Chapter 6

WIRING SYSTEMS

Topic 6.1 Factors Affecting the Suitability of Wiring Systems

Reading

Standards Australia 2007, *AS/NZS 3000:2007 Electrical installations*, Sydney, Part 2 Section 3

[Ref. R-6-B]

Introduction

All electrical installations require some degree of planning in order to comply with relevant regulations and customer requirements. The backbone of any electrical installation is the wiring or cabling system and this includes cabling and associated enclosures and supports

In selecting a wiring system consideration must be given to:

- the degree of support required and available for the cabling and cabling enclosures;
- fire protective measures – i.e. some circuits such as lifts or firefighting equipment require special arrangements;
- reliability of connections, or ease of changing connections or position of equipment;
- mutual detrimental influences, i.e. the effect of one cable on another cable;
- the protection required against external influences,
- the actual cable sizes which must suit:
- current requirements of the circuit,
- voltage drop considerations,
- and fault loop impedance;
- the cost of the system not only in material terms but installation time.

Construction Methods

The wiring system chosen is dependent on the type of building, construction methods and materials and the building's function, i.e. factory, office block, flats, etc. Construction methods can be multi-level, single level, underground, with materials that may be timber, steel, aluminium, concrete, brick, or mixtures of all of these.

The method of construction used will be set by the purpose and budget of the building under construction. Typical construction methods are;

Domestic

Domestic construction can typically include:

- timber / steel frame
- brick veneer
- PVC or aluminium clad
- cavity or double brick

- Steel re-enforced concrete slab.

The cavity between frame and cladding or brickwork offers a suitable a medium for cables such as T.P.S. (Thermoplastic Sheathed) and orange circular. The cavity provides both a path and mechanical protection for cables, minimising installation cost and improving the finished appearance. In double brick construction it will be necessary to “chase” cables into walls.

Industrial and Commercial (non-domestic)

Some typical Industrial and Commercial building methods include:

Precast concrete.

Precast concrete is a construction product produced by casting concrete in a reusable mould which is then cured in a controlled environment, transported to the construction site and lifted into place.

Post-cast or Post tensioned concrete.

In post-tensioned concrete the steel re-enforcing is tensioned after pouring concrete into removable formwork. The concrete component is cast with steel reinforcing strands installed in a way that protects them from bonding with the concrete

Prefabricated building

Prefabricated building is a type of building that consists of several factory-built components or units that are assembled on-site to complete the unit.

Standard In-situ cast concrete.

Standard In-situ cast concrete formwork must be constructed and concrete is transported to the building site. Any services required such as electrical require careful planning with conduits and pipes installed into the formwork prior to concrete pour. Close liaising is required with structural engineers to ensure that conduits, pipes, etc. do not affect the structural integrity of the poured slab.

Installation Conditions

The method used to install wiring must be suitable to the type of wiring selected and the environment in which it is installed. Naturally not all wiring systems are suitable for any environment; reductions in current carrying capacities (de-ratings) may also result if for example, more than 1 circuit is grouped with other circuits in which case de-rating of all cables in the group is required.

Depending on AS/NZS3000 requirements cables can be installed either enclosed or unenclosed. Unenclosed cables require sheathing.

Examples of unenclosed cables are:

Category A: Insulated and sheathed cables on a cable ladder or tray

Category B: MIMS (Mineral insulated metal sheathed) cable fixed directly to a concrete wall

Category C: Insulated and sheathed armoured cable buried direct in ground

Examples of enclosed cables are:

Category A: Insulated unsheathed cables in steel conduit fixed to brick wall

Category B: Insulated and sheathed cables in cable trunking fixed to a wall

Category C: MIMS cable in trunking fixed to a wall

See table 3.1 of Ref. R-6-B for more examples.

External Influences

Ref. R-6-B requires that wiring systems be able to operate safely and function properly in the conditions to which they are likely to be exposed at the point of installation. The conditions as per Ref. R-6-B are:

i. **Ambient temperature.**
Wiring systems must be selected and installed so as to be suitable for the highest and lowest local ambient temperatures, with allowances to be made for expansion of materials due to temperature variations.

ii. **External heat sources.**
Wiring systems must be protected against the effects of heat from external sources such as solar radiation and any heat sources presented by industrial equipment, e.g. boilers, furnaces, etc.

iii. **Presence of water or high humidity.**
Wiring systems must be selected and installed so that high humidity or the entry of water does not cause damage. Where a wiring system may be subjected to wave action (water), protection against excessive flexing and mechanical damage must be considered.

iv. **Presence of solid foreign bodies.**
Wiring systems must be selected and installed so as to minimize the entry of solid foreign bodies during installation, use and maintenance.

v. **Presence of corrosive or polluting substances.**
Where the presence of corrosive or polluting substances is likely to give rise to corrosion or deterioration, parts of the wiring system likely to be affected must be suitably protected or manufactured from materials resistant to such substances. This clause also requires selection of materials such that galvanic action does not occur

vi. **Impact.**
Wiring systems must be selected and installed so as to minimise the risk of mechanical damage.

vii. **Vibration.**
Wiring systems subject to vibration that is likely to cause damage to the wiring system, including all cables, fixings and connections, must be suitable for the conditions.

viii. **Other mechanical stresses.**
Wiring systems must be selected and installed so as to minimise damage to

cable insulation, sheathing and connections during installation, operation and maintenance.

ix. **Presence of flora.**
Where the presence of flora is expected to constitute a hazard, either the wiring system must be selected accordingly, or special protective measures adopted.

x. **Presence of fauna.**
Where the presence of fauna is expected to constitute a hazard, either the wiring system must be selected accordingly, or special protective measures adopted.

xi. **Solar radiation (direct sunlight).**
Where a wiring system may be exposed to direct sunlight, either a wiring system suitable for the conditions must be selected and installed, or adequate shielding must be provided.

xii. **Hazardous areas.**
Wiring systems installed in areas subject to explosive gas and dust atmospheres must be selected and installed in accordance with relevant regulations.
(Clause 7.7 of Ref. R-6-B and AS/NZS 2381.1 and AS/NZS 61241.14.)

Selecting Wiring Systems

Wiring systems are a combination of the cable type, supports and where required the enclosure that protects the cable. Table 3.1 of Ref. R-6-B shows common combinations. Not all cable types are suitable for use with all enclosures/supports.

Commonly Used Cable Types

Some of the common types of cable are shown in the following figures. It should be noted that this is only a small selection of the available cables which come in an almost infinite array of configurations. Cables are generally described by the following properties:

- Conductor material
  copper or aluminium
- Number of conductor strands.
  This determines the flexibility of the cable.
- Conductor size
  This is one of the main factors which determines current carrying capacity.
- Insulation material and thickness.
  This determines the cable’s voltage rating, and operating temperature. It is also a detrermining factor of current carrying capacity.
- Number of cores.
  For multicore cables this is the number of cores which are insulated and sheathed.

For power cables this ranges from single to 5 core which allows for the three phase plus neutral and earth as separate conductors.

Figure F-6-1-1(a)
Unsheathed building wire

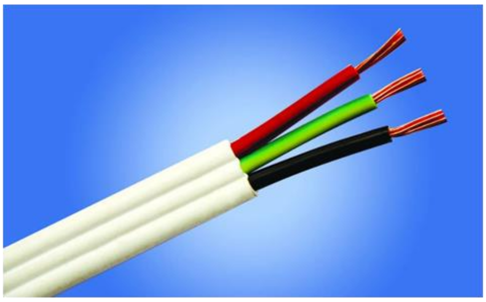

Figure F-6-1-1(b)
Flat Insulated and sheathed cable

Figure F-6-1-1(c)
Mineral Insulated Metal Sheathed cable (MIMS)

Figure F-6-1-1(d)
Armoured Cable

Figure F-6-1-1(e)
Circular Insulated and sheathed cable

Figure F-6-1-1(f)
XLPE(Cross Linked Polyethylene) High Voltage Cable

Enclosed Cables

Clause 3.10.1 of Ref. R-6-B states, "Insulated, unsheathed cables shall be enclosed in a wiring enclosure throughout their entire length." TPI cables (Thermo-plastic insulated cables or more commonly known as building wire) must be enclosed in conduit or similar enclosure, to provide double insulation, mechanical protection, and cable support.

The exception to the above requirement is if unsheathed cables are installed:

- as aerial conductors
- in an enclosed wall cavity between an accessory and a wiring enclosure or sheathing terminated within 100 mm of the hole over or within which the accessory is mounted;
- within switchboards, metering and similar enclosures;
- as earthing or equipotential bonding conductors
- as an extra-low voltage circuit

The types of enclosures permitted for TPI cables are:

- Steel conduits
- Flexible metal conduit
- Rigid and flexible insulating conduit.
- Corrugated insulating conduit
- Cable trunking systems
- Other wiring enclosures providing mechanical protection at least equivalent to those listed above

While TPI cables in most cases always require some form of enclosure, TPS cables in most cases do not. However where TPS cables are "likely to be disturbed" mechanical protection is required when they are run on the surface of a wall or on the underside of a ceiling or roof. Cables installed within a ceiling are **not** expected to be subject to mechanical damage and do not require additional mechanical protection (enclosure).

Un-enclosed Cables

Only cables which are double insulated are suitable for un-enclosed installation. As there is no wiring enclosure to provide support for the cable, devices such as clips, cleats, ladders and cable tray are used as support. The type of support will depend on the building construction, where the cables are being installed and the number of cables requiring support.

Underground cables

Underground cables may be installed either buried direct or in an enclosure. Smaller conductors are normally enclosed for mechanical protection. The enclosure also allows for repair or upgrades to larger size or additional number of phases. Larger cables such as street distribution mains are direct buried to reduce cost. Single insulated or unsheathed cables are not permitted to be installed buried direct.

Underground wiring systems are classified as one of three types. The type of cable and form of enclosure determine the category assigned to the underground wiring system

Category A: the wiring system is inherently suitable for installation below ground and no further mechanical protection is required.

Category B: the wiring system is suitable for installation below ground only with additional mechanical protection provided for the cable or cable enclosure

Category C: the wiring system is laid within a channel chased in the surface of rock

Tables 3.5 and 3.6 of Ref **R-6-B** summarise underground wiring system categories.

Aerial cables

To cover large distances at minimal cost an aerial wiring system is used. The types of cable which are suitable as aerials are listed in rule 3.12.1 of Ref **R-6-B**.

Figure F-6-1-2
Catenary Cable System

Catenary Wiring Systems

Catenaries are used to support the mass of cables not suitable for aerial wiring (See **Figure F-6-1-2**). For example a circular TPS cable strung between two supports of any distance will not be able to support its own weight. Depending on the distance it will stretch and possibly even break. The solution is the catenary support. The requirements for cables in catenary system are listed in rule 3.13.1 of Ref **R-6-B**.

Safety Service Wiring Systems

Formally known as emergency systems electrical safety services supply such apparatus as:

- fire detection
- warning and extinguishing systems
- smoke control systems
- evacuation systems
- lifts.

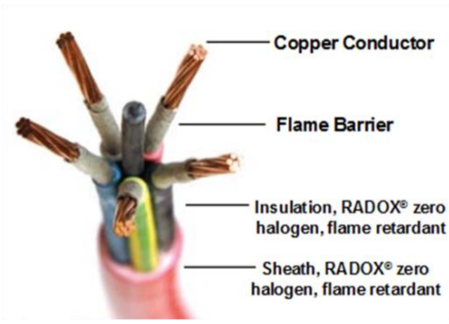

Figure F 6.1-3
"Radox" flame retardant cable

Any electrical wiring system that could be described as "emergency equipment" or an "essential service" is required to maintain supply when exposed to fire. Normal organic based insulations will fail in a very short period of time in such conditions cutting power to the safety services when they are most needed. Cables such as MIMS (Figure **F-6-1-1 (c)**) or Radox (Figure **F-6-1-3**) are required.

Section 7.2 of Ref **R-6-B** outlines the requirements for Safety Services installation and Appendix H of Ref **R-6-B** provides guidance on the application of the WS classification of wiring systems, in accordance with AS/NZS 3013. This system classifies wiring systems according to their ability to:

- maintain circuit integrity under fire conditions for a specified period and;
- maintain circuit integrity against mechanical damage of specified severity.

Busbar Trunking (Busway) Systems

Busbar trunking has several key advantages over conventional wiring systems (See **Figure F-6-1-4**). On-site installation times are reduced compared to hard-wired systems, thus leading to cost savings. It provides increased flexibility in design and versatility with regard to future modifications.

Distribution busbar distributes power along its length through tap-off points along the busbar, typically at 0.5 or 1 m centers. Tap-off units are plugged in along the length of the busbar to supply a load; this could be a sub distribution board or, in a factory, to individual machines. Tap-offs can normally be added or removed with busbar live, eliminating production down time.

Installed vertically the same systems can be used for rising-mains applications, with tap-offs feeding individual floors. Certified fire barriers are available at points where the busbar passes through a floor slab. Protection devices such as fuses, combination switch fuses or circuit breakers are located along the busbar run, reducing the need for large distribution boards and the large quantities of distribution cables running to and from installed equipment.

Busbar trunking systems are used in a variety of applications, including production plants, workshops, assembly lines, warehouses, distribution centers, supermarkets, retail outlets etc.

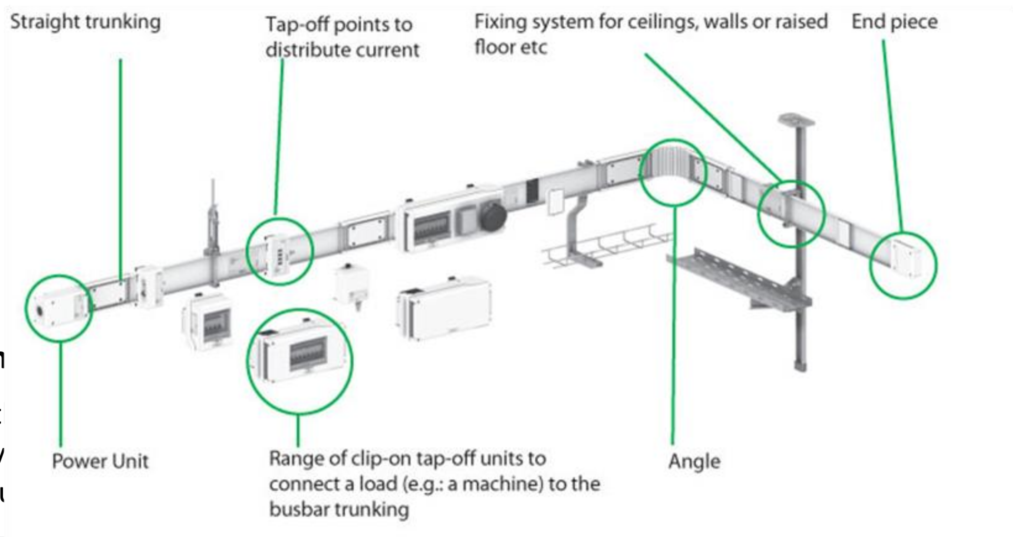

Figure F 6.1-4 Busbar Trunking (Busway) Systems

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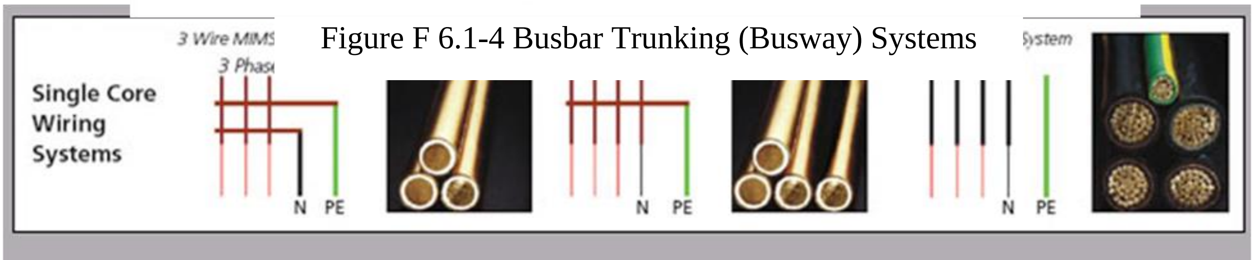


In a MIMS 3 wire ESR multiphase wiring system, the combined cross sectional area of the

Summary of Common Wiring Systems:

Aerial conductors.

