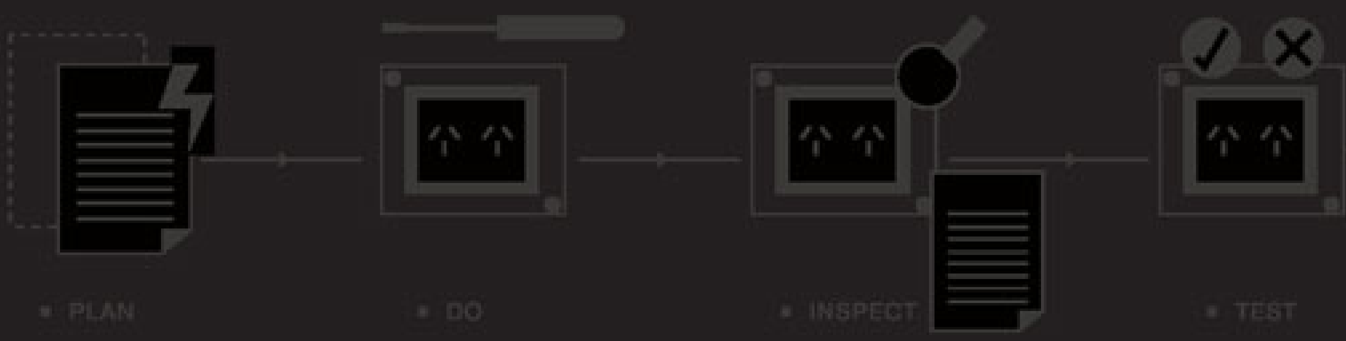


ELECTRICAL WIRING PRACTICE

AS/NZS 3000:2007

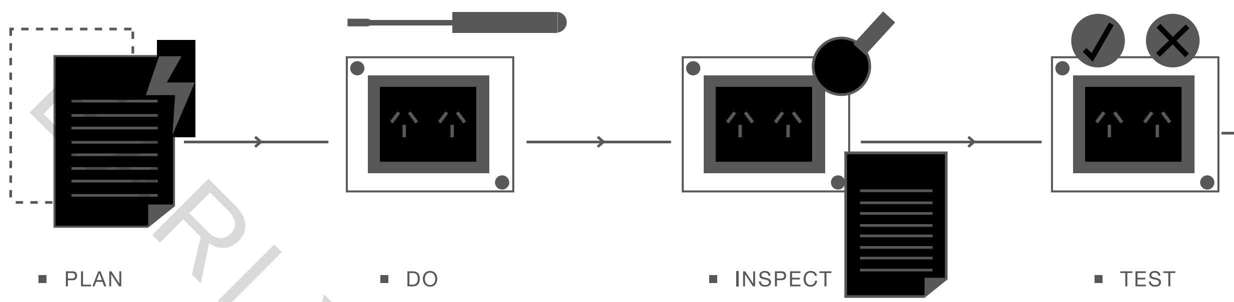
VOLUME 2

KEITH PETHEBRIDGE
IAN NEESON

7th EDITION

McGraw Hill Education

worldskills Australia



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Sydney New York San Francisco Auckland
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About the authors

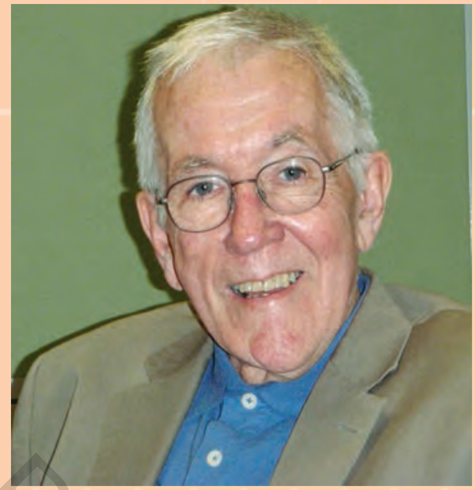
Keith Pethebridge

Keith Pethebridge has been an author of *Electrical wiring Practice* since the first edition. Before retirement, he was Senior Head Teacher in Electrical Trades at the Sydney Technical College, now the Sydney Institute of TAFE. Keith also worked as a consultant for apprentice training nationally. Sadly Keith passed away in March 2010 and will be sadly missed by family, friends and colleagues.

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 their 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 been a member of the judging team for the National Electrical and Communications Association (NECA) NSW Excellence Awards.



Ian Neeson

Preface

Approach

The 7th edition of *Electrical Wiring Practice* is a complete revision 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 3000:2007 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.

Taking a practical approach, the two volumes of *Electrical Wiring Practice* employ clear visual tools to illustrate the knowledge and practices required by specified products and the 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 these volumes 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 new wiring 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
- **Solutions**—Solutions are provided for all questions, either directly or where appropriate by reference to a figure or table in the text.

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:

- ACTEW Corporation
- Australian Plastic Products
- Ausra
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- Clipsal
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- Coates Hire
- Construction Information Systems Ltd (NATSPEC)
- Eddy Electric
- Emona Instruments
- Fluke Australia
- Heyday Group
- Hilti Australia
- Moduline
- National Electrical and Communications Association (NECA)
- NHP
- Olex Cables
- Prysmian Cables
- Pyrosales
- SAI Global Ltd
- Standards Australia
- Stowe Australia
- Unistrut
- VASS Electrical Industries
- WorkCover NSW

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The development of this addition 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 Greg Bryant, Michael Buhagiar, Mike Frew, Paul Plummer, John Shearston, Bob Taylor, Rado Starec, Brian Thomas, Eddy Lange, Gary Smith and to Antony Neeson for his artistic prowess.

I'd also like to thank the publishing team at McGraw-Hill for their hard work throughout the production of this book: Michael Buhagiar, Michael McGrath, Amanda Evans, Stephanie Erb, Jane Richardson, Astred Hicks and Haidi Bernhardt.

This edition is dedicated to Keith Pethebridge who got me started.

Ian Neeson

WorldSkills International Competition

Category: Electrical Installations

Australia's Silver Medallist

At just 23 years of age, John Rudge has achieved what many people only dream about—the honour of representing one's country.

After winning a Gold Medal in the Electrical Installations category at the WorldSkills Australia Macquarie Regional Competition in 2005, John progressed to the WorldSkills Australia National Competition in Melbourne 2006, where he won a Gold Medal and the accolade of Australia's Best.

At the 2007 WorldSkills International Competition in Shizuoka, Japan, John competed against the world's best electricians, returning home with a Silver Medal.

'It has been an amazing eye opener to compete at an international level. It has also given me the confidence to tackle any challenge.'

Following his success in Japan, John started a new job with OMYA Australia where his role is to maintain and update PLC software for their five plants throughout Australia and New Zealand. In 2008 John was named the Electrical Installations International Expert, mentoring and training the 2009 Electrical Installations *Skillaroo*, Gavin Press.

'WorldSkills Australia has made me a stronger person and my work is up to international standards, keeping the client, my boss and myself a lot happier.'

John Rudge: 2007 Skillaroo

WorldSkills Australia

WorldSkills is Australia's largest and most prestigious trade and skills competition, encouraging young people to rise to the challenge of stimulating competition. For the past 28 years this not-for-profit organisation has motivated over 70 000 young Australians to participate in WorldSkills Australia programs.

Their mission is to challenge young people, their teachers, trainers and employers to achieve world class standards in work skills and promote the status of vocational education and training across Australia. Through a program of competitions, aligned to the National Training Packages, WorldSkills Australia works to ensure that today's young people have the skills and abilities to compete within a rapidly changing global marketplace.

world skills Australia

A portion of the profits from this book will go to WorldSkills Australia.

For further information about WorldSkills Australia competitions visit www.worldskills.org.au.

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 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

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.

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 (USA). 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.

Exercises

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

Information boxes

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

CAUTION

Electrical workers in a service or maintenance role 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

Irrespective of a specification, all electrical installations must comply with *Part 1 (Section) Scope, application and fundamental principles* of the *Wiring Rules*.

EXERCISE 3.4

You are selecting a cable for a particular circuit and need to know the smallest permitted conductor size that can be used. The conductor size of a cable is determined by its current-carrying capacity.

1 Open the *Wiring Rules* at *Section 3* and turn to *Clause 3.4 Current-carrying capacity*.
2 Read *Clause 3.4.1 General* which refers to compliance with the AS/NZS 3008.1 series of cable selection Standards.
3 Go to *Note 1* of the clause to find that *Appendix C, Paragraph C.3* provides a set of current ratings for common simple circuits that comply with AS/NZS 3008.1.

This example of cross-referencing to other Standards is typical throughout the *Wiring Rules* and demonstrates how the *Appendices* are used to help apply the Rules.

AS/NZS 3008.1 Series

Electrical Installations—Selection of cables

Part 1: Cables for alternating voltages up to and including 0.6/1 kV

This important Standard gives all the informtion 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

Isolate and lockout all supplies to equipment to be worked on. Some equipment may become energised by the operation of control devices, such as hot-water systems with off-peak supply.

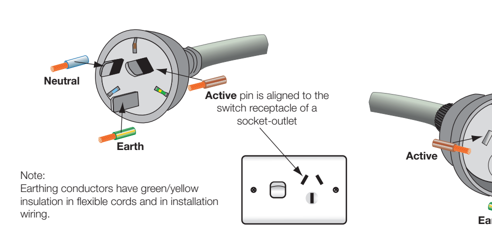
DANGER

Test before you touch

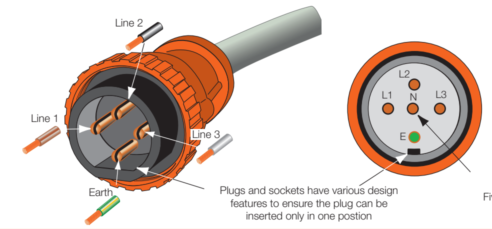
Do not rely on cable colours or markings as the only means of identification. Before connecting or disconnecting a cable, always follow safe testing procedures in order to know if the cable is safe to work on and to confirm its function.

Figures

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



◄ **Figure 2.8a** Making up a single-phase cord extension lead



◄ **Figure 2.8b** Connecting a multiphase 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 determined by Ohm's Law is

$I = V/I$

where

I = current in amperes

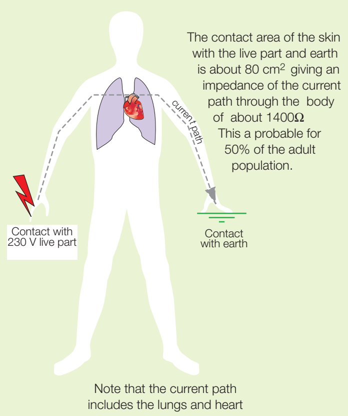
V = touch in voltage

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.



▲ **Figure 2.11** Hand to hand electric shock

Acronyms

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

Acronyms

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

Summary

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

Summary

2.1 Occupational/workplace health and safety

Legislation, regulations, codes of practice and standards
About occupational health and safety OHS, Figure 2.1a
OHS consultation and managing risk
How risk is managed, Figure 2.1b
Assessing risk, Table 2.1

2.4 Hazards of working with electricity

Dangers of arc faults, Figure 2.4a
Precautions with fallen cables, Figure 2.4b
Effects of electric current on the human body, Figure 2.4c and Table 2.6
Consequences of shock
Effects on the heart, Figures 2.4d and 2.4e

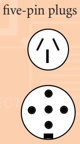
Review Questions

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. Answers to these questions can be found in the back of the book.

Review questions

1 Name the legislation and regulations governing workplace health and safety in your jurisdiction.
2 What are 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 the 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 How is safety managed in the workplace?
8 List the ways in which are hazards identified.

26 What is the hazard of a wrong polarity connection at a appliance?
27 Name one type of appliance that must not be earthed.
28 Mark the correct polarity of the single-phase three-pin and three-phase five-pin plugs viewed from the back.

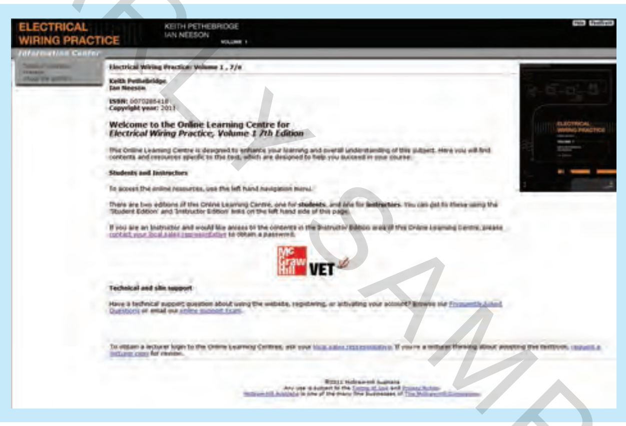


29 How are earthing conductors identified?

Supplements for instructors

Online LearningCentre

www.mhhe.com/au/pethebridge7e



The following supplements are provided for instructors free of charge. These are available on the Online Learning Centre that accompanies *Electrical Wiring Practice*.

Instructor Resource Manual

The Instructor's Resource Manual provides the instructor with a chapter-by-chapter summary of the text, solutions to all end-of-chapter questions, and additional teaching resources to enhance students' learning.

Art Work Library

All images and illustrations within this book are also available individually in our online Art Work Library so that instructors have the flexibility to use them in the format that best suits their needs.

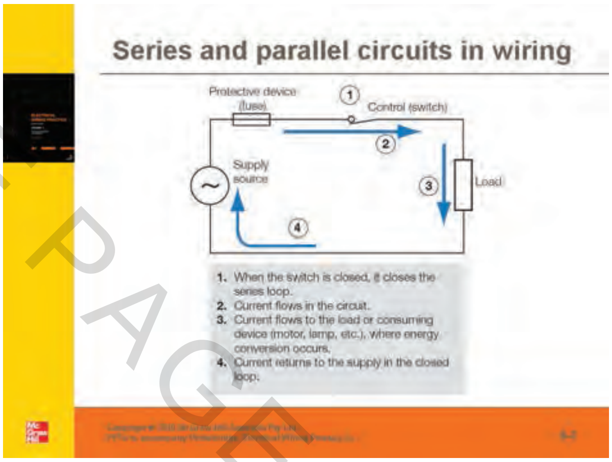
EZ TEST

EZ Test online

EZ Test is a flexible and easy-to-use testing program. It generates tests that can be exported to other course management systems (such as Web CT and Blackboard) and can be used to create hardcopy tests. Many questions of varying degrees of complexity are available.

PowerPoint® slides

Available to all instructors on the Online Learning Centre are PowerPoint® presentations featuring a summary of key points in each chapter.



Test Bank

A Test Bank of questions is available to assist instructors to set examinations quickly and easily. This may be provided as a simple document file, or formatted for delivery in WebCT or EZ Test, McGraw-Hill's exclusive test generator.

14

installation planning and design—selecting cables and protective devices

Learning outcomes

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

- explain the factors affecting installation design
- understand the content of Standards used in selecting cable for an electrical installation
- arrange an electrical installation into circuits
- allocate the number of points on a circuit in accordance with Wiring Rules requirements
- describe the factors affecting the type and size of cables selected for particular circuits
- explain how the following factors affect the current-carrying capacity of a cable
  - maximum demand
  - ambient temperature
  - installation conditions
  - direct sunlight
  - grouping
  - cables installed in ground
  - harmonic current
- use AS/NZS 3008.1 to select cables based the minimum current-carrying capacity for a given circuit
- use AS/NZS 3008.1 to select cables based on voltage drop using A.m/V values for a given circuit
- select cables based on earth fault-loop limitations
- explain the meaning of the short-circuit temperature performance of cables.

As mentioned in Chapter 6 there is a design aspect to planning an installation. Even before a quotation can be given, materials ordered or work commenced the following information about the job must be known:

- the type and load of the current-using equipment in the installation
- the current required to supply the installation
- the most effective arrangement of circuits for the installation
- the current demand of each circuit
- circuit protection
- most suitable wiring systems and cable types
- route length of cables
- cable conductor sizes.

This chapter deals with these design aspect and the process of selecting cables and protective devices for particular applications and draws attention to compliance requirements and reference material of the AS/NZS 3000:2000 *Wiring Rules*, and AS/NZS 3008.1: *Electrical Installations—Selection of Cables Part 1.1: Cables for Alternating Voltages up to and Including 0.6/1 kV—Typical Australian Installation Conditions.* (Note: Part 1.2 covers New Zealand installation conditions.)

Other information that must be determined in the design is prospective fault current and overcurrent protection needs which were dealt with in Chapter 10.

14.1 Factors affecting installation design

The electrical installation process starts with the design. No matter how small the installation is, there are a number of fundamental points to consider. *Clause 1.6.1* of the *Wiring Rules* requires that an electrical installation be safe for people to use, function correctly and be compatible with the electricity supply.

As a starting point it is necessary to gain a clear understanding of the factors that will affect how the installation is designed. Figures 14.1a outlines factors to consider related to the available supply and Figure 14.1b outline factors relative to the installation itself.

Figure 14.1c shows the relationship between main clauses of the *Wiring Rules* and the selection standards to help alleviate, what may appear at first to be a complication of requirements for arranging and selecting equipment for electrical installations.

At this point, it is appropriate to review the clauses and appendixes of the Standard series *AS/NZS 3008.1: Electrical Installations—Selection of Cables*. Part 1 of the series is based on the temperature conditions of Australia, while Part 2 applies to New Zealand.

Clause 3.4.1 of the *Wiring Rules* specifies that:

'Every conductor shall have a current-carrying capacity in accordance with AS/NZS 3008.1.1, not less than the current to be carried by it.

AS/NZS 3008.1 thus becomes the reference for cable selection covering the cable types and installation methods in common use and for working voltages up to and including 0.6/1 kV a.c. This standard may seem a bit daunting at first glance with its 5 sections, 62 tables and 2 appendices but when seen in its logical arrange it becomes fairly straightforward to use.

Although *Appendix C Paragraph C3* of the *Wiring Rules* provides current rating for simple installations the authors emphasis that any electrician 'worth their salt' must be skilled in using AS/NZS 3008.1.

Clause 1.3 of *AS/NZS 3008.1* mentions alternative specifications that may be used for determining the current-carrying capacity of certain cable types and installation methods not covered by the Standard.

ATTENTION

An electrical installation must be designed so that it is safe and convenient to operate and maintain. To comply the wiring system must satisfy both the *Wiring Rules* and the energy distributor's requirements, as well as the conditions set down in any job specification or design brief. Specifically:

- the various current-using equipment shall be divided into a logical arrangement of circuits (*Clause 2.2*)
- the wiring system shall be able to withstand the environment in which it is installed and its intended use, without deterioration or damage (*Clause 3.1.2 (e) and (f)*)
- cables shall be able to carry the current demanded by the load without overheating (*Clauses 3.1and 3.4*)
- cables shall be able to carry the current demanded by the load without exceeding the maximum permissible voltage drop (*Clauses 3.1.2(b) and 3.6*)
- cables shall be protected from damage by overcurrent (*Clause 2.5*).

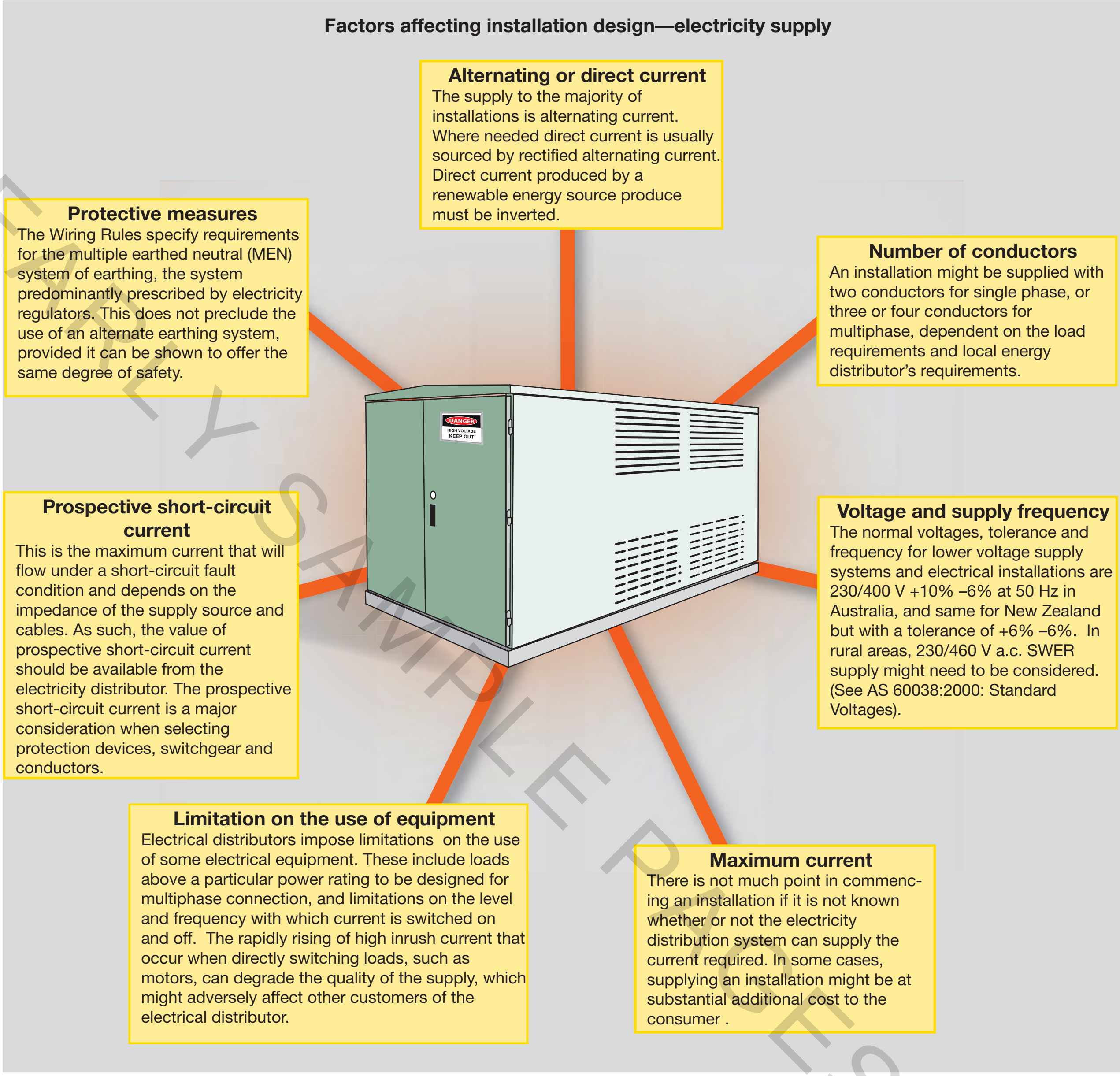


Figure 14.1a Factors affecting installation design—electricity supply

14.2 Arranging an electrical installation into circuits

A major aspect in designing an electrical installation is arranging the installation into circuits as required by the *Wiring Rules Section 1 Clause 1.6.5* with the deemed to comply arrangement given by *Section 2, Clause 2.2 Arrangement of electrical installations* and other related clauses as shown in Figure 14.1c.

