetic induction, the principle underlying the conversion of mechanical to electrical energy in modern generators. He produced the first transformer, which forms the basis of our modern transmission and distribution systems. He has been called the father of modern electrical engineering.
1824–1887	Gustav Kirchhoff	Physicist	Among other notable discoveries, he developed laws to calculate current and voltage in complex circuits. In their simplest forms, these have become intuitive to the competent electrotechnology practitioner.
1831–1879	James Clerk Maxwell	Mathematician and physicist	Set the foundation for modern physics with his theoretical work on kinetics and electromagnetism. He was the first to express the basic laws of electricity and magnetism in a unified way.
1857–1894	Heinrich Hertz	Physicist	Working on the theories developed by Maxwell, he discovered the existence of electromagnetic waves. The unit of frequency, hertz (Hz), is named after him.

Gradually, as **alternators** (generators that produce alternating current), motors, transformers and equipment progressively improved, three-phase a.c. generation, transmission and distribution was adopted worldwide. This was due mainly to economies in transmission and to the simplicity and efficiency of transformation from high to low voltage or vice versa. Most modern Australian systems are of a standard three-phase a.c. type.

Table 1.2 Milestones in the utilisation of electricity

1846–1914	George Westinghouse, Entrepreneur and businessman	Transformed the ideas of great inventors and engineers like Tesla into commercial reality. These included the transformer and the induction motor, heralding the a.c supply system we have today.
1847–1931	Thomas Edison, Inventor and entrepreneur	Produced the first commercial incandescent lamp and developed the first major electrical distribution system based on direct current.
1856–1943	Nikola Tesla, Engineer	Tesla's patents and theoretical work form the basis of the alternating current electrical system we know today. He developed the a.c. motor (also known as an induction motor), which is probably the most important single development in the industrial use of electricity. A great engineer.
1862–1919	Mikhail Dolivo-Dobrovolsky, Engineer, electrician and inventor	Accredited with developing the three-phase a.c. system.
1857	First commercial use of an arc lamp in a lighthouse at Dungeness, England.	
1863	Portion of Sydney lit up on 11 June by a high-powered arc lamp on Observatory Hill.	
1879	Electricity first sold to the public in the USA.	
1880	First public supply in Melbourne, Victoria (VIC).	
1881	First public supply in England at Godalming.	
1883	First public supply in Brisbane, Queensland (QLD).	
1883	First public supply in Adelaide, South Australia (SA).	
1888	First public supply in Tamworth, New South Wales (NSW).	
1891	First public supply in Perth, Western Australia (WA).	
1892	First public supply in Sydney, NSW.	
1893	First public supply in Hobart, Tasmania (TAS).	
1920s and 1930s	Establishment of state owned and operated electricity generation and supply systems.	
1994	Following New Zealand's lead, Australian governments agreed to the introduction of competition in the generation, distribution and supply of electricity.	
1994–1996	Corporatisation of state owned generation and distribution assets: some sold to private operators and some operated by state governments.	
1996	Establishment of the National Electricity Market Management Company Limited (NEMMCO) to manage the marketing of electricity in the new competitive climate and maintain security of the power system.	
1998	The National Electricity Market (NEM)* commenced a wholesale market for electricity supply in the interconnected power systems of QLD, NSW, Australian Capital Territory (ACT), Snowy Hydro Limited, VIC and SA.	
2000s	Progressive implementation of competition in the retailing of electricity, allowing end-users to choose their energy supplier. This has required the installation of new energy meters and information technology systems to process transfers of customers between registered energy retailers.	
2005	Tasmania became a participant in the NEM with the interconnection of its power system to Victoria via the undersea cable across Bass Strait known as BassLink.	

* The vast and sparsely populated distance between western and eastern Australia make it uneconomical for WA to be interconnected to the NEM power systems; however, WA is embarking on a similar competitive energy market, expected to be operating by 2010.

1.2 Modern generation methods

The bulk of electrical energy produced today is obtained from a rotating turbine attached to an electrical generator. Energy used to drive turbines is extracted from steam, flowing water, hot gases and wind. In Australia, as in most other countries, the prime source for producing steam to drive turbines is coal. However, there are exceptions, such as France, where coal contributes less than 4 per cent and nuclear energy is the prime source. Other fuels used to produce steam are natural gas, petroleum and concentrated sunlight.

Hydroelectric systems use the controlled flow of water from dams to drive turbine generators. In some suitable coastal locations the energy from tidal flows is another source used to drive turbine generators.

In gas turbine generators the hot gases produced by burning natural gas or oil are used to directly drive the turbine. More recently these are being supplemented with a variety of renewable energy sources.

Modern generating systems fall into the following groups:

- power stations using thermal energy released from burning coal, oil or natural gas to produce steam or hot gases, known as thermal stations
- power stations using thermal energy released by nuclear reaction, known as nuclear power stations
- power stations using the kinetic energy of moving water, known as hydroelectric stations (the most common form of renewable energy)
- other renewable energy sources such as biogas from landfill, geothermal, solar energy or kinetic energy from wind and wave movement.

In addition to these there are many small diesel-engine driven generators for electricity supply in areas remote from the main power network and these are becoming more common as standby supply in non-domestic installations.

Thermal power stations utilise the heat energy derived from burning coal, oil or natural gas to convert water to steam, and the steam is used at high pressure to drive a turbine that is directly coupled to an alternator producing electrical energy. The concept is illustrated in Figures 1.1 to 1.3. Coal and nuclear thermal power plants may take many hours, if not days, to achieve a steady state power output. Since they require a long period of time to heat up to operating temperature, these plants are used to supply large amounts of base-load demand.

The voltage (V), 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.

Although nuclear power stations are similar in many respects to 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. However, nuclear electricity generation is well established in the USA, Canada, Europe, India, Japan and China. Preliminary work was commenced at Jervis Bay, NSW, for the first Australian nuclear power station, but this work ceased in 1974.

The Intergovernmental Panel on Climate Change (IPCC), a peak scientific body of the United Nations, concluded in their Fourth Assessment Report. *Climate Change 2007* that our climate is warming as a result of greenhouse gases produced mainly from human activity, in particular, from gas emissions into the atmosphere from

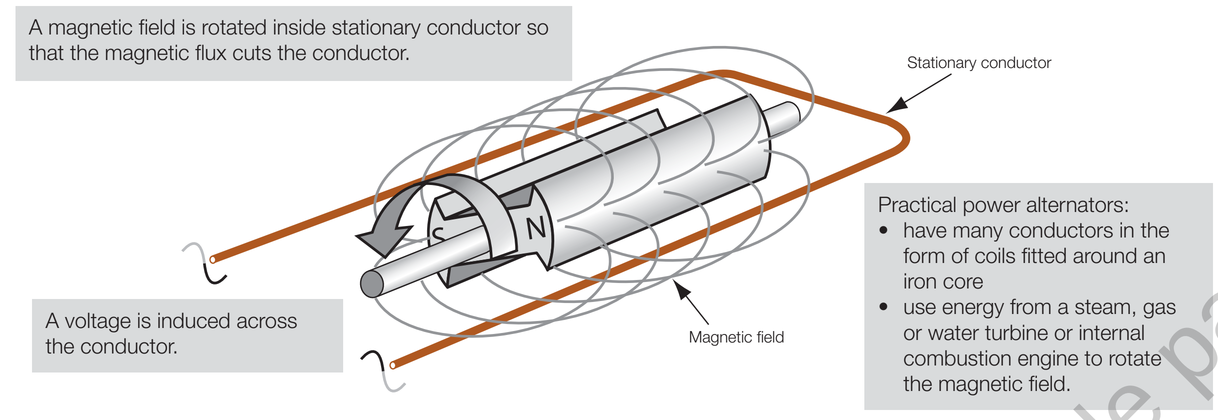
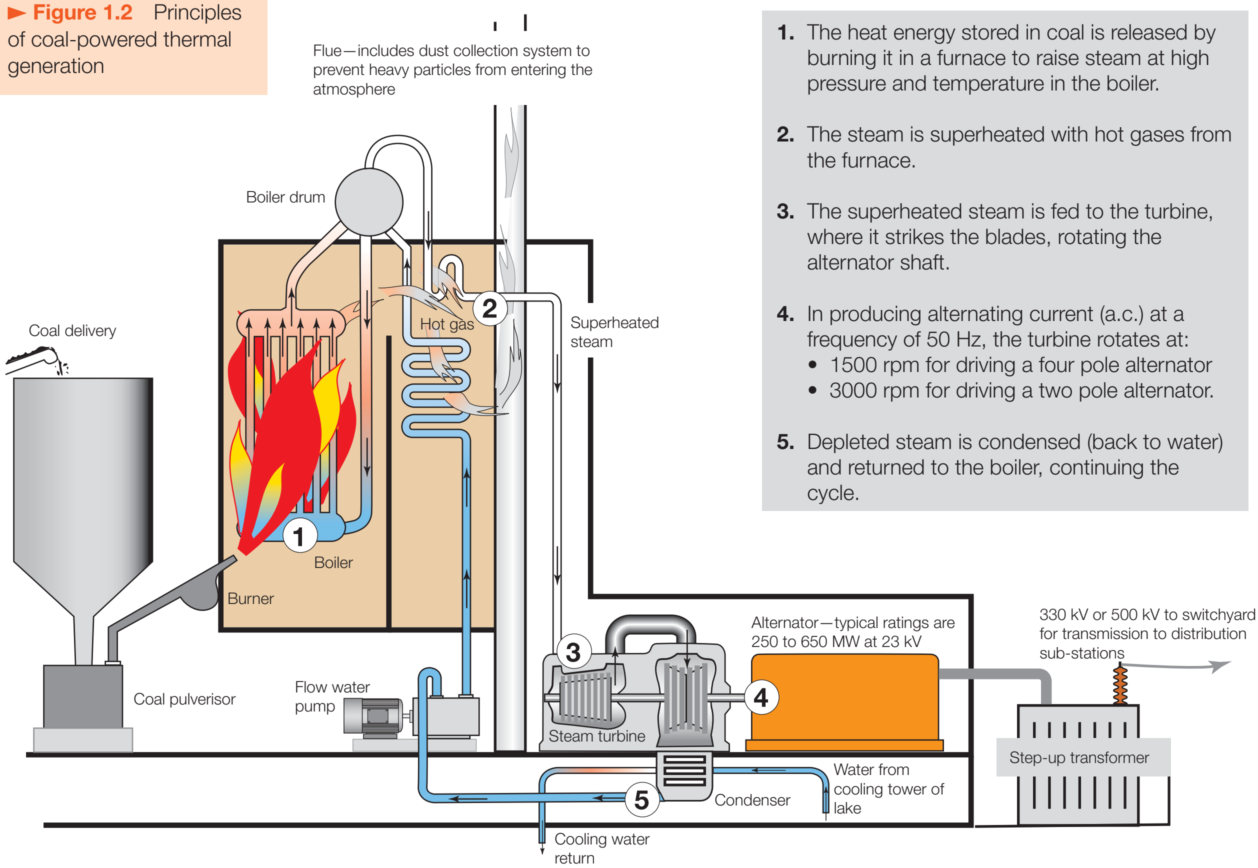