Aerial conductors are either bare or insulated, chosen mainly for low cost reticulation of power over long distances as a cheaper alternative to underground wiring or catenary systems. Aerial cables used outdoors may be subject to lightning strike, damage from motor vehicle collisions; termites etc. and have a poor visual impact on the environment.

Catenary systems.

Catenary systems use multistranded double insulated cables supported on steel catenary wire and are commonly used for temporary installations, such as building sites, to distribute power, or in permanent installations, such as large exhibition halls, to support cables and luminaires above the ground, or to support cables in roof spaces above suspended ceilings.

Cable trays' and ladders.

These are open enclosures, used to support double insulated and MIMS cables, normally in industrial installations, where other support is not available.

Cable ducts.

These are closed enclosures larger than a conduit which often form hidden cableways in floors or on walls or ceilings.

Troughing.

Troughing is similar to duct but with removable lid.

Busbar trunking systems or Busways.

This is popular in factories or other installations requiring the flexibility to move equipment around within an installation without rewiring circuits. Plug in busway forms a type of submain, with plug in points fitted with protective devices situated above the equipment they supply. If equipment is moved it is simply unplugged from the old position and plugged back in at the new location.

Track systems.

Like a mini plug in busway, these are often used for flexible lighting design (track lighting).

Underground wiring systems.

These are used for the underground distribution of power in areas where aerial or catenary conductors are not allowed or where they are considered unsightly. Section 3.11 of Ref **R-6-B** relates to the three categories of underground wiring systems and the cable types and enclosures required.

Under carpet wiring systems.

This type of system is installed between the floor and carpet. It is expensive but requires little disturbance of the building structure.

Modular wiring systems.

These use pre-connected sections of cables which plug together on the job, allowing large commercial jobs to be wired and terminated quickly with minimum use of tools.

Thermo plastic sheathed' (TPS).

TPS cables are probably the most used wiring system as it incorporates conductors, insulation and a protective layer in one convenient, easy to install package. It is used in most domestic installations concealed in wall and ceiling spaces, in industrial and commercial installations on cable tray, catenary support, in ceiling spaces or in troughing systems.

Conduit systems.

Conduit can be either nonmetallic or metallic, of the rigid, flexible or corrugated types. Conduit systems are used to support and protect single or double insulated cables where the building structure does not provide the support or protection required. Nonmetallic conduit has a high expansion rate. Expansion joints must be fitted during installation to allow for the movement of the conduit with changes in temperature. Steel conduit is more expensive and takes longer to install but gives better mechanical protection and requires less support than nonmetallic conduit. Steel conduit enclosing single insulated cables must be earthed.

Mineral Insulated Metal Sheathed (MIMS) Cable.

MIMS and fire rated cables (Radox cable) may be used in higher temperature areas or for the supply of power to firefighting equipment etc. (safety services). MIMS cable is sometimes used as a quality wiring system which is required to have a long life. These cables may be operated at higher temperatures than other cables but must be segregated from cables of a lower temperature rating.

Tutorial 6.1

TQ.6.1 A cable or wiring system suitable for installation in a concrete slab would be:

[Source: Ref R-6-A, Section 3, Tutorial Question 1, P107]

a. Unenclosed TPI cable
b. Bare MIMS cable
c. TPI cable enclosed in rigid PVC conduit
d. Unenclosed TPS cable

TQ.6.2 A suitable wiring system used as sub-mains to a site shed on a construction site is:

[Source: Ref R-6-A, Section 3, Tutorial Question 2, P106]

a. Thermoplastic sheathed cables with Catenary.
b. Flexible insulated conductors.
c. Polymeric insulated cable
d. Annealed copper conductors

TQ.6.3 A suitable wiring system used to supply machinery on a factory production line is;

[Source: Ref R-6-A, Section 3, Tutorial Question 3, P106]

a. Thermoplastic sheathed cables with catenary.
b. Busbar trunking (busway)
c. MIMS cables on a cable tray
d. TPI conductors in medium duty conduit.

TQ.6.4 A suitable wiring system used as aerial cable without further support is:

[Source: Ref R-6-A, Section 3, Tutorial Question 4, P106]

a. Thermoplastic sheathed cables
b. Flexible insulated conductors
c. Polymeric insulated cable
d. Annealed copper conductors

TQ.6.5 A suitable wiring system for supply to a lift is:

[Source: Ref R-6-A, Section 3, Tutorial Question 5, P106]

a. V90 SDI cables on cable tray
b. V75 TPI cables in PVC rigid conduct
c. MIMS cables on a cable tray
d. TPS cables sharing the same conduit as power and light circuits.

TQ.6.6 A suitable wiring system for smoke detectors connected to a fire indicator panel is:

[Source: Ref R-6-A, Section 3, Tutorial Question 6, P107]

a. TPS cable
b. TPI in steel conduit
c. Radox cable
d. XLPE on cable tray

TQ.6.7 A suitable wiring system for sub-main in a factory is:

[Source: Ref R-6-A, Section 3, Tutorial Question 7, P107]

a. TPS cable
b. TPI in steel conduit
c. Radox cable
d. XLPE on cable tray

TQ.6.8 A suitable wiring system for light fitting in suspended ceiling of a shopping centre is:

[Source: Ref R-6-A, Section 3, Tutorial Question 8, P107]

a. TPS cable
b. TPI in steel conduit
c. Radox cable
d. XLPE on cable tray.

TQ.6.9 A suitable wiring system for vandal proof light fitting in bus shelter is:

[Source: Ref R-6-A, Section 3, Tutorial Question 9, P107]

a. TPS cable
b. TPS in steel conduit
c. Radox cable
d. XLPE on cable tray

TQ.6.10 A suitable wiring system for a sub-main to a detached garage in a domestic installation is:

[Source: Ref R-6-A, Section 3, Tutorial Question 10, P107]

a. TPS cable.
b. TPI in steel conduit.
c. TPI in heavy duty conduit.
d. TPI suspended on a Catenary.

TQ.6.11 A suitable and cost effective wiring system for irrigation pump on a rural property is:

[Source: Ref R-6-A, Section 3, Tutorial Question 11, P108]

a. Aluminium aerials

b. TPI in steel conduit.

c. TPI in heavy duty conduit.

d. 4 core + earth XLPE orange circular buried direct.

TQ.6.12 What is the minimum depth of cover of a Category A underground wiring system, external to a building, below natural ground:

[Source: Ref R-6-A, Section 3, Tutorial Question 12, P108]

a. 300mm

b. 500mm

c. 600 mm

d. Not permitted

TQ.6.13 A TPS wiring system installed within a PVC conduit in a concrete floor on, or above the ground would be deemed to have the same current carrying capacity as cables installed:

[Source: Ref R-6-A, Section 3, Tutorial Question 13, P108]

a. Enclosed in air

b. Buried direct in the ground

c. Unenclosed in air

d. Enclosed in underground enclosure.

TQ.6.14 Cables enclosed in heavy-duty conduit, and chased into rock to a depth of not less than 50 mm, fall into the underground wiring system category of:

[Source: Ref R-6-A, Section 3, Tutorial Question 14, P108]

a. Category A

b. Category B

c. Category C

d. Not permitted as underground wiring.

TQ.6.15 When single-insulated wire is installed in trunking or toughing that has a removable lid:

[Source: Ref R-6-A, Section 3, Tutorial Question 15, P108]

a. the cables must be taped together and held in position

b. the lid must be held in position with cable ties

c. building wire is not permitted in a duct which has a lid

d. the lid shall not be removed without a special tool if the duct is readily accessible.

TQ.6.16 The minimum height above ground for insulated live aerial conductors over a roadway is:

[Source: Ref R-6-A, Section 3, Tutorial Question 16, P109]

a. 3.0m
b. 4.6 m
c. 5.5m
d. Insulated conductors are not permitted over a roadway

TQ.6.17 Mineral insulated metal sheathed (MIMS) cables, which are buried in the ground without further enclosure, must be:

[Source: Ref R-6-A, Section 3, Tutorial Question 17, P109]

a. protected by a suitable serving
b. classed as a category A wiring system
c. protected by a type 'D' circuit breaker
d. buried at a depth of not less than 0.75 metre.

TQ.6.18 The maximum current rating for a HRC fuse protecting a circuit with a maximum demand of 20 A and wired with a cable rated at 28 A would be:

[Source: Ref R-6-A, Section 3, Tutorial Question 19, P109]

a. 18A.
b. 20 A.
c. 25 A.
d. 28 A.

TQ.6.19 A wiring system for a safety service has a WS classification of WS52. This means the wiring system can maintain its integrity under fire conditions for;

[Source: Ref R-6-A, Section 3, Tutorial Question 22, P110]

a. 52 minutes.
b. 60 minutes.
c. 5 hours.
d. 120 minutes.

TQ.6.20 The maximum permitted operating temperature of a V90 insulated conductor in normal use is:

[Source: Ref R-6-A, Section 3, Tutorial Question 24, P110]

a. 90° C
b. 75° C
c. 40° C
d. 25° C

Topic 6.2 Maximum Demand

Readings

Standards Australia 2007, *Wiring Rules,* (AS/NZS 3000), Standards Australia, Sydney. (Ref R-5-B) Part 2 Sections 3

NSW Trade and Investment 2011, *Service and Installation Rules of New South Wales*, Dept. of Energy, Utilities and Sustainability, Sydney. (Ref R-5-C) Sections 2.6, 3.3, 3.4

Introduction

When designing a new electrical installation it is necessary to predict the power requirements for all parts of the installation. This is especially so for consumers mains and sub-mains in an installation, which will have some diversity as all loads may not be connected at the same time. The methods of determining maximum demand of consumers' mains and sub-mains are outlined in AS/NZS 3000. **Figure F-6-2-1** shows an example of a typical installation.

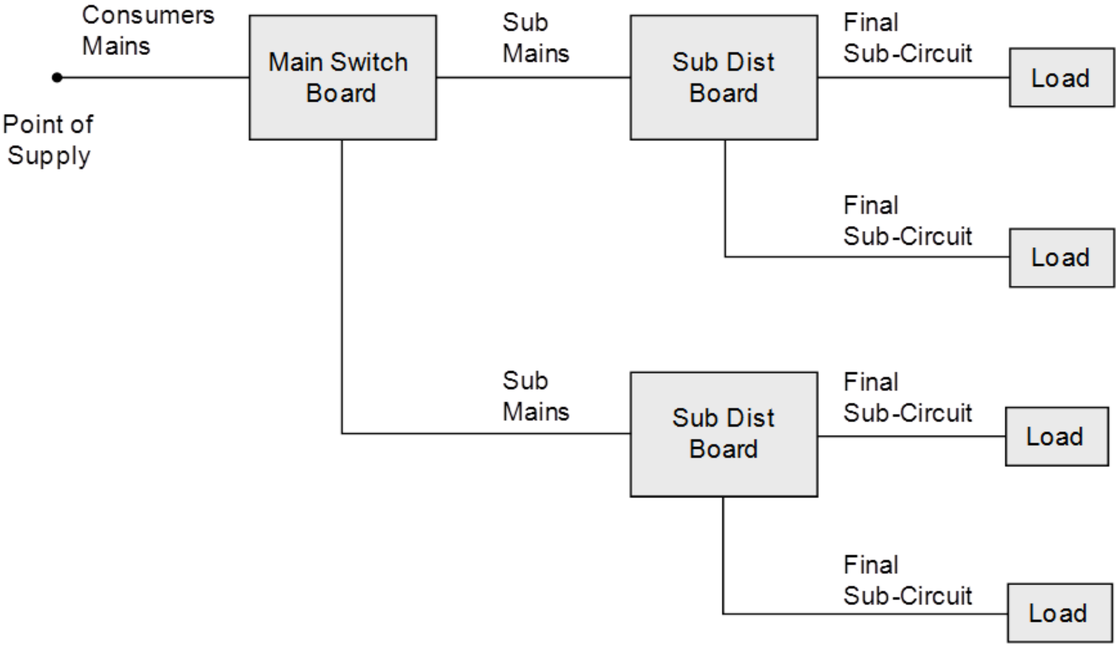
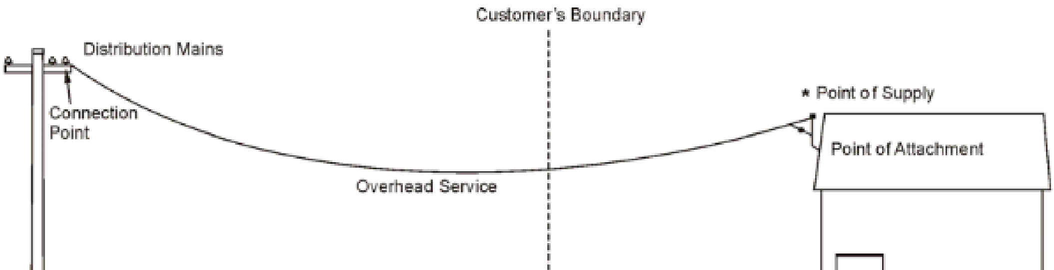


Figure F-6-2-1
Typical Electrical Installation

Consumers Mains Definition

From Ref R-6-C (1.2.5) the definition of consumers' mains is:

Consumers' mains are the conductors between the point of supply and the main switchboard and form part of an electrical installation. Consumers' mains may be overhead, underground or within a structure. Refer Figures F-6-2-2 and F-6-2-3.




Customer's Boundary
Termination enclosures, pit or pillar
Point of Supply

Methods of Determining the Maximum Demand

The maximum demand of consumers mains (from the consumers terminals to the main switchboard in the installation) and sub mains (between the main or other switchboard to distribution boards) is the subject of Clause 2.2.2 of **Ref. R-6-B** and may be determined by:

- measurement (only possible in existing installations);
- calculation, using Appendix C of **Ref. R-6-B**;
- limitation by fixed current circuit breaker (inconvenient if the c/b trips);
- assessment (used for unusual loads, or installations where the number and type of loads is not known) (See Table C3 of **Ref. R-6-B**)

The supply authority may set minimum cable sizes and types and installation conditions for consumer's mains.

Underground Consumer's Mains

All underground services must be four-wire three phase, except for single domestic premises, duplexes and builder's services. In these cases a two-wire single-phase service is permissible provided the service cable does not require a direct buried joint.

Service cables must be XLPE insulated PVC sheathed, and be comprised of either:

- Single core cables; or
- One 4-core circular cable; and
- Must comply with AS/NZS 4026:2001.

Service cables with a cross-sectional area (CSA) of 240mm^2 must be of four-core aluminium, XLPE insulated, PVC sheathed construction. Single core cables shall only be connected at pillars or to service tails.

Overhead Consumer's Mains

Overhead service cable must comply with AS/NZS 3560.1 Electric cables - XLPE insulated-aerial bundled - For working voltages up to an including 0.6/1 kV.

Determining the Maximum Demand of Consumers Mains

Calculation of Maximum Demand.

Calculation of maximum demand in consumer's mains and sub-mains is the simplest method of ensuring that minimum adequate cable sizes can be used.

NOTE: For installations supplied by two or three phases:

- The maximum demand must be calculated for each active conductor separately;
- The single phase loads must be arranged so that the loads in each phase are balanced to within specified limits (25 A is the maximum difference allowed by Clause 1.10.3 of NSW Service & Installation Rules (Ref **R-6-C**)).

- The maximum demand in the consumer's mains (or sub-mains) is the maximum demand of the highest loaded active conductor.

Many loads in an installation are not always turned on at the same time or only for short periods. This means that some 'diversity' can be applied in determining the maximum demand in consumer mains and sub-mains, allowing mains and sub-mains to have a maximum demand much less than the total current of all the individual loads, and cables smaller than that required to carry the total current for all loads.

Load Groups and Contribution to Maximum Demand.

When calculating maximum demand in consumer's mains and sub-mains:

- Individual loads are allocated to load groups such as lighting, socket outlets, cooking ranges etc.;
- Each load group is assessed as contributing a value of current to the maximum demand, which may be less than the total load ('diversity allowance');
- The assessed contribution to the maximum demand of each load group is given in Table C1 (domestic installations), Table C2 (non-domestic installations) and Clause C2.5.2 (welding machines) of **Ref R-6-B;**
- The maximum demand per phase is the sum of the assessed contributions by all the load groups on that phase supplied by that active conductor.