The arrangement of an electrical installation must ensure safety, minimise inconvenience if a fault occurs, and facilitate safe inspection, testing and maintenance. Before a satisfactory arrangement can be achieved, information about several aspects of the electrical installations and equipment should be sought; some considerations are raised in Figure 14.2b.

Typically, separate circuits are allocated for:

- lighting
- socket-outlets
- heating appliances
- cooking appliance
- air conditioning appliances
- motors driving plant and machinery
- control and monitoring equipment
- the various safety services.

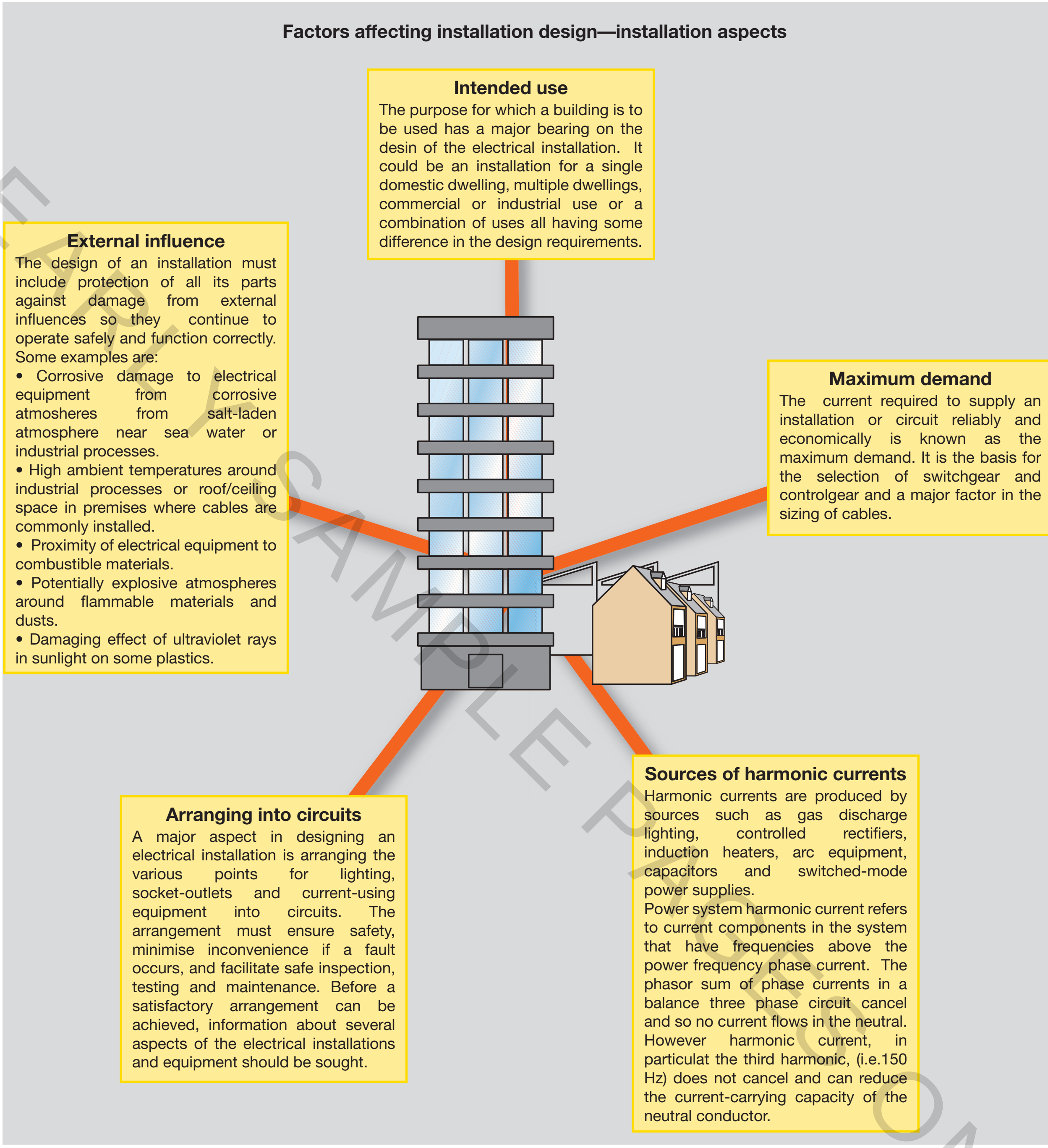
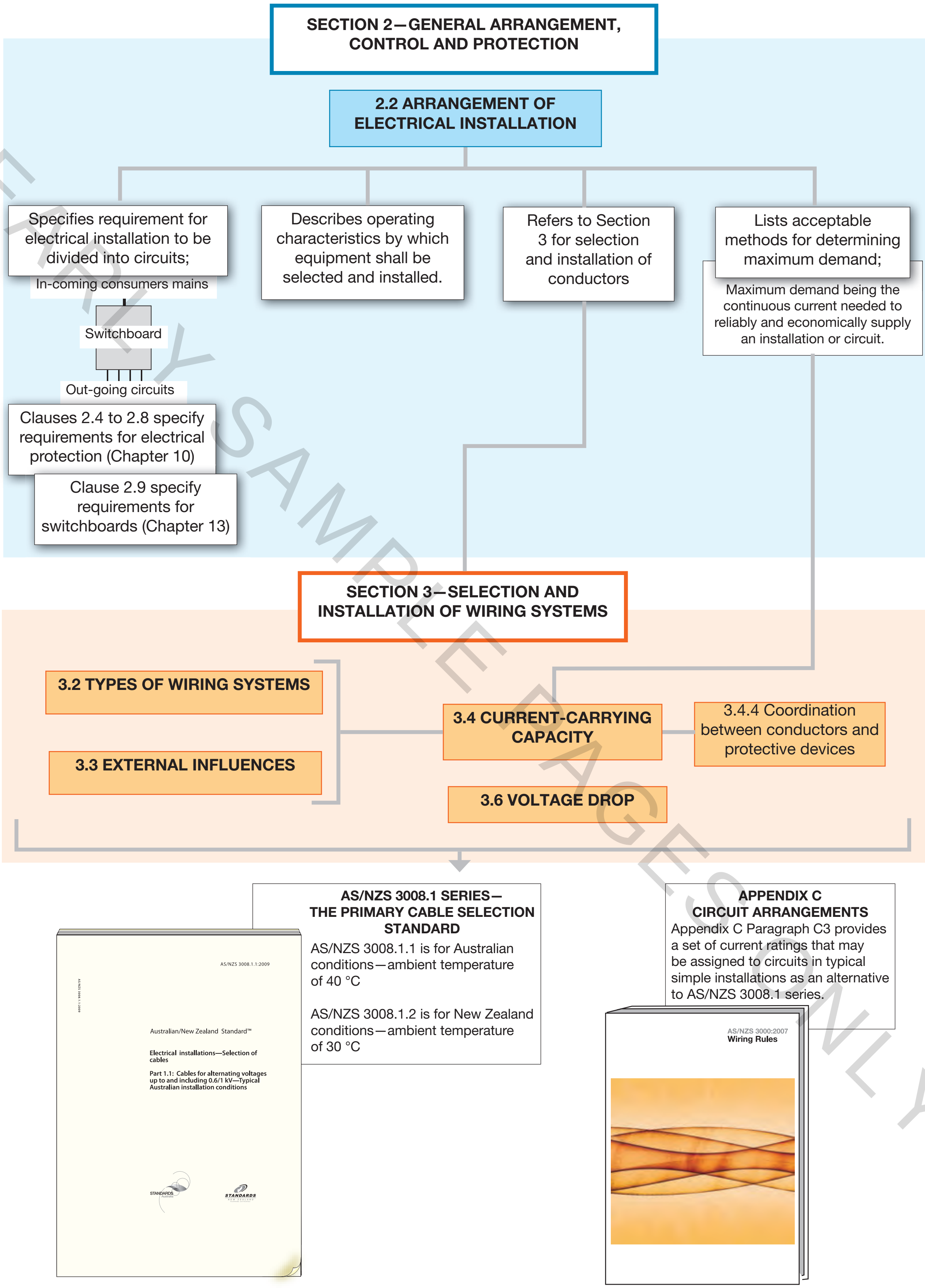


Figure 14.1b Factors affecting installation design—installation aspects

The number and type of circuits required is to be determined by the load on the circuit and the expected variation in load. This may include the use of more than one distribution board meaning that submains will be part of the installation arrangement. Typical situations where additional distribution boards are used is shown in Figure 14.2b.

Number of points on a circuit

Even though the *Wiring Rules* only gives guidance in allocating the number of points that may be connected on one circuit, factors outlined in Figure 14.2b should be considered before deciding the number of points to connect on each circuit.



▲ **Figure 14.1c** Relationship of *Wiring Rules* clauses and selection standards

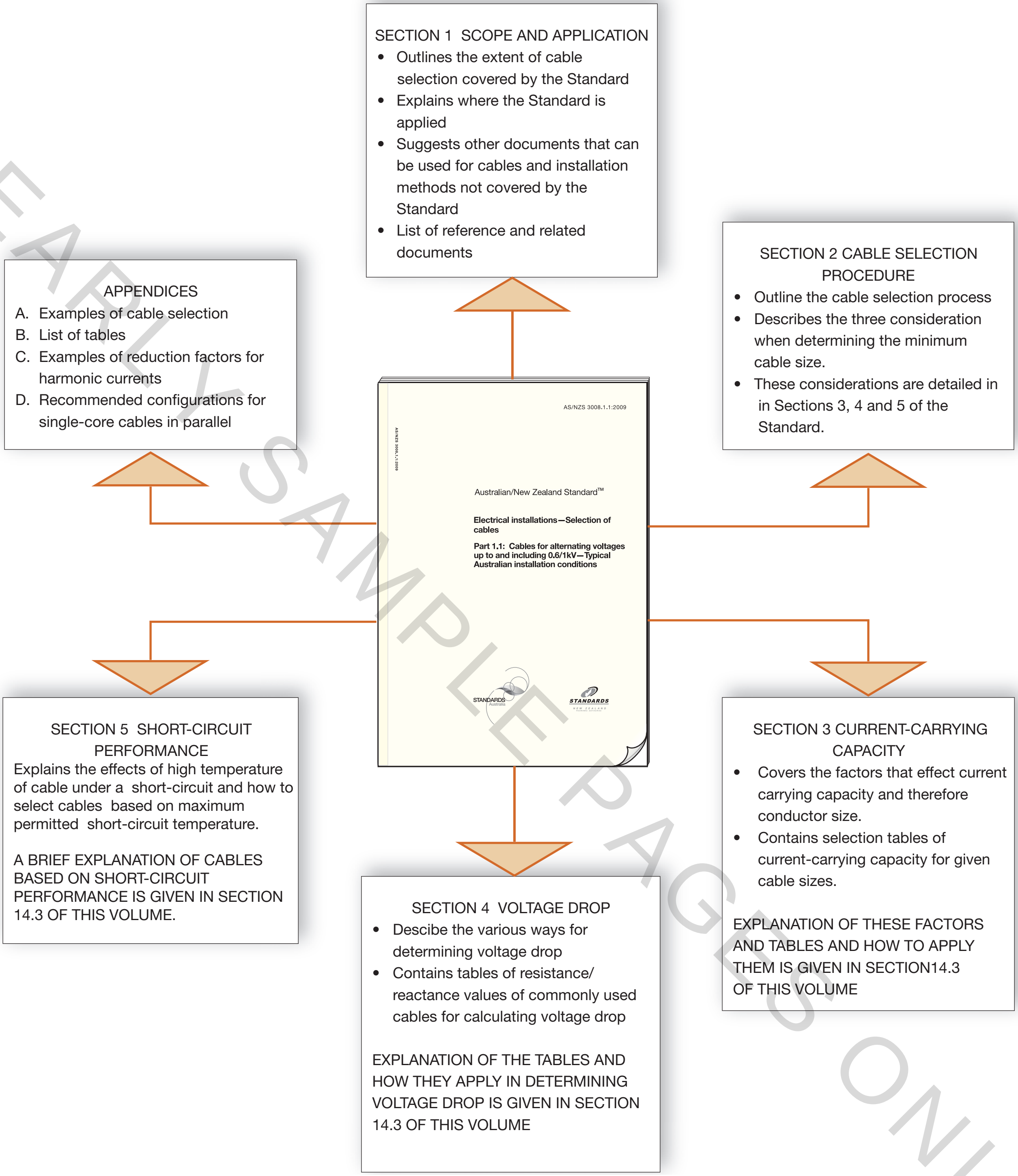
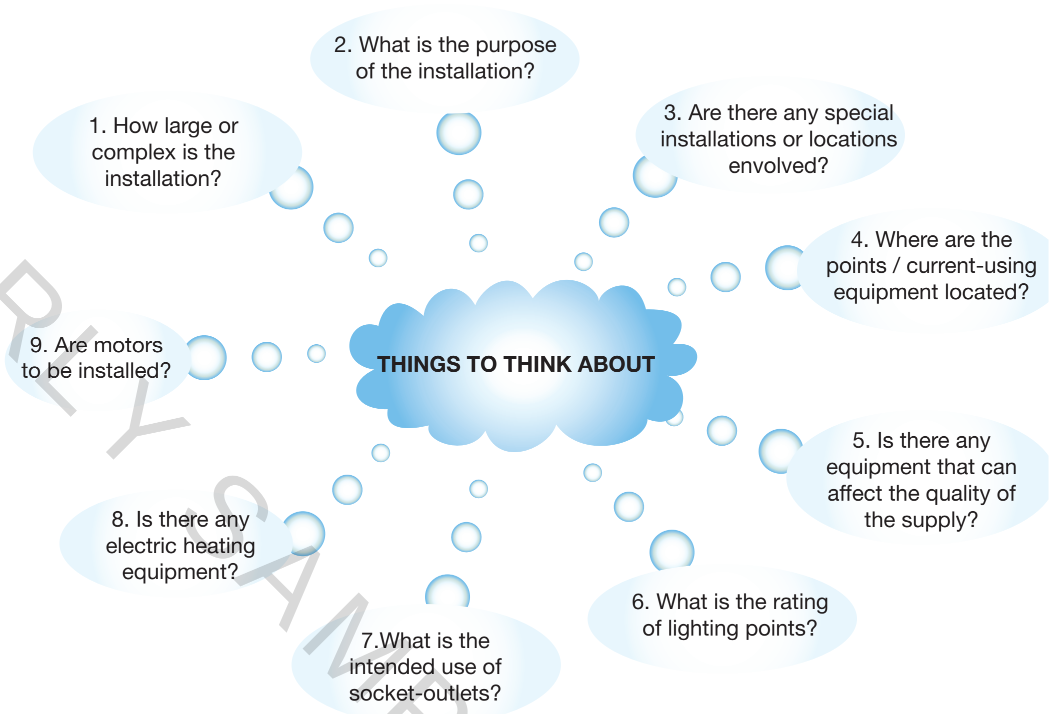


Figure 14.1d Overview of AS/NZS3008.1

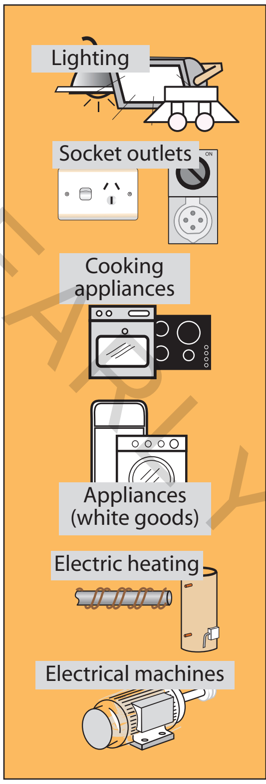
Irrespective of the number of circuits and the number of points connected on one circuit, the requirement for protection and safety must be met. In other words, the rating of the circuit protection device must not be greater than the current-carrying capacity of the cable, and the current-carrying capacity of the cable must be sufficient to supply the load under the expected normal operating conditions.

Arranging an installation into circuits



1	**How large or complex is the installation?** It is not sufficient to know whether or not an installation is 'domestic' or 'non-domestic'. One domestic installation might simply consist of light points and socket-outlets, while another might also include a range of appliances, climate control, integrated security, entertainment and an energy management system. Likewise, non-domestic installations can vary greatly in the extent and complexity of the loads they comprise.
2	**What is the purpose of the installation?** The final use of many commercial and industrial developments is often not known at the design and planning stages. In these cases, the design of the electrical installation might need to include allowance for additional loads and circuits. Agreement on this should be sought from the owner or end user (if known) and the basis of the final design documented.
3	**Are there any special installations or locations envolved?** How circuits for equipment associated with swimming pools, bathrooms and other damp areas are treated might influence the arrangement of circuits. The requirement for any emergency system must also be considered. The *Wiring Rules* calls up other Standards dealing with specific installations, such as hazardous areas, which might affect the arrangement of circuits.
4	**Where are points/current-using equipment located?** Thought might need to be given to the provision of distribution boards where loads/points are some distance from the main switchboard. In many cases, this will be a more economical solution and help deal with the possibility of excessive voltage drop and fault-loop impedance.
5	**Is there any equipment that can affect the quality of the supply?** The effects of a low power factor and switching transients need to be taken into account. A low power factor can increase the current demand on a circuit by as much as 100 per cent. Discharge lighting and electronic control devices can harmonics causing overcurrent in the supply neutral
6	**What are the ratings of lighting points?** It is preferable to know the ratings of each luminaire to be installed, but this is not always the case at the installation design stage. The rating attributed to each point should have some basis such as previous similar compliant installations. The ratings given in the footnotes of *Tables C1* and *C2* in *Appendix C* of the *Wiring Rules* could be used as a guide.
7	**What is the intended us of socket outlets?** Socket-outlets are often installed for convenience and it is not intended that all will be supplying load at the same time. For example, socket-outlets in passageways and public areas are usually intended for the use of portable cleaning equipment and the like. On the other hand, it is reasonable to assume that socket outlets installed in parts of a premises that do not have a permanently connected climate control might at some time supply a room heater.
8	**Is there any electric heating equipment?** Electric heating equipment such as cooking ranges, space heating and process heating, whether designed for single-phase or multiphase operation, will obviously affect the circuit arrangement. Also, the heating might be intended to operate on a different tariff to other parts of the installation. It might be appropriate to apply diversity to a circuit supplying a cooking appliance where it can be established with the customer that it is not intended that all elements in the appliance will be used at the same time.
9	**Are motors to be installed?** The arrangement of circuits for motors is generally determined by their purpose and in many cases is part of designated equipment such as air conditioning, lifts, process and manufacturing plant, and consideration should be given to the methods of starting. This might require the installation of submains and a dedicated distribution board.

Figure 14.2a Arrangement of circuits—things to think about



Designed each circuit so that small overloads of long duration do not frequently occur; frequent overloading of circuit conductors can deteriorate the cable and reduce the life of the insulation

Avoid connecting all socket-outlets intended for the supply of high-demand appliances on the one circuit

Limit the number of socket-outlet on a circuit intended for fixed Class I appliances, such as washing machines, to avoid nuisance tripping of RCDs from standing leakage currents

Allow the number of circuits sufficient to ensure that maintenance can be carried out with minimum inconvenience

Provide a separate circuit for each item of equipment that has a current rating greater that 20 A per phase

Provide a separate circuit for items of equipment that have essential functions such as security and emergency services

Use Table C8 in Appendix C of the Wiring Rules for guidance on the current allocation of each item on a circuit.