Figure 1.1 Principles of electrical generation

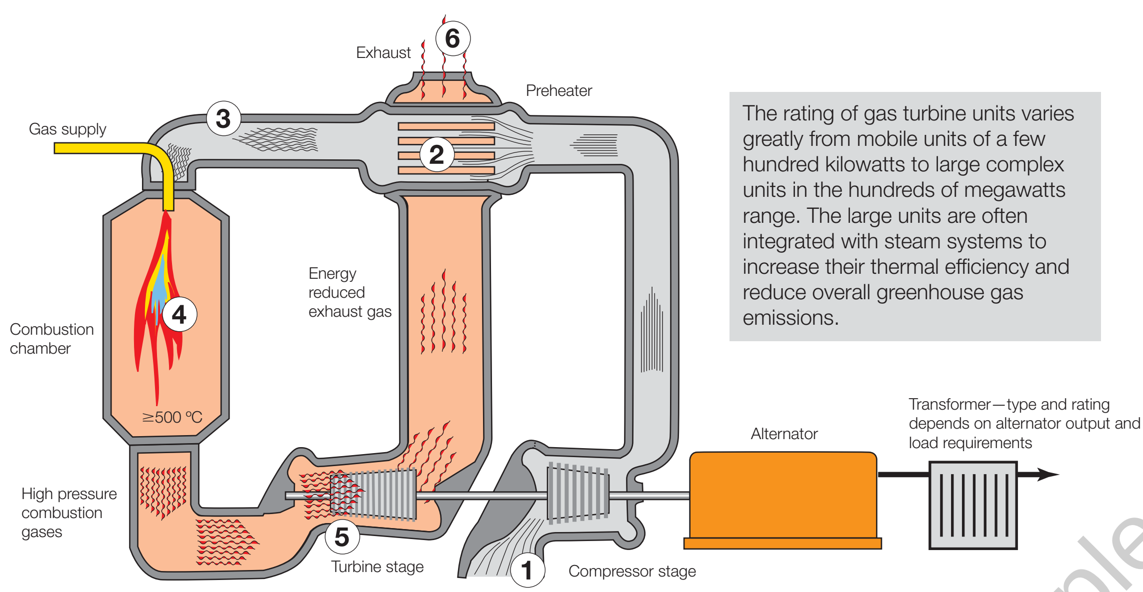
► Figure 1.2 Principles of coal-powered thermal generation



1. The heat energy stored in coal is released by burning it in a furnace to raise steam at high pressure and temperature in the boiler.
2. The steam is superheated with hot gases from the furnace.
3. The superheated steam is fed to the turbine, where it strikes the blades, rotating the alternator shaft.
4. In producing alternating current (a.c.) at a frequency of 50 Hz, the turbine rotates at:
   - 1500 rpm for driving a four pole alternator
   - 3000 rpm for driving a two pole alternator.
5. Depleted steam is condensed (back to water) and returned to the boiler, continuing the cycle.

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 cogeneration systems the exhaust gas is used in space, water or process heating increasing the thermal efficiency on 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 1.3 Principles of gas-powered thermal generation

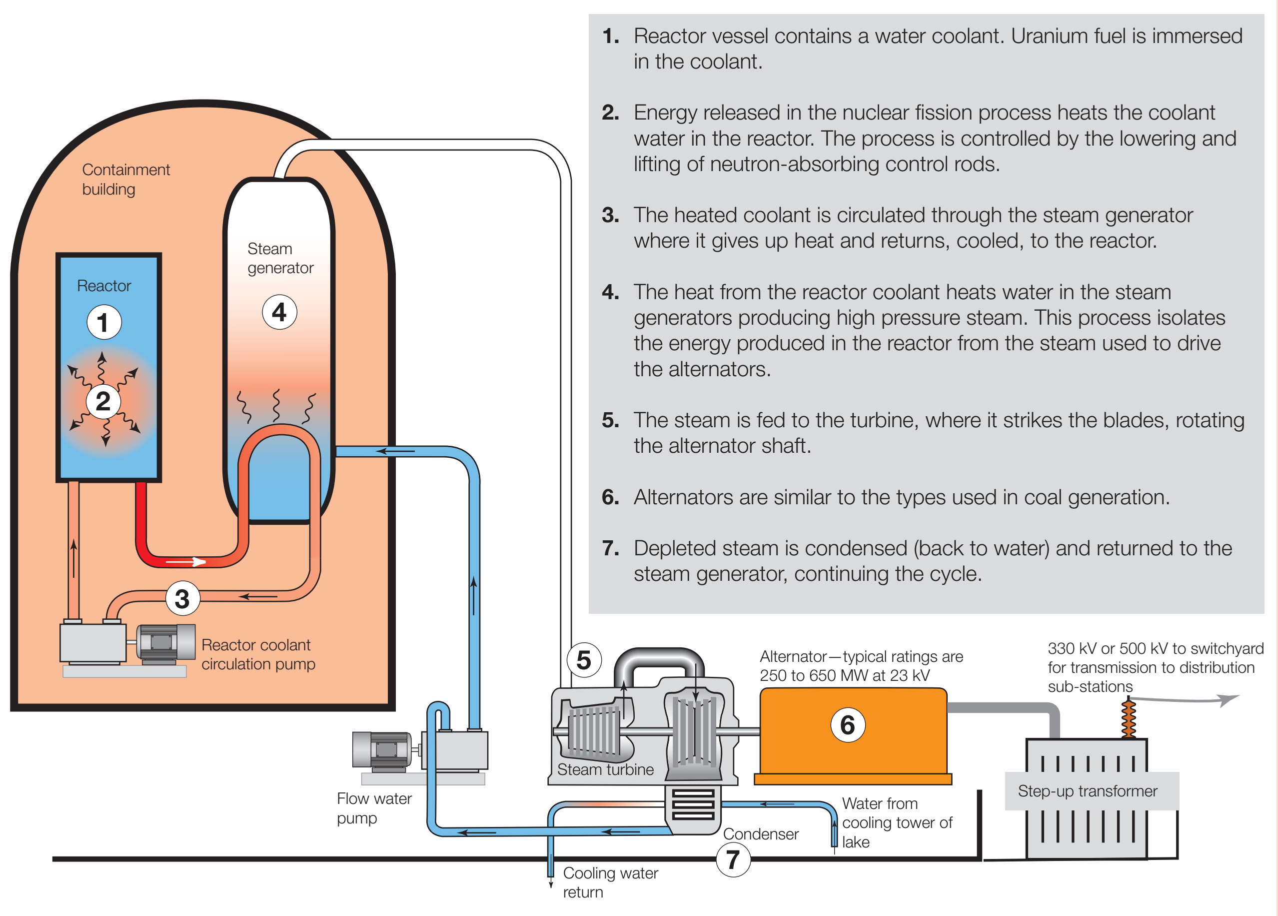


Figure 1.4 Principles of nuclear-powered thermal generation

burning fossil fuels such as coal. This has prompted debate on the question of using nuclear power (see Figure 1.4) for electricity generation in Australia as an alternative to coal. However, success with current research into clean coal technology, which endeavours to collect and safely store greenhouse gases produced from burning coal, means that coal may remain the preferred fuel for base-load generation in the immediate future.

1.3 Renewable energy and sustainable energy practices

While greenhouse gases occur naturally in the atmosphere, human activities such as land clearing and the burning of fossil fuels are increasing the concentration of these gases. In recognition of this problem, international efforts are concentrated on curbing greenhouse gas emissions across all sectors of the economy. These initiatives include providing incentives to individuals and enterprises to adopt sustainable energy practices. For example, individual consumers can apply to purchase sustainable energy electricity from their energy retailer, which commits itself to acquiring the equivalent amount from renewable energy sources.