Determining the maximum demand in consumer's mains and sub-mains is different from determining it for the final sub-circuit. For determining maximum of final sub-circuits tables C4 to C6 of **Ref R-6-B** apply.

Local supply authorities stipulate the maximum total load for single and two phase supplies. For example, single phase for total loads up to 100A, two phase for total load greater than 100A and up to 200A (maximum 100A per phase) and three phase for total load over 200 A (split over three phases). An installation is supplied with three phase where individual three phase loads are installed such as a three phase motors (multi-phase supply may not be available in some rural areas).

By **Ref R-6-B** (Clause 1.5.3.3) if a consumer has a motor over 2kW a 3-phase supply may be requested:

- Calculations must be done separately for each conductor and only for the loads connected to it.
- Column 2 of Table C1 of **Ref R-6-B** gives instructions for each load group in single domestic installations, that is individual houses (consumers mains) or individual home units in a block (sub mains).
- Columns 3, 4 or 5 of Table C1 of **Ref R-6-B** gives instructions for each load group in multiple domestic installations that is for consumer's mains in blocks of home units.
- Column 2 of Table C2 of **Ref R-6-B** gives instructions for each load group in non-domestic residential installation such as hospital, hotels etc.

- Column 3 of Table C2 of **Ref R-6-B** gives instructions for each load group in non-domestic installation such as factories, shops, offices.
- The contributions of each load group for each conductor are added together to obtain the maximum demand in each active conductor.
- A check is made to ensure the load across all conductors is balanced to satisfy the local supply authority and may need to be re-arranged if necessary

By **Ref R-6-C** (Clause 1.10.3): The loading of an installation, or a separately metered part of an installation, which is supplied by more than one phase, must be arranged so that the maximum demand in an active service conductor is not more than 25A above the current in any other active service conductor. The total current in the service neutral conductor of a three phase supply must not exceed the highest simultaneous current in any active conductor, including the effects of harmonic currents. The electricity distributor may agree to other limits.

Maximum Demand on Consumers Mains (Domestic)

Single Domestic

The maximum demand of consumers mains in single domestic premises, or of individual units (townhouses or villas) in blocks of home units (townhouses or villas) is calculated using column 2 of Table C1 of **Ref R-6-B**.

Example X-6-2-1

Calculate the maximum demand of the single phase consumer's mains for a single domestic dwelling (house) with the following loads:

15 - lighting points;
16 - double 10A sockets outlets (doubles count as 2);
4 - single 10A socket outlets;
1 - 4.6 kW storage type hot water system;
1 - 11.4 kW cooking range.

Solution.

Using Table C1 Column 2 of **Ref R-6-B**:

Load Group	Load	Calculation	Demand
A(i)	15 x lights	3A	3.0A
B(i)	36 x 10A socket outlets	10 + 5 = 15A	15.0A
C	11.4kW range	11,400/230 x 0.5	24.8A
F	4.6kW hot water	4600/230 = 20A	20A
		Maximum Demand	62.8A

Multiple Domestic

The maximum demand of consumer's mains in multiple domestic premises (blocks of home units) is calculated using columns 3, 4 or 5 of Table C1 of **Ref R-6-B**. Column 3 is used where there are between 2 and 5 units per phase in the installation. Column 4 is used for between 6 and 20 units per phase and column 5 is used for 21 or more units per phase.

<u>Example X-6-2-2</u>

Determine the Maximum Demand of the consumer's mains for a block of 24 home units connected across three phases where each unit is supplied with single phase supply only. Each unit has the following loads:

11 - lighting points;

7 - double socket outlets;

3 - single socket outlets;

1 - 15A socket outlet;

1 - 9.2kW range;

1 - 4.4 kW storage water heater.

There is no communal load

<u>Solution.</u>

Using Table C1 Column 4 (24/3 = 8 units per phase):

Load Group	Load	Calculation	Demand
A(i)	11 - lights	5 + (0.25 x 8)	7.0A
B(i)	17 - 10A socket outlets	15 + (3.75 x 8)	45.0A
B(ii)	1 - 15A Outlet	10A	10.0A
C	Ranges	2.8 x 8	22.20A
F	Hot Water	6 x 8	48.0A
		Maximum demand	132.2A per phase

As the load is identical on each phase the load is balanced. The CSA of the consumer's mains can now be determined using AS 3008.1. Table C6 of AS 3000 does not specify cable sizes above 25mm^2.

Unit Loads

Note that in load groups A to C and E to G there is no reference to the number or rating of loads in individual units in columns 3 to 5, the loading being assigned as either a fixed value (e.g. 15A total for ranges in load group C, column 3) or assigned values per unit (e.g. 2.8A/unit for load group C column 4). In load group D (fixed space heating or air conditioning) the full connected load per phase is required to calculate the maximum demand component for this load as 0.75 times connected load per phase.

Community Loads

Loads in common areas (foyers, stairwells, community laundries, garages, common recreational or outdoor areas etc.) are covered in load groups H to M. In large blocks the community loads may be connected over three phases (due to lifts, fire pumps, air conditioning in common areas etc.) but in smaller blocks, where the common area loads are only single phase the supply authority may allow connection of these loads to single phase only, to reduce the metering required. If this is the case the number of units per phase may need to be assigned to allow for community loads.

Example X-6-2-2

Determine the Maximum Demand of the consumer's mains for a block of 24 home units connected across three phases but each unit is supplied with single phase supply only. Each unit has the following loads:

lighting points	11
double socket outlets	7
single socket outlets	3
15A socket outlet	1
9.2kW range	1
4.4 kW storage water heater	1

There is no communal load.

Solution.

Using Table C1 Column 4 @ 24/3 = 8 units per phase:

Load Group	Load	Calculation	Demand
A(i)	11 - lights	5 + (0.25 x 8)	7.0
B(i)	17 - 10A socket outlets	15 + (3.75 x 8)	45.0

B(ii)	1 - 15A Outlet	10A	10.0
C	Ranges	2.8 x 8	22.4
F	Hot Water	6 x 8	48.0
	Maximum demand (per phase)		132.4

As the load is identical on each phase the load is balanced. The CSA of the consumer's mains can now be determined using AS 3008.1. Table C6 of AS 3000 does not specify cable sizes above 25mm^2.

Load Balancing

If this block of 24 home units, with 8 units connected per phase, had a community load of 35 amperes the maximum demands per phase would be out of balance if the 35 amperes were placed on one phase. This could be overcome by either:

a. Adjusting the number of units per phase so that there were 9 units on phases A and B, and 6 units plus the community loads on phase C. In this case the load would still not be balanced, but it would be close.

b. Distributing the communal load as evenly as possible across the three phases. This is possibly the better solution as the communal power and lighting circuits could be split between the phases and the loss of one phase would not completely disable the communal services.

Maximum Demand on Consumers Mains (Non Domestic)

Non Domestic Maximum Demand

When calculating non domestic installations such as factories, shops and offices, table C2 of AS3000 (**Ref R-6-B**) is used. The load that is installed is more likely to be used more frequently than in a domestic installation, therefore less diversity is applied. The contribution to the maximum demand of each load group will be closer to the connected load.

Example X-6-2-3.

Determine the maximum demand of an industrial installation comprising:

6	twin x 36W fluorescent lights rated at 0.46A each;	1	single phase 2.2kW instantaneous water heater;
12	mercury vapour high bay lights rated at 1.8A each;	1	single phase 3.6kW storage water heater;
21	single phase double 10A socket outlets;	1	three phase 5 kW, 9A compressor;
2	three phase 10A socket outlets;	1	three phase 4.1 kW, 8A milling machine;
2	15A single phase socket outlets;	1	three phase 2.2 kW, 5A lathe;
2	three phase 20A socket outlets;	1	three phase 370W,1A pedestal drill;
		1	three phase 560W, 3A grinder;
		1	single phase, 400V electric arc welder rated at 14A.

Solution.

Using Table C2 Column 3 and balancing loads over all phases as much as possible:

Load Group	Load	Calculation	A Phase	B Phase	C Phase
A	6 x 0.46A Fl Lts (C □)	6 x 0.46 = 2.76A (2.8A)			2.8A
A	12 x MV Lts (A & C □)	6 x 1.8 = 10.8A	10.8A		10.8A
B(i)	21 x 2 x 1□ 10A S/Os => (14/□)	{1000 + (750 x 15)} / 230	53.3A	53.3A	53.3A
B(i)	2 x 3□ 10A S/Os	add extra 2 points above			
B(iii)	2 x 3□ 20A S/Os	20 + (0.75 x 20) =35A	35.0A	35.0A	35.0A
B(iii)	2 x 1□ 15A S/Os (A & B□)	(0.75 x 15) = 11.25A (11.3A)	11.3A	11.3A	
C	1 x 1□ 2.2kW Inst HW(B□)	2,200/230 = 9.6A		9.6A	
D	1 x 9A motor	9 + (0.75 x 8) + 0.5(5 + 3 + 1) = 19.5A	19.5A	19.5A	19.5A
D	1 x 8A motor				
D	1 x 5A mtor				
D	1 x 3A motor				

D	1 x 1A motor				
G	1 x 1⍰ 3.6kW storage HW	3600/230 = 15.7A			15.7
H	1 x 400V 14A welder		14.0A	14.0A	
		Maximum Demand	137.3A	142.7A	137.1A

Non Domestic Energy Demand Method

Where the load details of equipment being installed in non-domestic installations such as factory units, shops, offices and rental properties is unknown, an estimate is made. The electrical demand will vary from tenant to tenant. In these cases an estimate based on experience gained from other similar installations can be made using table C3 of **Ref R-6-B** and then converting the VA value to a current using the formula:

$$I_L = \frac{S}{\sqrt{3}V_L}$$

Where:

I_L = the line current /maximum demand current in Amperes

S = the energy demand in VA

V_L = the line voltage of the supply in volts.

Example X-6-2-4

A small retail complex consisting of 3 shops at street level (280m^2 each) and 3 offices (250m^2 each) on the first floor. All shops and offices have reverse cycle air conditioning. Determine the maximum demand of this commercial installation.

Solution.

Type of Occupancy		Energy Demand		
	Load	Area	Average VA/m^2	Demand
Shops	Light and power	840 m^2	70	58800 VA
	Air conditioning	840 m^2	30	25200 VA
Offices	Light and power	750m^2	50	37500 VA
	Air conditioning	750m^2	25	18750 VA
			Total	140250 VA

Maximum demand: $I_L = \frac{S}{\sqrt{3} \times V_L} = \frac{140250}{\sqrt{3} \times 400} = 203A$ per phase

Non Domestic Energy Demand Method

Example Calculation 5.

A small retail complex consisting of 3 shops at street level (280m^2 each) and 3 offices (250m^2 each) on the first floor. All shops and offices have reverse cycle air conditioning. Determine the maximum demand of the sub-main supplying the individual shops and offices.

Type of Occupancy		Energy Demand		
	Load	Area	Average VA/m^2	Demand
Shops	Light and power	280 m^2	70	19600 VA
	Air conditioning	280 m^2	30	8400 VA
			Total	28000 VA
Offices	Light and power	250m^2	50	12500 VA
	Air conditioning	250m^2	25	6250 VA
			Total	18750 VA

Shop Maximum demand $$I_L = \frac{S}{\sqrt{3} \times V_L} = \frac{28000}{\sqrt{3} \times 400} = 41\text{A per phase}$$

- A 50A H.R.C. fuse or circuit breaker would be selected as the protection device.
- A cable size is then selected to that it has a current carrying capacity higher than or equal to 50A after any applicable de-ratings have been applied.

Office Maximum demand $$I_L = \frac{S}{\sqrt{3} \times V_L} = \frac{18750}{\sqrt{3} \times 400} = 28\text{A per phase}$$

- A 32A H.R.C. fuse or circuit breaker would be selected as the protection device.
- A cable size is then selected to that it has a current carrying capacity higher than or equal to 32A after any applicable de-ratings have been applied.

Maximum Demand on Sub Mains (Domestic and Non Domestic)

The methods used to calculate the maximum demand of sub-mains are exactly the same as for consumer's main as stated in **Ref R-6-B** clause 2.2.2;

- Calculation
- Assessment
- Measurement
- Limitation

The only variation is that only the load connected to the sub-main is included in the calculation of the sub-main.

Sub-mains in Single Domestic Installations

In modern domestic installations the space available on the customer's main switchboards has decreased, supply authorities are requiring larger "foot prints" for metering equipment. There has also been an increase in the number of final sub-circuits and protection devices such as 2 pole combination RCD/MCB and voltage surge diverters fitted in main switch boards.

It is now common practice in larger installations, to run a sub-main to a location such as the garage or kitchen. A distribution board placed in the kitchen shortens the runs of a majority of the final sub-circuits, reducing cost and provides the convenience to customer of not having to go outside to reset a tripped circuit breaker. Sub-mains are also used to supply out buildings such as granny flats or garages.

Unlike consumer's mains, sub-mains are **electrically protected** at their origin. The nominal rating of the protection device is set by the sub-mains maximum demand.

Column 2 of Table C1 in **Ref R-6-B** is used to calculate the maximum demand. For multiple domestic installations, each unit is treated as a single domestic installation for the purpose of calculating maximum demand for sub-mains

Sub-mains in Non-domestic Installations

The procedure to determine the maximum demand of sub-mains in a non-domestic installation is the same as for consumer's mains, but only the load in that section of the building is included.

Tutorial 6.2

TQ.6.21 Calculate the maximum demand of the single phase consumer's mains for a single domestic dwelling (house) with the following loads

[Source: Ref R-6-A, Section 4, Activity 6 , P119]

22 - Light points

24 - Double 10A Socket Outlets

1 - 15A socket outlet

1 - 6.0 kW cook top

1 - 3.9 kW wall oven

1 - 4.4 kW storage H.W.S.

Load Group	**Load**	**Calculation**	**Demand**
		Maximum Demand	

TQ.6.22 Calculate the maximum demand for the single domestic single phase installation.

[Source: Ref R-6-A, Section 4 Tutorial, Q11 , P129]

32 - lighting points;

3 - 500W flood lights

27 - double 10A socket outlets;

5 - single 10A socket outlets;

1 - 4.4 kW controlled load water heater;

1 - 10.2 kW Range.

1 - 8 A split system Air conditioner

Load Group	Load	Calculation	Demand
		Maximum Demand	

TQ.6.23 63 town houses are to be connected to a 3 phase supply. Calculate the maximum demand for the multiple domestic installation.

[Source: Ref R-6-A, Section 4 Tutorial, Q12 , P130]

Each unit has the following load:

12 - Light points

11 - Double 10A Socket Outlets

1 - 8.0 kW Range

1 - 4.4 kW storage H.W.S.

Community load:

48 - Compact fluorescent (0.22A each) for Car park lighting

10 - Bollard lights (0.15A each)

2 - single 10A socket outlets house power

No of Units: Phase A ________ Phase B ________ Phase C ________

Load Group	Load	Calculation	A	B	C
		Maximum Demand			

TQ.6.24 Use AS3000 to calculate the maximum demand on the consumer's mains for a factory with the following load:

[Source: Ref R-6-A, Section 5 Tutorial, Q6 , P152]

18 - high bay MH luminaries rated at 2.6A each (6/phase)

33 - 10A double single phase socket outlets (11/phase)

4 - 32A three phase socket outlets

3 - 20A three phase socket outlets

2 - three phase induction motors rated at 42A

1 - three phase induction motors rated at 28A

2 - 400V single phase arc welders a rated current of 18A.

Load Group	Load	Calculation	A	B	C
		Maximum Demand			

TQ.6.25 33 town houses are to be connected to a 3 phase supply. Calculate the maximum demand for the consumer's mains of the multiple domestic installation.

[Source: Ref R-6-A, Section 5 Tutorial, Q7 , P153]

Each unit has the following load:

22 - Light points

18 - Double 10A Socket Outlets

1 - 8.0 kW Range

1 - 4.4 kW storage H.W.S.

1- 14A Air conditioner

Community load:

24 - Compact fluorescent (0.22A each) for Car park lighting

10 - Bollard lights (0.15A each)

10 - single 10A socket outlets house power

No of Units: Phase A ________ Phase B ________ Phase C ________

Load Group	Load	Calculation	A	B	C
		Maximum Demand			

TQ.6.26 Calculate the maximum demand for the single phase sub- main of an individual unit in the multiple domestic installation of question TQ.6.25.