TABLE C8
GUIDANCE ON THE LOADING OF POINTS PER FINAL SUBCIRCUIT

Cable cross-sectional area[a] (mm²)	Rating of circuit-breaker[a] (A)	Contribution of each point (A) (sum must not exceed rating of circuit-breaker)						Maximum connected load for a range[de] (W)
		Lighting points[f]	10 A single or multiphase socket-outlets[cghi]		15 A single or multi-phase socket-outlets[hi]	20 A single or multi-phase socket-outlets[hi]	Permanently connected fixed or stationary appliances[g] or water heaters	
			Non-domestic installations without permanent airconditioning	All domestic installations and non-domestic installations with permanent airconditioning				

ZS 3000:2007

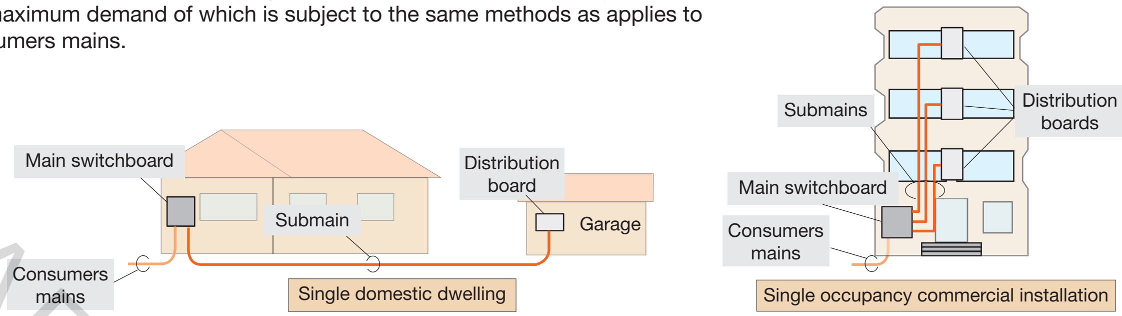
▲ **Figure 14.2b** Using more than one switchboard—typical situations

DID YOU KNOW?

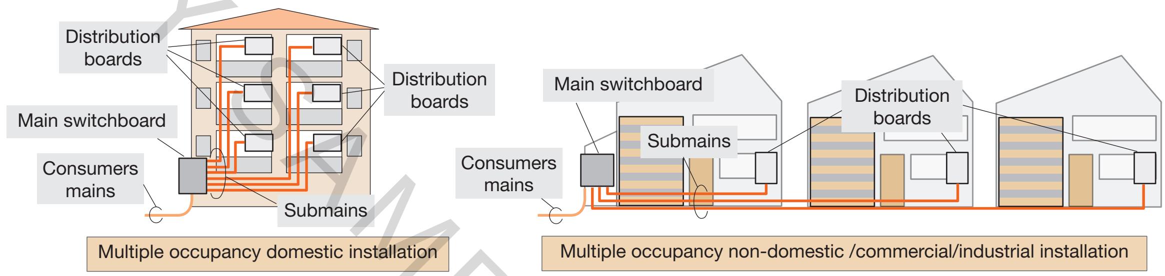
Manufacturing standards allow an RCD with a rated tripping current of 30 mA a tolerance of ± 7.5 mA while standards for class one appliance permit a standing leakage current not exceed 5 mA. So too many such appliances connected to one circuit will likely cause nuisance tripping.

14.3 Factors affecting cable selection

Once the arrangement of circuits is decided the cables for each circuit are selected. Before this can be done a number of interrelated factors must be well thought-out. Apart from the economic aspects the installation designer must take into account the current requirements of the installation and circuits (Maximum demand), external influences, A submain is the circuit supplying a distribution board as defined by *Clause 1.4.41* the maximum demand of which is subject to the same methods as applies to consumers mains.



Examples of additional distribution boards installed in single occupancy installations to reduced the route length of final subcircuits



Examples of distribution boards installed in each occupancy of a multiple-occupancy installations to provide control of the individual installations in accordance with *Clause 2.3* and reduced the route length of final subcircuits.

Figure 14.2c How many points should be connected to one circuit?

installation methods and limitation requirements of voltage drop, earth-fault loop impedance and in some circumstance cable short-circuit performance. Each of these is discussed in this section.

Maximum demand

The continuous current required to supply an installation or circuit effectively (i.e. reliably and economically) is known as the **maximum demand** (see Figure 14.3a). It is the basis for the selection of switchgear and control gear and a major factor in the sizing of cables.

The experience of energy distributors over many years, together with statistical and field research, has shown that the level of continuous current needed to supply an installation is somewhat less than the total current of all the individual loads (i.e. current-using equipment) in an installation. This is because either not all loads are switched on at the same time, and/or when they are, some are switched on only for short periods. The same is true for final subcircuits supplying a varying load, such as those supplying cooking and welding equipment.

Current-carrying capacity of the cable

The maximum continuous current that a cable can carry without exceeding its maximum permissible temperature is known as the current-carrying capacity of the cable.

REMEMBER

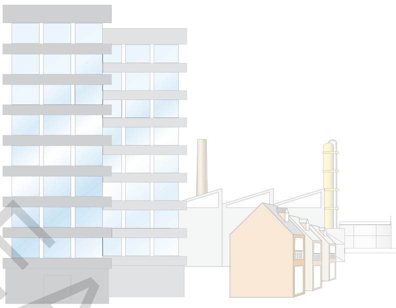
Heat is produced in a conductor when it carries current due to the conductor's resistance. The amount of heat produced is expressed as:

$H = I^2Rt$

where H = amount of heat produced in joules
I = cable current in amperes
R = resistance of cable in ohms
t = time for which current flows in seconds.

The resistance of a conductor decreases with an increase in its cross-section area and therefore less heat will be produced for the same current.

The heat produced in the conductor is an energy loss, known as the I^2R loss.

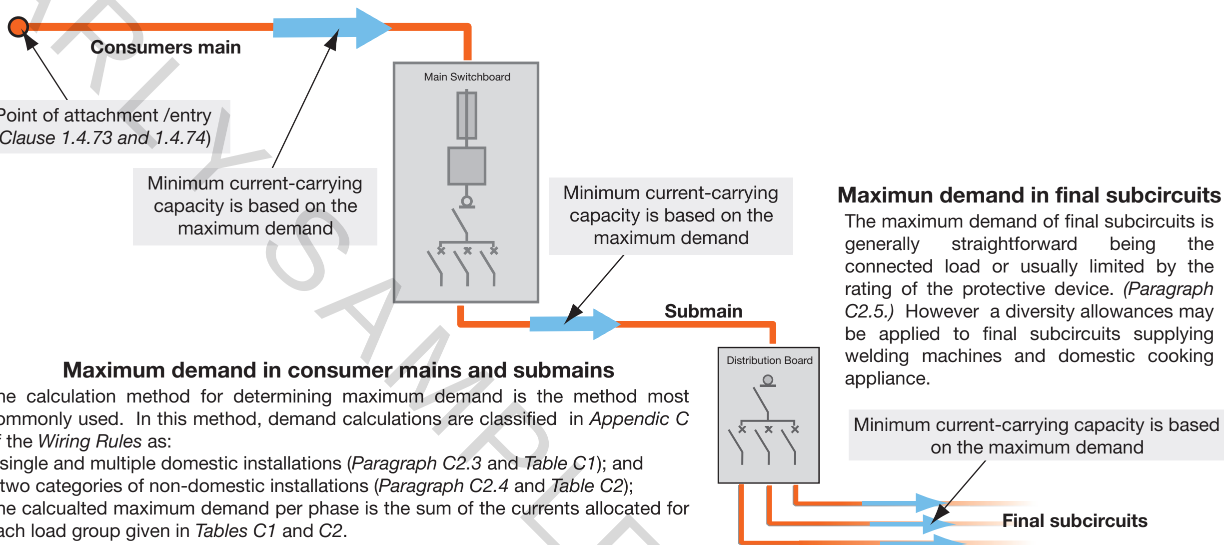


Maximum demand

The continuous current required to supply an installation or circuit reliably and economically is known as the maximun demand for that installation of circuit.

Factors having a bearing on the maximum demand

- The duty cycle of loads; that is, the duration and times of day they are used;
- How local climatic conditions affect the use of heating and cooling loads;
- The duty rating and power demand of loads such as motors;
- The purpose of the premises; for example, single or multiple residence, hotel, hospital, commercial, manufacturing facility;
- Supply arrangements;
- Possibility for growth in demand; and
- Local conditions such as extremes in ambient temperature.



Maximun demand in final subcircuits

The maximum demand of final subcircuits is generally straightforward being the connected load or usually limited by the rating of the protective device. *(Paragraph C2.5.)* However a diversity allowances may be applied to final subcircuits supplying welding machines and domestic cooking appliance.

Maximum demand in consumer mains and submains

The calculation method for determining maximum demand is the method most commonly used. In this method, demand calculations are classified in *Appendic C* of the *Wiring Rules* as:

- single and multiple domestic installations (*Paragraph C2.3* and *Table C1*); and
- two categories of non-domestic installations (*Paragraph C2.4* and *Table C2*);

The calcualted maximum demand per phase is the sum of the currents allocated for each load group given in *Tables C1* and *C2*.

Alternatively, for non domestic installations the maximum demand can calculated from the sum of the energy per square metre of floor area allocated to each load group given in *Table C3*

Figure 14.3a About maximum demand

For a given maximum demand and cable type the factors that affect the minimum conductor size needed to carry the current (current-carrying capacity) are:

- ambient temperature
- cables installed unenclosed, enclosed and/or in thermal insulation
- cable installed in direct sunlight
- grouping of cables
- cables installed in ground
- harmonic current.

These factors are explained in Figures 14.3b-2 to 6.

Cables installed in the ground

The maximum current-carrying capacity of cables installed in the ground, whether directly or in an underground enclosure, is slightly less than the same cable installed spaced in air. Derating/rating factors for cable installed in ground applicable to variations in ambient temperature and grouping of cables have been shown in Figures 14.3b-2 and 5. However the two other factors that must be applied are the depth at which cables are laid and thermal resistivity of the soil as explained in Figure 14.3b-6.

ATTENTION

Derating/rating factors

A derating factor is used where the condition to which it applies can result only in an increase cable size, like when cable are closely grouped. See *AS/NZS 3008.1 Tables 21 to 26(2)*.

A rating factor is commonly used where the condition to which it applies can result in either an increase of decrease in cable size, like ambient temperature. See *AS/NZS 3008.1 Tables 27(1) to 28*.

Applying a de-rating/rating factor:

$$I_C = \frac{I_{MD}}{k}$$

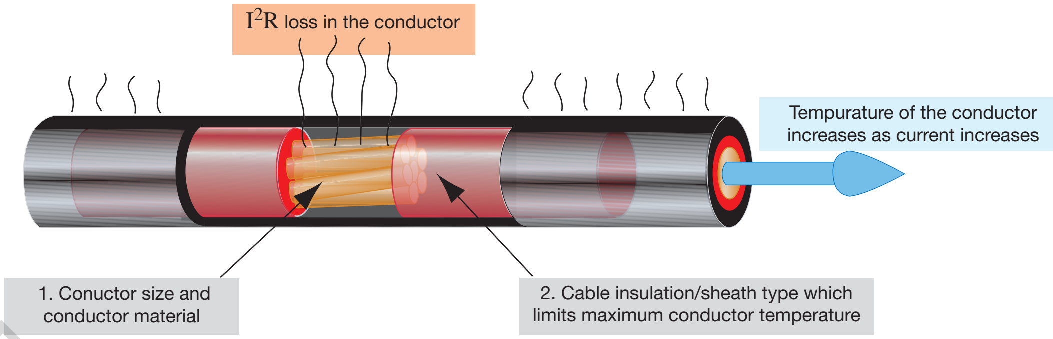
Where: I_C is the minimum current carrying capacity for the cable

I_{MD} is the maximum demand for the circuit, and

k is the de-rating/rating factor

Applying more than one de-rating/rating factor to a cable:

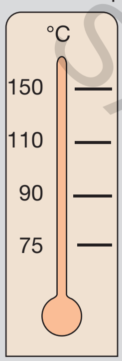
$$I_C = \frac{I_{MD}}{k_1 \times k_2 \times etc}$$



The structural features of a cable that limit its current-carrying capacity

1. Copper has a much lower resistance than aluminium and therefore has a higher current-carrying capacity for a given conductor size.

2. The maximum permitted conductor temperature for common polymeric insulation types is:



insulant types 150 fibrous or polymeric

insulants types R-HF-110, R-E-110, X-HF-110

insulants types X-90, X-HF-90, R-EP-90,R-HF-90,RCSP-90;

thermoplastic insulant.

Mineral insulated metal sheathed (MIMS) cable

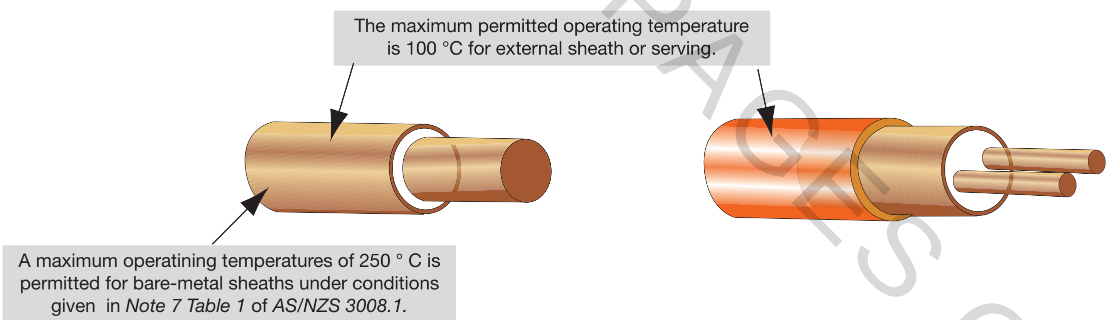


Figure 14.3b-1 Features of a cable that limit its current-carrying capacity

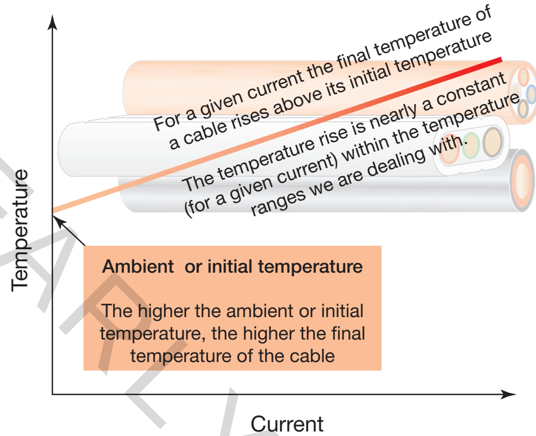
Effects of harmonics on balance three-phase systems

Power system harmonics are voltage or current components in the system that have frequencies above the fundamental supply frequency. The most harmful being the 3rd harmonic i.e. 150 Hz (3 × 50 Hz) as it can cause overheating line and neutral conductors as shown in Figure 14.3b-7. Higher order harmonic (e.g. 9th and 12th) may also cause overheating if more than 10% of content of the phase current.

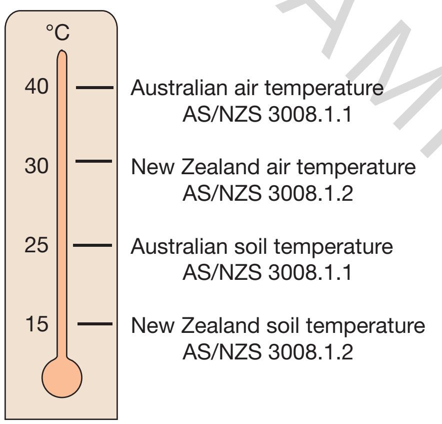
Varying load

The heating effect of a current is due to some average current value. Advantage may be taken of this when determining the maximum demand of a circuit, which in turn usually determines the current-carrying capacity of the circuit cables. For example, if a duty cycle can be established, an equivalent steady current can be determined under specific design (*Wiring Rules, Clause 1.9.4*). Similarly, *Appendix C* of the Rules, *Paragraph C2.5* provides criteria for the duty cycles of welding machines.

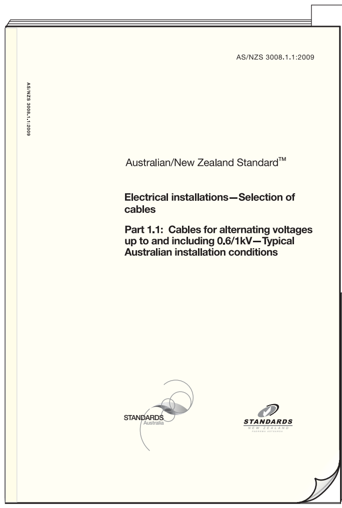
Ambient temperature



The ambient temperature base, for the current-carrying capacities of AS/NZS 3008.1 series



Where it could be shown that the prevailing ambient temperature in a particular locality in Australia is 30 °C or less, then it would be justifiable to use the current values given for New Zealand conditions in AS/NZS 3008.1.2. The reverse could be applied in New Zealand.



The notes in Clause 3.5.3 of AS/NZS 3008.1 series explain some installation conditions that can affect ambient temperature and might result in a de-rating or up-rating of the cable's current-carrying capacity.

Effects of ambient temperature

The following shows an extracted from Table 27(1) AS/NZS 3008.1.1 giving ambient temperature rating factors for cables in air or heated concrete slabs for Australian conditions. The same tables in AS/NZS 3008.1.2 give rating factors for New Zealand conditions.

1	2			6	7	8	9
Conductor temperature °C	Rating factor						
	Air and concrete slab ambient temperature..., °C						
	15	20	30	35	40	45	50
150	1.11			1.02	1.00	0.98	
110	1.16			1.04	1.00	0.96	
90	1.26			1.05	1.00	0.94	
80	1.31			1.06	1.00	0.92	
75	1.35			1.07	1.00	0.91	

Lower ambient temperatures increase current carrying capacity making a smaller conductor size possible

Higher ambient temperatures decrease current carrying capacity making a larger conductor size likely

The following shows an extracted from Table 27(2) AS/NZS 3008.1.1 giving ambient temperature rating factors for cables buried direct in ground or in underground wiring enclosures for Australian conditions. The same tables in AS/NZS 3008.1.2 give rating factors for New Zealand conditions.

1	2		4	5	6
Conductor temperature °C	Rating factor				
	Soil ambient temperature, °C				
	10	15	20	25	30
110	1.08		1.03	1.00	0.97
90	1.11		1.03	1.00	0.97
80	1.13		1.04	1.00	0.96
75	1.14		1.05	1.00	0.95

Lower ambient temperatures increase current carrying capacity making a smaller conductor size possible

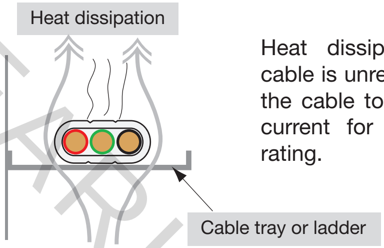
Higher ambient temperatures decrease current carrying capacity making a larger conductor size likely

Figure 14.3b-2 Effects of ambient temperature

The effect of installation conditions and example of how the resulting current-carrying capacity is shown in tables in *AS/NZS 3008.1*

The example are extracted from *Table 10 (AS/NZS 3008.1.1)* showing the current-carrying capacity of 2.5mm^2 two-core sheathed cable with thermoplastic insulation (75°C)

Cable installed in air spaced from a surface

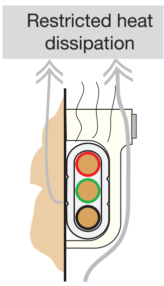


Heat dissipation from the cable is unrestricted allowing the cable to carry maximum current for its temperature rating.

Conductor size	Spaced		
	Cu		Al
mm^2	Solid/ Stranded	Flexible	
1	18	19	—
1.5	24	24	—
2.5	34	32	—

Maximum current-carrying capacity for ambient temperature of 40 °C

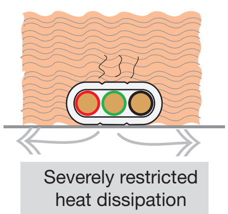
Cable installed in air fixed to a continuous surface



Heat dissipation from the cable is partcially restricted slightly reducing its current-carrying capacity

Touching		
Cu		Al
Solid/ Stranded	Flexible	
17	18	—
22	23	—
31	30	—

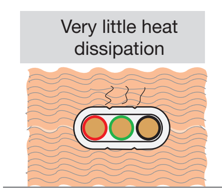
Cable partially surrounded by bulk thermal insulation



Heat dissipation from the cable is severely restricted reducing its current-carrying capacity to ≤ 75% of the unrestricted value.

	Partially surrounded by thermal insulation, unenclosed	
mm^2	Cu	Al
1	11	—
1.5	14	—
2.5	20	—

Cable totally surrounded by bulk thermal insulation



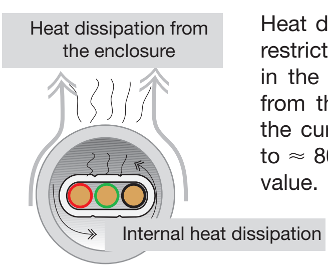
Little heat can dissipate from the cable reducing its current-carrying capacity to ≤ 50% of the unrestricted value.