Sustainable energy is a term that means both an efficient use of energy from any source (that is, using less energy to provide the same service) and energy from renewable sources such as hydro, geothermal, solar, wind and tidal movement. Note that renewable energy is not energy extracted from materials such as the burning of fossil fuels, but is the conversion of energy already existing in nature to other more useful sources such as electricity. (The use of solar thermal energy for hot-water systems is discussed in Volume 2.)

Renewable energy sources

Hydroelectric power stations, such as those used in the eastern states of Australia and in the 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.

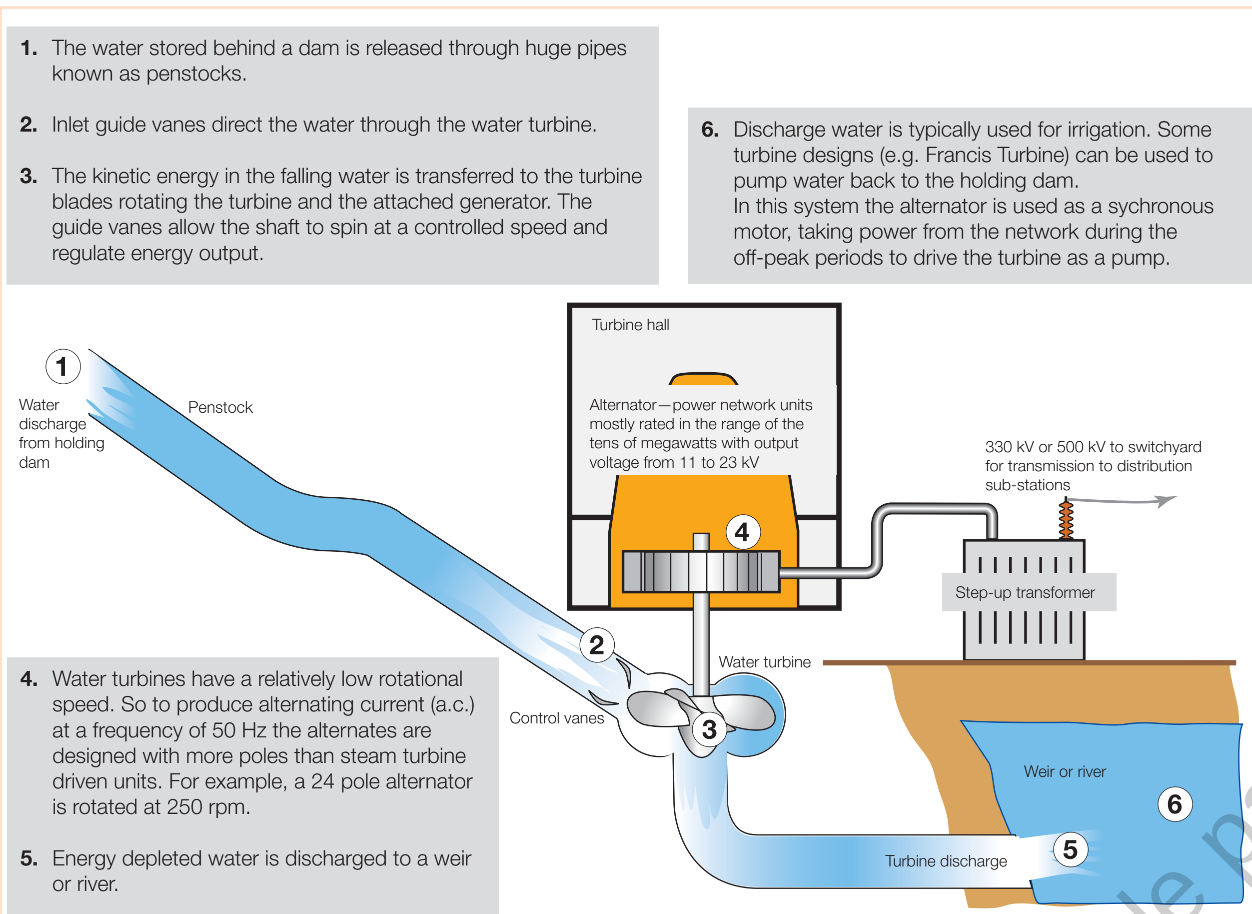
The main local source of electrical energy in Tasmania is hydroelectric, producing 60 per cent of Australia's renewable energy (see Figures 1.5, 1.6a and 1.6b). BassLink, commissioned in 2005, connects Tasmania to the eastern Australia electricity grid, allowing the island state to sell electricity from its major renewable source to the mainland user. More importantly, it allows Tasmania to buy electricity from the mainland during long periods of drought when dam storage levels for electricity generation may fall substantially.

While conventional power stations need boilers to produce steam to drive generators, some countries can do without them as they can use steam produced from water heated naturally underground; these schemes are termed geothermal. The first geothermal power station was built in 1913 at Larderello in Italy, and the second was commissioned in 1958 at Wairakei in New Zealand. The Wairakei and the Ohaaki (commissioned in 1989) power stations account for about 8 per cent of the total generating capacity of the Electricity Corporation of New Zealand.

Initially only a few renewable energy sources, such as hydro and geothermal, have been considered viable by electricity generators and distributors. However, through government initiatives and the growing need to develop other sources of renewable energy, their contribution to the public supply network is increasing.

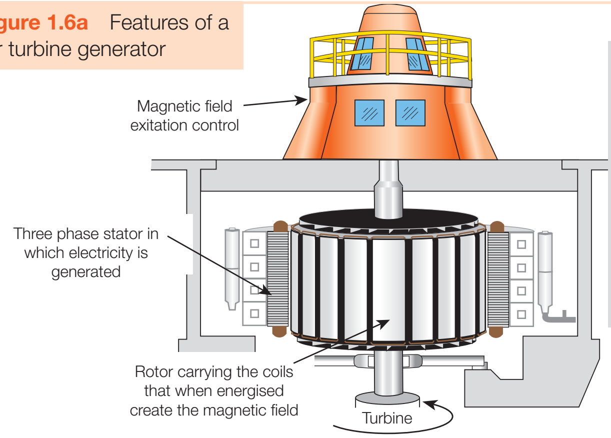
'Hot rock' technology is a form of geothermal energy being developed in South Australia where the high thermal energy that exists in rock some 3 kilometres (km) below the earth's surface is being retrieved to produce steam to drive generators. The principles are shown in Figure 1.7.

Solar energy can be converted to electrical energy by directing sunlight onto a photovoltaic (PV) array. PV solar cells have been used for some time to produce small amounts of power on satellite stations, and by telecommunications companies for such applications as outback relay stations and microwave communication systems. They are also used for remote-area power supply (RAPS) systems. Rechargeable batteries are an essential part of any RAPS system; they store the electrical energy produced by the PV cells for times when the demand for power exceeds supply, such as at night or on an overcast day.



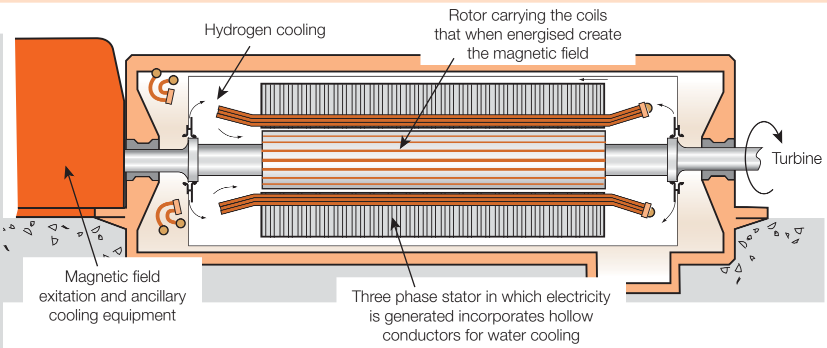
▲ **Figure 1.5** Principles of hydro power generation

► **Figure 1.6a** Features of a water turbine generator



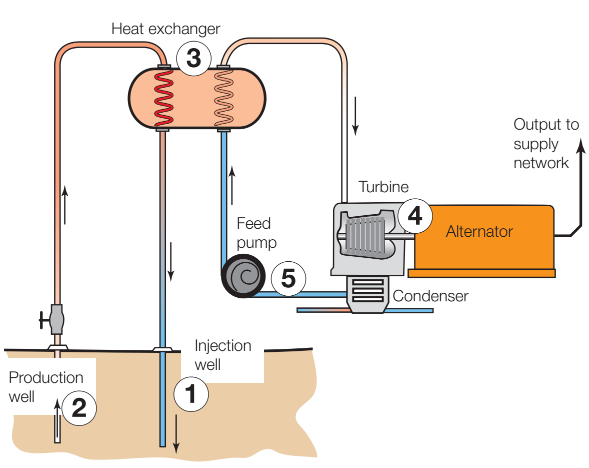
Hydro generators
The spinning speed of water turbines is relatively low compared with steam and gas turbines. Therefore to generate the standard frequency of 50 Hz hydro generators are designed with as many as 24 poles resulting in a machine of large rotor diameter and short axial length. Hydro generators 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.