[Source: Ref R-6-A, Section 5 Tutorial, Q8 , P154]

Load Group	Load	Calculation	Demand

Topic 6.3 Cable Selection Based on Current Carrying Capacity Requirements

Introduction

The selection of cable size is dictated by the current it must supply to the load, and initially this may seem a simple matter in that current that a cable may carry safely depends on its cross sectional area. However there are many other factors to be considered.

The current-carrying capacity of a conductor depends on:

- its insulation temperature rating;
- the electrical resistance of the conductor material;
- frequency of the current, in the case of alternating current;
- ability to dissipate heat, which depends on conductor geometry and its surroundings;
- ambient temperature.

This topic together with data from AS/NZS 3008.1.1 will help you in selecting cables that will deliver the required current to a load safely. Thus in a more practical approach the current carrying capacity of a cable depends the allowable temperature rise of the cable before damage to insulation begins to occur. Factors that alter the current carrying capacity of a conductor are:

- Type of enclosure (e.g. metal conduit, ducting etc.)
- Medium that the cable is run in (e.g. surrounded by thermal insulation, in air, underground etc.)
- How many cables are grouped together
- Ambient temperature the cable is installed into (e.g. boiler room, cool room etc.

Installation Conditions

Current carrying capacity is the maximum continuous current that a particular cable can carry without overheating. Conditions which affect current carrying capacity, and thus the size of cable conductor needed for a circuit, are:

- ambient temperature;
- type of cable, i.e. ability of the insulation/sheathing to transmit heat
- installation method which could include cables installed in:
    - air;
    - thermal insulation;
    - conduits, ducts and trunking
    - underground

Table 3 of AS3008.1.1 2009 (**Ref R-6-D**) gives guidance to installation methods:

Table 3(1) unenclosed in air

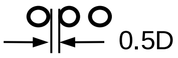
Table 3(2) Enclosed

Table 3(3) buried direct in the ground

Table 3(4) underground wiring enclosures

In all tables in **Ref R-6-D** only the current carrying conductors are generally shown. In other words in single phase circuits only the active and neutral conductors are shown. In three phase circuits the load is assumed to be balanced so the neutral conductor is not shown to keep the diagram simple.

Single core cables can be configured;

- Trefoil 
- Laid flat touching 
- Laid flat separated 

The separation between cables improves the heat dissipation of the conductors and improves current carrying performance. Laying the cables in trefoil reduces magnet effects. It is important not to confuse **separation** between conductors with cable supports systems that **space** the cable from surfaces such as walls and ceilings. If cables are installed so that they are in contact with cables of another circuit they are said to be **grouped** (see table 1 of **Ref R-6-D**)

The current-carrying capacity of a cable will be affected by the presence of certain external influences as summarised below. Under such conditions the current-carrying capacity given in Tables 4 to 21 of **Ref R-6-D** must be corrected by the application of an appropriate rating factor or factors obtained from Tables 22 to 29.

External influences:

- grouping of cables;
- ambient temperature;
- depth of laying
- different soil types for underground cables;
- varying loads
- thermal insulation
- direct sunlight.
- Harmonic currents
- Parallel cables.
- Electromagnetic interference.

The circuit protection device selected to protect the cable will also affect the cable current carrying capacity as follows:

- Circuit Breaker - 100% of current carrying capacity of cable (x 1).
- H.R.C. fuse - 90% of current carrying capacity of cable (x 0.9).
- Semi-enclosed rewireable fuses **existing installations only** 80% of current carrying capacity of cable (x 0.8).

The "standard" conditions of installation and operation to avoid de-rating are given by **Ref R-6-D** as;

Ambient **air** temperature	40°C
Ambient **soil** temperature	25°C
Depth of laying cable underground	0.5m
Soil thermal resistivity	1.2°C.m/W
Cable grouping	single cable
Harmonic distortion	See table 2 of **Ref R-6-D**
Circuit protection	circuit breaker

De-Rating Factors

Tables 2 and 22 to 29 of **Ref R-6-D** show the de-rating factors that must be applied to cables if they have installation conditions that differ from "standard". The de-rating factor for grouping of circuits is listed in the final column of each table for tables 3(1) to 3(4) as shown in figures **F-6-3-1** and **F-6-3-2**

TABLE 3(1)

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

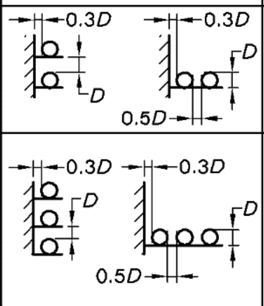
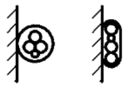
1	2	3	4	5	6
Item No.	Cable details (see Note 2)	Reference drawing (see Note 3)	Current-carrying capacity table reference	Methods of installation for cables deemed to have the same current-carrying capacity (See Notes 4, 5 and 6)	Derating table for more than one circuit
1	Two single-core cables		Tables 4 and 5 Columns 2 to 4 Table 6 Columns 2 and 3	Cables with minimum cable separation in air as shown for horizontal and vertical mounting and installed— (a) spaced from a wall or vertical surface; (b) supported on ladders, racks, perforated trays, cleats or hanger; or (c) suspended from a catenary wire.	23
2	Three single-core cables		Tables 7 and 8 Columns 2 to 4 Table 9 Columns 2 and 3		
3					22

Figure F-6-3-1 – Part Table 3(1) from AS/NZS 3008.1.1:2009

Foot notes at the bottom tables 3(1) to 3(4) give guidance to which de-rating table to use for installation conditions other than the grouping of cables as shown in figure **F-6-3-2**.

			Columns 4 and 5	plaster or render on a wall;	22
13	Three-core cables		Tables 13 and 14 (see Note 4) Columns 5 to 7 Table 15 Columns 4 and 5	(c) in a ventilated trench or open trunking; or (d) in a switchboard or similar enclosure	

NOTES:

1 *D* equals the cable outside diameter or in the case of a flat multicore cable the maximum dimension of the cable.

2 Earthing conductors, lightly loaded neutral conductors of three-phase circuits and conductors subject only to momentary loading, such as control wiring, shall not be counted in the number of cable cores.

3 See column headings of Tables 4 to 15.

4 See Table 22 for the derating factor applicable to a single circuit fixed to the underside of a ceiling or similar horizontal surface.

5 See Tables 23 and 24 for the derating factors applicable to a single circuit fixed to perforated or unperforated trays.

6 See AS/NZS 3000 for the restricted installation conditions of certain types of cable, e.g. unarmoured cables in plaster or cement render on walls.

Figure F-6-3-2 Part Table 3(1) (Footnotes) from AS/NZS 3008.1.1:2009

Example X-6-3-1

A single phase V75 T+E (Twin and Earth) cable installed on perforated cable tray in a factory with ambient air temperature of 55°C.

Step 1: From tables 3(1) to 3(4) find appropriate installation method – in this case table 3(1) item 9

Step 2: As there is only one circuit no de-rating factor for grouping applies.

Step 3: From table 27(1), for a V75 cable at an ambient air temperature of 55°C the de-rating factor is 0.72

Example X-6-3-2

A three phase V75 4 core +E cable installed in an underground conduit with ambient soil temperature of 35°C.

Step 1: From tables 3(1) to 3(4) find appropriate installation method – in this case table 3(4) item 4

Step 2: As there is only one circuit no de-rating factor for grouping applies.

Step 3: From table 27(2), for a V75 cable at a soil temperature of 35°C the de-rating factor is 0.89

Example X-6-3-3

A single phase V75 T+E cable installed on perforated cable tray in a factory touching 3 other circuits.

Step 1: From tables 3(1) to 3(4) find appropriate installation method – in this case table 3(1) item 9

Step 2: From tables 3(1) item 9 column 6, read off the appropriate de-rating table in this case table 24

Step 3: From table 24 item 13 column 8, the de-rating factor is 0.8

Installation Conditions that Avoid De-Rating

(Ref R-6-D Clause 3.5.2.2)

When cables are secured to supports such as ladder or cable tray it is preferred to space the cables of different circuits from each other to allow the circulation of air around the conductors. If cables must be grouped it is better to group cables in small groups.

Current Carrying Capacity Tables in Ref. R-6-D

Selecting Cable Size Based on Current Rating.

Selection of cable size based on current carrying capacity is based on;

$I_B \leq I_N \leq I_Z$

Where: I_B = Maximum demand or expected load current

I_N = Nominal current rating of the protective device

I_Z = Rated current carrying capacity of a conductor

What this formula states is the rated current carrying capacity of a conductor (I_Z) must be greater than or equal to the nominal current rating of the protective device (I_N) which in turn must be greater than or equal to the maximum demand or expected load current of the conductor (I_B).

The steps involved in determining the minimum current carrying capacity (I_Z) of the conductor are:

i. determine the current requirements, maximum demand (IB) for the circuit;

ii. determine the current rating of the protective device (IN) to be used. Table 8.1, 8.2 and B1 of Ref, R-6-B shows standard protection device ratings up to 200A;

iii. decide which cable type and installation method to use;

iv. apply de-rating/rating factor from tables of Ref. R-6-D for the installation environment conditions where applicable;

v. Select a minimum conductor size for the look up current rating (or next largest) from tables of Ref. R-6-D. The actual current rating of the cable under these conditions will be the current rating from the table times de-rating factor/s. If there is more than one de-rating factor the overall de-rating factor is the product of all de-rating factors that apply.

Current Carrying Capacities of Cables

The current carrying capacities for various types of commonly used cables and installation methods are given in Tables 4 to 21 of **Ref. R-6-D** (see Figure **F-6-3-3**)

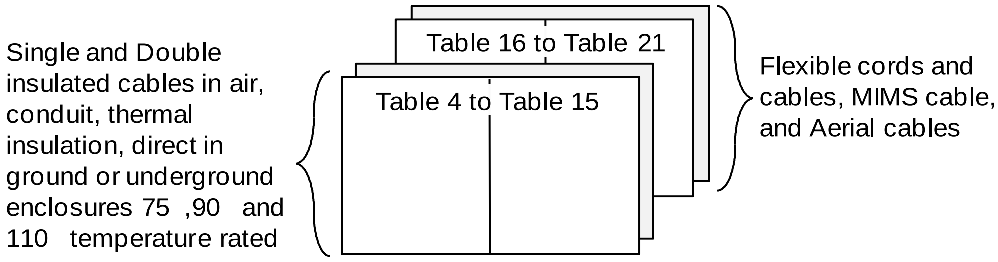


Figure F-6-3-3 AS3000 Tables for cord and cable types

The current carrying capacity of a cable may be reduced or increased when particular external influences are present. In these cases a de-rating factor or rating factor must be applied before the correct minimum size conductor can be determined. Tables 22 to 29 of Ref. R-6-D provide de-rating/rating factors for various external influences.

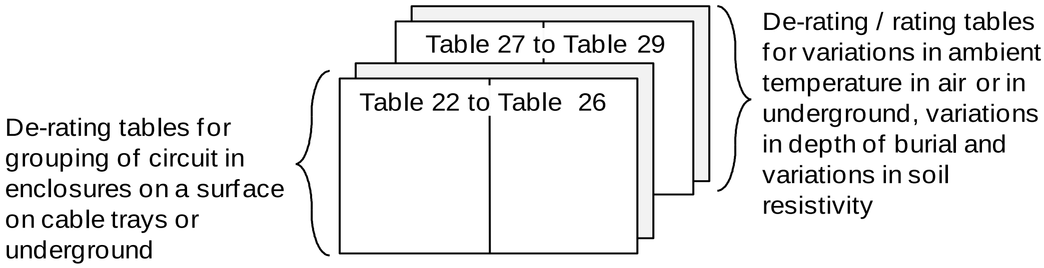


Figure F-6-3-4 AS3000 Tables for de-rating factors

Which Table to Use.

Tables 4 to 15 of **Ref. R-6-D** are the most frequently used current carrying capacity tables, they cover the most commonly used cables types and cable grouping arrangements. Tables 16 to 21 cover the more unusual cables such as flexible, MIMS and aerial cables. Table 3 gives directions as to which of these tables to use for various cable configurations and installation methods. Table 3 is arranged in four parts as shown in Figure **F-6-3-5.** Each Table 3(1) to 3(4) has the same format as shown in Figure **F-6-3-6**.

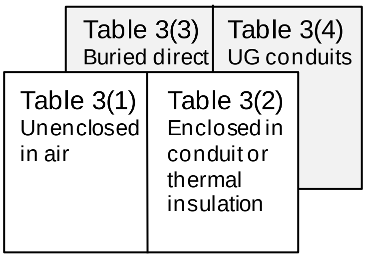


Figure F-6-3-5 AS3000 Tables for installation method

AS/NZS 3008.1.1:2009 30

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	Methods of installation for cables deemed to have the same current-carrying capacity (See Note 3)	Derating table for more than one circuit

Row No.

Description of cable configuration ie. No of cables/cores.

Diagram of installation method.

Current carrying capacity table and column to use.

Other installation methods with the same current carrying capacity

De-rating table to use for grouped circuits.

Figure F-6-3-6 AS3000 Headings for Table 3

How to use Table 3

The steps involved in using Table 3 are:

i. Look up the Table 3 that applies to how the cable is to be installed. For example you would you use Table 3(2) enclosed, for a cable enclosed in conduit.

ii. Go down column 2 and match a description of the cable configuration you are to use against a reference drawing in column 3 that shows you how the cable is to be installed. For example three single core cables installed in conduit in air:

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	Methods of installation for cables deemed to have the same current-carrying capacity (See Note 3)	Derating table 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, cement render, masonry or concrete in a wall or floor; (c) a concrete slab on or above the surface of the ground; or (d) a ventilated trench. Cables installed in— (a) a wiring enclosure on a wall; or (b) an enclosed trench with a removable cover.	22
2	Three single-core cables		Tables 7 and 8 Columns 15 to 17 Table 9 Columns 11 and 12		

Figure F-6-3-7 Extract from AS3000 Table 3(2)

iii. Column 4 on the same row gives the current carrying capacity tables and columns to use to select the minimum conductor size.

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, cement render, masonry or concrete in a wall or floor; (c) a concrete slab on or above the surface of the ground; or (d) a ventilated trench. Cables installed in— (a) a wiring enclosure on a wall; or (b) an enclosed trench with a removable cover.	22
2	Three single-core cables		Tables 7 and 8 Columns 15 to 17 Table 9 Columns 11 and 12		

Figure F-6-3-8 Extract from AS3000 Table 3(2)

iv. The reference drawing in column 3 may not fully show how you intend to install the cable. In this case check column 5 for a description of installation methods deemed to be the same.

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, cement render, masonry or concrete in a wall or floor; (c) a concrete slab on or above the surface of the ground; or (d) a ventilated trench. Cables installed in— (a) a wiring enclosure on a wall; or (b) an enclosed trench with a removable cover.	22
2	Three single-core cables		Tables 7 and 8 Columns 15 to 17 Table 9 Columns 11 and 12		

Figure F-6-3-9 Extract from AS3000 Table 3(2)

When cables are to be installed with cables of other circuits, a de-rating factor must be applied. Column 6 gives the table to use to find the correct de-rating factor for groups of cables. For example a three core cable installed unenclosed in air on cable tray with two other circuits;

TABLE 3(1) *(continued)*

1	2	3	4	5	6
Item No.	**Cable details (see Note 2)**	**Reference drawing (see Note 3)**	**Current-carrying capacity table reference**	**Methods of installation for cables deemed to have the same current-carrying capacity (See Notes 4, 5 and 6)**	**Derating table for more than one circuit**
9	Two-core cables	0.3D D	Tables 10 and 11 (see Note 5) Columns 2 to 4 Table 12 Columns 2 and 3	Cables with minimum spacings in air as shown and installed— (a) spaced from a wall or vertical surface; (b) supported on ladders, racks, perforated or unperforated trays, cleats or hangers; (c) in a switchboard or similar enclosure; or	24
10	Three-core cables	0.3D D	Tables 13 and 14 (see Note 5) Columns 2 to 4 Table 15 Columns 2 and 3		
11				(d) suspended from a catenary or as a self-supported overhead cable.	22

Figure F-6-3-10 Extract from AS3000 Table 3(1)

How De-Rating (and Rating) Factors are Applied

The rated current carrying capacity of a cable (I_Z) when installed with cables of other circuits is **decreased** by a de-rating factor. The result can mean a larger cable is required for the circuit. The following points regarding de-rating factors should be noted:

a. De-rating factor applied to a particular cable results in a reduction in current carrying capacity for that cable.

b. De-rating can be avoided by installing cables with minimum spacing as shown in Figure 1 of **Ref. R-6-D**.

c. When using HRC fuses as the circuit protective device, a de-rating factor of 0.9 will automatically apply to the current carrying capacity of the cable.

d. Rating factors (Tables 27 to 29) are applied to cables in ambient temperatures (other than 40°C air temperature or 25°C soil temperature) in the same way as de-rating factors. Rating tables are not given in the Table 3 schedule.