Completely surrounded by thermal insulation, unenclosed	
Cu	Al
7	—
9	—
13	—

Note the dramatic reduction in current-carrying capacity compared with a cable spaced in air

Note.
Bulk thermal insulation such as fibreglass 'batts' is used to improve the energy efficiency of buildings.

Cable installed in an enclosure



Heat dissipates is somewhat restricted being first internally in the enclosure and in turn from the enclosure reducing the current-carrying capacity to ≈ 80% of the unrestricted value.

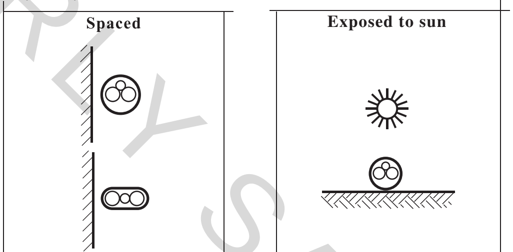
Wiring enclosure in air		
Cu		Al
Solid/ Stranded	Flexible	
16	16	—
20	20	—
28	27	—

Figure 14.3b-3 Effects of installation conditions

Effects of direct sunlight

Even though ambient temperature might be within specified limits, a cable's ability to transfer heat to the surroundings could be decreased due to its absorbing heat energy from an external radiant heat source. A prime example of this is where cables are subject to direct sunlight. Often the cable sheath colour for these situations is black, which absorbs heat quite readily.

Extracted from Table 10 (AS/NZS 3008.1.1) showing the current-carrying capacity of 2.5mm^2 two-core sheathed cable with thermoplastic insulation (75 °C)



Conductor size mm^2	Spaced: Cu Solid/ Stranded	Spaced: Cu Flexible	Spaced: Al	Exposed to sun: Cu Solid/ Stranded	Exposed to sun: Cu Flexible	Exposed to sun: Al
1	18	19	—	15	16	—
1.5	24	24	—	19	20	—
2.5	34	32	—	27	26	—

Compare the recuction in current-carrying capacity between 'space' and 'exposed to sun'

Figure 14.3b-4 Effects of cable installed in direct sunlight

As explained in *Clause 3.5.6* of *AS/NZS 3008.1*, the current-carrying capacities and de-rating factors given are based on continuous loading conditions on all conductors. Up-rating factors may be applied where intermittent or cyclic load variations occur or where all conductors cannot be loaded simultaneously.

Other up-rating factors include low ambient temperature conditions and use of a cable to supply a continuous load below the cable's rated current-carrying capacity. The use of an alternative de-rating factor to those published in *Tables 22* to *26(2)* of *AS/NZS 3008.1* may be justified where there is a mixture of loaded and unloaded cables and the connected loads have a known diversity, or where there is a known cycle or shape for a daily load pattern.

The current carrying capacity of all common types of cables and derating and rating factors are given in the tables of Section 3 of AS/NZS 3008.1 as shown in figure 14.3d

Voltage drop and earth fault-loop limitation

Both voltage drop and earth fault-loop impedance limit the maximum route length of a circuit for given conductor size load current and protective device. *Clauses 1.6.4* and *3.6* of the *Wiring Rules* limit voltage drop to 5 % for an installation; in extra-low-voltage (**ELV**) circuits, it is 10 per cent. This is the voltage drop across the series arrangement of circuits in the installation from the point of supply to the furthest current-using device or point in each final subcircuit, as shown in Figure 14.3e-1.

Recalling the that voltage drop is proportional to both current and resistance; that is:

$$V = IR,$$

and resistance is proportional to resistivity of the conductor material (i.e. copper or aluminium) and conductor length and inversely proportional to its cross-sectional area (csa), that is;

$$R \bullet \rho L/A$$

Applied to the voltage drops in an installation;

V is the voltage drop across the conductor
I is the current carried by the conductor
R is the resistance of the conductor, and
ρ is the resistivity of the conductor material
(Cu 1.72 × 10^8; Al 2.83 × 10^8)
L is the length of the conductor
A is the csa of the conductor

The foregoing shows that the factors to considered when selecting cables to meet voltage drop limits are the load current; the conductor size and route length of a circuit.

A cables (in a series group) selected for a installation may satisfy their current-carrying requirements, however, the resistance of the cable might be too high due to the length of the cable runs to meet voltage drop limitations. In this case, the cable size (cross-sectional area) of one or more cables (in the series group) will need to be increased.

The earth fault-loop impedance (EFLI) is the impedance of the conductors in the series path taken by the current in the event of a fault between an active conductor and an earth. As discussed in Chapter 8, the earth fault-loop is made up of the distribution transformer and supply conductors external to the installation, and the active and protective earthing conductors within the installation. The impedance of the earth fault-loop, in most cases majority of which is resistance, must be sufficiently low to:

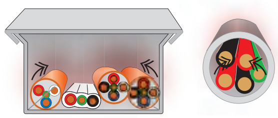
- allow enough current to flow to operate the protective device and disconnect the supply in a prescribed time
- therefore limit the rise in touch voltage as required by the *Wiring Rules, Clauses 1.5.5.3* and *2.4.2.*

Note that additional explanations of touch voltage is given in *Appendix B, Paragraph B4* of the *Wiring Rules.*

The focus here in selecting cables is the internal EFLI as reviewed in Figure 14.3e-2.

In a similar way to voltage drop EFLI is dependant the cable resistance, in this case the size (csa) of the active

The effect of cables of more than one circuit installed in groups



Mutual heating between cables and restricted air movement within the enclosures

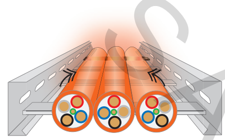
This example is extracted from Tables 22 (AS/NZS 3008.1.1) showing the derating factor for bunched circuits of single and multcore cables.

Item No.	Arrangement of cables (see Notes 1 & 2)	Derating factors — Number of circuits 1	2	3	4	5
1	Bunched in air	1.00	0.87	0.75	0.72	0.70
2	Bunched on a surface or enclosed	1.00	0.80	0.70	0.65	0.60

In the example of the circuits installed in conduit the conductors are increase one size, e.g. from 2.5 mm^2 to 4.00 mm^2

In the example of the circuits installed in trunking the conductors are increase two sizes, e.g. from 2.5 mm^2 to 6.00 mm^2

The ability of a cable to dissipate heat to the surrounding environment is reduced when it is installed in contact with cables of other circuits. Grouping cables inhibits the free circulation of air around each cable and promotes the mutual heating of the cables in the group.
Derating of cables effectively increases conductor size required.



Mutual heating between cables installed touching and restricted air movement

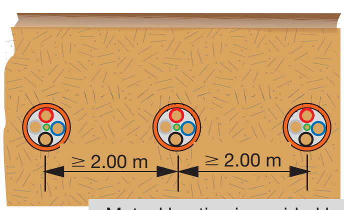
This example is extracted from Tables 24 (AS/NZS 3008.1.1) showing the derating factor for circuits of multcore cables installed on supports in air.

Item No.	Installation		Number of tiers or rows of cable supports	Derating factors — Number of cables 1	2	3
13	Ladder supports racks and cleats	Touching (see Note 6)	1	1.00	0.87	0.82
14			2	1.00	0.86	0.80
15			3	1.00	0.85	0.79
16						

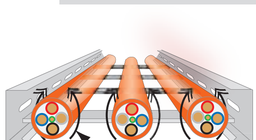
In this example of the circuits conductors are increase two sizes, e.g. from 2.5 mm^2 to 6.00 mm^2

Cables of more than one circuit suitably spaced

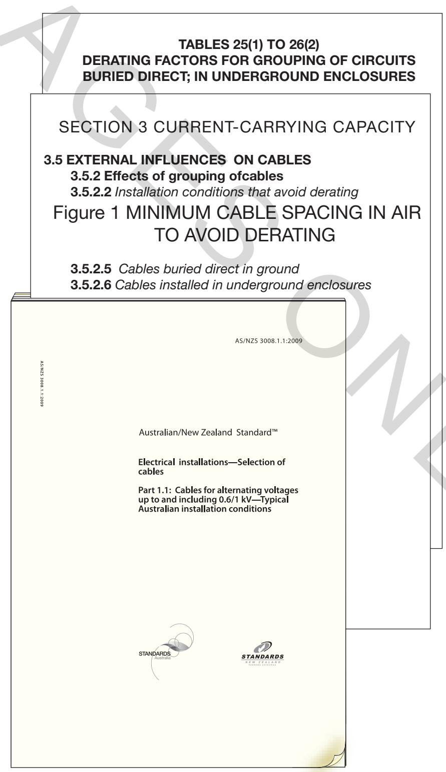
In these examples of cables installed in ground and in air de-rating of cables due to grouping is avoided by installing cables with sufficient clearances to prevent mutual heating.



Mutual heating is avoided by this minimum spacing



Heat is dissipated by the air free to circulate around each cable when spaced as specified in *AS/NZS3008.1 Figure 1*


TABLES 25(1) TO 26(2)
DERATING FACTORS FOR GROUPING OF CIRCUITS BURIED DIRECT; IN UNDERGROUND ENCLOSURES

SECTION 3 CURRENT-CARRYING CAPACITY

3.5 EXTERNAL INFLUENCES ON CABLES
3.5.2 Effects of grouping ofcables
3.5.2.2 *Installation conditions that avoid derating*
Figure 1 MINIMUM CABLE SPACING IN AIR TO AVOID DERATING

3.5.2.5 *Cables buried direct in ground*
3.5.2.6 *Cables installed in underground enclosures*

AS/NZS 3008.1.1:2009

Australian/New Zealand Standard™

Electrical installations—Selection of cables

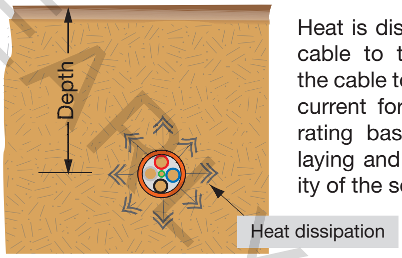
Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV—Typical Australian installation conditions

▲ **Figure 14.3b-5** Effects of grouping of cables

Cables installed in ground

The current-carrying capacity of cables installed in the ground, whether directly or in an underground enclosure, is slightly less than the same cable installed spaced in air.

This example is an extract from *Table 10 (AS/NZS 3008.1.1)* showing the current-carrying capacity of 2.5mm² two-core sheathed cable with thermoplastic insulation (75°C)



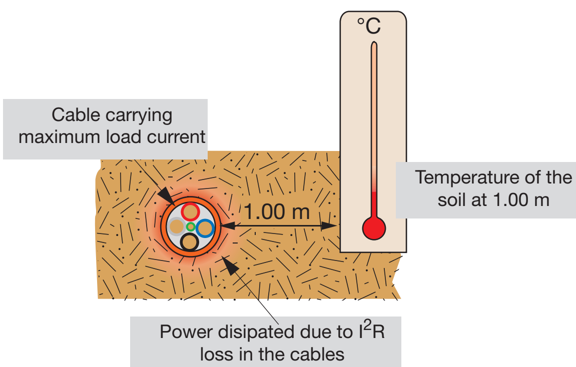
Heat is dissipated from the cable to the soil allowing the cable to carry maximum current for its temperature rating based on depth of laying and thermal resistivity of the soil .

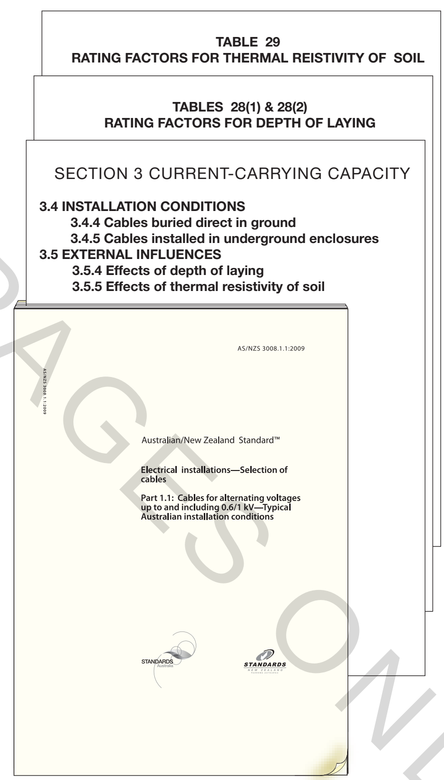
Conductor size	Buried direct		Underground wiring enclosure		
			Cu		
mm^2	Cu	Al	Solid/ Stranded	Flexible	Al
1	17	—	17	18	—
1.5	21	—	21	22	—
2.5	30	—	30	29	—

Maximum current-carrying capacity for ambient soil temperature of 25 °C

Thermal resistivity of soil

Soil thermal resistivity is the resistance to heat flow between the cable and the ambient environment of the soil. It is measured as the temperature in degrees centigrade for a metre of soil per watt dissipated by cables carrying the maximum load current (i.e. °C.m/W).



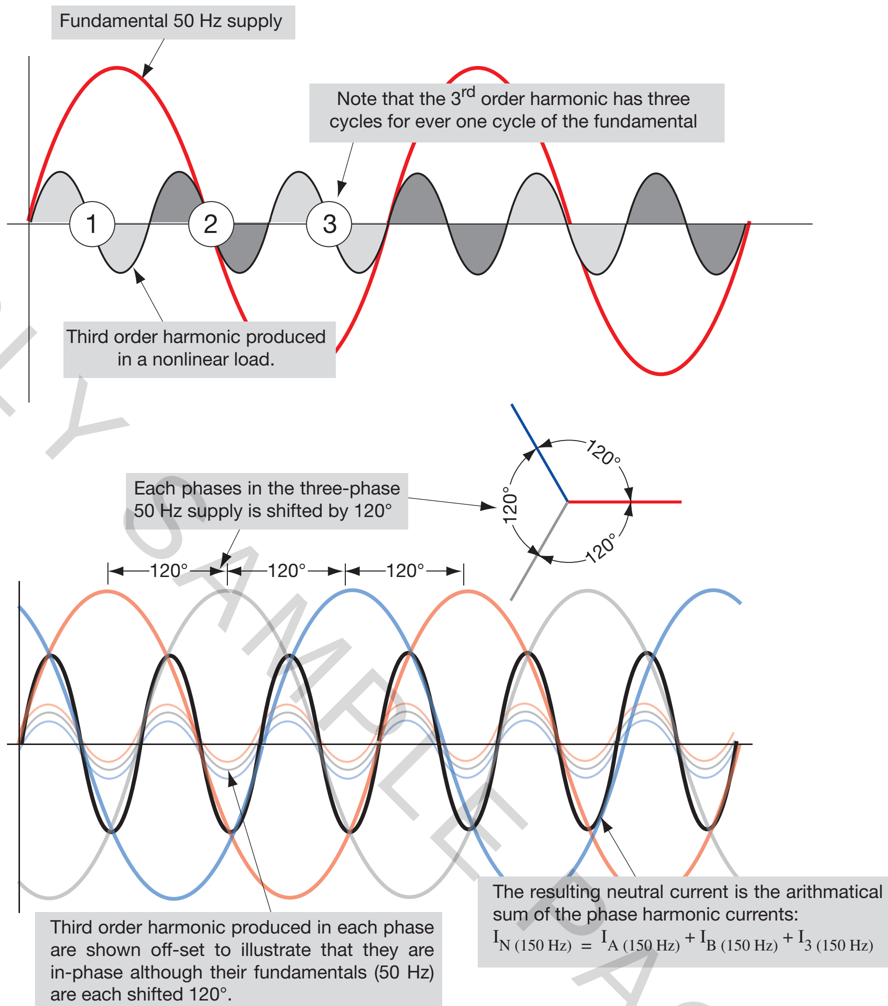


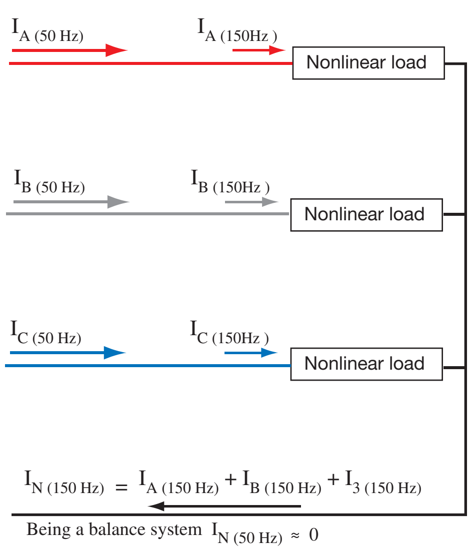
The rating factors are based on a soil thermal resistivity of 1.2 °C.m/W. Higher values mean less heat is dissipated and therefore a derating factor will apply leading to the selection of a larger conductor size.

AS/NZS 3008.1, Clause 3.5.5 gives guidance on thermal resistivity and common backfill mixtures for maintaining at the base of 1.2 °C.m/W.

Figure 14.3b-6 Cables installed in ground

How harmonic current can cause overheating of line and neutral conductor





Clause 3.5.2 of the *Wiring Rules* specify criteria for the current-carry capacity of neutral conductors. The cable selection standard *AS/NZS 30081, Clause 3.5.9* and *Table 2,* specify reduction factors that apply to 4-core and 5-core cables where the third-harmonic content of phase current is greater that 15%. Examples of how these reduction factor are applied are given in *Appendix D* of the standard.

Harmonics are produced in nonlinear components of loads such as gas discharge lighting banks, variable speed drive, soft starters, controlled rectifiers, induction heaters, arc equipment, and switched-mode power supplies. The resulting distortion of the supply waveform not only causes overheating of cables but reduces power factor, makes reading of revenue meters inaccurate and increases heat in transformer, motors and generators.

The harmonic content of a load devices should be obtainable from manufacturers. In many cases where harmonics is a significant problem, filters are used to mitigate their effects.

▲ **Figure 14.3c** How harmonic current can cause overheating of line and neutral conductors

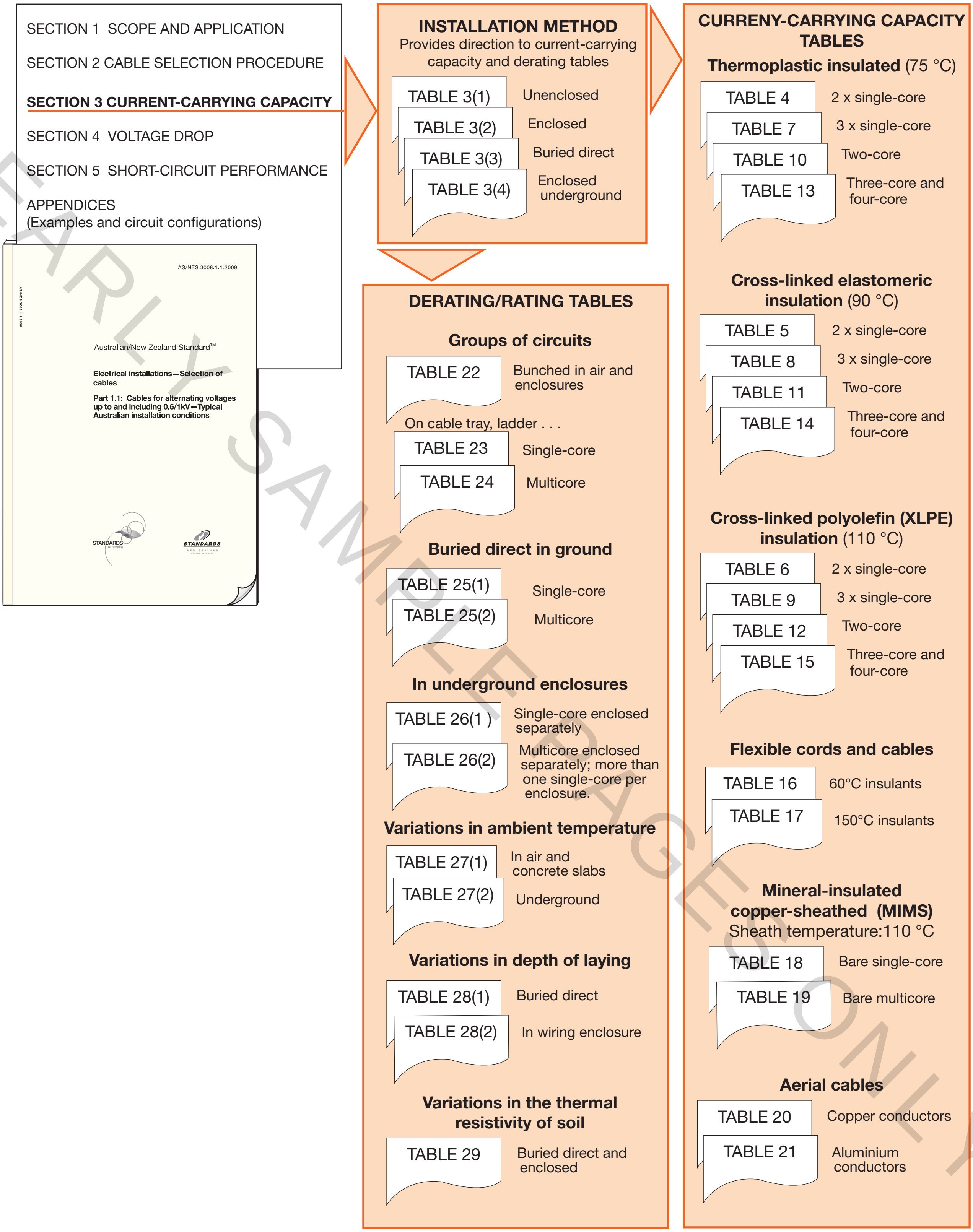


Figure 14.3d Current-carrying capacity, Section 3 AS/NZS 3008.1

Voltage drop across a series arrangement of circuits in an installtion

Voltage drop limitation (*Wiring Rules Clause 3.6*) applies to any series arrangement of circuits in an installation such as the consumers main and a final subcircuit, or as shown below the consumers mains, a submains in series with two different final subcircuits.