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 relative 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 1.6b** Features of a steam turbine generator

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.

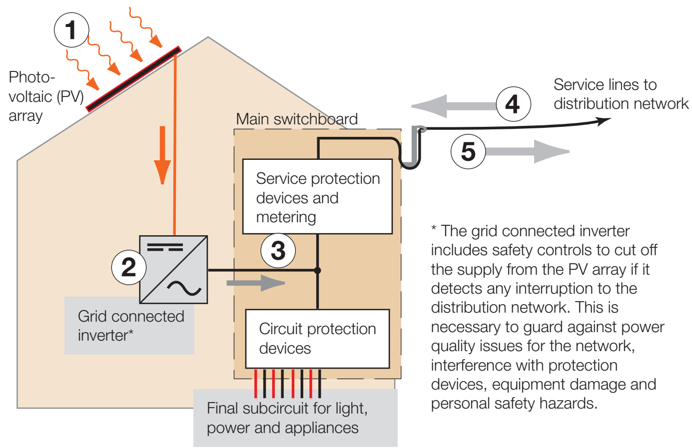


▲ **Figure 1.7** Principles of geothermal power generation from hot rock

Individual consumers who are connected to the public distribution system can supplement their electricity use by installing a roof-mounted array of PV solar cells as shown in Figure 1.8a. Although these systems supply clean renewable energy they are initially expensive, even with a government subsidy, and those who choose to install them do so on environmental grounds. Their uptake is greater in countries where the government subsidies are substantial. Large scale PV power stations are currently in the planning stage, using new generation solar cell technologies.

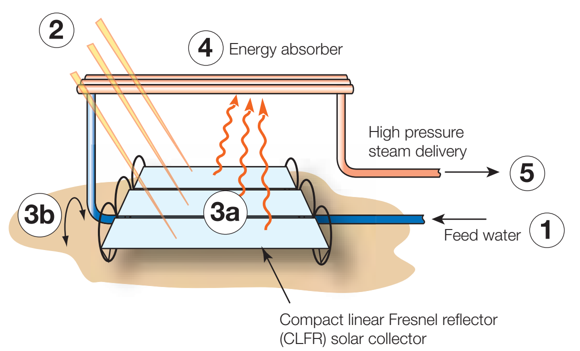
The use of heat from sunlight (i.e. solar thermal energy) has commonly been used in solar hot-water systems for many years. Now solar thermal energy is proving to be an effective method for generating larger amounts of electricity. In these systems inexpensive solar collectors are used to develop high-temperature hot water for steam generators. A pilot plant has been installed at Macquarie Energy's Liddell Power Station in the Hunter Valley (NSW) where it is used to supplement coal use. A 2000 megawatt (MW) solar thermal power station using this technology is planned for installation in the US. The principle is shown in Figure 1.8b. Using thermal storage technology the station is intended for base-load supply as an alternative to coal, gas and nuclear power stations.

Two other sources of renewable energy, which have up until the 1990s only been the subject of research in Australia, are wind-generated and wave-generated electrical energy.



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 1.8a 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 (285ºC).
5. Steam is fed to turbines similar to conventional steam generation plants.

Figure 1.8b Principles of solar thermal power generation AUSRA

Since the 1990s Australian state governments, together with electrical energy companies, have embarked on the development of wind farms as a cost-effective renewable source of electricity generation. By 2006 Australia had a wind-generating capacity in excess of 800 MW with the expectation that this will increase substantially in the next decade (see Figure 1.9).

Currently there are several wind farms throughout New Zealand with a total capacity in excess of 170 MW.

In 1990, the Hydro-Electric Commission of Tasmania commissioned a Norwegian company to study the feasibility of installing a wave power plant on King Island in Bass Strait. The study, completed in 1991, showed that the project was not economical.

With this type of system, waves move into a narrowing concrete channel and spill into a reservoir. Electricity is generated as water runs through turbines back to the sea at a lower level. A more promising method for harnessing energy from the ocean involves use of special buoys that capture the energy from wave motion in a hydraulic system to drive on-board generators. Portugal is the first country to commercially harvest wave energy in this way with a wave farm of three machines generating 2.25 MW and plans to expand capacity to 70 MW.

The most exciting project in harvesting wave energy is CETO technology, a system of underwater pumping units invented in Australia. A commercial demonstration farm is being developed in Western Australia for operation in 2009.

Unlike other wave energy systems currently under development around the world, the CETO wave power converter is the first unit to be fully submerged and to produce high-pressure seawater from the power of waves.

By delivering high-pressure seawater ashore, the technology allows the production of either zero-emission electricity (similar to hydroelectricity) or zero-emission freshwater (utilising standard reverse-osmosis desalination technology). It also means that there is no need for under-sea grids or high-voltage transmission, or costly marine qualified plants.

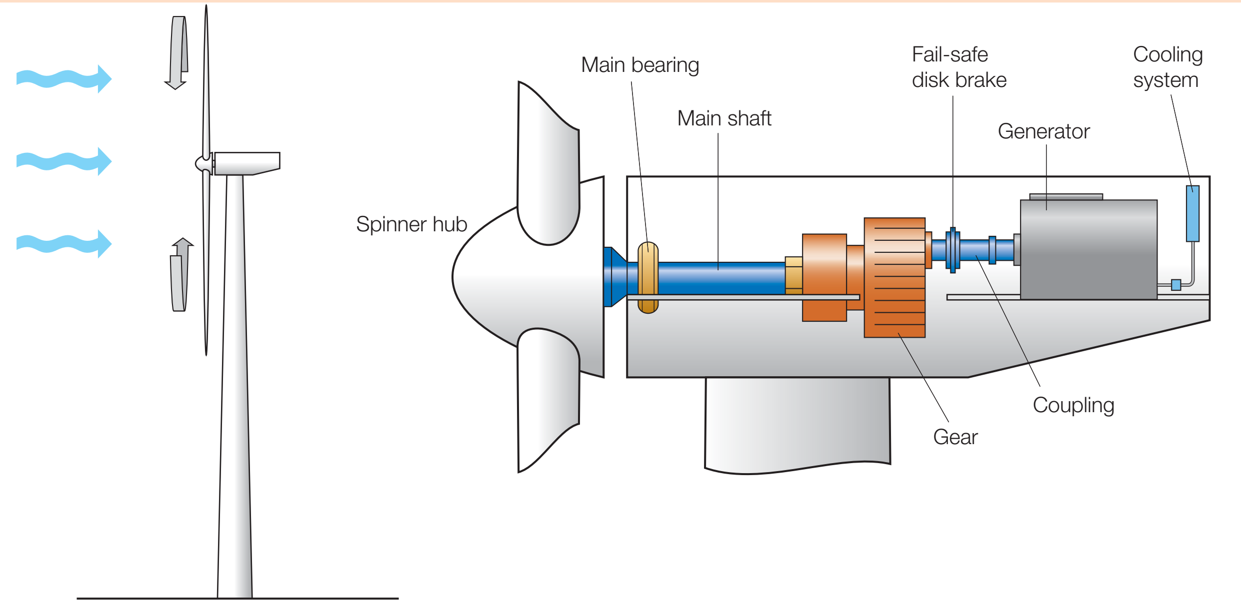


Figure 1.9 Principles of wind power generation

CETO units are fully submerged and permanently anchored to the sea floor, meaning that there is no visual impact as the units are out of sight. Figure 1.10 shows how wave power is converted to electricity. This also assists in making them safe from the extreme forces that can be present during storms. They are self-tuning to tide, sea state and wave pattern, making them able to perform in a wide variety of wave heights and in any direction. CETO units are manufactured from steel, rubber and hypalon materials, all proven for over 20 years in a marine environment.

The detrimental effects on the world's environment from the burning of fossil fuels such as coal show that there is an increased need for renewable forms of energy production.

1. The CETO wave power converter units produce high pressure sea water from the power of waves.
2. High pressure sea water is piped ashore where it is directed to electricity generation, desalination or both.
3. The kinetic energy in the high pressure sea water is transferred to the turbine blades rotating the turbine and the attached generator.
4. As with hydro generation, the alternator is designed with many poles in order to produce alternating current (a.c.) at a frequency of 50 Hz at the relatively low rotational speed of the water turbine.
5. Energy depleted sea water is returned to the sea.
6. High pressure sea water can be directed to desalination during periods (off-peak) when electricity demand is low. The water is fed through a reverse-osmosis process, supplementing fresh water reserves.