Tables 4 to 21

Table 3 of **Ref. R-6-D** can be used as an index to find which table from 4 to 14 has the equivalent current carrying capacity for that cable configuration and installation conditions. Tables 15 to 21 are not mentioned in table 3 as they are for different cable types (flexible cords, MIMS cables, aerial conductors etc.). When selecting conductor size for these cables consult the appropriate table directly. De-rating and rating factor from the appropriate Tables 22 to 29 must be applied where necessary.

Cable Selection

Limitation of Cable Temperatures

Clause 3.4.2 of **Ref R-6-B** stipulates operating temperature limits for different cable types and these are summarised in Table 3.2 of the same reference. For example the maximum **Normal use** operating temperature for:

- Twin + E and orange circular V75 cables is 75°C
- Twin + E and orange circular V90 cables is 90°C
- XLPE (X90) insulated cables is 90°C
- MIMS cable is 100°C

Conductors in Parallel

Clause 3.4.3 of **Ref R-6-B** provides guidelines on paralleling cables. Current-carrying capacities for circuits comprising parallel multi-core cables or groups of single-core cables may be determined from the sum of the current-carrying capacity of the various cables connected in parallel provided that:

a. cables shall be not less than 4 mm^2; and

b. grouping of cables shall not affect the cooling of each parallel cable, or group, by the ambient air or the ground; and

c. the load current sharing between each parallel cable, or group shall be sufficient to prevent overheating of any cable or group.

Example – Parallel Cables

Determine the current carrying capacity of two sets of 70mm^2 copper single core XLPE cables laid in trefoil on cable ladder. Each set is touching the other. Protection is by H.R.C. fuse.

Table 3(1)	Item 5	Table 8	column 5	CCC = 240A
De-rating (Grouping)	Table 23	column 7	2 circuits = 0.95	
De-rating (H.R.C. fuse)	0.9			

I_Z = 2 x 240 x 0.95 x 0.9 = 410A

Select a 400A H.R.C. fuse as protection device

I_B = 400A

I_N = 400A

I_Z = 410A

Is $I_B \leq I_N \leq I_Z$? => Yes

Neutral Conductor Size

Clause 3.5.2 of **Ref R-6-B** provides guidelines on neutral conductor size for various types of circuits and in summary states:

a. For single-phase two-wire circuit the neutral conductor or conductors must have a current-carrying capacity not less than

   i. the current-carrying capacity of the associated active conductor; or

   ii. the total current to be carried, where there is more than one active conductor

b. For multiphase circuit the current-carrying capacity of the neutral conductor must not be less than that determined in accordance with the following:

   i. Where a circuit supplies a substantial load that generates harmonic currents, e.g. fluorescent lighting, computers, soft starters, variable speed devices or other electronic devices, the third and any higher order harmonic current generated in the equipment shall be added to the maximum out-of-balance load to determine the current to be carried by the neutral conductor

   ii. The current carrying capacity of a circuit shall be not less than that of the current-carrying capacity of the largest associated active conductor

c. The minimum size of a combined protective earth and neutral (PEN) conductor of consumers mains, or of a submain to an outbuilding of an electrical installation forming a separate MEN installation in accordance with Clause 5.5.3.1, shall:

   i. comply with the requirements of Item (a) or Item (b) above, as appropriate; and

   ii. be not less than that of an earthing conductor as required by Clause 5.3.3.

Protective Earthing Conductor Size

Clause 5.3.3.1.2 of **Ref R-6-B** provides guidelines on selection of Protective Earthing Conductor and in summary states that size of protective earthing conductor should be selected from Table 5.1 in relation to the cross-sectional area of the largest active conductor supplying the portion of the electrical installation to be protected or by calculation, in accordance with Clause 5.3.3.1.3. As examples, the minimum size of the protective earthing /main earthing conductor for :

- 2.5 mm^2 TPI copper active conductors enclosed in L.D. PVC conduit is 2.5 mm^2 (from Table 5.1)
- 10mm^2 copper, 3 phase XLPE single core final sub-circuit installed on cable tray is 4 mm^2 (from Table 5.1).
- Sub-mains are 3 phase 95mm^2 Aluminium XLPE single core cables installed in underground enclosures is 16 mm^2 (from Table 5.1).

Cable Selection

Following is an example of cable selection using AS3008.1.1:2009 (**Ref R-6-D**)

The maximum demand current for the sub-mains of a non-domestic installation has been calculated to be 135 amperes. The type of cable to be used is four single core, non-armoured, XLPE insulated, sheathed copper cables laid touching in open trunking. The cables are to be protected by a circuit breaker.	
Minimum Circuit Breaker Rating that could be used	160A
Table Number 3(?) / Item Number ?	Table 3(1), Item 8
Table Number ? / Column Number ?	Table 8 Column 5
Cable Size / Current rating from table	50mm^2 / 176A
Protective earthing conductor cable size	16mm^2

Coordination between conductors and protective devices (AS3000 Clause 2.5.3.1)	
I_B = Maximum demand current	135A
I_N = Nominal current rating of the selected protective device	160A
I_z = Current Carrying Capacity of the selected cable after any de-rating has been considered.	176A (Table 22 derating = 1)
Is $I_B \leq I_N \leq I_Z$?	YES
Would the cable need to be upgraded?	NO
If so, select the new cable size.	N/A

Adjustable Circuit Breakers (200A - 400A)

When a circuit requires a protection device larger than 200A an adjustable circuit breaker (Figure **F-6-3-11)** may be used to match the setting of the breaker to the capacity of the cable. This way no capacity between the preset size of the breaker and the cable is lost.

$$\text{Setting\%} = \frac{I_Z}{I_N} \times \frac{100}{1}$$

Circuit Breaker Increment Settings

1.0 0.95 0.9 0.8 0.63 0.5 0.4

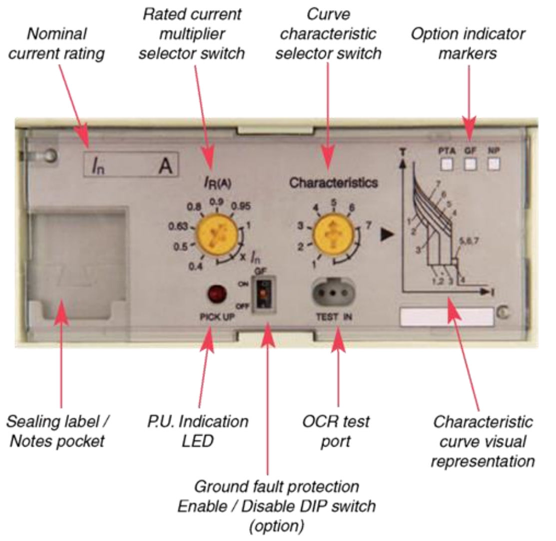


Figure F-6-3-11 Adjustable circuit breaker

Example – Setting an Adjustable circuit breaker

Four single core 70 mm^2 XLPE copper cables are installed laid flat touching as a single circuit on cable ladder. What size and current setting of an adjustable C.B. will allow the full optimisation of the cable current carrying capacity.

Table 3(1)	Item 5	Tables 8	column 5 to 7	CCC = 240A

$$\text{Setting\%} = \frac{I_Z}{I_N} \times \frac{100}{1} = \frac{240}{250} \times \frac{100}{1} = 96\%$$

A 250 A Adjustable C.B. is now set to **95%** of its rated value to match the protection device to the cable rating. Had a preset C.B. rated at 250 A been used a larger cable would have been required.

Tutorial 6.3

For questions TQ.6.27 to TQ.6.42, use AS 3000:2007 and AS3008.1.1:2009 to determine:

- The derating factors for the cables;
- The required cable size,
- The protective device rating,
- The minimum protective earth (PE) size, and
- Values for I_B, I_N, & I_Z.

As part of your answer:

- Identify the table and column numbers used from the referances, and
- State whether the instalation complies with the relationship $I_B \leq I_N \leq I_Z$

TQ.6.27 The maximum demand current of a sub-main cable, has been calculated to be 172 amperes. The type of cable to be used is a 4 core, non-armoured, V75 insulated and sheathed circular cable with copper conductors. The cable is to be saddled directly to a vertical surface (e.g. wall), open to the air and is to be protected by a circuit breaker.

[Source: Ref R-6-A, Section 6, Tutorial Q1, P186]

Table No ____________ Column No ____________ Cable Size ____________ PE Size ____________

I_B = ____________ I_N = ____________ I_Z = ____________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.28 The maximum demand current of a single phase domestic installation has been calculated to be 80 amperes. Select a cable size for the consumer's mains for with following stipulations:

i. Type of Cable to be used:
SDI, non-armoured, XLPE cable with copper conductors.

ii. Method of installation:
Enclosed in heavy duty PVC conduit in ceiling and partially surrounded by thermal insulation.

iii. Circuit protection:
Unprotected consumer's main

[Source: Ref R-6-A, Section 6, Tutorial Q2, P187]

Table No ____________ Column No ____________ Cable Size ____________ PE Size ____________

I_B = ____________ I_N = ____________ I_Z = ____________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.29 The maximum demand current for the sub-mains of a non-domestic installation has been calculated to be 185 ampere. The type of cable to be used is four single core, non-armoured, V75 insulated, unsheathed copper cables laid touching in open troughing. The cables are to be protected by H.R.C. fuses.

[Source: Ref R-6-A, Section 6, Tutorial Q3, P187]

Table No ________ Column No ________ Cable Size ________ PE Size ________

I_B = ________ I_N = ________ I_Z = ________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.30 The maximum demand current of a non-domestic installation has been calculated to be 141 amperes. The type of cable selected for the consumer's mains for this installation is to be 4 single core, V75 insulated, sheathed cables with copper conductors which are to be run in non-metallic conduit, which in turn is to be saddled to an external wall. Determine the size of the consumer's mains if they are to be protected by HRC fuses.

[Source: Ref R-6-A, Section 6, Tutorial Q4, P187]

Table No ________ Column No ________ Cable Size ________ PE Size ________

I_B = ________ I_N = ________ I_Z = ________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.31 A sub-mains cable size is to be selected for a domestic installation with the following information:

i. Type of Cable - 2 core, V75, flat insulated and sheathed, non-armoured cable with copper conductors including earth conductor.

ii. Method of Installation - Clipped to a ceiling joist in air.

iii. Maximum demand current - 27 ampere

iv. Protection device - Circuit Breaker

[Source: Ref R-6-A, Section 6, Tutorial Q5, P188]

Table No ________ Column No ________ Cable Size ________ PE Size ________

I_B = ________ I_N = ________ I_Z = ________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.32 A final sub-circuit is to be run in a non-domestic installation for the purpose of supplying power to a reverse cycle air conditioner. The full load current of the appliance has been calculated to be 35A. The type of cable to be used is two single core, V75 insulated and unsheathed copper cables with earthing conductor and will be protected by circuit breakers. The cable is to be run in a non-metallic conduit and saddled to an external wall.

[Source: Ref R-6-A, Section 6, Tutorial Q6, P188]

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.33 Circuit protection and cable size are to be selected from the information given:

i. Maximum Demand Current - 188 ampere.

ii. Cable type - 4 core, X.L.P.E. circular, insulated and sheathed armoured cable with aluminium conductors.

iii. Method of installation - To be buried directly in the round to a depth of 0.5 metres below the ground surface in an ambient soil temperature of 25 degrees Celsius.

iv. Circuit Protection - Circuit breaker.

[Source: Ref R-6-A, Section 6, Tutorial Q7, P189]

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.34 Four single core, V75 insulated, unsheathed copper cables are to be run in non-metallic PVC conduit installed in the ground to a depth of 0.5 metres below the ground surface in an ambient soil temperature of 25 degrees Celsius. Each single core cable is to be installed in its own conduit, laid touching in the ground and be protected by a circuit breaker. The maximum demand current to be carried by the cable has been calculated to be 400 ampere. Determine the minimum permissible cable size for the above;

[Source: Ref R-6-A, Section 6, Tutorial Q8, P189]

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.35 Two circuits of two core V90, insulated and sheathed flat copper cables are to be installed directly in the ground to a depth of 0.5 metres below the ground surface in an ambient soil temperature of 25 degrees Celsius and be protected by H.R.C. fuses. The cables will be laid flat in the ground and spaced at a distance of 0.15 metres apart. Each cable must be able to safely carry a full load current of 20 amperes. From the above information, determine the minimum permissible cable size.

[Source: Ref R-6-A, Section 6, Tutorial Q9, P190]

Derating Table Number: __________ Column No __________ DR __________

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.36 Two circuits of two core V90 non-armoured, insulated and sheathed cables with copper conductors are to be clipped to the underside of a ceiling in a single layer formation. The cables are to be touching. Each circuit is to carry a load current of 34 ampere and will be protected by circuit breakers. Determine the minimum permissible cable size for each circuit from the information supplied.

[Source: Ref R-6-A, Section 6, Tutorial Q10, P190]

Derating Table Number: __________ Column No __________ DR __________

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.37 Four circuits of three core, V90 TPS circular cables with copper conductors are to be bunched together in closed trunking which in turn is to be fixed to a wall in a horizontal position and open to air. Each circuit is to carry a maximum demand current of 54 amperes and will be protected by circuit breakers. Determine the minimum permissible size of the cables to meet the above requirements.

[Source: Ref R-6-A, Section 6, Tutorial Q11, P191]

Derating Table Number: __________ Column No __________ DR __________

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = ___________ I_N = ___________ I_Z = ___________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.38 Four circuits of four core HFI-90-TP thermoplastic insulated and sheathed non-armoured circular cables with copper conductors are to be buried directly in the ground to depth of 0.5 metres below the ground surface in an ambient soil temperature of 25 degrees Celsius. The cables are to be laid spaced 0.15 metres from each other. The circuits are to be protected by HRC fuses and the full load current of each circuit has been calculated to be 125 ampere. Determine the minimum permissible cable size for each of the above circuits.

[Source: Ref R-6-A, Section 6, Tutorial Q12, P191]

Derating Table Number: ___________ Column No ___________ DR ___________

Table No ___________ Column No ___________ Cable Size ___________ PE Size ___________

I_B = ___________ I_N = ___________ I_Z = ___________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.39 Six circuits, each which consist of three single core XLPE (X-HF-110) unsheathed PVC insulated copper conductors, are to carry a maximum demand current of 32 ampere and be protected by circuit breakers. Each circuit will have its three single core conductors enclosed in a separate PVC conduit. i.e. Three conductors to a conduit. The six conduits will be buried in the ground to a minimum depth as specified by the requirements of AS/NZS3000:2007 (Note: Not under a continuously paved concrete area). The soil temperature is assumed to also meet the AS/NZS3008. 1.1 minimum requirements. Each conduit will be horizontally laid in single layer formation and spaced a distance of 0.3 metres from each other. Determine the minimum permissible cable size for each circuit.

[Source: Ref R-6-A, Section 6, Tutorial Q13, P192]

Derating Table Number: ___________ Column No ___________ DR ___________

Table No ___________ Column No ___________ Cable Size ___________ PE Size ___________

I_B = ___________ I_N = ___________ I_Z = ___________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.40 Two circuits of three single core V90, single double insulated non-armoured cables with copper conductors, are to be fixed to a single tier horizontally mounted perforated cable tray in a trefoil formation. Each trefoil formation will be touching. Each circuit will carry a maximum demand current of 42.5 ampere and will be protected by circuit breakers.

[Source: Ref R-6-A, Section 6, Tutorial Q14, P192]

Derating Table Number: __________ Column No __________ DR __________

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.41 One circuit, consisting of three single core V90 insulated, unsheathed non-armoured cables with copper conductors is to carry 175 amperes and be enclosed in non-metallic conduit buried in the ground to a depth of 1.25 metres below the ground surface in an ambient soil temperature of 25 degrees Celsius. Protection for the circuit is via circuit breakers. Determine the minimum permissible cable size of the circuit.