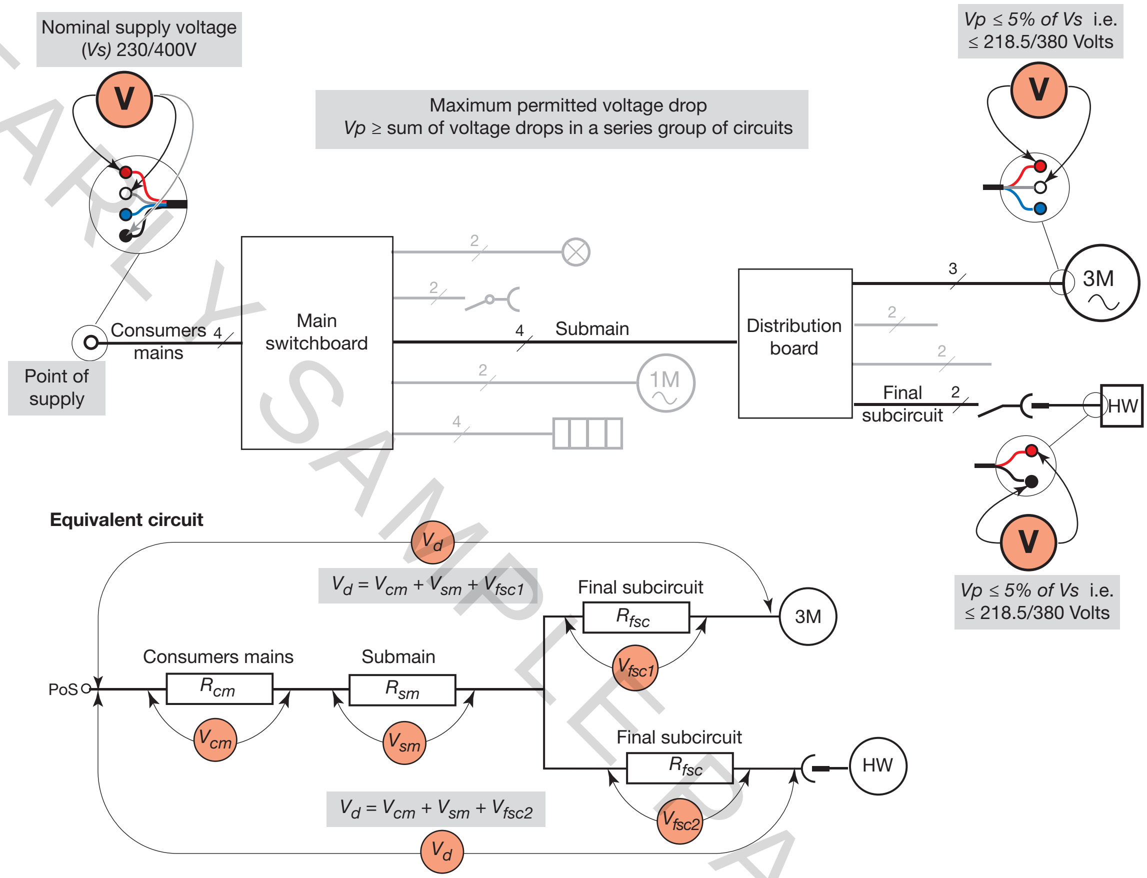


Figure 14.3e-1 Voltage drop across a series arrangement of circuits in an installation

conductor and the protective earthing conductor and the route length of the circuit. Given the previous discussion on voltage drop, it is clear that the maximum route length of a circuit must satisfy the limitation of both the earth fault-loop impedance and voltage drop.

Of concern is that the route length of the cables selected on the basis of voltage drop does not result in a fault-loop impedance that is too high. Generally, cables for single-phase that comply with the limits of voltage drop will, in most instances, be within the limits of fault-loop impedance. This does not mean that the integrity of the fault-loop impedance for each circuit should not be verified, because such checking is an essential part of ensuring that the protective measures required in an electrical installation will operate as intended.

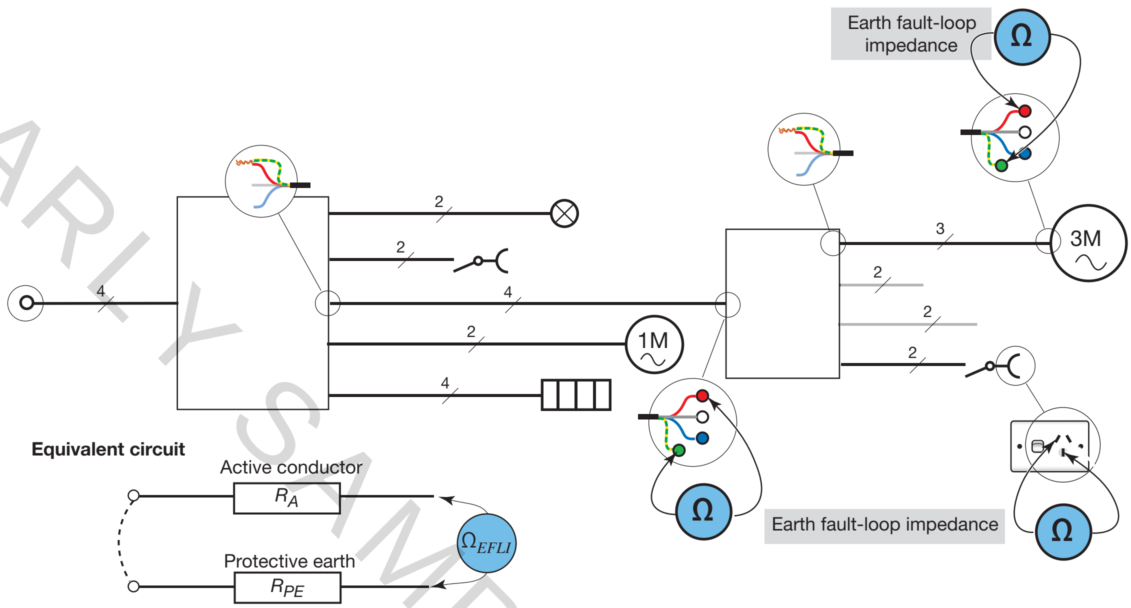
Note that *Wiring Rules Appendix B Paragraph B5* and *Table B1* provide information on the maximum length of circuits—this only related to EFLI.

Relationship between cables and protective devices

The purpose of assigning current-carrying capacities to cables is to obtain the most economic use of cables and at the same time ensure the continuing safe function of the electrical installation. The previous discussion and examples has shown that the current-carrying capacity or rating of a cable varies depending on the conditions in which it is installed. The particular ratings are assigned so that maximum-permissible cable temperatures allowed for the cable is not exceeded in normal use. If cables are operated above their current-carrying capacity, insulation will deteriorate, increasing the likelihood of insulation breakdown and risk of injury to persons or damage to property. For this reason, *Clause 2.5.3.1* of the *Wiring Rules* requires circuit conductors to be protected against overload.

Internal earth fault-loop impedance

Earth fault-loop impedance requirements (*Wiring Rules Clauses 1.5.5.3; 2.4.2 and 5.7.4*)) applies to all circuits in an installation The factors affecting the earth fault-loop impedance are the resistance of the active and associated protective earthing conductors; that is, the conductor size and route length. The installation shown is the same as in Figure 14.3-1 for voltage drop emphasing that both voltage drop and EFLI limits must be satisfied.



▲ **Figure 14.3e-2** Internal EFLI in an installation

The simultaneous operation of a number of appliances on a circuit of socket-outlets or a motor with a mechanical fault are typical examples that cause overloading of cables (i.e. they have to carry current higher than their current-carrying capacity).

The current required to trip a circuit breaker in the conventional time is taken as 1.45 times its nominal current rating, and for a fuse (complying with AS 2005 series), the fusing current is 1.6 times its nominal current rating. Therefore, where a fuse is used, it is de-rated to 90 per cent (1.45/1.6) of its rated value. For example, a fuse with a nominal current rating of 20 A becomes 18 A (20 × 0.9) for purpose of providing overload protection.

The main point is that, when selecting cables for their current-carrying capacity, consideration should also be given to the protective device being used. The maximum demand of final subcircuits can be regarded as the nominal current rating of the circuit protective device. This should be sufficient current to supply the load and must not be greater than the current-carrying capacity of the cables.

In addition to overload protection discussed here, protection against indirect contact and short-circuit currents must be provided. Protection and protective devices are discussed in Chapter 10.

14.4 Determining maximum demand

The continuous current required to supply an installation or circuit reliably and economically is known as the **maximum demand**. It is the basis for the selection of switchgear and control gear and a major factor in the sizing of cables.

The experience of energy distributors over many years, together with statistical and field research, has shown that the level of continuous current needed to supply an installation is somewhat less than the total current of all the individual loads (i.e. current-using equipment) in an installation. This is because either not all loads are switched on at the same time, and/or when they are, some are switched on only for short periods. The same is true for some final subcircuits, such as those supplying lighting and socket-outlets.

A number of methods are used throughout the world for determining a load current representing the assumed maximum demand of an installation, and wide research has been carried out to arrive at satisfactory methods for its estimation. If the estimated demand figure is too high, money is wasted in cables and equipment of higher rating than necessary; whereas, if it is too low, the wiring

SECTION 1 SCOPE AND APPLICATION

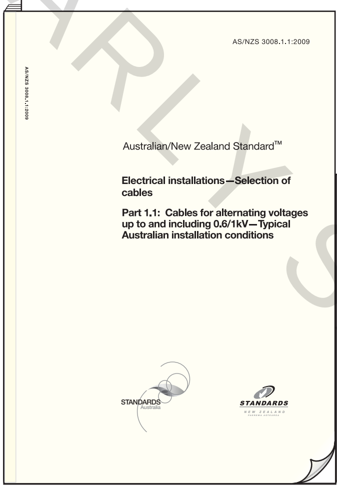
SECTION 2 CABLE SELECTION PROCEDURE

SECTION 3 CURRENT-CARRYING CAPACITY

SECTION 4 VOLTAGE DROP

SECTION 5 SHORT-CIRCUIT PERFORMANCE

APPENDICES
(Examples and circuit configurations)



DERMINATION OF VOLTAGE DROP:

- *Clause 4.2** from mV/A.m values
- *Clause 4.3* from circuit impedance
- *Clause 4.4* from cable operating temperature
- *Clause 4.5* from load power factor
- *Clause 4.6* in unbalancd multphase circuits

REACTANCE AND RESISTANCE OF CABLE AT 50 HZ TABLES

Cable reactance

- TABLE 30 Common cable
- TABLE 31 Flexible cords and cables
- TABLE 32 MIMS cables
- TABLE 33 Aerial conductors

a.c resitance of cables

- TABLE 34 Single-core cables
- TABLE 35 Multicore cables with circular conductors
- TABLE 36 Multicore cables with shaped conductors
- TABLE 37 Flexible cords and cables
- TABLE 38 MIMS cable
- TABLE 39 Aerial conductors

THREE-PHASE VOLTAGE DROP mV/A.m TABLES

Cables with copper conductors

- TABLE 40 Single-core laid in trefoil**
- TABLE 41 Single-core laid flat touching
- TABLE 42 Multicore with circular conductors

Cables with aluminium conductors

- TABLE 43 Single-core laid in trefoil**
- TABLE 44 Single-core laid flat touching
- TABLE 45 Multicore with circular conductors

Flexible cables and cords

- TABLE 46 Single-core laid in trefoil**
- TABLE 47 Single-core laid flat touching
- TABLE 48 Multicore

Mineral-insulated metal-sheathed (MIMS) cables

- TABLE 49 Single-core and multicore laid in trefoil**

Aerial cables

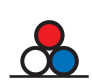
- TABLE 50 Copper conductors
- TABLE 51 Aluminium conductors

Note:

* **The method described by Clause 4.2 is the most commonly used.**

** **Cable installation arrangements:**

Flat, touching

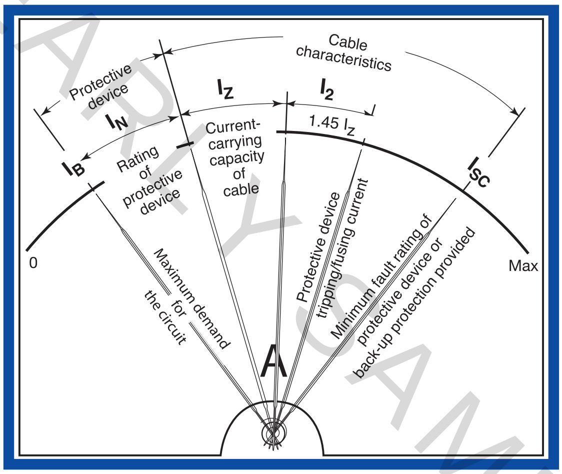


Trefoil

Figure 14.3f Voltage drop, Section 4 AS/NZS 3008.1

Co-ordination of cables and protective devices

The *Wiring Rules* stipulates that, in the event of an overload, a protective device (circuit breaker or fuse) must disconnect the supply before the temperature rise caused by the excess current damages the cable insulation, circuit connections or adjacent cables. To do this without the inconvenience of nuisance tripping, *Clause 2.5.3.1* of the Wiring Rules requires the following relationships to be met :



$I_B \le I_N \le I_Z$

and $I_2 \le 1.45\ I_Z$

where I_B = the maximum demand of the circuit (current needed to supply the load)

I_N = the nominal current rating of the protective device

I_Z = current-carrying capacity of the cable (IZ)

I_2 = the current ensuring the operations of the protective device to disconnect the supply.

Figure 14.3g Co-ordination of cables and protective devices

will be subject to high voltage drop, overload resulting in overheating, and perhaps shock and fire hazards.

Clause 2.2.2 of the *Wiring Rules* sets out methods for determining maximum demand in consumers mains, submains and final subcircuits.

Australia and New Zealand follow the general principles set down by the international Standards body, the International Electrotechnology Commission (IEC). *Clause 2.2.2* of the *Wiring Rules* accepts any of the methods for estimating maximum demand as outlined in Table 14.1.

The maximum demand of final subcircuits is generally straightforward being the connected load and usually limited by the rating of the protective device. However Paragraph C2.5 of the Wiring Rules provides information on diversity allowances that apply to final subcircuits supplying welding machines and domestic cooking appliance.

Calculating maximum demand in consumers main and submains

The underlying purpose of all methods used to determine maximum demand is to arrive at a figure for the selection of mains, submains, switchgear, metering and protective equipment. The demand figure must be adequate yet economical in its use of material and equipment, allow efficient supply to the consumer and include an allowance or reserve capacity for any anticipated additional load.

Table 14.1 Methods of estimating maximum demand in consumers mains and submains

Method	Application	*Wiring Rules* reference
Calculation	The one most commonly used. Because the various loads in an installation are used for diverse purposes and at diverse times a **diversity allowance** is applied to each load type in different installations for determining the maximum demand figure. It is probably more accurately referred to as **after diversity maximum demand**.	*Clause 2.2.2 (a) Appendix C Paragraphs C2.3, 2.4 and 2.4.3. Tables C1, C2 and C3.*
Assessment	Used where a large load, (e.g. a motor) or special equipment, (e.g. an X-ray machine) is involved. The assessment is based on experience, records of similar types of loads or electrical specifications and on manufacturers' recommendations. The assessment method is invariably used in consultation with the local energy distributor, and may insist that this method is used for a particular installations or load types.	*Clause 2.2.2 (b)*
Measurement	This method is typically used when additions are to be made to an existing installation and the present maximum demand is not known. A maximum demand indicator or recorder is connected to indicate a figure representing the highest sustained demand over any 15-minute period. The energy distributor may use this method to check the accuracy of a calculated or assessed value and, where the measure value is shown to be greater, it is deemed the maximum demand for the installation.	*Clause 2.2.2 (c)*
Limitation	The maximum demand is limited by overcurrent tripping current of a fixed or load setting circuit-breaker	*Clause 2.2.2 (d)*

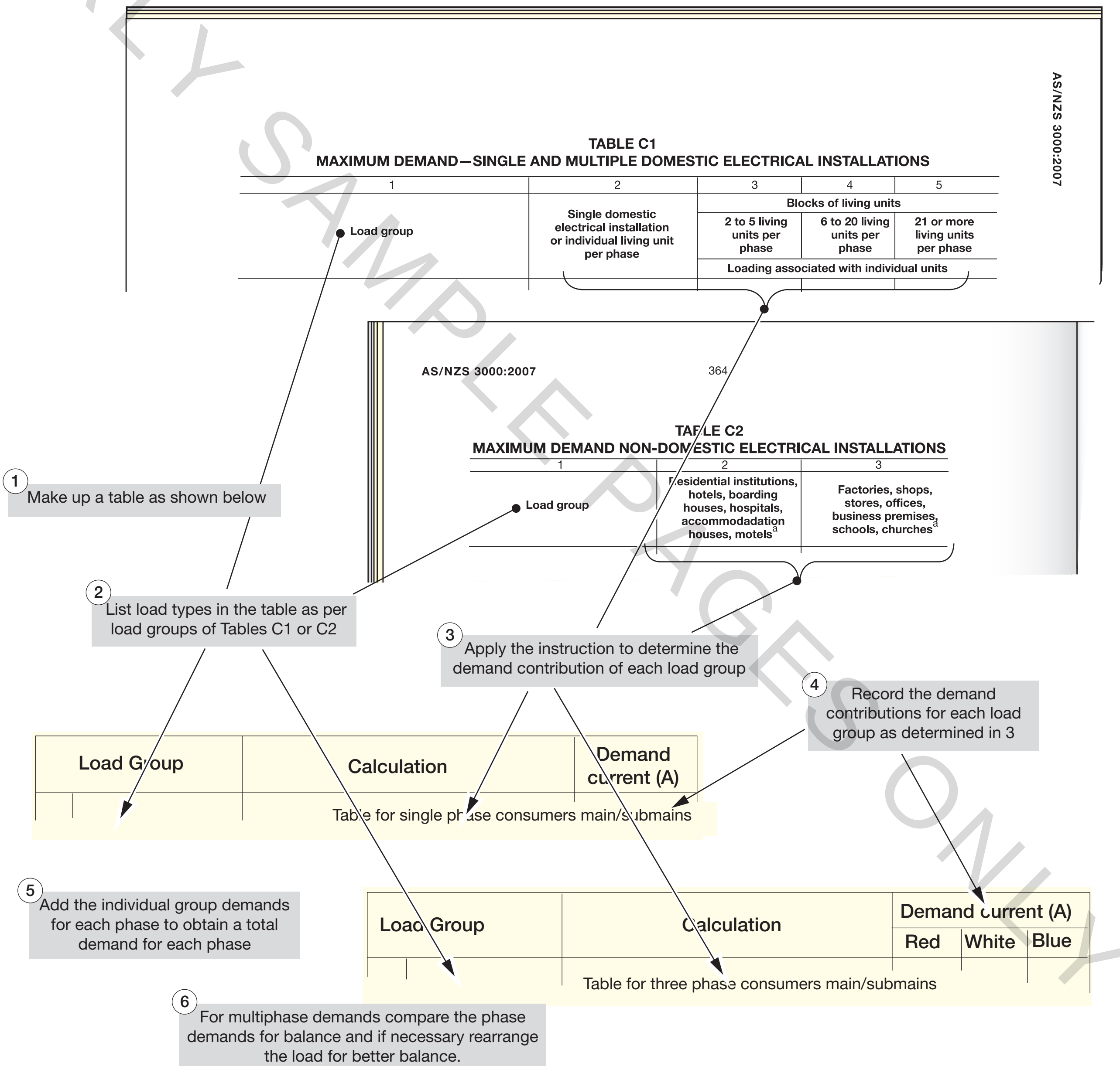
As previously mentioned the calculation method for determining maximum demand is the method most commonly used. In this method, demand calculations are classified as:

- single and multiple domestic installations (Paragraph 2.3 and Table C1)
- non-domestic installations (Paragraph C2.4 and Table C2).

Where an installation consists of both domestic and non-domestic, known as multiple installations, the applicable load allocation given in Tables C1 and C2 are used.

As previously mentioned maximum demand of final subcircuits is generally considered as being the connected load and usually limited by the rating of the protective device.

The methods used for demand calculations of all types of installations base on the current allocated to load groups are much the same. However, the need to set out demand calculations in a logical and systematic manner is most important. An effective layout of demand calculations will reduce the possibility of error and allow for easy checking of mathematics, load grouping and phase balancing. The suggested approach is illustrated Figure 14.4a and the examples that follow.



Note.
Calculating to one decimal point is sufficiently accurate for the demand contribution of the individual load groups. However it is not unreasonable to round up the total maximum demand figure to the next whole number as cable current-carrying capacities are given as whole number values.