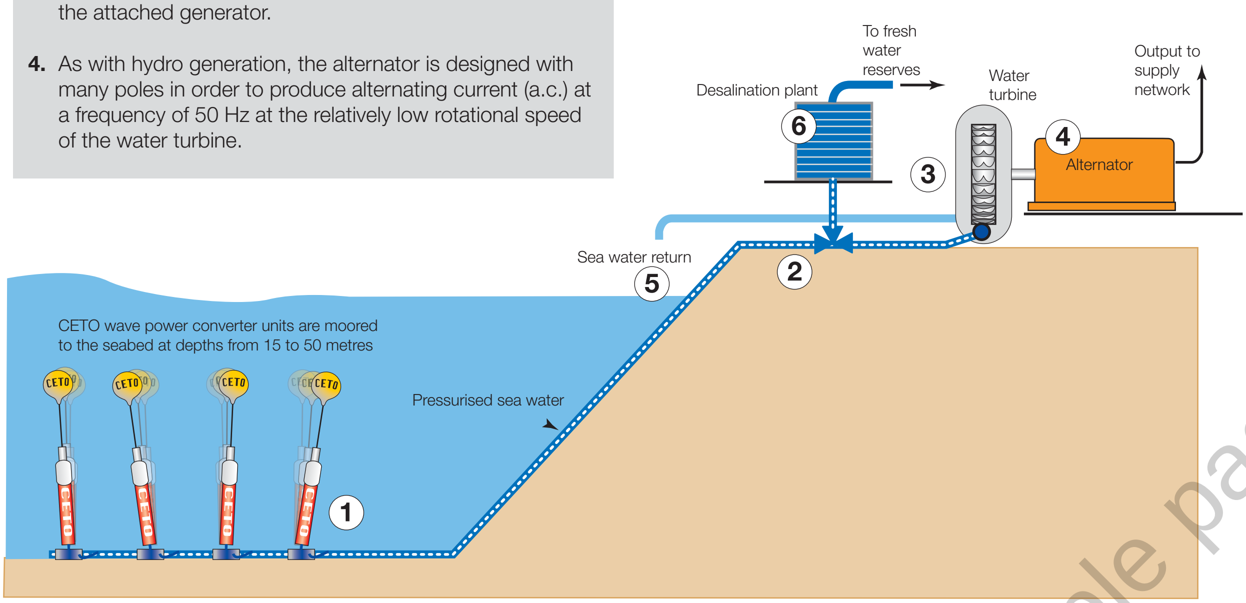


Figure 1.10 How it works—CETO wave energy system CETO

However, the capital costs of these methods of generation for large scale, grid-connected power remain high compared with coal-fired and gas-fired methods. Economics seems to be the main obstacle to the increased use of renewable energy sources; however, with government initiatives such as subsidies and carbon trading schemes, and emerging renewable energy technology, its adoption should increase substantially in the next decade.

Generating and using energy efficiently

Much of the thermal energy, such as steam or hot gases, that is produced for direct use in manufacturing processes tends to be lost to the atmosphere through flue and exhaust systems. The same is true of thermal electricity generation plants. The efficiency of energy use can be increased by utilising the waste energy 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 1.3 on p. 6). 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.

The Building Code of Australia (BCA) and New Zealand Building Code (NZBC) include requirements for buildings to be more energy efficient, achieved in part by the electrical installation. You will learn more about this and sustainable work practices in following chapters and as you progress through your training.

1.4 Electricity transmission and distribution systems

Generating stations are the main source of electrical energy, but for this energy to be utilised, it must be conveyed from the energy source to the consumer. Public supply first consisted of a large number of small power stations, many privately owned and each supplying a relatively small local area. Only in the large cities was the interchange of power between supply authorities practicable. Consequently, in the event of a severe overload or breakdown in the local supply system a blackout would occur. The only way to avoid a blackout would have been heavy investment in standby power plants and this was uneconomical.

Supply engineers came to realise that the best way to provide a reliable and economical supply was by state-wide or country-wide transmission-line grids fed by large generating stations. The power stations could be located on fuel reserves, saving fuel transport and handling costs, and the stations could be connected directly to a state's grid system. Many small, uneconomical power stations could be shut down and their combined loads supplied by large, efficient units via the grid. Some of the advantages of this are:

- large generating units are more efficient in operation than small ones
- less reserve plant is required to supply peaks of supply demand, or in an emergency
- many 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 QLD, NSW, ACT, VIC, SA, TAS and Snowy Hydro Limited; the New Zealand grid interconnects the power systems of the North and South Islands
- centralised control results in economies in both generation and operation.

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. For complete reliability and service, the design for the transmission system must provide for the:

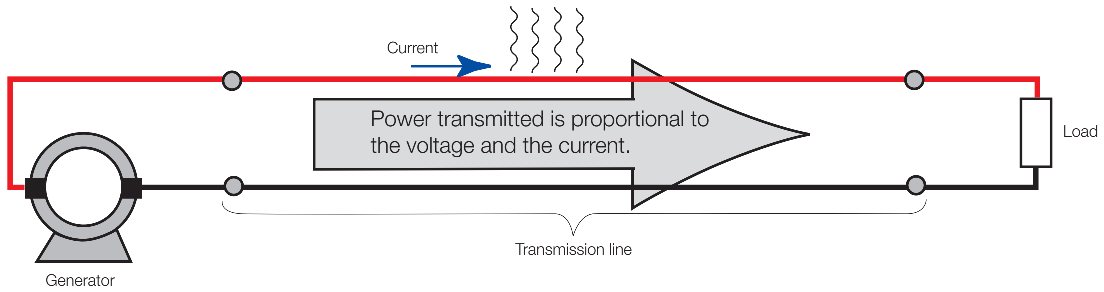
- continuity of supply under any conditions of breakdown, overload or emergency
- full protection of the system from external or internal hazards
- complete flexibility of the system for maintenance, power interchange or switching purposes.

Early in the 20th century, a controversy arose over the respective merits of a.c. and d.c. systems. The disadvantage of the d.c. system was the difficulty it presented in changing generated voltages to the high-voltage values needed for efficient transmission over any great distance, as shown in Figure 1.11. Eventually the system evolved to the three-phase a.c. system (HVAC) we have today.

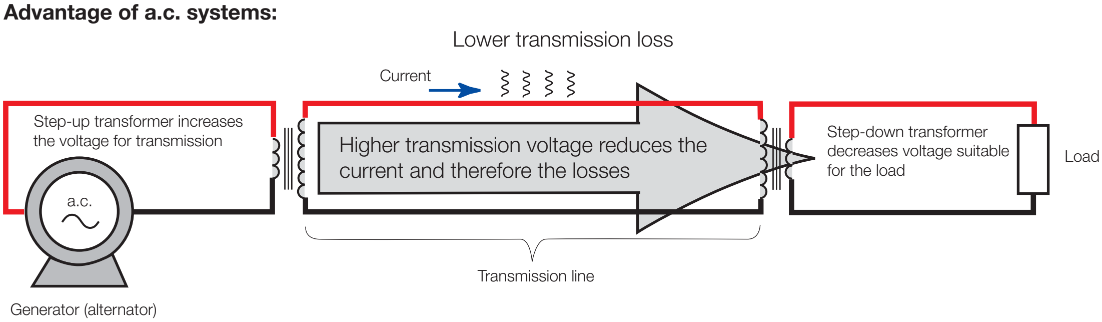
Only in later years was this disadvantage overcome by the development of a.c. to d.c. conversion and d.c. to a.c. inversion equipment, leading to the successful installation of some high-voltage d.c. (HVDC) transmission lines, as illustrated in Figure 1.12.

Disadvantage of early d.c. systems:

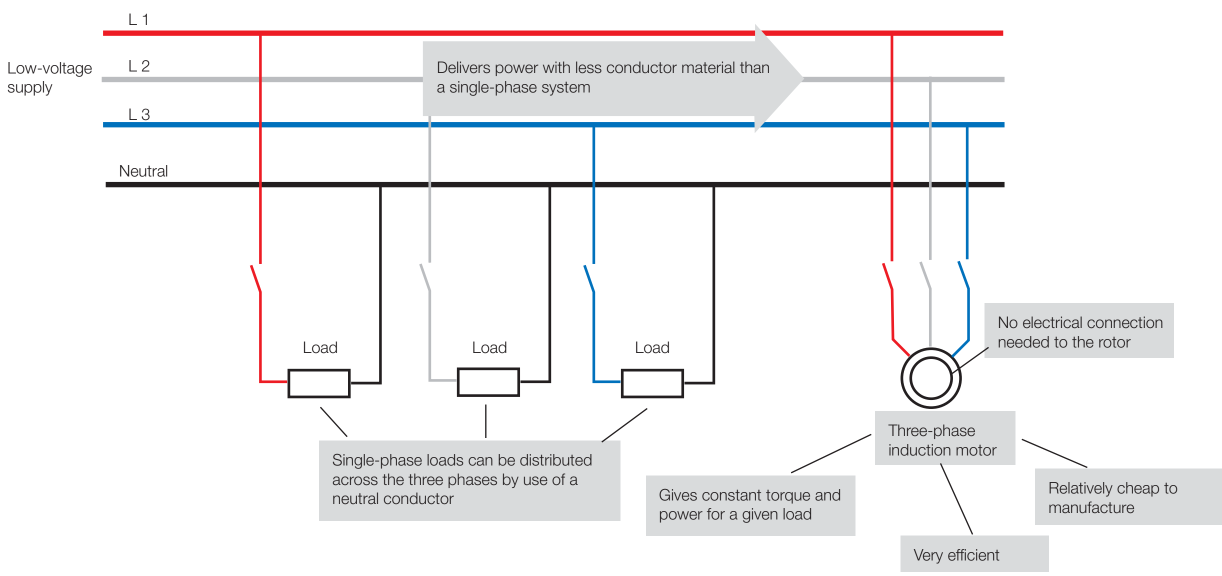
Transmission power loss because heat in wires is in proportion to the current squared. For example, halving the current will reduce the power lost to one-quarter, i.e. $(\frac{1}{2})^2$.



