Chapter 6

WIRING SYSTEMS

Safe Electrical Design

Topic 6-3

CABLE SELECTION BASED ON CURRENT CARRYING CAPACITY REQUIREMENTS

INSTALLATION CONDITIONS

- Current carrying capacity (CCC) is the maximum continuous current that a particular cable can carry without overheating.
- Conditions which affect CCC, and thus the size of cable conductor needed for a circuit, are:
  - ambient temperature;
  - type of cable, ie ability of the insulation/sheathing to transmit heat
  - installation method

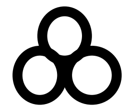
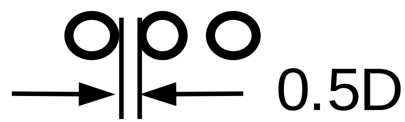
INSTALLATION CONDITIONS

- installation method examples are cables installed in:
  - air;
  - thermal insulation;
  - conduits, ducts and trunking
  - underground

INSTALLATION CONDITIONS

- 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. (A & N for 1-phase circuits and phase conductors for 3-phase circuits)
    - .

INSTALLATION CONDITIONS

- Single core cables can be configured;
  - ➢ Trefoil 
  - ➢ Laid flat touching 
  - ➢ Laid flat separated 

- Separation between cables improves the heat dissipation of the conductors and improves current carrying performance.
- Laying the cables in trefoil reduces magnet effects.

INSTALLATION CONDITIONS

- 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 CCC capacity of a cable will be affected by the presence of certain external influences as summarised below.

INSTALLATION CONDITIONS

- 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.

INSTALLATION CONDITIONS

- Under such conditions the CCC 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.

INSTALLATION CONDITIONS

- The circuit protection device selected to protect the cable will also affect the cable CCC 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).

INSTALLATION CONDITIONS

- “Standard” conditions of installation and operation to avoid de-rating are given by **Ref R-6-D** as;

CONDITION	**STANDARD**
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

INSTALLATION CONDITIONS

- 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

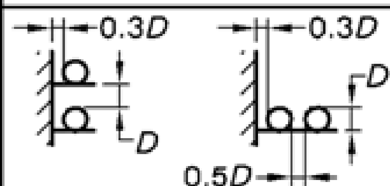
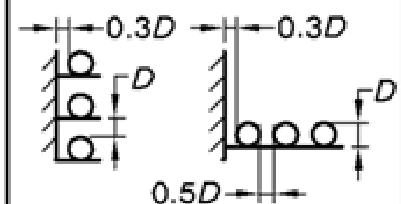
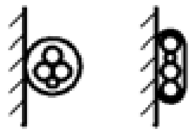
1	2	3	4	5	6
Item No.	**Cable details (see Note 2)**	**Reference drawing (see Note 3)**	**Current-carrying capacity table reference**	**Methods of installation for cables deemed to have the same current-carrying capacity (See Notes 4, 5 and 6)**	**Derating table for more than one circuit**
1	Two single-core 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

Fig **PF-6-3-1 –** Part Table 3(1) from AS/NZS 3008.1.1:2009

			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.

Fig **PF-6-3-2 –** Part Table 3(1) (Footnotes) from AS/NZS 3008.1.1:2009

INSTALLATION CONDITIONS

- 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 PF-6-3-1**.
- Some examples of determining de-rating factors follow:

EXAMPLE Ex-6-3-1
Determining De-rating Factors

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 Ex-6-3-2
Determining De-rating Factors

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(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 Ex-6-3-3
Determining De-rating Factors

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 derating table in this case table 24.

Step 3: From table 24 item 13 column 8, the derating factor is 0.8

INSTALLATION CONDITIONS

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 AS3008.1.1 2009 (Ref R-6-D)

Selecting Cable Size Based on Current Rating.

- Selection of cable size based on current carrying capacity is based on;
- $I_B \leq I_N \leq I_Z$
- In words, this states that the rated CCC of a conductor ($\mathbf{I_Z}$) must be greater than or equal to the nominal current rating of the protective device ($\mathbf{I_N}$) which in turn must be greater than or equal to the maximum demand or expected load current of the conductor($\mathbf{I_B}$)

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

<u>Selecting Cable Size Based on Current Rating</u> (Cont'd)

- The steps involved in determining the minimum CCC (I_Z) are:
  1) determine the current requirements, maximum demand (I_B) for the circuit;
  2) determine the current rating of the protective device (I_N) to be used. Table 8.1, 8.2 and B1 of AS/NZS 3000:2007 shows standard protection device ratings up to 200A;
  3) decide which cable type and installation method to use;
  4) apply de-rating/rating factor from tables of Ref. R-6-D for the installation environment conditions where applicable;

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

Selecting Cable Size Based on Current Rating (Cont'd)

5) 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.

- 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**

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

- The CCC 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.

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

Which Table to Use.

- Tables 4 to 15 of **Ref. R-6-D** are the most frequently used CCC tables, covering 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.