Figure 14.4a Systematic method for calculating maximum demand

Note. Calculating to one decimal point is sufficiently accurate for the demand contribution of the individual load groups. It is reasonable to round up the total maximum demand figure to the next whole number as cable current-carrying capacities are given as whole number values.

Single and multiple domestic demand

The footnotes to Table C1 and the worked examples in Appendix C of the Wiring Rules provide a guide to the calculation of maximum demand for single and three-phase domestic and multiple domestic installations. These should be studied together with the following examples.

DID YOU KNOW?

Electricity distributors specification for the number of phases supplied to installations that only have single-phase loads is usually based on the total maximum demand for the installation. As an example a distributor may provide an installation with single-phase where maximum demand ≤70 A, two-phase where maximum demand is > 70 A ≤140 A and three-phase where maximum demand is > 140 A. Installations that include three phase appliances, such as motors are supplied with three phases, as are installations consisting of multiple occupancies, such as a block of flats.

EXAMPLE 1

Determine the maximum demand for a single-phase 230 V installation that comprises:

23 lighting points

2 × 15 A plug socket-outlets

6 single and 10 double socket-outlets

10 kW range

4.8 kW controlled load water heater

4 × 300 W floodlights in swimming pool area.

Use *Table C1*, *column 2*, and list or tabulate the load groups to solve the problem as shown in Table 14.2. Note that, even with lower maximum-demand current values, a minimum rating for a consumer's mains in a domestic installation is usually stipulated by the energy distributor.

Table 14.2 Example 1—maximum demand calculation for a simple single domestic installation

	Load group	Calculation	Demand current
A(i)	23 lighting points	3 + 2 = 5 A	5.0
A(ii)	4 × 300 W floodlights	$\frac{4 \times 300}{230} \times 0.75 = 3.9A$	3.9
B(i)	6 single + 10 double socket outlets	10 + 5 = 15 A	15.0
B(ii)	2 × 15 A socket outlets	Allow 10 A	10.0
C	10 kW range	$\frac{10000}{230} \times 0.5 = 21.7A$	21.7
F(i)	4.8 kW controlled load water heater	$\frac{4800}{230} = 20.9A$	20.9
		Total demand	76.5 i.e. 77.0 A

EXAMPLE 2

A single domestic installation comprises:

42 light points

4 × 300 W floodlights

48 socket-outlets

6.65 kW oven, 2.4 kW hotplates

Three-phase ducted air conditioning rated at 10.6 A per phase

1.2 kW pool pump rated at 3.6 A.

4.8 kW spa heater

Note that this installation will require a three-phase supply because of the ducted air conditioning.

To determine the maximum demand, arrange the load for balance over the three phases as in Table 14.3a, then employ Table C1, column 2 (individual living unit) as shown in Table 14.3b.

Table 14.3a Example 2—arrangement of load across three phases

Red	White	Blue
21 light points	21 light points	
		4 × 300 W floodlights
16 Socket outlets	16 Socket outlets	16 Socket outlets
	6.65 kW oven	2.4 kW hotplate
10.6 A Air conditioning	10.6 A Air conditioning	10.6 A Air conditioning
4.8 kW spa heater		3.6 A pool pump

Table 14.3b Example 2—maximum demand calculations for a single domestic installation supplied with three phase

	Load group	Refer Table Col.	Calculation	Demand current (A)		
				Red	White	Blue
A(i)	Light points	C1 Col 2	21 points per phase 3 + 2 = 5A	5.0	5.0	0
A(ii)	Floodlights	C1 Col 2		0	0	3.9
B(i)	Socket outlets	C1 Col 2	16 point per phase	10.0	10.0	10.0
C	Oven	C1 Col 2		0	14.4	0
C	Hotplates	C1 Col 2		0	0	5.2
D	Air conditioning	C1 Col 2	10.6 × 0.75 = 7.9 A	7.9	7.9	7.9
G	Spa heater	C1 Col 2	4800 × 0.75 = 15.7 A	15.7	0	0
L	Pool pump	C2 Col 2	Full load (3.6 A)	0	0	3.6
			Total demand per phase	38.6	37.3	30.6

Phase demands

The phase demands should now be examined to see whether or not balance can be improved. In the case of example 2, a small improvement could be made by moving the spa heater (15.7 A) from red phase to blue phase and both the hotplate (5.2A) and pool pump (3.6 A) form blue phase to red phase, resulting in demands of 31.7 A, 37.3 A and 37.5 A for the red, white, and blue phases respectively. Always check for balance because, although only a small improvement is achieved for this example, a significant improvement can often be made in other cases.

Maximum demand for a multiple phase installation is taken as the heaviest loaded phase, in this example this is blue phase at 38 A.

DID YOU KNOW?

Electricity distributors place requirements on installation supplied with multiple phases for balancing the maximum demand across phases. Typically phases must be balance be within a percentage of demand current or a maximum current value. Check this out in the local service rules for your area.

EXAMPLE 3

A block of units includes:

2 three-bedroom units

8 two-bedroom units

6 one-bedroom units.

Each unit is connected to a single-phase supply and fed by submains from the main switchboard. The individual unit loads are:

- three-bedroom unit

  16 lights

  18 socket-outlets in unit; 1 socket-outlet in common laundry

  8 kW range

  4.8 kW continuous water heater (80 W/L)
- two-bedroom unit

  14 lights

  14 socket-outlets in unit; 1 socket-outlet in common laundry

  8 kW range

  4.8 kW continuous water heater (80 W/L)
- one-bedroom unit

  13 lights

  12 socket-outlets in unit; 1 socket-outlet in common laundry

  7 kW range

  3.6 kW continuous water heater (80 W/L)
- community services

  9 socket-outlets

  10 lights: 6 × 75 W, 4 × 150 W outside lights.

Determine the maximum demand for the installation.

In multiple domestic installation the contribution of each load group is dependant on the number of units per phase as given in *Wiring Rules Table C1 Columns 3, 4 and 5.* It is first necessary to balance the units over the phases shown as in Table 14.4a. Postpone balancing community services until it is seen how the first totals of phase demands work out.

Employ *Table C1*, as shown in Table 14.4b.

Table 14.4a Example 3—balancing the unit load

	Red	White	Blue
	1 × 3 Br	1 × 3 Br	2 × 2 Br
	2 × 2 Br	2 × 2 Br	2 × 2 Br
	2 × 1 Br	2 × 1 Br	2 × 1 Br
Units per phase	5	5	6

Table 14.4b Example 3—multiple domestic maximum demand calculation

Load group		Refer' Table, Col.	Calculation	Demand current (A)		
				Red	White	Blue
5 units per phase						
A(i)	Light points	C1, Col 3	Allow 6 A (total)	6.0	6.0	
B(i)	Socket outlets	C1, Col 3	10 + (5 × 5) = 35*A*	35.0	35.0	
C	Range	C1, Col 3	Allow 15 A (total)	15.0	15.0	
F	Water heater	C1, Col 3	6 × 5 = 30	30.0	30.0	
6 units per phase						
A(i)	Light points	C1, Col 4	5 + (0.25 × 6) = 6.5 A			6.5
B(i)	Socket outlets	C1, Col 4	15 + (3.75 × 6) = 37.5 A			37.5
C	Range	C1, Col 4	2.8 × 6 = 16.8 A			16.8
F	Water heater	C1, Col 4	6 × 6 = 36 A			36.0
			Total demand current for units	86.0	86.0	96.8
It can now be seen that the best load balance for the installation is for the community loads divided between the lowest unit loaded phases i.e. red and white phases.						
Community services						
H	Lights	C1, Col 3,4, 5	(6 × 75) + (4 × 150) = 1050 W; $\frac{1050}{230}$ = 4.6*A*		4.6	
I	5 Socket outlets	C1, Col 3,4, 5	2 × 5 = 10A	10.0		
I	4 Socket outlets	C1, Col 3,4, 5	2 × 4 = 8A		8.0	
			Total phase demands	96.0	99.4	96.8
Maximum demand is that of heaviest loaded phase, in this case, white phase at 100 A						

Maximum demand for a multiple phase installation is taken as the heaviest loaded phase, in this example this is blue phase at 102A.

The maximum demand of the submains to each individual living unit is calculated in the same way as the maximum demand for a single domestic dwelling; that is, by the application of *Table C1, columns 1* and *2* as shown in Tables 14.4c.

Table 14.4c Example 3—maximum demand calculations for submains for each unit

Three-bedroom unit

	Load group	Calculation	Demand current
A(i)	16 lighting points	Allow 3 A	3.0
B(i)	19 socket outlets	Allow 10 A	10.0
C	8 kW range	$\frac{8000}{230} \times 0.5 = 17.4A$	21.7
F(i)	4.8 kW continuous water heater	$\frac{4800}{230} = 20.9A$	20.9
		Total demand	55.6 i.e. 56 A

Two-bedroom unit

	Load group	Calculation	Demand current
A(i)	14 lighting points	Allow 3 A	3.0
B(i)	15 socket outlets	Allow 10 A	10.0
C	8 kW range	$\frac{8000}{230} \times 0.5 = 17.4A$	21.7
F(i)	4.8 kW continuous water heater	$\frac{4800}{230} = 20.9A$	20.9
		Total demand	55.6 i.e. 56 A

One-bedroom unit

	Load group	Calculation	Demand current
A(i)	13 lighting points	Allow 3 A	3.0
B(i)	13 socket outlets	Allow 10 A	10.0
C	7 kW range	$\frac{7000}{230} \times 0.5 = 15.2A$	15.2
F(i)	3.6 kW continuous water heater	$\frac{3600}{230} = 15.7A$	15.7
		Total demand	45.9 i.e. 44 A

Non-domestic demand

It can be seen that the maximum demand assessments considered so far follow a common pattern, and a broadly similar approach may be used for a non-domestic installation such as a commercial building, factory or residential institution. *Paragraph C2.4.1* and *Table C2*, together with *Paragraph C2.5.2.2* (where welding machines are installed), should be used to determine the various diversity factors to be applied to the load groups.

EXAMPLE 4

A commercial/industrial complex consists of eight separate occupancies. The distribution board for each occupancy is supplied from a main switchboard for the complex as shown in the diagram below. Determine the maximum demand for the submains to a unit; allow 10% for additional future load. Note. The unit distribution board is a standard multi-pole panel board with phases sequenced red, white and blue across ever three poles.

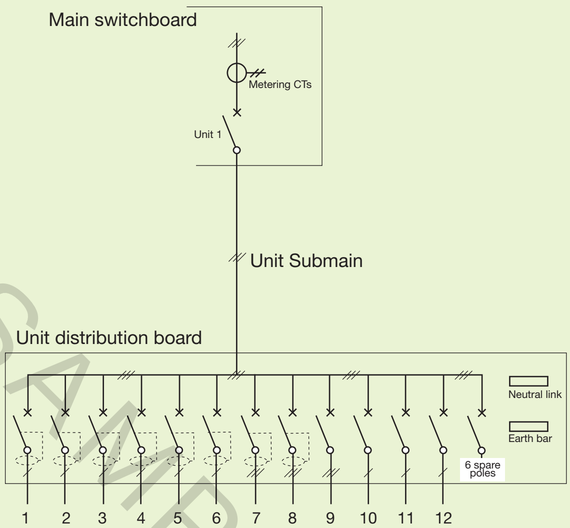


Figure Example 4

Table 14.5a Example 4—load for each unit

Circuit	Load group	Rating	Quantity
1	400 W High bay MV luminaires	2.1 A	6
2	400 W High bay MV luminaires	2.1 A	6
3	2 × 36 W Fluorescent troffer	0.38 A	10
4	400 W Flood lights	1.9 A	2
5	Single-phase socket outlets	10 A	10
6	Single-phase socket outlets	15A	1
7	Three-phase socket outlets	10 A	4
8	Three-phase socket outlets	20 A	1
9	Three-phase socket outlets	32 A	1
10	Water heater	2.4 kW	1
11	Oven	1.2 kW	1
12	Split air conditioner	15 A	1

Table 14.5b Calculation of maximum demand for the submain to each unit

Load group		Refer' Table, Col.	Calculation	Demand current (A)		
				Red	White	Blue
A	6- 400 W High bay MV luminaires	C2 Col 3	$6 \times 2.1 = 12.6$ A	12.6		
A	6- 400 W High bay MV luminaires	C2 Col 3	$6 \times 2.1 = 12.6$ A		12.6	
A	10 – 2 × 36 W Fluorescent troffer	C2 Col 3	$10 \times 0.38 = 3.8$ A			3.8
A	2- 400 W Flood lights	C2 Col 3	$2 \times 1.9 = 3.8$A	3.8		
B(ii)	10 – 10 A single-phase socket outlets	C2, Col. 2,3	$\frac{1000 + (100 \times 9)}{230} = 8.3A$		8.3	
B (iii)	1 – 15 A single-phase socket outlets	C2 Col 3	15 A			15.0
B (iii)	4 – 10 A three-phase socket outlets	C2 Col 3	$\frac{1000 + (100 \times 3)}{230} = 5.7A$	5.7	5.7	5.7
B (iii)	1 – 20 A three-phase socket outlets	C2 Col 3	$20 \times 0.75 = 15$ A	15.0	15.0	15.0
B (iii)	1 – 32 A three-phase socket outlets	C2 Col 3	Full rating	32.0	32.0	32.0
C	1- 2.4 kW water heater	C2 Col 3	$\frac{2400}{230} = 10.4A$		10.4	
C	1-1.2 k W Oven	C2 Col 3	$\frac{1200}{230} = 5.2A$			5.2
			Allow 10% of heaviest loaded phase	8.4	8.4	8.4
			Total phase demands	77.5	96.4	85.1

As is the case for consumers, main maximum demand for a multiple phase submain is taken as the heaviest loaded phase, in this example this is white phase at 97 A.

Where an energy distributor has a separate tariff, it may prefer the lighting to be connected on one phase for economy in metering, unless lighting forms a major part of the load.

14.5 Selection of minimum cable size based on current-carrying capacity

The current-carrying capacity of a cable must not be less than the current to be carried by the cable (i.e. the maximum demand of the circuit) that it supplies. The maximum demand, together with the previously discussed factors affecting current-carrying capacity, is the basis for determining the minimum conductor size for a particular application. This is provided that voltage drop and EFLI limitations and short-circuit performance are satisfied.

Selection guide

The following examples will provide a guide to the selection of conductor sizes and should be studied in conjunction with the *AS/NZS 3008.1*. These examples refer to and are extensions of the examples for calculating maximum demand in Section 14.4 of this chapter.

EXAMPLE 5

In the case of the single domestic dwelling of Example 1 (page 24) the maximum demand was calculated at 77 A. (Note that the *Wiring Rules* place no minimum requirement for consumer's mains; however, energy distributors commonly stipulate a minimum cable size, for example, 16 mm^2.) The consumers mains are to be single core V75 thermoplastic-sheathed (TPS) stranded copper cables installed in heavy duty PVC conduit in air in accordance with *Wiring Rules Clause 3.9.7.1.2 (i)* for consumers mains without short-circuit protection.

A starting point for referring to the correct current-carrying capacity tables in *AS/NZS 3008*.1 is the *Table 3* series, in this case Table 3 (2) for cables installed in a wiring enclosure.

TABLE 3 (2)

SCHEDULE OF INSTALLATION METHODS FOR CABLES DEEMED TO HAVE THE SAME CURRENT-CARRYING CAPACITY AND CROSS-REFERENCES TO APPLICABLE DERATING TABLES — ENCLOSED

1	2	3	4	5	6
Item No.	Cable details (see Note 1)	Reference drawing (see Note 2)	Current-carrying capacity table reference	Method of installation for cables deemed to have the same current-carrying capacity (See Note 3)	Derating tables for more than one circuit
1	Two single-core cables		Tables 4 and 5 Columns 15 to 17 Table 6 Columns 11 and 12	Cables in wiring enclosures installed in — (a) air; (b) plaster, cementrender, masonary or concrete in a wall or floor;	
2			Tables 7 and 8	(c) ...	

The three tables referenced cover one of the three insulation types and maximum conductor temperature.

Figure 1 Example 5

As you can be see, Item 1 of the table shows that the current-carrying reference tables for two single core installed in a wiring enclosure in air are Table 4 or 5 columns 15 to 17 or Table 6 columns 11 and 12.

Turning to theses tables in turn you can see that, Table 4 covers cables with thermoplastic, 75°C insulants and applies to non-armoured, sheathed and unsheathed cables as indicated by Note 1 to the table.

TABLE 4
Australian conditions

mm^2	CU Solid/ Stranded	Flex
1	13	
1.5	18	
2.5	24	
4	32	
6	41	
10	54	
16	70	
25	94	
35	112	

TABLE 4
New Zealand conditions

mm^2	CU Solid/ Stranded	Flex
1	15	
1.5	21	
2.5	27	
4	36	
6	47	
10	62	
16	80	
25	107	

Figure 2 Example 5

Column 15 of the Table 4 for Australian condition shows that a 25mm^2 cable with a current-carrying capacity of 94 A is the lowest size able to carry 77 A. Under New Zealand conditions Table 4 shows that the lowest size cable is 16 mm^2, having a current-carrying capacity of 80 A.

EXAMPLE 6

The multiphase consumer's mains supplying the single domestic dwelling of Example 2 (page 25) are to be V75 insulated single core copper cable installed in polyvinyl chloride (PVC) conduit, underground. The maximum demand for each phase was determined as 31.7 A, 37.3 A and 37.5 A, respectively. The minimum current-carrying capacity for all cables is to that of the highest phase i.e. blue phase at 38 A.

For cables enclosed in underground pipes or ducts, Item 2 of Table 3(4) of AS/NZS 3008.1 refers the reader to Table 7, (which cover thermoplastic insulated cables with maximum conductor temperature of 75°C), and Columns 24 to 26 for the suitable conductor size. The table shows that 6.00 mm^2 cable with a current-carrying capacity of 45 A has sufficient current-carrying capacity. For New Zealand conditions the smaller size cable, 4.00 mm^2 with current-carry capacity of 40 A will comply. However, the energy distributor would likely insist on a larger cable for consumers mains, typically 16.00 mm^2, to allow for future additions and to accommodate short-circuit performance where the consumer's mains are unprotected.

EXAMPLE 7

In the multiple domestic installation of Example 3 (pages 26–28), each flat is to be connected to a single-phase supply and fed by unenclosed twin TPS (75°C) copper submain installed in air from the main switchboard. The consumer's mains are to comprise four-core X-90 (90°C) stranded copper cable enclosed in PVC conduit in air.

The phase with the highest maximum demand in the consumer's mains was previously calculated at 100 A. Reference to AS/NZS 3008.1, Table 14, Column 11 indicates that for Australian conditions a 35 mm^2 cable with current-carrying capacity of 114 A will meet the minimum requirements. For new Zealand a 25 mm^2 cable rated at 100 A would be sufficient. In either case main controls and equipment would be rated at 100 A.

The maximum demand of the submain cables are 56 A for the two- and three-bedroom units and 44 A for the one-bedroom unit. According to AS/NZS 3008.1, Table 10 the nearest-sized cable suitable is 10 mm^2 rated at 60 A to supply each two-bedroom and three-bedroom unit. The submain to each one-bedroom units would be adequately supplied by 6 mm^2 cable rated at 44 A. Note that the nearest preferred value for a protection device for the 6 mm^2 submains is 40 A. If a 50 A device is used, the submain will need to be increased to 10 mm^2. See 'Relationship between cables and protective devices' page 19 of this Chapter.

EXAMPLE 8

The submain to each unit of the commercial/industrial complex of Example 4 (pages 29–30) are to be a X-90 multicore copper cable installed in an underground wiring enclosure at a depth of 0.5 m and all touching for part of their length.

The highest phase maximum demand was calculated at 97 A. Consulting AS/NZS 3008.1. Table 3(4), item 4, Column 4 directs the reader to current-carrying capacity Table 14, Columns 25 to 27 for cable is to be installed as a single circuit. Column 6 reference Table 26(2) for derating factors applied to groups of circuits installed in separate enclosure.

Turning to Table 26(2), a derating factor of 0.70 is specified for 8 circuits (the 8 submains of this example) installed touching. Under these installation conditions the minimum current-carrying capacity is determined by

$$I_C = \frac{I_{MD}}{k}$$

Where: I_C is the minimum current carrying capacity for the cable

I_{MD} is the maximum demand for the circuit, and

k is the de-rating/rating factor

Then:

$$I_C = \frac{97}{0.7} = 139A$$

Returning to Table 14, column 25, the smallest size of conductor that will carry this current is 50 mm² in Australia and 35 mm² in New Zealand.

This example highlights the importance of installation design and the avoidance of group de-rating by following the minimum clearances and configurations shown in AS/NZS 3008.1. The minimum conductor size must satisfy both current-carrying capacity and voltage drop requirements. In the foregoing examples, it is necessary to ensure that voltage drop limitations are met. Voltage drop is more likely to be a significant factor in obtaining the cable size for circuits with non-distributive loads, where the maximum demand for the circuit is close to the current-carrying capacity of the cables.

14.6 Selection of minimum cable size based on voltage drop and earth fault-loop impedance (EFLI) limitations

Voltage drop

Voltage drop, the third consideration listed in section 14.3 for selecting a cable, is of great practical importance. The conductor size of a cable selected for a particular application must be such that excessive voltage drop does not occur when the conductor is carrying the maximum current that is has to carry, or the current that it is assumed it will be required to carry as determined in accordance with *Section 3* of the *Wiring Rules*.