Advantage of a.c. systems:

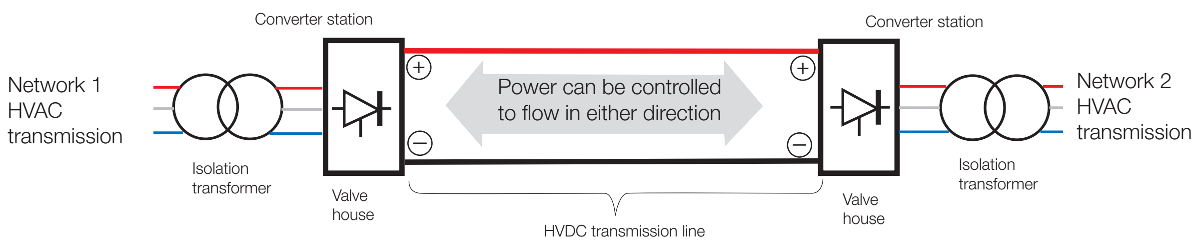


Some advantages of three-phase a.c. systems:



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 1.11 Direct current (d.c.) and alternating current (a.c.) systems



Some advantages of HVDC transmission:

- It has the ablity 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 1.12 Modern d.c. transmission

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 the thermal and hydroelectric power stations generate three-phase power at voltages dependent on the generator's specifications. Typical generation voltages are 11 kilovolts (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 with 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.

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. The general principles of transmission and distribution are illustrated in Figure 1.13.

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, for example, lighting or electrical machines, more energy is drawn from the system, and less energy is needed as electrical loads are switched off. In this way consumers actually determine 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 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 electrical devices to overheat. Correct supply frequency is important to prevent damage to generators and to consumers' electrical machinery and to maintain the accuracy of electric clocks and other timing devices.

As you can see, lines of communication in the control of the power network are of paramount importance. Most large power network operators have their own telecommunication network, typically a combination of microwave facilities and fibre optic cores embedded in transmission line earth wires

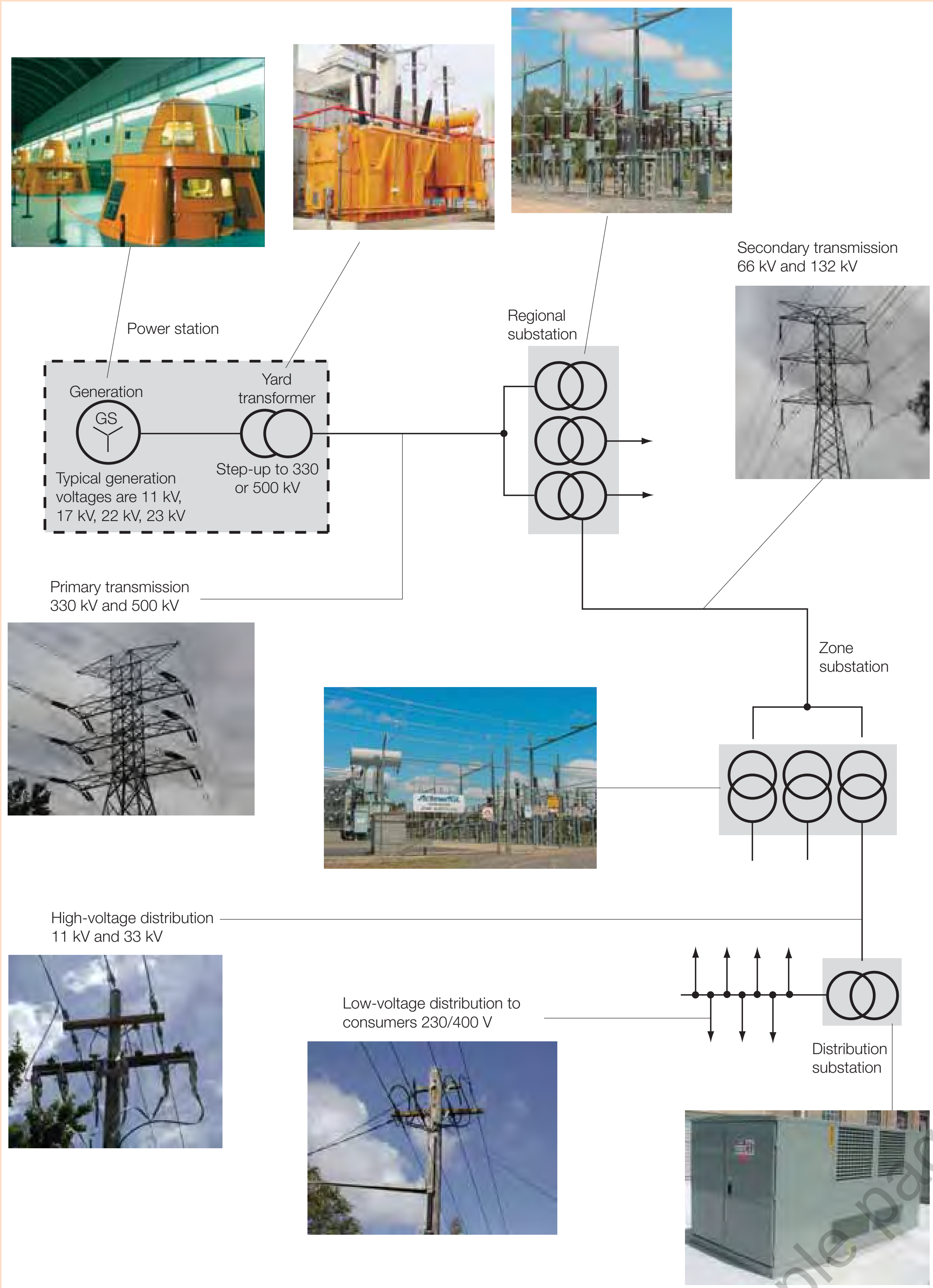


Figure 1.13 From power station to consumer ACTEW

(Chapter 4 includes an example of this type of cable.) Spare communication capacity is generally made available for leasing by other licensed telecommunication operators.

1.5 Distribution of electricity to consumers

The generation and transmission systems bring 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 is the wiring within the premises themselves.

Figure 1.14A shows that the final distribution of power is accomplished by high-voltage feeders that either:

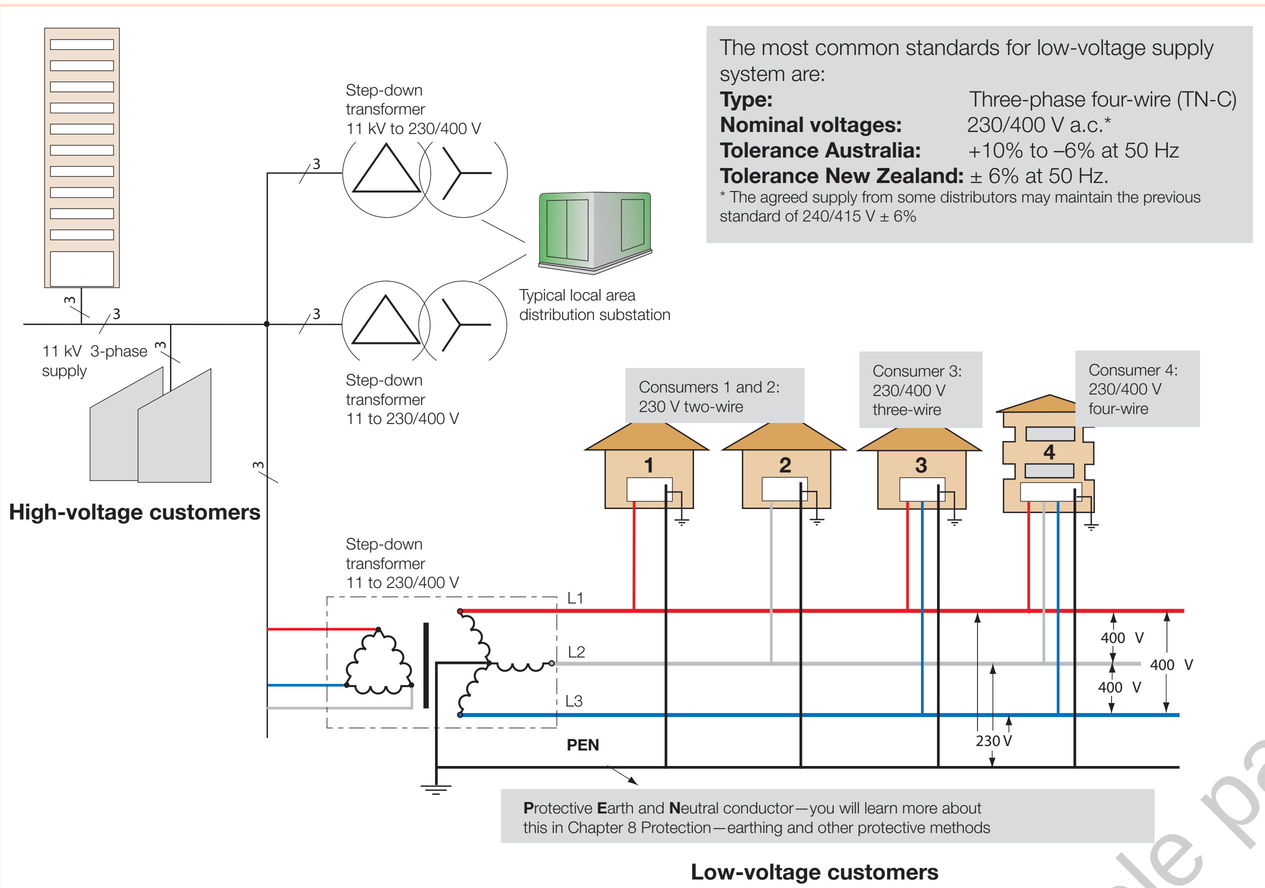
- go directly to bulk supply consumers, who have their own substation and facilities for low-voltage distribution on their premises
- go to a number of consumers fed from a common low-voltage network supplied by distribution transformers situated at strategic positions throughout the network.