[Source: Ref R-6-A, Section 6, Tutorial Q15, P193]

Derating Table Number: __________ Column No __________ DR __________

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

TQ.6.42 Two, four core X-HF-90 insulated and sheathed non-armoured circular cables with copper conductors are to be installed and connected in parallel to feed a three-phase load that draws a full load current of 400 ampere when in operation. The two cables form the one circuit that is to be protected by a circuit breaker. Each cable is to be installed in its own non-metallic conduit and buried in the ground to a depth of 0.5metres. The conduits are to be touching. Determine the minimum permissible size for each cable.

[Source: Ref R-6-A, Section 6, Tutorial Q16, P193]

Derating Table Number: __________ Column No __________ DR __________

Table No __________ Column No __________ Cable Size __________ PE Size __________

I_B = __________ I_N = __________ I_Z = __________ $I_B \leq I_N \leq I_Z$ Yes / No

Topic 6.4 Cable Selection Based on Voltage Drop Requirements

Introduction

Electrical cables made from either copper (Cu) or Aluminium (Al) have resistance. When an electric current flows in those conductors a voltage drop across the length of the cable will occur. This voltage drop will reduce the supply voltage available at the terminals of the load supplied by the cables.

Clause 3.6.2 of **Ref. R-6-B** states "The cross-sectional area of every current-carrying conductor shall be such that the voltage drop between the point of supply for the low voltage electrical installation and any point in that electrical installation does not exceed 5% of the nominal voltage at the point of supply". This means that for a 400/230 V system the voltage may drop to 380/218.5 and still comply with Australian Standards

Excessive voltage drop in an installation may cause:

- a reduction in the effective operation of appliances and lighting;
- overloading of cables if a fault occurs by delaying the operating time of circuit protection devices;
- over-heating of motors, noticeable when the voltage reduction is more than 5%.

The effect of voltage drop must be considered when selecting cables, especially for circuits which have long route lengths (i.e. length of cable) and circuits with relatively high currents.

Voltage drop (V) in the cables of a circuit is caused by the current in the circuits (I) and the resistance (R) of the circuit

$$V_{DROP} = I \times R_{cable}$$

Factors that determine the voltage drop in a cable are the;

- Length of the cable.
- CSA of the cable.
- Current flowing in the cable.
- Type of material of the cable (copper or aluminium).
- Operating temperature of the cable and ability to dissipate heat.
- Installation method of the cable (trefoil, laid flat or in a multi-core cable).

The voltage drop on any given combination of the above can be predicted before the cable is selected and installed by using tables 40 to 51 of Section 4 of **Ref. R-6-D** (AS3008.1.1-2009).

Voltage Drop Tables in AS3008.1.1 (2009)

Tables 40 to 51 of **Ref. R-6-D** show values of $\mathbf{V_c}$ in Millivolts per Ampere Metre for a number of copper and aluminium cable configurations. The value of $\mathbf{V_c}$ was determined by passing a current of 1 Ampere, through a 1 metre length of conductor, in sizes from 1mm^2 to 630mm^2 for both copper and aluminium conductors at operating temperatures ranging from 45° to

110° C. as shown in **Figure F-4-1-1**. The temperature used is the maximum **normal use** operating temperature as shown in table 1 of **Ref. R-6-D**. The voltage drop across the 1 metre length of conductor is then recorded as V_c.

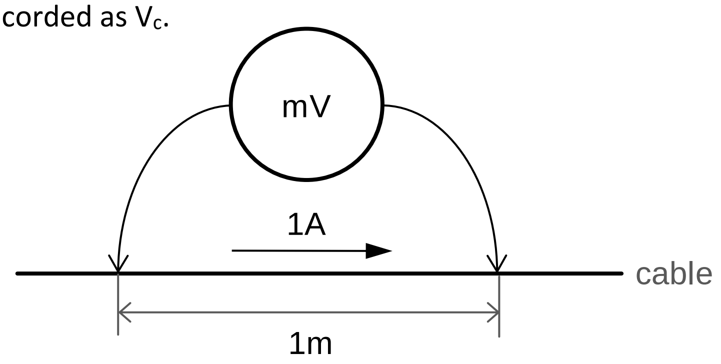


Figure F-6-1-1 Circuit configuration to find V_C (mV/A.m)

All of the values listed in tables 40 to 51 are 3 phase values of V_c. When performing a voltage drop calculation the value of V_c is obtained directly from the table.

The 3 phase values of V_c were obtained using the **line current** (I_L) of a balanced 3 phase circuit. The 3 phase values of V_c require adjustment when applied to a 1 phase circuit to allow for current flowing in the neutral.

If the voltage drop of a single phase cable needs to be calculated, the 3 phase value of V_c for a given cable size (from tables), must be converted to a single phase value of V_c;

$$V_C(1\Phi) = \frac{2}{\sqrt{3}} \times V_C(3\Phi) = 1.155 \times V_C(3\Phi)$$

When the single phase value of V_c has been calculated, the single phase value of V_c must be converted to a 3 phase value of V_C. The CSA of a suitable cable is then found from a table;

$$V_C(3\Phi) = \frac{\sqrt{3}}{2} \times V_C(1\Phi) = 0.866 \times V_C(1\Phi)$$

A characteristic of a 3 phase circuit is that it has lower ‘losses’, than a single phase circuit of the same material, length and CSA. The 3 phase V_c for an equivalent conductor is always smaller than the V_c of single phase circuit.

Voltage Drop Calculations Using AS3008.1.1

To determine the **actual voltage drop** for a given cable size, use the equation;

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

Where:

V_d = the actual voltage drop, in volts

V_c = the value found from **Ref. R-6-D** tables in mV/A.m

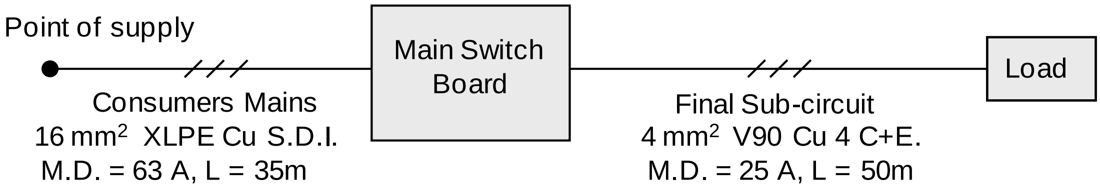
L = the route length of circuit, in metres

I = the current to be carried by the cable, in amperes.

To find the total voltage drop for an entire installation the voltage drops of the consumer's mains and final sub-circuits (FSC) are added together.

Example – Calculating V_d

Calculate the voltage drop for the installation.



Solution:

For consumer mains, XLPE cable, from Table 1, max. Operating temperature is 90°C

V_c found from Table 41 as 2.55 mV/A.m (Note 2.55 mΩ/m)

For consumers mains

$$V_d = \frac{V_c \times L \times I}{1000} = \frac{2.55 \times 35 \times 63}{1000} = 5.62V$$

For the final sub-circuit V90 cable by definition, max. Operating temperature is 90°C

V_c found from Table 42 as 10.2 mV/A.m

For FSC

$$V_d = \frac{V_c \times L \times I}{1000} = \frac{10.2 \times 50 \times 25}{1000} = 12.75V$$

Total voltage drop is $V_d = 5.62 + 12.75 = 18.37V$

Single Phase Installations

When an installation contains single phase circuits the values of V_C must be converted to single phase values and then used in the voltage drop equation.

Three Phase Installations with Single Phase Circuits

If an installation is supplied by three phase and has single phase circuits within the installation, both single and three phase voltage drops must be converted to a common unit value so they can be added together. Both values can be converted to a percentage of their nominal value, or the 3 phase V_d may be converted to a single phase V_d, by dividing it by √3, in the same way a line voltage (V_L) of 400V is converted to a phase voltage (V_P) of 230V.

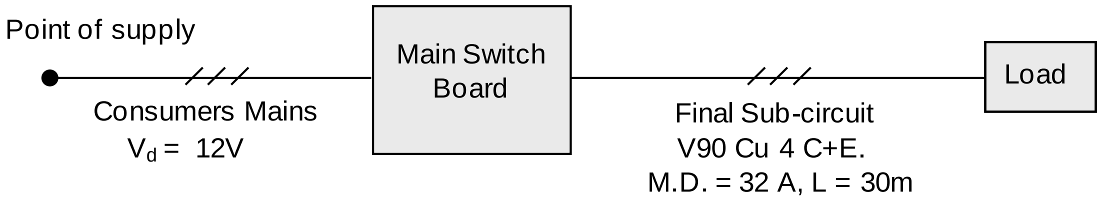
Cable Selection Based on Voltage Drop

Cables sizes are selected in order not to exceed a certain voltage drop figure. Thus the following equation (as presented in the previous section) is used to determine Vc and then Tables 40 to 51 of Ref R-6-D are consulted to select appropriate cable size.

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

Example - Cable Selection Based on Voltage Drop

For the installation below:



a. Calculate the maximum permissible voltage drop (V_P) for the f.s.c.

b. Calculate the maximum permissible value of V_c

c. Determine the minimum cable size

Solution:

a. Assuming 400/230V supply, the total allowable voltage drop between the point of supply and the load is 5% of 400V, i.e. 20V

As the consumer mains has a 12V drop the FSC allowable volt drop is 8V

b. Then: $$V_c = \frac{1000V_d}{L \times I} = \frac{1000 \times 8}{30 \times 32} = 8.333\text{mV/A.m}$$

c. Minimum cable size from Table 42 is 6 mm^2

Three Phase Installations with Single Phase Circuits

As previously discussed, the 3 phase V_d is calculated and then must be converted to a single phase V_d. This is done by either converting both 3 phase and 1 phase voltage drops to a percentage, or by dividing the 3 phase V_d by √3. A single phase V_P is then found and used to calculate a single phase V_c. This is then converted back to a three phase V_c so that the cable size can be determined by looking up the table.

Maximum Length of Cable Based on Voltage Drop

Example – Maximum Length of Cable Based on Voltage Drop

Calculate the maximum length of a 3 phase 2.5mm^2 V75 multicore copper cable protected by a 20A C.B, if the permissible voltage drop is 12V.

Solution:

From Table 42: V_c = 15.6 mV/A.m

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

$$L = \frac{1000V_d}{V_c \times I} = \frac{1000 \times 12}{15.6 \times 20} = 38.46\text{m}$$

Tutorial 6.4

TQ.6.43 The voltage drop between the point of supply a low voltage electrical installation and any point in that electrical installation must not exceed ______ of the nominal voltage at the point of supply;

[Source: Ref R-6-A, Section 7, Tutorial Q5, P219]

a. 2%
b. 5%
c. 7%
d. 10%

TQ.6.44 An acceptable line voltage drop across an entire 400V installation would be;

[Source: Ref R-6-A, Section 7, Tutorial Q7, P220]

a. 15V
b. 21V
c. 30V
d. 40V

TQ.6.45 Where the point of supply is the low voltage terminals of a substation located on the premises containing the electrical installation and dedicated to the installation, the permissible voltage drop may be;

[Source: Ref R-6-A, Section 7, Tutorial Q8, P220]

a. 2%
b. 5%
c. 7%
d. 10%

TQ.6.46 The drop in voltage at any point in an extra-low voltage electrical installation shall not exceed ______ of the nominal value when all live conductors are carrying the circuit-operating current. *[Source: Ref R-6-A, Section 7, Tutorial Q9, P220]*

a. 2%
b. 5%
c. 7%
d. 10%

TQ.6.47 To convert values of VC listed in the Voltage Drop Tables of AS3008.1.1, to a single phase values of VC, the table value must be multiplied by; *[Source: Ref R-6-A, Section 7, Tutorial Q10, P220]*

a. 1
b. 1.155
c. √3

d. 0.866

TQ.6.48 For the installation shown below determine:

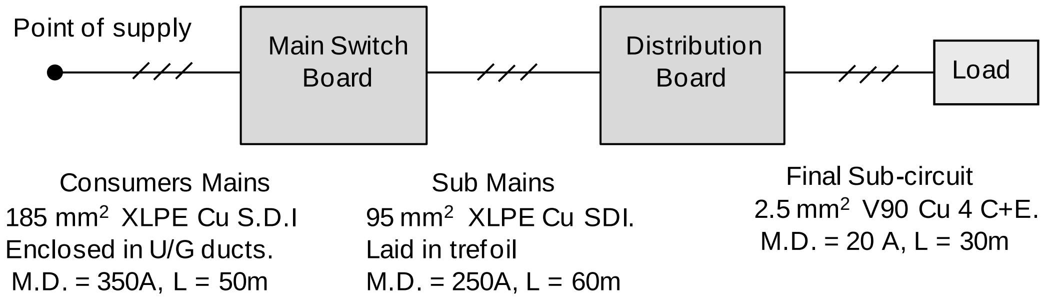
[Source: Ref R-6-A, Section 7, Tutorial Q11, P221]

a. Consumer's Mains V_d

b. Sub Mains V_d

c. F.S.C. V_d

d. Total V_d



TQ.6.49 For the installation shown below determine:

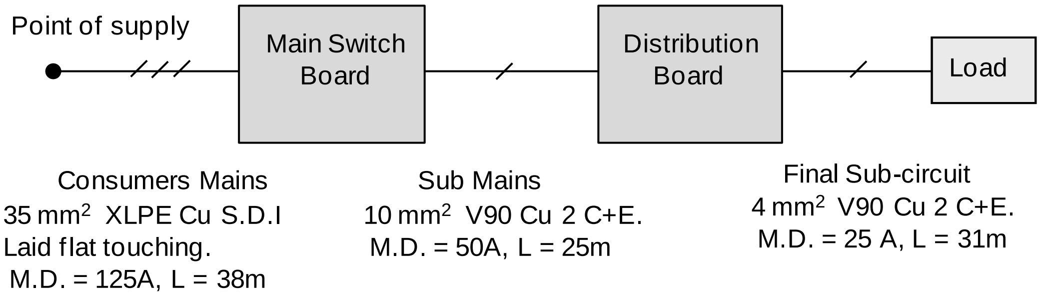
[Source: Ref R-6-A, Section 7, Tutorial Q12, P222]

a. Consumer's Mains V_d

b. Sub Mains V_d

c. F.S.C. V_d

d. Total V_d



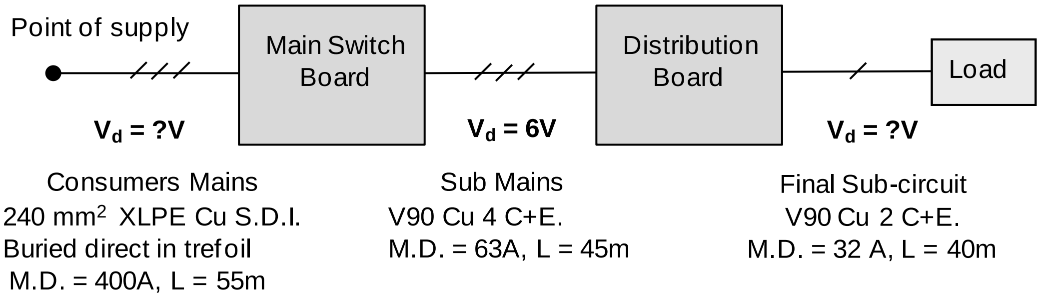
TQ.6.50 For the installation shown below determine:

[Source: Ref R-6-A, Section 7, Tutorial Q13, P223]

a. Consumer's Mains V_d

b. Sub Mains c.s.a

c. Final sub-circuit c.s.a.