Where route lengths of circuits are short and where de-rating factors apply, the current-carrying capacity usually determines cable size, and voltage drop might not influence cable selection. On the other hand, where circuits have relatively high maximum demand and long route lengths, the voltage drop is more likely to be the deciding factor for cable size in association with any rating factors and current-carrying capacities. Excessive voltage drop would not only reduce the voltage available to the load equipment, but could cause cable overheating by limiting the magnitude of short-circuit currents and by increasing the time delay before protection can operate (see Chapter 10, 'Electrical protection and protective devices').

Remember maximum permitted voltage drop applies to all series groups of circuits in an installation as previously discussed (see Figure 14.3e-1 page 19) .

Selecting cables based on voltage drop limitations

Section *4* of AS/NZS 3008.1 describes several ways for selecting cable with regard to voltage drop or verifying whether cable selected on other criteria (e.g. current-carrying capacity) does not exceed voltage drop limits for the circuit. These include determination of voltage drop from:

- millivolt per ampere-metre values (*Clause 4.2* of AS/NZS 3008.1)
- circuit impedance (*Clause 4.3* of AS/NZS 3008.1)
- cable operating temperature (*Clause 4.4* of AS/NZS 3008.1)
- load power factor (*Clause 4*.5 of AS/NZS 3008.1).

The first two are basic methods, applied where the route length and load current of circuits are known. The methods using cable temperature and power factor are applicable where the cable size is known and gives a more accurate result. A simplified method for determining maximum percentage voltage or cable size where load current and circuit route length are known is provided in the *Wiring Rules, Appendix C Paragraph C4*. (See 'Other methods of determining voltage drop' page 38)

The most common methods for selecting cables based on voltage drop limitations are the millivolt per ampere-metre method and the simplified method given in the *Wiring Rules* and will be the methods dealt with here. In the millivolt per ampere-metre method, the smallest conductor that meets the voltage drop limitations for a given circuit is a cable with a unit value (millivolts per ampere-metre) equal to or less than that determined by the equation:

$$V_c = \frac{V_d 1000}{L \times I}$$

and $V_p =$ sum of voltage drops on circuit run where V_c = cable voltage drop, for each ampere, across each metre of cable length; the voltage drop over a metre of cable is very low so the value of Vc is given as millivolts per ampere-metre (mV/A.m)

V_d = actual voltage drop in volts

V_p = permissible voltage drop on the circuit (e.g. 5 per cent of supply voltage, i.e. 11.5 V for 230 V supply and 20 V for 400 V supply)

L = route length of circuit in metres, which is the distance from the load terminals to the point of supply (fuse or circuit breaker) or between any two points under consideration

I = the current carried by the cables in amperes, normally the maximum demand current.

The unit of voltage drop 'millivolt per ampere-metre' is the voltage drop for each metre of cable length and ampere of current. Because the voltage drop across each metre of cable is low it is expressed in millivolts.

The unit values of voltage drop (mV/A.m) are given in *Tables 40* to *51* of *AS/NZS 3008.1* and are for balanced three-phase circuits for various cable configurations, materials and conductor temperature.

Note: Unit values of voltage drop for single-phase circuits obtained from the above equation must be multiplied by 0.866 to convert them to three-phase values for determining the minimum conductor size from the voltage drop tables. Conversely, unit values given in the tables are multiplied by 1.155 to convert them to single-phase values.

Three worked examples are included in *Appendix A* of *AS/NZS 3008.1* and the following examples are given to further your understanding of this important topic. The tables referred to in the examples are those in *AS/NZS 3008.1*.

EXAMPLE 9

A 230 V 15 A load is to be supplied by a two-core V75 thermoplastic-insulated TPS copper cable, run as surface wiring (unenclosed) with a route length of 40 m. What is a suitable conductor size for the cable if the voltage drop in the single-phase voltage drop consumer's mains is 1 V?

$$V_C = ?$$
$$V_d = (5-1)\%\text{ of }230\text{ V} = 9.2\text{ V}$$
$$L = 40\text{ m}$$
$$I = 15\text{ A}$$

$$V_c = \frac{1000\,V_d}{L \times I} = \frac{1000 \times 92}{20 \times 15}$$
$$V_c = 15.33\text{ mV/A.m}$$

This is the maximum-permissible *Vc*, but it must be converted to a three-phase value for reference to the tables of AS/NZS 3008.1.1. Therefore:

three-phase value = 15.33 × 0.866

= 13.28 mV/A.m

Reference must now be made to the relevant table; in this case, *Table 42*, which shows that 2.5 mm² cable has a unit value of voltage drop of 15.6 mV/A.m, while a 4.0 mm² cable has a value of 9.71 mV/A.m, making 4.0 mm² cable the smallest suitable. Note that the cable selected must have a voltage drop equal to or less than the calculated maximum drop permitted. Always check the current rating of the cable selected on voltage drop considerations, because it is sometimes possible for a cable to fulfil voltage drop considerations but not comply with current-carrying requirements.

EXAMPLE 10

A single-phase final subcircuit is limited to a voltage drop of 6 V due the voltage drop in the consumer's mains and submains. The circuit is wired in twin V75 thermoplastic-insulated TPS copper cable, unenclosed, to supply a 30 A 230 V factory load at a distance of 8 m from the protective circuit breaker at the distribution board. What size cable should be selected?

$$V_c = ? \qquad V_d = 6\text{ V} \qquad L = 8\text{ M} \qquad I = 30\text{ A}$$

$$V_c = \frac{1000\,V_d}{L \times I} = \frac{1000 \times 6}{8 \times 30} = 25\text{ mV/A.m}$$

Converting to a three-phase value:

$$V_c = 25 \times 0.866 = 21.65\text{ mV/A.m}$$

Using *Table 42*, conductor temperature 75ºC, it can be seen that a 1.5 mm² cable fulfils the voltage drop considerations, but its current-carrying capacity is only 21 A (*Table 10*, Column 5), and to comply with *Clause 3.4* of AS/NZS 3000, a 2.5 mm² cable rated at 30 A is necessary.

EXAMPLE 11

A three-phase 400 V motor having a rated full-load current of 50 A is to be supplied by a three-core 1/1 kV MIMS cable with a route length of 60 m from the main switchboard to the motor position in a boiler room. Determine the minimum size of cable required for the circuit if the voltage drop in the consumer's mains is 8 V:

$$V_c = ? \qquad = 20 - 8 \qquad V_d = 12\text{ V} \qquad L = 60\text{ m} \qquad I = 50\text{ A}$$

$$V_c = \frac{1000\,V_d}{L \times I} = \frac{1000 \times 12}{60 \times 50} = 4.00\text{ mV/A.m}$$

Reference to *Table 48* for MIMS cable, conductor temperature 100ºC, shows that a 10 mm² cable is suitable, with a V_c value of 3.92 mV/A.m. Checking the current-carrying capacity of the cable, *Table 19,* column 5 shows that the cable is able to carry 73 A.

The equation: $$V_c = \frac{1000\,V_d}{L \times I}$$

may of course be transposed to provide:

1. The maximum route length permitted for a particular cable and current:

$$L = \frac{1000\,V_d}{V_c \times I}$$

2. The maximum current permitted on a cable if route length and cable type are known:

$$I = \frac{1000\,V_d}{L \times V_c}$$

EXAMPLE 12

What is the maximum-permissible route length for a three-phase 400 V three-wire circuit, protected by a 30 A ‘C’-type circuit breaker, using 6 mm² thermoplastic-insulated unsheathed V90 copper cables in PVC conduit? Because of voltage drop in the consumer’s mains, the voltage drop in the circuit is limited to 3.5 per cent.

To determine the maximum-permissible route length, so as not to exceed the maximum voltage drop permitted, first transpose the voltage drop equation. Then:

$$\begin{aligned} L &= ? \\ V_c &= 6.81 \text{ mV/A.m (Table 40)} \\ &= 400 \times 0.35 \\ V_d &= 14 \text{ V} \\ I &= 30 \text{ A} \end{aligned}$$

$$\begin{aligned} L &= \frac{1000\, V_d}{V_c \times I} \\ &= \frac{1000 \times 14}{681 \times 30} \\ L &= 68.5 \text{ m} \end{aligned}$$

EXAMPLE 13

A 4 mm² V75 two-core TPS copper cable, unenclosed, is supplying a 10 A load on a 230 V circuit, which has a route length of 50 m. What additional current could this cable carry without exceeding the permissible voltage drop for the circuit (V_d) of 9.2 V?

Table 42 shows that for a 4.00 mm² cable the three-phase V_c = 9.71, and multiplying by 1.155 = 11.22 mV/A.m for the single-phase circuit in question. To determine the maximum current that may be carried by the cable while not exceeding permissible voltage drop, first transpose the equation for the current. Then:

$$\begin{aligned} I &= \frac{1000\, V_d}{L \times V_c} \\ &= \frac{1000 \times 42}{50 \times 1122} \\ &= 16.4 \text{ A} \end{aligned}$$

Accordingly, the load may be increased to 16.4 A, an increase of 6.4 A. Notice, however, that the 16.4 A is the maximum current permissible, because of the long cable run, but is well below the cable’s current-carrying capacity of 39 A shown in, *Table 10, Columns 5.*

EXAMPLE 14

An existing 95 m run of three-core 4 mm² V75 thermoplastic-insulated sheathed cables supplies a three-phase 400 V 19 A motor in a factory; protection is by a 20 A ‘D’-type circuit breaker. It is proposed that a small 400 V 2 A motor be added, bringing the cable loading up to 24 A. Is this permissible if the voltage drop in the circuit must not exceed 18 V?

First check voltage drop limitation for the required current-carrying capacity:

$$\begin{aligned} I &= ? \\ V_c &= 9.71 \text{ mV/A.m } (\textit{Table 42}) \\ V_d &= 18 \text{ V} \\ L &= 95 \text{ m} \end{aligned}$$

$$\begin{aligned} I &= \frac{1000\, V_d}{L \times V_c} \\ &= \frac{1000 \times 18}{45 \times 9.71} \\ &= 19.51 \text{ A} \end{aligned}$$

The maximum current is 19.51 A for the maximum-permissible voltage drop, and so the additional 2 A is not allowed; only 0.51 A additional load could be added. Due to the voltage drop considerations, the current-carrying capacity of the cable has been reduced from 33.0 A (*Table 12, Column 5*) to 19.51 A.

This and similar problems might also be approached by assuming that the proposed load is carried by the cable and calculating the voltage drop (V_d) using the equation

Using the values of example 14, above:

$$V_d = \frac{V_c / L}{1000}$$

$$V_d = \frac{9.71 \times 29 \times 95}{1000}$$

$$= 26.75 \text{ V}$$

The value calculated exceeds the stipulated voltage drop of 18 V by 8.75 V; therefore the additional load may not be connected.

Summation of voltage drops

As previously explained, voltage drop, commencing at the point of supply, comprises a series of successive voltage drops, which must be added to obtain the total voltage drop as specified by *Clause 3.6 of AS/NZS 3000*. The current used for determining voltage drop may be the total connected load or the maximum demand of the circuit.

Clause 3.6.2 indicates that the value of current used for calculating voltage drop need not exceed the total of the connected load or the maximum demand for a circuit. For final subcircuits, this can be taken as the current rating of the circuit protective device. Diversity is given to circuits supplying distributive loads such as socket-outlets and lighting where half the current rating of the protective device is used.

For a mixed three-phase and single-phase load, it is usual to obtain the voltage drop in each line conductor separately and add:

$$\text{Total } V_d = \frac{V_d \text{ due to three} - \text{place load}}{\sqrt{3}} + V_C \text{ due to single} - \text{place load}$$

With a two-phase three-wire supply, that is, two phases and neutral, taken from a standard 120° three-phase earthed-neutral system, the assigned table values for V_c in mV/A.m may be multiplied by 0.75 for use in the voltage drop calculation.

If supply is single-phase three-wire, such as the single-wire earth-return (SWER) system in rural areas, with two actives at 180° and the neutral from an earthed centre tap, then the assigned table values of Vc in mV/A.m may be multiplied by 0.5.

Excessive voltage drop

Now that you have developed your skills in calculating voltage drop in the various circuits of an installation, you should turn your attention to methods that might be adopted to avoid excessive voltage drop in practice. Example 15 is a demonstration.

EXAMPLE 15

Figure 14.6a illustrates the particulars of an installation in which the total voltage drop from the commencement of the consumer's mains to a 3.6 kW air conditioner exceeds the permissible value. Circuit breaker protection is used for all circuits.

The overall voltage drop of 14.2 V is 2.7 V above that permitted; the main and submain voltage drops are acceptable. Referring to *Table 42* of *AS/NZS 3008.1.1,* 2.5 mm^2 cable has a three-phase voltage drop of 15.6 mV/A.m. Therefore:

single-phase voltage drop $= 15.6 \times 1.155$

$= 18$ mV/A.m

The most practical solution here would be to wire the final subcircuit in 2.5 mm^2 cable with a V_c of 18 mV/A.m, thus reducing the subcircuit voltage drop to:

$$\frac{18 \times 12 \times 15}{1000} = 324 \text{ V}$$

and the overall voltage drop to 11.2 V, which is acceptable.

Voltage drop in an a.c. circuit is the product of current and impedance; that is:

$V = IZ$

If voltage drop is excessive, **the impedance or current must be reduced** to lower it. Usually the load current cannot be altered, and so impedance must be reduced.

In general wiring, the main component of the impedance is conductor resistance. Remember resistance is proportional to the length of the conductor, changes if the conductor material changes, and varies inversely with the cross-sectional area of the conductor. An options at the installation planning/design stage for the reduction of impedance and hence voltage drop as shown in Figure 14.6b.

As it is usually impractical to reduce the length of an exiting circuit, the only alternative is to increase the conductor size (cross-sectional area), as was done in example 15. This is the only option that can be adopted in the majority of cases.

Other methods of determining voltage drop

The previous examples used the method described in *Clause 4.2* of *AS/NZS 3008.1*, which provides an approximate but conservative solution for sizing cables with regard to voltage drop.

Clauses 4.3 to *4.6* of *AS/NZS 3008.1* provide other methods for determining a more accurate value of actual voltage drop (Vd) or for check the value obtain using the method of *Clause 4.2*. Table 14.3 gives a summary of all acceptable methods for determining voltage, where they are best used and relevant *AS/NZ3008.1* reference tables.

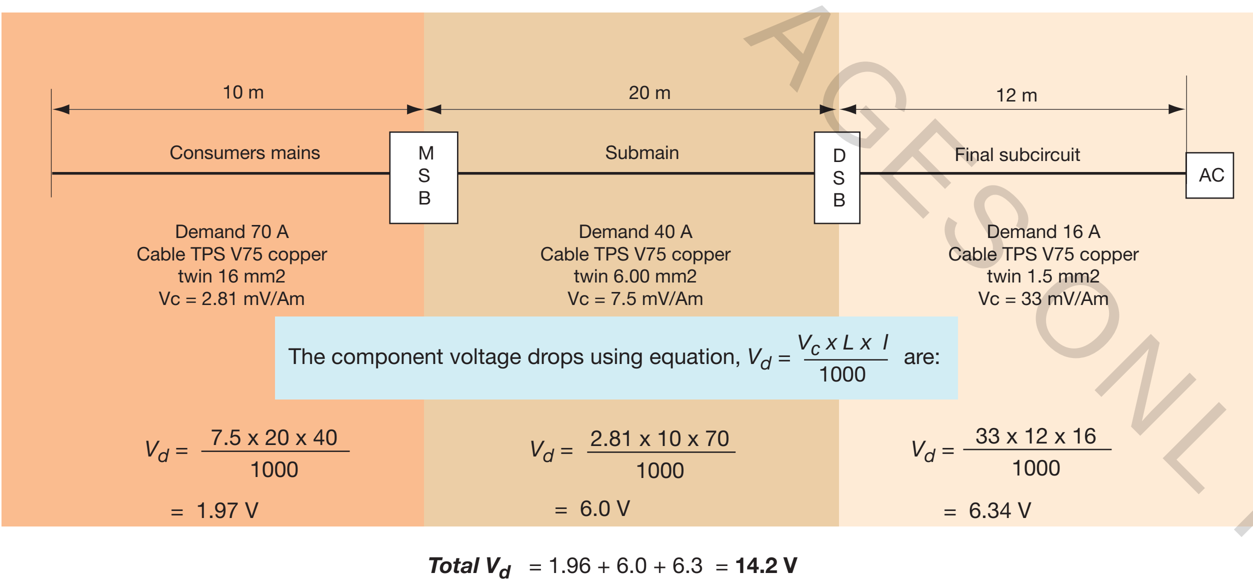
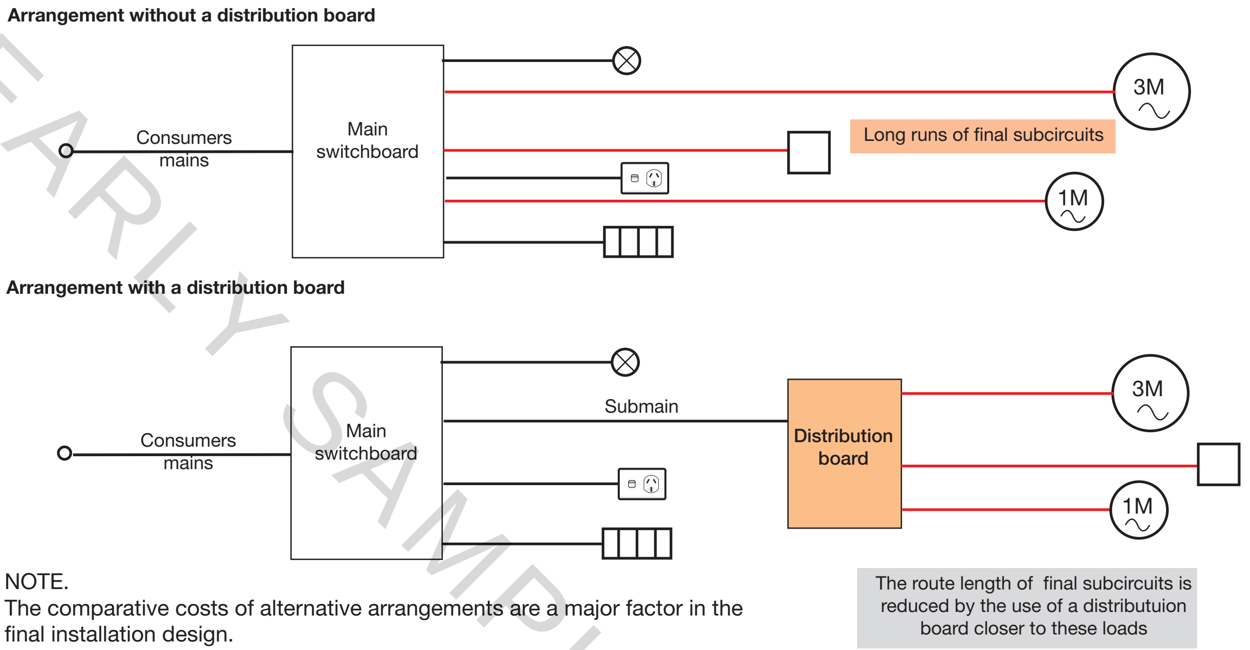


Figure 14.6a Example 15—excessive voltage drop

Avoiding exessive voltage drop

In the planning/design stage long runs of conductors having small cross-sectional areas, with their resultant high voltage drops can be avoided by using distribution boards situated as close as practical to the centre of the electrical load. With the approval of the energy distributor, it is sometimes possible to reduce the length of the consumer's mains by a suitable point of attachment and main switchboard position.



NOTE.
The comparative costs of alternative arrangements are a major factor in the final installation design.

Figure 14.6b Avoiding excessive voltage drop

A simplified method for determining voltage drop is provided in the *Wiring Rules, Appendix C Paragraph C4*. It allows the cable size circuit, length and/or % voltage drop to be determined using ampere-metres per percent of voltage drop (*A.m per %*V_d) values rather than V_c values directly. It also provides for percentage voltage drops in single- and three-phase circuits in series group to be added directly. The *Wiring Rules, Table C4* provides values *A.m per %*V_d for single and three phase circuits for V75 cables, sizes 1.mm² to 95 mm².

Examples of the application of this method are given in *Paragraph C4* of the *Wiring Rules.*

Ampere-metres per percent of voltage drop value for other cable temperatures can be tabulated from the expression:

$$\frac{10 \times V_O}{V_C}$$

Where V_o = Supply voltage
V_c = Unit value of voltage drop (mV/A.m) for a given conductor size and temperature for a given circuit power factor given in the voltage drop table of *AS/NZS 3008.1*

Earth fault-loop impedance

The effect of voltage drop limitations on a circuit is to limit its route length for a given cable size and maximum demand.