The low-voltage supply to the consumer depends on the type and rating of the load to be connected, and may be a:

- 230 V two-wire supply (one active conductor and one neutral), most common for single domestic dwellings
- 230/400 V three-wire supply (two active conductors and one neutral) where the single-phase demand is higher or single-phase 400 V equipment, such as a welder, is installed
- 230/400 V four-wire supply (three active conductors and one neutral) where the demand is highest or where three-phase loads such as motors are installed. The single-phase loads must be balanced across the three phases.

A single-phase three-wire 230/460 V a.c. system is in current use for isolated supplies, usually in remote rural districts. The system is known as the single-wire earth-return (SWER) as transformer primary is supplied by a single wire, the return being via the general mass of earth, and is typical of that shown in Figure 1.14b. Supply of 230 V is available for standard single-phase 230 V light and power loads, whereas for heavy loads such as welders and large motors, a 460 V single-phase supply is available.

The three-phase four-wire low-voltage distribution in which the fourth conductor has the combined function of



▲ **Figure 1.14a** Distribution to urban consumers

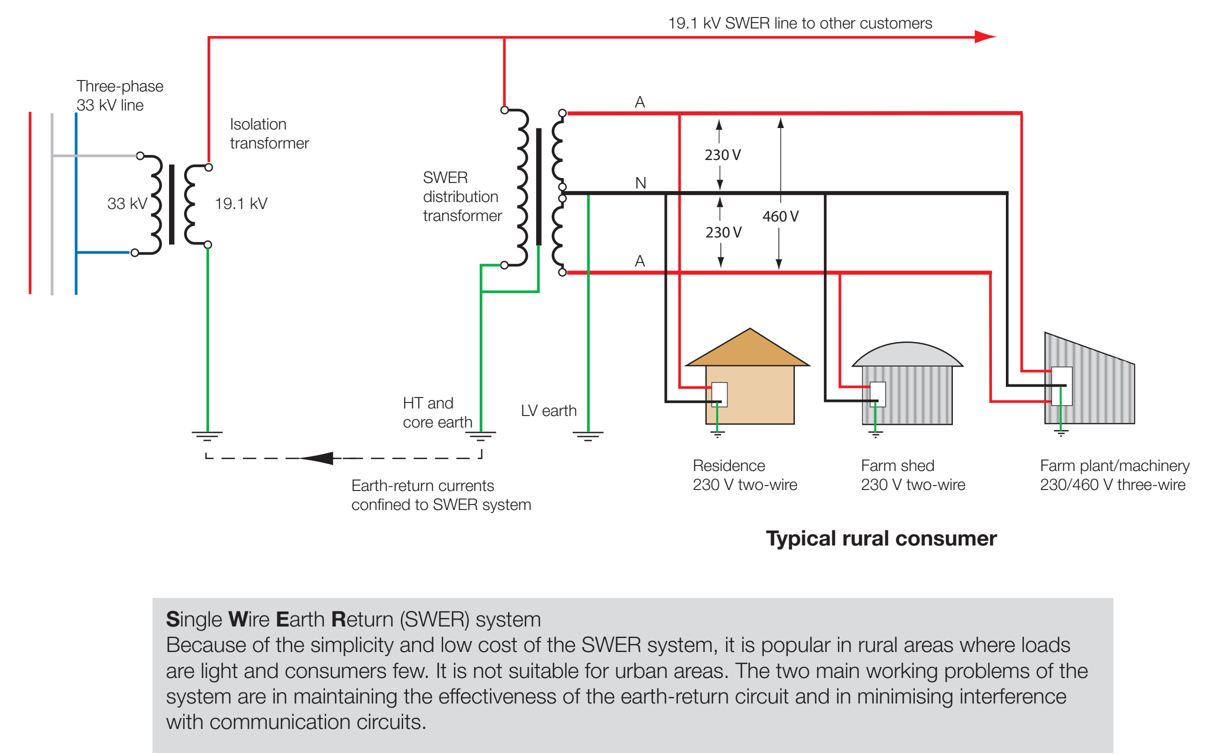


Figure 1.14b Distribution to rural or remote consumers

protective earth and neutral, as described in this section, is by far the most commonly used system throughout Australia and New Zealand and is the system referred to in *Part 2* of the *Wiring Rules*.

1.6 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 for inspection and testing to ensure 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, to complete the picture of electricity distribution from generator to use, you need to gain an understanding of the basic concepts that determine how electricity is distributed within the electrical installation.

The *Wiring Rules* require that an electrical installation be divided into circuits, with devices for control and protection against faults and over-current. Basic arrangements for a small and larger installation are shown in Figure 1.15. An important difference between the low-voltage distribution supply to the consumer and the consumer's installation is that the protective-earth and neutral (PEN) conductor of the distribution system is divided in the consumer's installation into separate protective-earth (PE) conductors and neutral (N) conductors. You will learn more about this in Chapter 8.

Connection of the completed and tested installation to the local distributor's mains is the final step in getting a supply of electricity to the consumer's premises. Forms to request supply are provided by various electricity distributors for completion by the electrical contractor or customer, and they are basically similar but may differ in detail and layout.

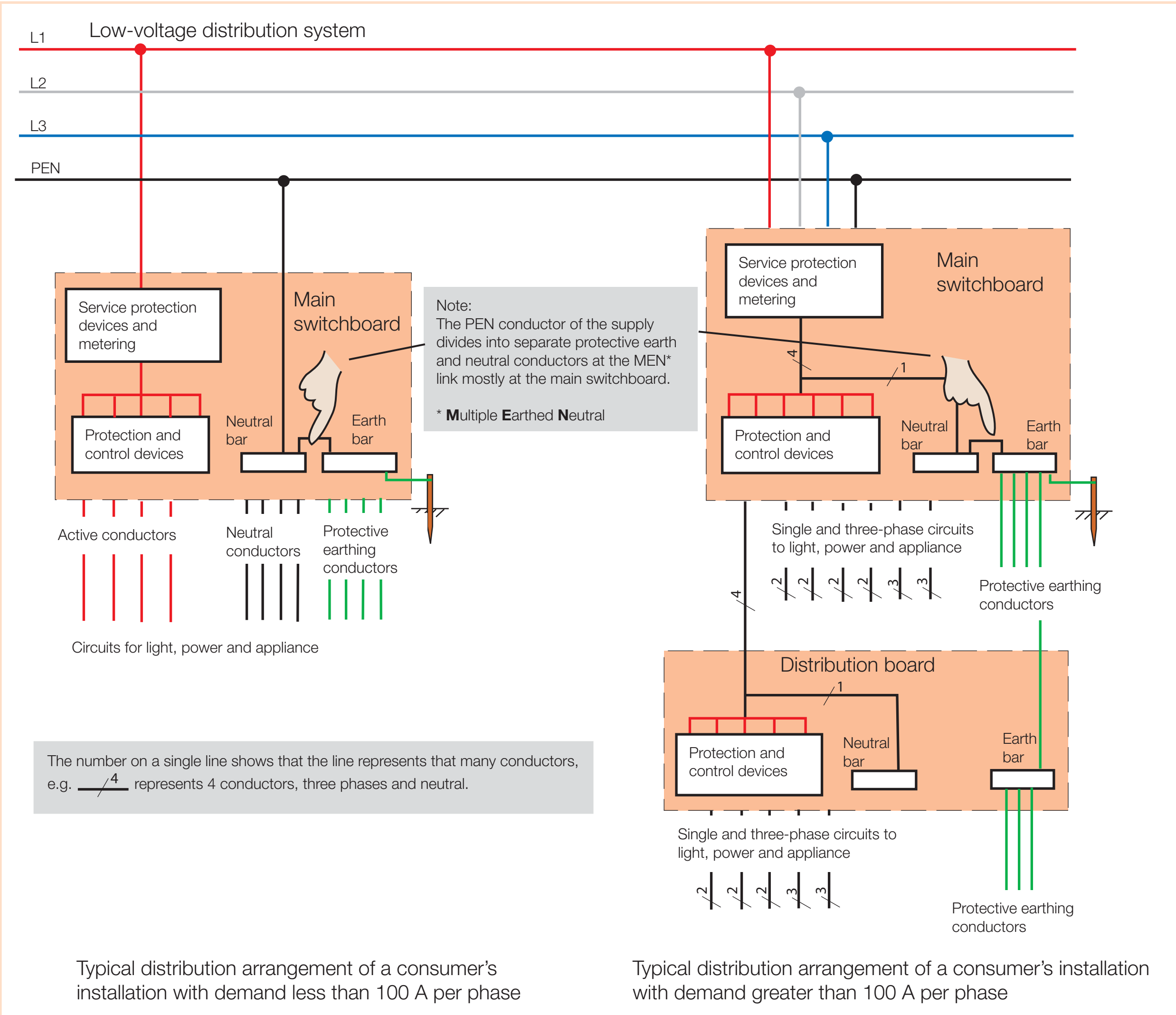


Figure 1.15 Examples of the typical arrangement of consumer installations

Getting connected to the supply network

Electrical work, whether a new installation or alterations and additions to existing installations, requires cooperation between the consumer, the distributor and the electrical contractor. To this end distributors and electrical regulatory authorities have processes in place that must be followed to ensure the network's quality of service to all consumers and the safety of the service and electrical installations. Across most jurisdictions the process for connecting an electrical installation to the supply network is much the same and this is outlined in the following points.