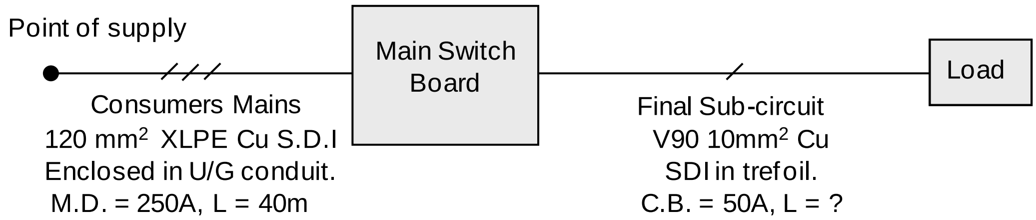


TQ.6.51 For the installation shown below determine:

[Source: Ref R-6-A, Section 7, Tutorial Q14, P224]

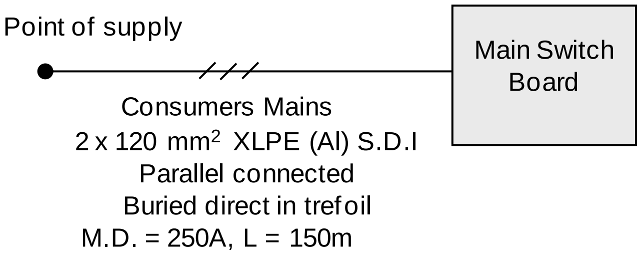
a. Consumer's Mains Vd

b. Final sub-circuit maximum length.



TQ.6.52 Calculate the voltage drop on the paralleled consumers mains shown below (hint see AS3000 clause 3.6.3).

[Source: Ref R-6-A, Section 7, Tutorial Q15, P225]



Topic 6.5 Cable Selection Based on Earth Fault Loop Impedance Requirements

Introduction

This section examines the effect of fault loop impedance on the selection of conductor sizes in circuits. Voltage drop limits the maximum length of conductors when current is flowing under normal operating conditions i.e. from phase to phase or phase to neutral.

Earth fault loop impedance limits the maximum length of conductors when current is flowing under earth fault conditions i.e. from phase to earth. The protective earthing conductor is usually smaller than the active or neutral conductors; its impedance will be higher than that of the active or neutral conductors. Under earth fault conditions the combined impedance of the fault path from active to protective earthing conductor will be higher than the impedance of a fault path from active to active, or active to neutral. In long cable runs because of the higher impedance from active to protective earthing conductor the fault current will be lower than that of a fault on a cable of a shorter length. The lower the earth fault current, the longer the circuit protection device will take to operate. In the time that it takes to operate the circuit protection device a touch voltage will be present on the exposed conductive parts of the apparatus under fault. If a person is in simultaneous contact with the exposed conductive part and earth they are said to be in “indirect contact with live parts”.

One of the fundamental safety principles required by the 2007 edition of AS3000 (Ref R-6-B) is **fault protection** (protection from indirect contact with live parts). The most commonly used method for providing this protection is automatic disconnection of supply. Automatic disconnection of the supply **(Clause 2.4.2 of Ref R-6-B)** shall be achieved by:

- provision of a system of earthing in which exposed conductive parts are connected to protective earthing conductors, and;
- automatic disconnection of the fault by an over-current protective device or an RCD within the disconnection time.

Each circuit in an electrical installation is to be protected such that automatic disconnection of supply will occur within the specified disconnection time when a fault of negligible impedance occurs between an active conductor and a protective earthing conductor or an exposed conductive part anywhere in the electrical installation.

This condition is met when the impedance of the path taken by the fault current, known as the earth fault-loop, is low enough to allow sufficient current to flow to cause the protective device to operate within the specified time.

The earth fault-loop in an MEN system is as shown in figure B5 of **Ref R-6-B**, reproduced below

- The fault current flows from the supply transformer to the fault through the active conductors.
- It returns on the fault side of the installation MEN connection through the Earth conductor.

- From the MEN the fault current returns along the Neutral conductor to the supply transformer.

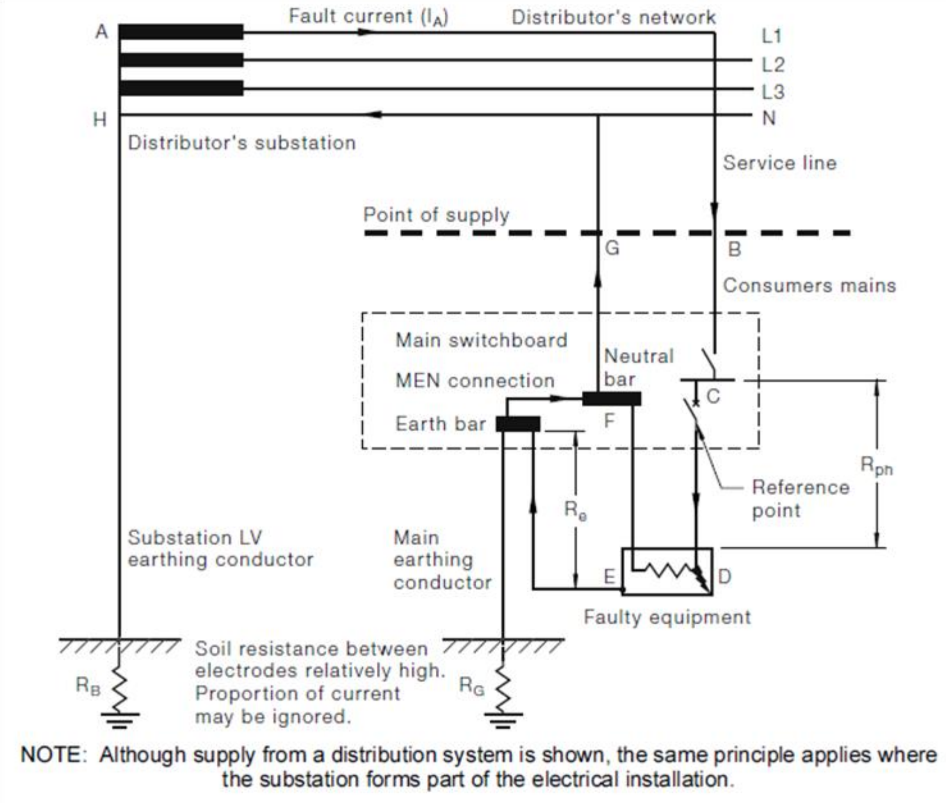


FIGURE B5 MEN SYSTEM (SIMPLIFIED)—SHOWING FAULT CURRENT (I_a) PATH (EARTH FAULT-LOOP)

Figure F-6-5-1 –Figure B5 of AS/NZS 3000:2007

Cable Impedance Tables in AS/NZS3008.1.1

The total earth fault loop impedance is the sum of the supply transformer impedance and the impedance of all cables in the path between the supply and the fault.

For cable ratings up to 400A, the reactance can be ignored and calculations are done using only the A.C. resistance. Larger cables should take reactance into account The A.C. resistance of conductors in any given combination of cables can be predicted before the cable is selected and installed by using tables 34 to 39 of Section 4 of Ref-R-6-D.

The unit values in tables 34 to 39 of Ref-R-6-D are given in Ohms per kilometer (Ω/km). To calculate the A.C. resistance of a given conductor use the equation;

$$R = \frac{R_C \times L}{1000}$$

Where:

R = the resistance of the cable in Ohms (Ω)

R_C = the table value in ohms per km (Ω/km)

L = the length of the conductor in meters (m)

Calculating Cable A.C. Resistance (R_C)

Example X-6-5-1: Determining R_C from Tables

Calculate the A.C. resistance of a single conductor in a 45m length of 10 mm^2, 4 Core and Earth (4C + E) V90 Copper (Cu) cable.

Solution:

From Ref R-6-D, Table 35, Column 4, for 10 mm^2 cable R_C = 2.33 Ω/km

and

$$R = \frac{R_C \times L}{1000} = \frac{2.33 \times 45}{1000} = 0.105\Omega$$

Earth Loop Impedance Calculations

Any circuit protected by an RCD satisfies the requirements of earth fault loop impedance. RCD's that protect light and power circuits must have a rated residual current of not greater than 30mA (Ref R-6-B section 2.6.3). Calculation of earth fault loop impedance to these circuits is pointless. The low current (<30mA) and extremely fast operation (<300mS) ensure automatic disconnection of supply within the required time. Type 'S' RCD's which have a rated residual current in the range of 100 to 300mA (Ref R-6-B clause 2.6.2.3) used to protect against the initiation of fire, will also satisfy earth fault loop impedance requirements.

Circuits **that require** additional protection by RCD's (Ref R-6-B section 2.6.3):

Residential (domestic) installations

- Socket outlets
- Lighting points
- Directly connected hand-held electrical equipment

Other electrical (non-domestic) installations

- Socket-outlets not exceeding 20A.
- Lighting circuits not exceeding 20 A.
- Final sub-circuits supplying directly connected hand-held electrical equipment, e.g. hair dryers or tools.

Circuits that are not RCD protected, to which earth fault loop impedance should be applied, include;

- Socket outlets exceeding 20A.
- Fixed or stationary (mass exceeds 18 kg) equipment
- Sub-mains

Disconnection Times

When an earth fault occurs a touch voltage appears on exposed conductive parts. This touch voltage will be disconnected quickly if the earth fault loop impedance is low enough to ensure a large current flow occurs to operate the circuit protection quickly. This is done in miniature circuit breakers by the magnetic trip mechanism. If the fault current is too low the circuit breaker will trip by the thermal mechanism. The longer time a person is in contact with a touch voltage the greater the risk of injury to the person. Clauses 1.5.5.3(d) and 5.7.2 of Ref R-6-B specify time in which automatic disconnection of supply must occur.

Clause 1.5.5.3(d) of **Ref R-6-B** states:

> The maximum disconnection time for 230/400 V supply voltage shall not exceed the following:
>
> (i) 0.4 s for final sub-circuits that supply:
>
> (A) socket-outlets having rated currents not exceeding 63 A; or
>
> (B) hand-held Class I equipment; or
>
> (C) portable equipment intended for manual movement during use.
>
> (ii) 5 s for other circuits including sub-mains and final sub-circuits supplying fixed or stationary equipment.

The total earth fault loop impedance (Z_S) is calculated by: (R-6-B section B4.5);

$$Z_s = \frac{U_0}{I_a}$$

Where:

Z_S = the total earth fault loop impedance in Ohms (Ω)

U_O = the nominal phase voltage in volts (V)

I_a = current causing automatic operation of the protective device in amperes (A) as follows:

Type B circuit breaker I_a = 4 x rated current of circuit breaker

Type C circuit breaker I_a = 7.5 x rated current of circuit breaker

Type D circuit breaker I_a = 12.5 x rated current of circuit breaker

Figure F-6-5-2 shows typical tripping curves for type C and D miniature circuit breakers. Type C circuit breakers are for general use (most common) and Type D circuit breakers are used for motor protection. From **Figure F-6-5-2** it can be seen that:

- To obtain a trip time of 0.4s for a C type circuit breaker requires a fault current of 7.5 times the circuit breaker rating
- To obtain a trip time of 0.4s for a D type circuit breaker requires a fault current of 12.5 times the circuit breaker rating
- To obtain a trip time of 5.0s for either type of circuit breaker requires a fault current of 4.0 times the circuit breaker rating

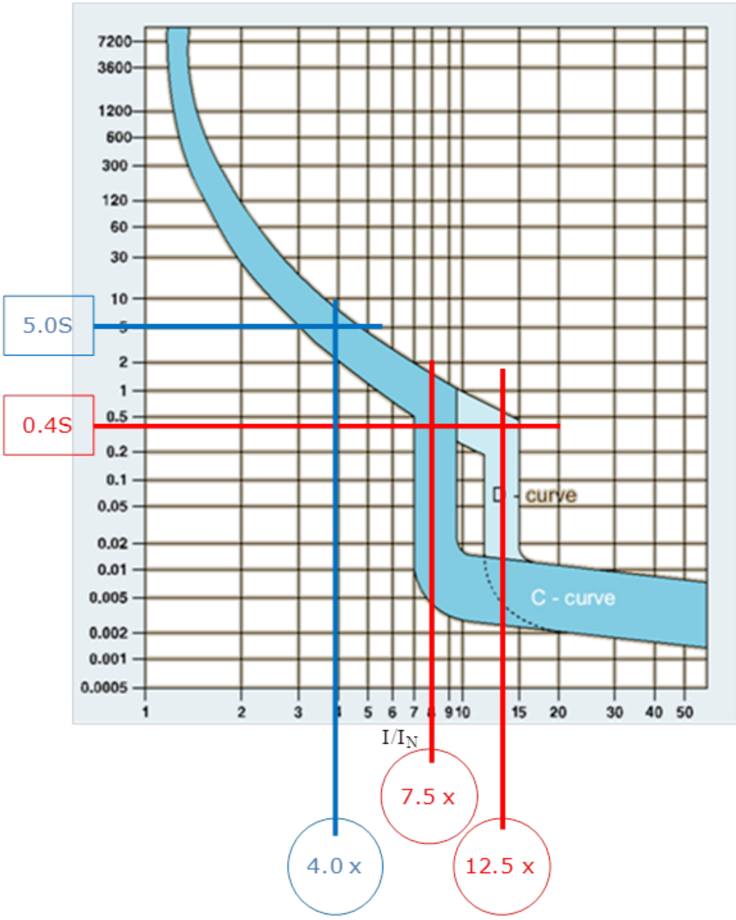


Figure F-6-5-2 – Clipsal 6 and 10 kA M.C.B. characteristic curve

When designing circuits for a 5 second disconnection time, the circuit protection manufacturer's data must be used. Calculations and table data in **Ref R-6-B** refers to a 0.4 second disconnection time. The value of 4 x in **figure F-6-5-2** is the current required to operate the circuit breaker within 5 seconds. This is not be confused with a type 'B' circuit breaker which will operate in 0.4 seconds if 4 times its rated current passes through it.

Total Earth Fault Loop Impedance (Z_S)

Example X-6-5-2: Calculating Z_s

Calculate the maximum permissible earth fault loop impedance (Z_S) of a circuit supplying a 32A three phase socket outlet that is protected by a type 'C' 32A M.C.B. in a 230/400 volt installation.

Solution:

$$Z_s = \frac{U_0}{I_a} = \frac{230}{7.5 \times 32} = 0.958\Omega$$

The maximum value of total earth fault loop impedance (Z_S) can also be found using table 8.1 of **Ref R-6-B**. Only 0.4 second disconnection times are shown for circuit breakers. If an earth fault loop impedance is required for a fixed or stationary appliance with a 5 second disconnection time it will have to be calculated.

Example X-6-5-3: Calculating Earth Fault Impedance

Determine the total earth fault loop impedance for a 25A socket outlet in data room protected by a 25A type C circuit breaker.

Solution:

From Clause 1.5.5.3(d) of **Ref R-6-B** Socket Outlet is less than 63A, therefore 0.4s disconnect time applies

From table 8.1 of **Ref R-6-B** $Z_s = 1.23\Omega$

Internal Earth Fault Loop Impedance (Z_{int})

The total earth fault loop impedance is made up of two parts. The **External** and **Internal** earth fault loop impedances (see figure F-6-5-1). In the vast majority of cases the impedance of the external section will be unknown. To simplify calculations it is assumed that at the circuit protection device (reference point) as shown in figure F-6-5-1, that at least 80% of the nominal supply voltage (230V) is available under earth fault conditions. When calculating the internal earth fault loop impedance 80% of the nominal supply voltage is used. If a larger value of voltage is present, a higher earth fault current will flow. The operating time of the protection device will be shorter and disconnect the circuit automatically in less time than is required.

The **internal** earth fault loop impedance (Z_{int}) is calculated from: (Ref R-6-B section B5.2.1);

$$Z_{int} = \frac{0.8U_0}{I_a}$$

Where:

Z_{int}	=	the **internal** earth fault loop impedance in Ohms (Ω)
U_0	=	the nominal phase voltage in volts (V)
I_a	=	current causing automatic operation of the protective device in amperes (A) as follows: Type B circuit breaker I_a = 4 x rated current of circuit breaker Type C circuit breaker I_a = 7.5 x rated current of circuit breaker Type D circuit breaker I_a = 12.5 x rated current of circuit breaker

Example X-6-5-4: Calculation of Permissible Z_{int}

Calculate the maximum permissible **internal** earth fault loop impedance (Z_{int}) of a circuit supplying a 32A three phase socket outlet that is protected by a type 'C' 32A M.C.B. in a 230/400 volt installation.

Solution:

$$Z_{int} = \frac{0.8 \times 230}{7.5 \times 32} = 0.767\Omega$$

Once the maximum permissible internal earth loop impedance is known, the maximum length of the cable can be determined so that the impedance of the cable is less than or equal to the maximum permissible **internal** earth fault impedance.