For example, a 3 per cent voltage drop applied to a final subcircuit with 2.5 mm² active conductors and protected by a 20 A circuit breaker is limited to a maximum route length of 19 m:

$$3\%\ V_d = 230 \times 0.03 = 6.9\ \text{V}.$$

Note: The three-phase V_c value for multicore 2.5 mm² cable at 75°C is 15.6 mV/A.m (*Table 42 AS/NZS 308.1*). Then:

$$\text{single-phase } V_c = 15.6 \times 1.155 = 18.02\ \text{mV/A.m.}$$

Then:

$$L = \frac{1000\,V_d}{V_c \times d} = \frac{1000 \times 69}{18.02 \times 20} = 19.15\ \text{m}$$

Table 14.6 Summary of methods for determining voltage drop

Method		Requirements	AS/NZS 3008.1 reference tables	Application
1. Actual voltage drop	$V_d = \frac{L \times I \times V_c}{1000}$	$V_P \geq$ sum of V_{ds} in series arrangement	Tables 40 to 50 give 3 Ø V_c values for various cable types, conductors unit material and size and cable temperature	Most commonly used method: Typically where route length and load current of balanced circuits are known.
2. Unit value	$V_c = \frac{1000 \times V_d}{L \times I}$	Select conductor size with unit value • calculated V_c		
3. Cable temperature Equations from AS/NZS 3008.1 series	$\left(\frac{I_o}{I_R}\right) = \frac{\theta_O - \theta_A}{\theta_R - \theta_A}$ Then use method 1 and 2	As for 1 or 2 Calculated temperature raised to nearest temperature given in tables for calculating Vc/Vd		Situations where the cable operating temperature in considerably less than the maximum figure.
4. Load power factor Equations from AS/NZS 3008.1 series	Single-phase $V_{d1\phi}$ = IL [2(R_c Cos θ + X_c Sinθ)] Three-phase $V_{d3\phi}$ = IL [3(R_c Cos θ + X_c Sinθ)]	As for 1	Tables 30–33 give X_c for various cable & cords. Tables 34 to 39 give R_c for various cable types, conductors and cable temperature limits	A more accurate method that takes into account load power factor. As for example circuits supplying large inductive loads such as motors.
5. Unbalanced multiphase circuits	$V_d = I_A \times L_A \times Z_{CA} + I_N \times L_N \times Z_{CN}$ may include cable temperature as variation as in method 3	As for 1	Tables 40 to 50 give 3 Ø V_c value Note $Z_c = \frac{V_c}{3 \times I}$ for a single conductor	Use where the current in each phase can be shown to be different magnitudes for consistent periods.

V_d = actual voltage drop
V_p = maximum permissible voltage drop
V_c = unit value of voltage drop in millivolts per ampere metre (mV/A.m)
I_o = operating current (A)
I_R = rated current given in Table 3 to 21
θ_o = operating temperature of cable when carrying Io (°C)

θ_R = rated maximum operating temperature from Table 1
θ_A = ambient air or soil temperature in °C
I = current flowing in cable
L = route length of circuit
R_c = cable resistance in ohms per metre
X_c = cable reactance in ohms per metre
Z_c = cable impedance in ohms per metre

Z_{cA} or $Z_{cN} = \sqrt{(R_c^2 + X_c^2)}$
I_A = current in active conductor
I_N = current in neutral conductor
L_A = route length of active conductor
L_N = route length of neutral conductor

Table 14.7 Example of comparison of maximum circuit lengths based on voltage drop and EFLI limitations

Protective device rating A	Active conductor mm^2	Earth conductor mm^2	Maximum circuit length for 3% 1Ø voltage drop V	Type C circuit breakers Maximum circuit length for EFLI limitations m
16	2.5	2.5	23	85
20	2.5	2.5	19	68
32	4.0	2.5	19	52
40	6.0	2.5	23	48
63	16.0	6.0	39	76

As described in Section 14.3, fault-loop impedance is the impedance of the conductors in the series path taken by the current in the event of a fault between an active conductor and an earth fault. The impedance of the fault loop, the majority of which in most cases is resistance, must be sufficiently low to allow enough current to flow to operate the protective device and disconnect the supply in a prescribed time.

The factors affecting the portion of the fault loop within an installation are the resistance of the active and associated protective earthing conductors; that is, the conductor sizes and route length. Like voltage drop, the effect is to limit the route length of a circuit.

The first concern here is that the route length of the cables selected on the basis of voltage drop does not result in a fault-loop impedance that is too high. Generally, cables for single-phase that comply with the limits of voltage drop will, in most instances, be within the limits of fault-loop impedance as shown by the example in Table 14.7.

This does not mean that the integrity of the fault-loop impedance for each circuit should not be verified, because such checking is an essential part of ensuring that the protective measures required in an electrical installation will operate as intended.

The maximum route length of a circuit ensuring the fault-loop impedance is sufficiently low is determined by the following equation:

$$L_{max} = \frac{0.8V \times S_{ph} \times S_{pe}}{I_a \times p(S_{ph} + S_{pe})}$$

where L_{max} = maximum route length in metres

V = nominal phase voltage (e.g. 230 V)

S_{ph} = cross-sectional area of the circuit's active conductor(s) in square millimetres

S_{pe} = cross-sectional area of the circuit's protective earthing conductor in square millimetres

I_a = current required for the protective device to operate and disconnect the supply (i.e. trip current setting of circuit breaker or fusing current for a fuse)

p = resistivity at normal working temperature in ohm-square millimetres per metre (i.e. 22.5×10^{-3} for copper conductors and 36×10^{-3} for aluminium conductors).

Note: *Paragraph B5.2.1(b)* of the *Wiring Rules* suggests that in most instances the voltage at the protective device will be 80 per cent or more when a fault occurs. However, this value will decrease as the distance from the supply increases, such as circuit supplied through a series of distribution boards, the effect being to reduce the maximum length of circuit. Best results are obtained when the impedance of the external portion of the fault loop or the prospective short-circuit current is known. This information could be obtained from the energy distributor or by testing the fault loop at the point where the protective devices are to be installed although.

Given the previous discussion on voltage drop, it is clear that the maximum route length of a circuit must satisfy the limitation of both the fault-loop impedance and voltage drop. That is:

$$L_{max} = \frac{0.8V \times S_{ph} \times S_{pe}}{I_a \times p(S_{ph} \times S_{pe})} = \frac{1000\ V_d}{V_c \times I}$$

EXAMPLE 16

The maximum route length determined in example 12 was 68.5 m for the three-phase circuit. Does this satisfy the fault-loop impedance limit?

L_{max} = ?

V = 230 V

S_{ph} = 6 mm²

S_{pe} = 2.5 mm² (from Table 5.1 of the Wiring Rules)

Ia = 225 A (mean tripping current for a Type C circuit breaker is 7.5 times rated current)

r = 22.5 ´ 10^{-3}

$$L_{max} = \frac{0.8V \times S_{ph} \times S_{pe}}{I_a \times p(S_{ph} \times S_{pe})}$$

$$= \frac{0.8 \times 230 \times 60 \times 2.5}{225 \times 0.0225 \times (60 + 25)}$$

= 64.12 m

The route length determined for voltage drop at 68.5 m is clearly too long to meet the limits of fault-loop impedance. The solution would be to increase the size of the protective earthing conductor to 4.0 mm², which would increase the maximum fault-loop impedance length to 87.23 m and thus satisfy both limitations, as shown below:

$$L_{max} = \frac{0.8 \times 230 \times 60 \times 4.0}{225 \times 0.0225 \times (60 + 4.0)}$$

= 87.23 m

EXAMPLE 17

Would impedance of the existing circuit in example 14 be low enough to trip the circuit breaker if a fault to earth occurs?

L_{max} = ?

V = 230 V

S_{ph} = 4 mm²

S_{pe} = 2.5 mm² (from Table 5.1 of the Wiring Rules)

I_a = 250 A (mean tripping current for this Type D circuit breaker is 12.5 times the rated current)

p = 22.5 × 10^{-3}

$$L_{max} = \frac{0.8V \times S_{ph} \times S_{pe}}{I_a \times p \times (S_{ph} \times S_{pe})}$$

$$= \frac{0.8 \times 230 \times 4.0 \times 2.5}{225 \times 0.0225 \times (4.0 + 25)}$$

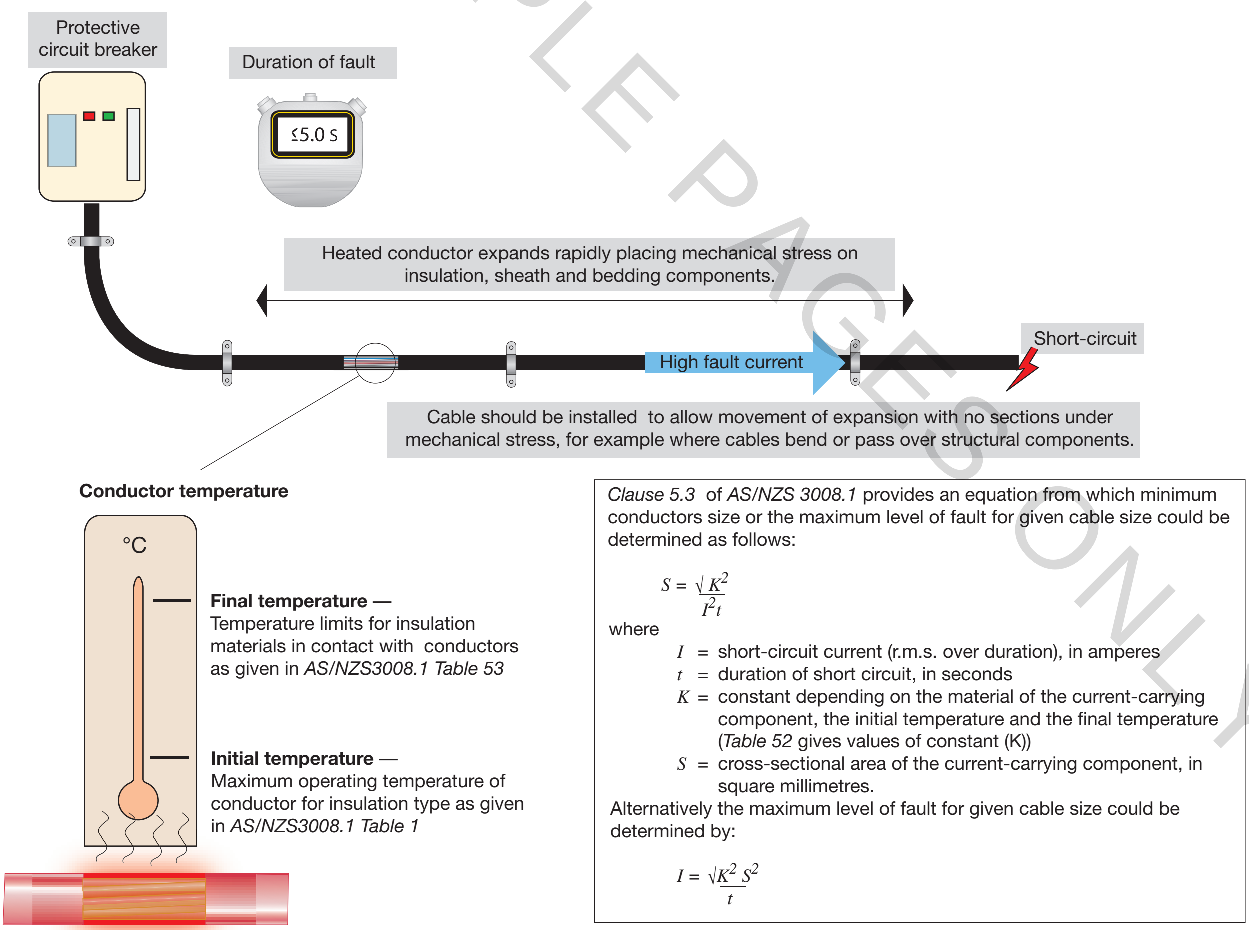
= 50.32 m

Clearly the route length of the circuit is excessive to meet the fault-loop impedance limits. The impedance to ensure operation of the protective device can be calculated from Ohm's Law Z = 0.8 V/Ia = 0.8 (230/250 = 0.73 Ω. The fault-loop impedance of the circuit at 95 m is approximately 1.39 Ω, as determined from the a.c. resistance values for 4.0 mm^2 and 2.5 mm^2 conductors given in *Table 35* of *AS/NZS 3008.1*.

Being an existing circuit and short of rewiring, the likely solution would be to install an RCD. Because RCDs have such a low trip current (in this case a 100 mA device would suffice), the impedance of the fault path is not as critical (Z = 0.8 V/I = 0.8 × 230/0.1 = 1840 Ω) as it is for a circuit breaker (0.73 Ω) in providing protection against indirect contact, in accordance with *Clauses 1.5.6* and *2.6* of the *Wiring Rules.*

14.7 Short-circuit temperature performance of cables

Section 5 of *AS/NZS 3008.1* provides guidance on the selection of cables likely to be subject to damage from a short-circuit. Under a short-circuit of negligible impedance i.e. a 'bolted fault', a cable will heat rapidly due to the high current that will flow. Cable temperature might rise to a point where the insulation, sheath or conductor is permanently damaged. This problem is usually limited to cables subject to high prospective fault currents, such as a consumer's mains connected directly from a distribution transformer to the main switchboard of a large installation. In this text, selecting cables on short-circuit temperatures limitations are given as a basic understanding of the concept and factors involved (figure 14.7) so that you may recognise such situation and seek advice from cable manufacturers or other experts in the field.



▲ **Figure 14.7** Concept of short-circuit temperature limitations of cables

Summary

14.1 Factors affecting installation design

Electricity supply, Figure 14.1a
Installation aspects, Figure 14.1b
Wiring Rules and selection standards, Figures 14.1c and 14.1d

14.2 Arranging an electrical installation into circuits

Arrangement of circuits, Figure 14.2a
Distribution in installations, Figure 14.2b
Number of points on a circuit, Figure 14.2c

14.3 Factors affecting cable selection

Maximum demand, Figure 14.3a
Current-carrying capacity of the cable, Figures 14.3b-1 to 14.3b-5
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Cables installed in the ground, Figure 14.3b-6
Effects of harmonics on balance three-phase systems, Figure 14.3c
Varying load, Figure 14.3d
Voltage drop and earth fault-loop limitation, Figures 14.3e-1, 14.3e-2 and 14.3f
Relationship between cables and protective devices, Figure 14.3g

14.4 Determining maximum demand

Methods of estimating maximum demand in consumer mains and submains, Table 14.1
Calculating maximum demand in consumers main and submains, Figure 14.4a
Single and multiple domestic demand, Examples 1, 2 and 3
Non-domestic demand, Examples 4

14.5 Selection of minimum cable size based on current-carrying capacity

Selection guide, Examples 5 to 8

14.6 Selection of minimum cable size based on voltage drop and earth fault-loop impedance (EFLI) limitations

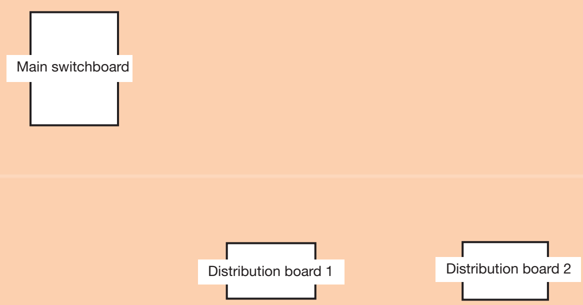
Selecting cables based on voltage drop limitations, Examples 9 to 14
Summation of voltage drops
Excessive voltage drop, Example 15 and Figures 14.6a and 14.4b
Other methods of determining voltage drop, Table 14.6
Earth fault-loop impedance, Table 14.7 and Examples 16 and 17

14.7 Short-circuit temperature performance of cables

Figure 14.7

Review questions

1. What must be known about an electrical installation before an work can commence?
2. Explain how the available electricity supply may effect the installation design.
3. Describe aspect of an installation that may affect its design.
4. What *Wiring Rules* requirement for the wiring system must be met in the design of an electrical installation?
5. List the *Wiring Rules Clauses* that must be considered when planning and selecting equipment for an electrical installation.
6. Outline cable selection procedures given in *AS/NZS 3008.1 Section 2*.
7. Where could you use the information in *Appendix C Tables C5* and *C6* of the *Wiring Rules*?
8. List the factors that that should to be considered when arranging an electrical installation into circuits.
9. When arranging an installation why is it necessary to consider the intended use of socket outlets?
10. What effect could the installation of electric motors have of how and an installation is arranged?
11. What effect does frequent overloading have on circuit wiring?
12. Why is it important to limit the number of socket outlets on a circuit for the connection of Class 1 appliance?
13. What is the maximum recommended number of light points on a 1.5 mm^2 circuit protected by a 16 A circuit breaker.
14. Describe two typical situation where the arrangement of the installation includes additional distribution boards.
15. Name an advantage in arranging an installation with a distribution board remote from the main switchboard.
16. In the diagram below show the basic arrangement of consumers mains, submain and final subcircuits.



17. Describe what is meant by the term 'maximum demand'.
18. What features limit its current-carrying capacity of a cable?
19. Name the type of cable that may have a maximum operating temperature of 250°C and the conditions under which this is permitted.
20. State the ambient temperature base for current-carrying capacity of cables in Australia and in New Zealand.
21. What is the effect on current-carrying capacity of a cable if it can be shown that the ambient temperature in which the cable is to be installed is lower than the base ambient temperature?
22. What is the current carrying capacity for a 6 mm^2 two core thermoplastic sheathed cable with stranded conductors installed spaced in air?
23. How would the current-carrying capacity of the cable in question 22 be affected if for 3.00 m of its route length it is installed partially surrounded by thermal insulation?
24. How can direct sun light effect a cable?
25. With aid of a diagram show how a group of three multicore cable would be install horizontally on 'ladder support' to avoid the need to derate their current-carrying capacity.
26. Determine the current-carrying capacity of a cable for a circuit with a maximum demand of 20 A where the cable is installed unenclosed on a cable tray bunched with two other circuits.
27. What installation conditions and external factor affect the current-carrying capacity of cables in underground wiring system.
28. Explain the term 'thermal resistivity of soil'.
29. Briefly explain the affects of 3rd harmonic in three-phase 4 four systems.
30. What information do *Tables 3(1)* to *3(4)* of AS/NZS 3008.1 provide.
31. Identify the group of *AS/NZS 3008.1* table that give current-carrying capacity for cables with cross-linked elastomeric (90 °C) insulation.
32. Which *AS/NZS 3008.1* table specifies de-rating factors for multicore cables for groups of circuits installed on cable tray.
33. What advantage can be taken in selecting cables for loads that have intermittent or cyclic operation.

34. Name three factors to consider when selecting cables to meet voltage drop limitations.

35. What limitations do voltage drop and earth fault-loop impedance place on a circuit?

36. Why is it necessary for the impedance of the earth fault-loop of a circuit to be low?

37. Name the conductors of a circuit that form the path of an internal earth fault-loop.

38. Describe the relationship required for each circuit between the conductors and the circuit protective device.

39. Describe the possible consequences of under estimating the maximum demand for an installation or circuit.

40. List four accepted for estimating the maximum demand in consumers main and submains.

41. Why is it important to set out maximum demand calculations in a logical and systematic manner.

42. Give two reason why an installation would be supplied with three-phase.

43.. Determine the maximum demand for the heaviest loaded phase of a rehabilitation hospital supplied with three-phase supplied by three-phase with the following load:

62	20 W compact fluorescent down lights rated at 0.16 A each
54	2 × 28 W fluorescent troffer luminaires rated at 0.30 A each
7	400 W floodlights
188	10 A socket outlets
5	15 A socket outlets
1	20 A socket outlet
1	13.6 kW range (arranged for connection across two phases)
1	4.0 kW food warmer
2	5.5 kW lift motors rated at 10.2 A per phase
1	4.0 kW hydrotherapy pool pump rated at 8.5 A per phase
2	10.4 kW Ducted Air conditioning units each rated at 20 A per phase

44. A three-phase submain supplies the distribution board in the processing area of a manufacturing complex. Determine the maximum demand for the submain given the following loads and allowing 15% for future increase.

4	2 × 36W fluorescent troffer luminaire each rated at 0.38A
16	400 W mercury vapour high bay luminaires each rated at 2.28 A
8	10A single-phase socket outlets
4	15A three-phase socket outlets
2	20A three-phase socket outlets
1	63A three-phase socket outlet
1	12 kW three-phase induction heater
1	15 kW motor rated at 27.1A per phase
3	7.5 kW motor rated at 13.54A per phase
2	3.5 kW motor rated at 6.48A per phase

45. Select a suitable cable for the consumers main of Question 43 given the that the point of supply is at an underground pillar 15 m from the main switchboard.

46. Explain the unit of voltage drop expressed as 'millivolt per ampere-metre'.

47. What is the minimum size 90 °C cable for the submain of question 44 given a route length of 36 m and a voltage drop not to exceed 2%.

48. When is voltage drop the likely to be the deciding factor in the minimum cable size for a circuit?

49. A single-phase final subcircuit is limited to a voltage drop of 5 V due the voltage drop in the consumer's mains and submains. The circuit is wired in twin V75 thermoplastic-insulated TPS copper cable, unenclosed, to supply a 30 A 400 V factory load at a distance of 18 m from the protective circuit breaker at the distribution board. What size cable should be selected?

50. What parameter limits the route length of a single-phase circuit with 3% voltage drop and comprising a 6.0 mm^2 active and 2.5 mm^2 earth conductors, protected by 40 A 'C' type circuit breaker.

51. What is the maximum route length of a circuit with 10 mm^2 active and 4.0 mm^2 protective earth conductor and protected by 50 A type 'D' circuit breaker?

52. Explain the possible consequences on a cable which has a 'bolted fault' short-circuit.