Notification of intention to carry out electrical work

Well before supply is given and prior to the installation of wiring, it is necessary to submit an application for supply, or notice of intention to carry out electrical installation work, to the local energy distributor. This notification should be completed in detail and signed by the consumer or electrical contractor, and applies to work that requires a change to the load or type of supply.

The main purpose of a notification is to inform the distributor of the extent of work so that they can make arrangements to ensure they have the capacity and the infrastructure to supply electricity to their customers. The technical information typically provided in a notification is listed in Table 1.3.

Financial contribution

The distributor may require a financial contribution by a customer or developer of installations or projects if these require major alterations or upgrading of supply network infrastructure in order to supply electricity to customers. Even in relatively modest installations, such as a single house,

Table 1.3 Typical information supplied in a notification to carry out electrical installation work

Type of installation	Whether the installation is new, an alteration to an existing installation or separation of existing supply for multiple customers or tariffs.
Service connection	Whether the service is underground, overhead or a combination of both and/or connected directly to a pole-mounted transformer.
Service size	Whether the installation requires 100 A, 200 A, 300 A, 400 A or a specified greater rating.
Number of installations	Whether this is for a single installation or multiple installation. For a multiple installation list the number of houses or units involved.
Premises type	Whether the premises are commercial or domestic or a combination of both.
Maximum demand	Current demand determined for each phase of the supply.
Other aspects	Estimated length of the service. Whether high-voltage supply is required. Whether proposed equipment may cause excessive voltage fluctuation (e.g. welders). Whether the installation includes a generator or other alternative source.

the final connection from the distributor's network to the consumer's installation comes at a cost to the consumer.

Verification of compliance

When the electrical installation is complete, the installing electrical contractor or supervising electrician must:

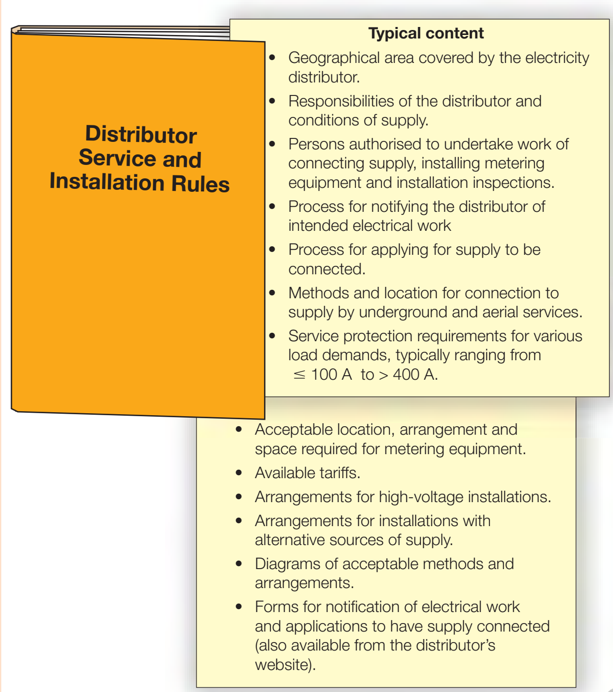
- visually inspect the work for compliance with the wiring regulations
- conduct tests in accordance with the *Clause 1.8* and *Section 8* of the *Wiring Rules* and prescribed by local regulations.

This is to ensure that the installation is safe and operates as intended (see Chapter 2).

Once the installation has been proven safe and compliant with the *Wiring Rules* and local regulations (e.g. Distributor service and installation rules, Figure 1.16), the electrical contractor must give the customer a signed formal document stating the compliance of the installation. The title of the compliance document may vary, such as certificate of compliance or certificate of electrical safety, depending on jurisdiction; however, their purpose is the same, that is, to maintain a safe electrical environment and act as a record to help to ensure electrical installation work is only carried out by licensed and competent persons. A copy may be given to the consumer.

Connecting the supply

Before connecting the supply, the energy distributor must visually inspect and test the installation. This is generally confined to the consumer's mains, the main earthing conductor, the main switchboard and particular types of installations such as those in hazardous areas (see Volume 2). However, in some cases the whole installation might be inspected under the distributor's regulatory obligation to conduct a schedule of checks to monitor the standard of electrical installation work carried out by electrical contractors and their employees. If the job is satisfactory, supply is connected. In some jurisdictions licensed registered independent inspectors are engaged to carry out inspection work.



Knowledge of local service and installation rules is a requirement for being granted an electrician's licence and together with the *Wiring Rules* it will become part of your studies as you progress through your training.

Figure 1.16 Distributor service and installation rules

In some areas an electrical contractor may gain authorisation status to carry out the connection of supply, and seal service and metering equipment to prevent illegal tampering with the supply. In this case, the contractor must be specially trained and carry specific safety and test equipment for the work.

Dealing with defective work

If an installation does not comply with all the tests or rules or is incomplete the energy distributor has the right to refuse supply. If the defect on the installation is major, that is, connecting it to the supply would render the installation potentially dangerous, the distributor will not connect the installation. On the other hand, if the defect is considered to be a minor one, supply is usually given. In either case, the installation inspector issues a defect notice to the customer listing the defects of the installation, and the electrical contractor must remedy the defects and arrange for a reinspection. Disciplinary action against electrical contractors for breach of compliance standards can be severe, depending on the degree of risk these breaches pose or the repetition of offences. An offending contractor may be imposed with more frequent inspections of their work until they can show work that is consistently free of defects. More serious offences may attract an infringement notice or fine, a licence suspension or a recommendation to undertake further training.

Situations requiring special procedures

There are also situations in which special procedures must be followed or arrangements made that alter or supplement those mentioned above. Examples are:

- where a progress inspection or inspections are necessary, such as in a large factory or a large building where sections might be required to operate before the completion of the whole installation
- in the case of a building service, to give supply to electrical equipment during building operations
- where additions or alterations require a changeover from existing metering, switchboard or consumer's mains to a new position or arrangement, particularly where minimum disruption of supply is required
- where there is an emergency or breakdown or the circumstances are such that the usual procedures would not provide the services required to meet the situation.

Summary

1.1 A brief history of electrical energy production and supply

Discoveries and development of electrical energy, Table 1.1

Brief history of the electricity supply industry, Table 1.2

1.2 Modern generation methods

Figures 1.1 to 1.4

1.3 Renewable energy and sustainable energy practices

Renewable energy sources, Figures 1.5 to 1.10

Generating and using energy efficiently

1.4 Electricity transmission and distribution systems

Figures 1.11 to 1.13

1.5 Distribution of electricity to consumers

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1.6 Distribution of electricity in the consumer's installation

Getting connected to the supply network, Figure 1.15

- Notification of intention to carry out electrical work, Table 1.3
- Financial contribution
- Verification of compliance, Figure 1.16
- Connecting the supply
- Dealing with defective work
- Situations requiring special procedures

Review questions

1 Who made the most important contribution to the electrical industry, in your opinion? Give reasons for your opinion.
2 How does coal-powered thermal generation work?
3 Describe the basic principle of electricity generation in an alternator.
4 At what voltages do steam turbine driven alternators produce electricity?
5 How is the steam that is used to drive the turbine isolated from the reactor in nuclear-powered thermal generation?
6 How is the thermal efficiency of a gas turbine alternator increased?
7 Why is it important to drive a generator at a particular constant speed?
8 Apart from being a clean energy source, what are some advantages of hydro generation over steam generation?
9 What is hot rock technology?
10 How can water be reused for power generation in a hydro scheme?
11 List some common applications of direct solar power generation.
12 Give an example of efficient use of energy.
13 What are the advantages of three-phase a.c. systems?
14 What is the main disadvantage of the original d.c. supply systems?
15 Describe the principles and advantages of modern d.c. transmission.
16 How are the conductors in a three-phase low-voltage system designated?
17 What are the primary and secondary transmission voltages?
18 What role do substations play in the transmission and distribution of electricity?
19 Who determines how much energy is needed from the electricity supply system at any one time?
20 What is the most common distribution system to consumers in Australia and New Zealand?
21 Explain the function of the fourth conductor in the three-phase low-voltage distribution system.
22 Illustrate a SWER system showing the typical voltages it supplies.
23 List the configurations of low-voltage supply to consumers.
24 How is the protective earth and neutral (PEN) conductor arranged in the consumer's installation?
25 Describe the *Wiring Rules* requirement for arrangement of electrical installations.
26 List the components of a consumer's installation that are installed at a main switchboard.
27 Briefly describe the main processes involved in connecting supply to a consumer's installation.
28 What actions are taken if an inspector finds an installation to be defective?
29 Name three aspects of electrical work typically covered in service and installation rules.
30 Describe a situation where special procedures are used for inspection and connection or disconnection of supply.