Cable Selection Based on Earth Loop Impedance

The major impact that earth fault loop impedance has on a circuit is to limit its length for a given CSA. Tables 34 to 39 of **Ref R-6-D** can be used to predict the earth fault loop impedance of a cable for a given length in the design stage. In most cases if the cable has been selected correctly based on current carrying capacity and volt drop the earth fault loop impedance will not be an issue. Normally voltage drop is the most significant factor that limits the length of a cable. Long cables which are lightly loaded however can be an issue.

Example X-6-5-5: Earth fault loop impedance

Calculate the maximum permissible earth fault loop impedance (Z_{int}) of a circuit supplying a hot water service type 'C' 20A M.C.B. in a 230/400 volt installation.

If this circuit is wired in 2.5 mm^2 2C+E V90 orange circular cable and the length of the cable run is 60m.

i. Determine the impedance of the cable between active and protective earthing conductors
ii. Does the circuit comply with AS 3000 requirement for earth fault loop impedance (Y/N) and why?
iii. Calculate the voltage drop on this section of cable.

Solution:

$$Z_{int} = \frac{0.8U_0}{I_a} = \frac{0.8 \times 230}{7.5 \times 20} = 1.227\Omega$$

i. Active and Protective earthing conductor impedance

   2.5mm^2 R_c = 9.45Ω/km (AS3008.1 Table 35 Col 4) assume 90°C

$$R = \frac{R_c}{1000} \text{ x } L \text{ x } 2 = \frac{9.45}{1000} \text{ x } 60 \text{ x } 2 = 1.134\,\Omega$$

ii. Yes less than 1.227Ω (from question part (a))

iii. V_C = 16.4 x 1.155 = 18.942mV/A.m (T42C8)

$$V_d = \frac{L \text{ x } I \text{ x } V_c}{1000} = \frac{60 \text{ x } 20 \text{ x } 18.942}{1000} = 22.73\text{V}$$

Maximum Length Based on Earth Loop Impedance

Table B1 of Ref R-6-B specifies maximum route lengths for a number of standard circuit protection device and cable size combinations. Only lengths relating to 0.4s disconnection times are shown.

Circuits supplying socket outlets and lighting points which are R.C.D. protected are not restricted in length by earth fault loop impedance, the R.C.D. will operate under active to earth fault conditions despite excessive earth fault loop impedance. Voltage drop on the circuit must still be considered.

Calculation of maximum length of conductors based on earth fault loop impedance.

If a cable/circuit breaker combination is not listed in table B1 of Ref R-6-B or the circuit supplied has a 5 second disconnection time the earth fault loop impedance must be calculated.

The **maximum route length** based on earth fault loop impedance (L_{max}) is calculated by (Ref R-6-B section B5.2.2);

$$L_{max} = \frac{0.8U_0 S_{ph} S_{pe}}{I_a \rho (S_{ph} + S_{pe})}$$

Where:

L_{max}	=	maximum route length in metres
U_O	=	the nominal phase voltage in volts (V)
ρ	=	resistivity at normal working temperature in Ω-mm^2/m (22.5 x 10^{-3} for copper and 36 x 10^{-3} for aluminium)
I_a	=	current causing instantaneous operation of the protective device in amperes (A), i.e. the current that assures operation of the protective fuse concerned, in the specified time
S_{ph}	=	cross sectional area of the active conductor of the circuit concerned in mm^2
S_{pe}	=	cross sectional area of the protective earthing conductor concerned in mm^2

The above equation was used to determine the maximum lengths of cables in table B1 of Ref R-6-B. If a circuit has a disconnection time of 5 seconds the mean tripping current of the protection device must be found from manufactures data (such as **Figure F-6-5-2**). The multiples of the nominal current are then applied to the nominal current rating to find I_a. The characteristic curves of circuit breakers in the 5 second range vary widely. The earth fault loop impedance must be calculated to suit the characteristic of the brand of circuit breaker actually used.

Example X-6-5-6: Maximum length of conductors

Use Section B5.2.2 of AS 3000 to calculate the maximum route length based on earth fault loop impedance for a 4mm^2 2C+E V90 circuit supplying a cook top protected by a C25A Clipsal M.C.B. in a 230/400 volt installation

Solution:

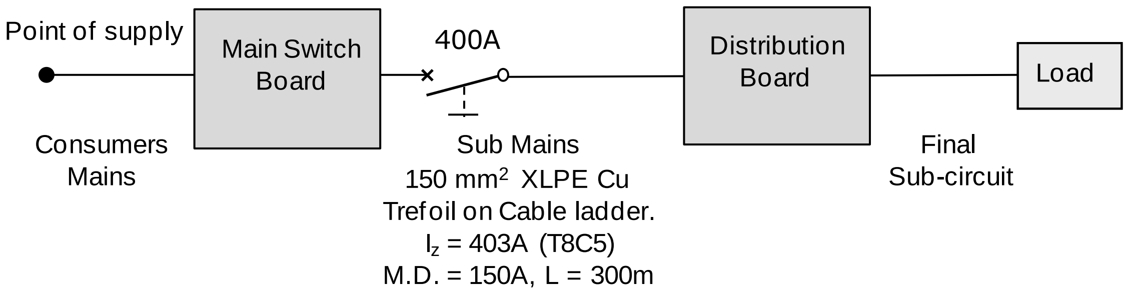
Notes:

1. From Table 5.1 of Ref R-6-B the earth conductor for a 4 mm^2 2C+E cable is 2.5 mm^2
2. The resistivity of copper is $\rho = 22.5 \times 10^{-3}$ Ω-mm^2/m
3. For a Type C CB is: $I_a = 7.5 \times I_N = (7.5 \times 25)$ A

$$L_{max} = \frac{0.8U_0S_{ph}S_{pe}}{I_a\rho(S_{ph} + S_{pe})} = \frac{0.8 \times 230 \times 4 \times 2.5}{7.5 \times 25 \times 22.5 \times 10^{-3}(4 + 2.5)} = 67m$$

The situation can arise, on a long run of cable, where cable size has been increased to compensate for voltage drop, the maximum demand (I_B) will be much lower than the current carrying capacity of the cable (I_Z). The Example below shows a case where both current carrying capacity and voltage drop comply with Ref R-6-B requirements, but the earth fault loop impedance does not.

Example X-6-5-7:



Clause 2.5.3.1 AS3000 Protection against overload $I_B \leq I_N \leq I_Z$.

In this case I_B (150A) is less than I_N (400A) and I_N is less than I_Z (403A), so protection against overload is provided.

Clause 3.6.2 AS3000 Voltage drop should not exceed 5% of nominal supply voltage.

When calculating voltage drop it is permitted to use the lower maximum demand current rather than the rating of the circuit breaker.

$$Vd = \frac{L \times I \times V_C}{1000} = \frac{300 \times 150 \times 0.316}{1000} = 14.22V$$

The voltage drop on the circuit is not excessive and complies with AS3000 requirements. While a 150A would be a more suitable rating of a circuit breaker, than the 400A device, it still complies with AS3000 requirements for overload protection and voltage drop.

Clause 1.5.5.3 AS300 Protection by automatic disconnection of supply

Circuits under fault conditions between active and earth must be automatically disconnected from the supply with the specified time. In this case for a sub-main, the required disconnection time is 5 seconds.

Clause 5.2.1 AS3000 Determination of maximum length $Z_{int} = \frac{0.8 \times U_O}{I_a}$

From manufactures data such as the graph shown in figure 6 of this section, the current required to operate the 400A C.B. in 5 seconds would be 8 x 400A which equals 3200A.

$$Z_{int} = \frac{0.8 \times U_O}{I_a} = \frac{0.8 \times 230}{8 \times 400} = 0.0575\Omega$$

From table 34 of AS3008.1.1

Active 150 mm^2

$$Z_{PH} = \frac{0.160 \times 300}{1000} = 0.048\Omega$$

Protective Earth 50 mm^2

$$Z_{PE} = \frac{0.494 \times 300}{1000} = 0.1482\Omega$$

$$Z_{Cable} = Z_{PH} + Z_{PE} = 0.048 + 0.1482 = 0.1962\Omega$$

The combined impedance of the cables (active and protective earthing conductor) is larger than the permitted internal earth fault loop impedance (Z_{int}). The 400A circuit breaker would take longer than 5 Seconds to operate.

The circuit does not comply.

<u>Solution 1</u>

Decrease the rating of the circuit breaker to 150A (I_a also changes)

$$Z_{int} = \frac{0.8 \times U_O}{I_a} = \frac{0.8 \times 230}{7.5 \times 150} = 0.1635\Omega$$

The circuit still does not comply. The impedance of the cable is greater than the permissible internal earth fault loop impedance.

<u>Solution 2</u>

Decrease the rating of the circuit breaker to 150A and increase the size of the protective earthing conductor.

$$Z_{PE} = Z_{int} - Z_{PH} = 0.153 - 0.048 = 0.105\Omega$$

Increase the protective earthing conductor to 70mm^2.

$$Z_{PE} = \frac{0.342 \times 300}{1000} = 0.1026\Omega$$

(AS3008.1.1 T34C5)

$$Z_{Cable} = Z_{PH} + Z_{PE} = 0.048 + 0.1026 = 0.15062\Omega$$

The cable impedance (0.15062Ω) is now less than the permissible internal fault loop impedance (0.1635Ω). **The circuit does comply.**

Tutorial 6.5

TQ.6.53 The internal earth fault loop path is from;

[Source: Ref R-6-A, Section 8, Tutorial Q1, P249]

a. active to neutral conductor
b. active to phase conductor
c. active to protective earthing conductor
d. phase to functional earthing conductor.

TQ.6.54 The external earth fault loop path is from;

[Source: Ref R-6-A, Section 8, Tutorial Q2, P249]

a. active to neutral conductor
b. active to phase conductor
c. active to protective earthing conductor
d. phase to functional earthing conductor.

TQ.6.55 The maximum permissible disconnection time to provide fault protection (protection against indirect contact), for a circuit supplying 10A socket outlets is;

[Source: Ref R-6-A, Section 8, Tutorial Q3, P249]

a. 0.4 seconds
b. 1.45 seconds
c. 5 seconds
d. 1 hour

TQ.6.56 The device that will operate to provide fault protection (protection against indirect contact) in the shortest time on a circuit supplying 10A socket outlets is;

[Source: Ref R-6-A, Section 8, Tutorial Q4, P249]

a. a H.R.C. fuse
b. an R.C.D.
c. a thermal magnetic circuit breaker
d. a thermal overload.

TQ.6.57 The maximum permissible disconnection time to provide fault protection (protection against indirect contact), supplying lighting points, is;

[Source: Ref R-6-A, Section 8, Tutorial Q5, P249]

a. 0.4 seconds
b. 1.45 seconds
c. 5 seconds
d. 1 hour

TQ.6.58 The device that will operate to provide fault protection (protection against indirect contact) in the shortest time on a circuit supplying lighting points is;

[Source: Ref R-6-A, Section 8, Tutorial Q6, P250]

a. a H.R.C. fuse.

b. an R.C.D.

c. a thermal magnetic circuit breaker

d. a thermal overload.

TQ.6.59 The maximum permissible disconnection time to provide fault protection (protection against indirect contact), for a sub-main rated at 63A, is;

[Source: Ref R-6-A, Section 8, Tutorial Q7, P250]

a. 0.4 seconds

b. 1.45 seconds

c. 5 seconds

d. 1 hour

TQ.6.60 The device that should not be used to provide fault protection, for a sub-main rated at 63A, is;

[Source: Ref R-6-A, Section 8, Tutorial Q8, P250]

a. a H.R.C. fuse.

b. an R.C.D.

c. a thermal magnetic circuit breaker

d. an electronic circuit breaker

TQ.6.61 When calculating the internal earth fault loop impedance the voltage present at the circuit protection device (reference point) is;

[Source: Ref R-6-A, Section 8, Tutorial Q9, P250]

a. 230V

b. 240V

c. 184V

d. 400V

TQ.6.62 The maximum value of earth fault loop impedance for a sub main protected by a 63 A H.R.C. fuse is;

[Source: Ref R-6-A, Section 8, Tutorial Q10, P250]

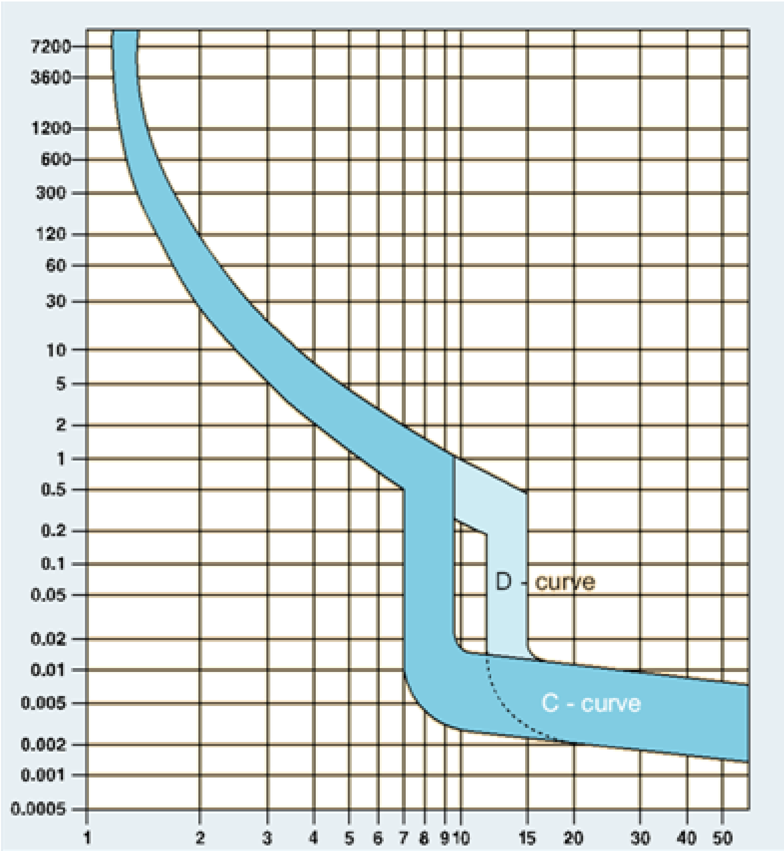
a. 0.55Ω

b. 0.94Ω

c. 1.53Ω

d. 1MΩ.

Tutorial questions TQ.6.63 to TQ.6.65 refer to following diagram:



TQ.6.63 Calculate the total earth fault loop impedance for a circuit supplying a hot water system protected by a Clipsal 20A type 'C' circuit breaker.

[Source: Ref R-6-A, Section 8, Tutorial Q11, P251]

TQ.6.64 Calculate the internal earth fault loop impedance for a circuit supplying a hot water system protected by a Clipsal 20A type 'C' circuit breaker.

[Source: Ref R-6-A, Section 8, Tutorial Q12, P251]

TQ.6.65 If the hot water system of question TQ.6.64 is wired in 2.5mm^2 Twin and Earth with a circuit length of 35 m;

[Source: Ref R-6-A, Section 8, Tutorial Q13, P252]

a. Calculate the internal earth fault loop impedance of the final sub-circuit (hint use AS3008.1.1 to determine Z_{ph} and Z_{pe})

b. Does the calculated internal earth loop impedance comply with AS3000?

c. Calculate the voltage drop on the H.W.S. final sub-circuit.

d. If 4.6V was lost on the consumers mains, does the final-sub circuit comply with AS3000 requirement for voltage drop? Y/N

TQ.6.66 A 50 mm^2 copper sub-main is protected by a 125A **H.R.C. fuse** with a route length of 80 m

[Source: Ref R-6-A, Section 8, Tutorial Q14, P252]

a. Determine from table 8.1 AS3000 the maximum permissible **internal** earth fault loop impedance.

b. Use table B1 of AS3000 to determine if the route length is compliant.

References for Chapter 6

R-6-A TAFE Training & Education Support Industry Skills Unit 2009, *UEENEEGOO7B - Select and arrange equipment for general electrical installations* , Industry Skills Unit, Meadowbank.

R-6-B Standards Australia 2007, AS/NZS 3000:2007 Electrical installations, Standards Australia, Sydney

R-6-C NSW Trade and Investment 2011, *Service and Installation Rules of New South Wales*, Dept. of Energy, Utilities and Sustainability, Sydney.

R-6-D Standards Australia 2009, Electrical installations - Selection of cables - Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV – Typical Australian installation conditions, (AS/NZS 3008.1.1), Standards Australia, Sydney.