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

<u>How to use Table 3</u> (Cont'd)

1) Look up the Table 3 that applies to how the cable is to be installed. For example **cable enclosed in conduit** - Table 3(2) is appropriate.
2) In column 2 of Table 3(2) match a description of the cable configuration to be used against a reference drawing in column 3 that shows how the cable is to be installed. For example three single core cables installed in conduit in air. (See Fig PF-6-3-3)

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		

Fig **PF-6-3-3 –** Part Table 3(2)

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

How to use Table 3 (Cont'd)

3) Column 4 on the same row gives the CCC tables and columns to use to select the minimum conductor size. (See Fig PF-6-3-4)

4) If reference drawing in column 3 does not fully show how the cable is intended to be installed, then check column 5 for a description of installation methods deemed to be the same. (See Fig PF-6-3-5)

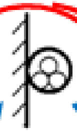
1	Two single-core cables		Tables 4 and 5 Columns 15 to 17 Table 6 Columns 11 and 12	Cables in wiring enclosures installed in— (a) air; (b) plaster, cement render, masonry or concrete in a wall or floor; (c) a concrete slab on or above the surface of the ground; or (d) a ventilated trench. Cables installed 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		

Fig **PF-6-3-4 –** Part Table 3(2)

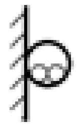
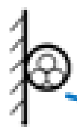
1	Two single-core cables		Tables 4 and 5 Columns 15 to 17 Table 6 Columns 11 and 12	Cables in wiring enclosures installed in— (a) air; (b) plaster, cement render, masonry or concrete in a wall or floor; (c) a concrete slab on or above the surface of the ground; or (d) a ventilated trench. Cables installed 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		

Fig **PF-6-3-5 –** Part Table 3(2)

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

How to use Table 3 (Cont'd)

3) 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 – see Fig PF-6-3-6

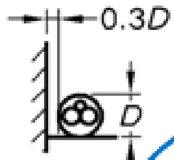
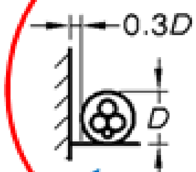
1	2	3	4	5	6
Item No.	**Cable details (see Note 2)**	**Reference drawing (see Note 3)**	**Current-carrying capacity table reference**	**Methods of installation for cables deemed to have the same current-carrying capacity (See Notes 4, 5 and 6)**	**Derating table for more than one circuit**
9	Two-core cables		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		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

Fig **PF-6-3-6 –** Part Table 3(2)

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

How De-Rating (and Rating) Factors are Applied.

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

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

How De-Rating (and Rating) Factors are Applied (Cont'd)

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

CURRENT CARRYING CAPACITY TABLES IN AS3008.1.1 2009 (Ref R-6-D)

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 CCC for that cable configuration and installation conditions.
- Tables 15 to 21 are not mentioned in table 3 as they apply to 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 AS/NZS 3000:2007 stipulates operating temperature limits for different cable types and these are summarised in Table 3.2.
- 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

CABLE SELECTION

Conductors in Parallel

- Clause 3.4.3 of AS/NZS 3000:2007 provides guidelines on paralleling cables.
- CCCs 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:
  - cables shall be not less than 4 mm^2; and

CABLE SELECTION

<u>Conductors in Parallel</u> (Cont'd)

- grouping of cables shall not affect the cooling of each parallel cable, or group, by the ambient air or the ground; and
- the load current sharing between each parallel cable, or group shall be sufficient to prevent overheating of any cable or group.

EXAMPLE Ex-6-3-4
Conductors in Parallel

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

Solution to EXAMPLE Ex-6-3-4 Conductors in Parallel

- **CCC = 400A**
- For detailed procedure in arriving at the above answer see Workbook Chapter 6, Topic 6-3

CABLE SELECTION

Neutral Conductor Size

Clause 3.5.2 of AS/NZS 3000:2007 provides guidelines on neutral conductor size for various types of circuits and in summary states:

a. For 1-phase 2-wire circuit the neutral conductor or conductors must have a CCC not less than
    i. the CCC of the associated active conductor; or
    ii. the total current to be carried, where there is more than one active conductor

CABLE SELECTION

Neutral Conductor Size (Cont'd)

b. For multiphase circuit the CCC 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

CABLE SELECTION

<u>Neutral Conductor Size</u> (Cont'd)

c. The minimum size of a combined protective earth and neutral (PEN) conductor of consumers mains, or of a sub-main 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.

CABLE SELECTION

Protective Earthing Conductor Size

- Size of protective earthing conductor is related to the CSA of the largest active conductor and is selected from Table 5.1 of AS/NZS 3000:2007. for example:
  - 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).

EXAMPLE Ex-6-3-5

Cable Selection using AS3008.1.1:2009

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.

Solution to EXAMPLE Ex-6-3-4 Conductors in Parallel

- **Cable Size is** 50mm^2 (176A)
- **Protective Earth Size is** 16mm^2
- For detailed procedure in arriving at the above answer see Workbook Chapter 6, Topic 6-3

CABLE SELECTION

Adjustable Circuit Breakers (200A - 400A)

- When a circuit requires a protection device larger than 200A an adjustable circuit breaker (Figure **F-6-3-7)** 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.

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 (VD) across the length of the cable will occur.
- This VD will reduce the supply voltage available at the terminals of the load supplied by the cables.

INTRODUCTION

- Clause 3.6.2 of AS/NZS 3000:2000 states “The CSA of every current-carrying conductor shall be such that the VD 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

INTRODUCTION

- Excessive VD 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 VD must be considered when selecting cables, especially for circuits which have long route lengths and circuits with relatively high currents.

INTRODUCTION

- 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).

INTRODUCTION

- 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 at various temperatures.
- 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 tables.

VOLTAGE DROP TABLES IN AS3008.1.1 (2009)

- The 3-phase values of V_c appearing in the tables 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 VD of a 1-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 1-phase value of V_c using formula:

VOLTAGE DROP TABLES IN AS3008.1.1 (2009)

$$\text{single phase voltage drop} = \frac{2}{\sqrt{3}} \times \text{three phase voltage drop}$$

- When the single phase value of V_c has been calculated, the 1-phase value of V_c must be converted to a 3-phase value of V_c. using :

$$\text{three phase voltage drop} = \frac{\sqrt{3}}{2} \times \text{single phase voltage drop}$$

- The CSA of a suitable cable is then found from a table;

VOLTAGE DROP TABLES IN AS3008.1.1 (2009)

- 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 (2009)

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

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

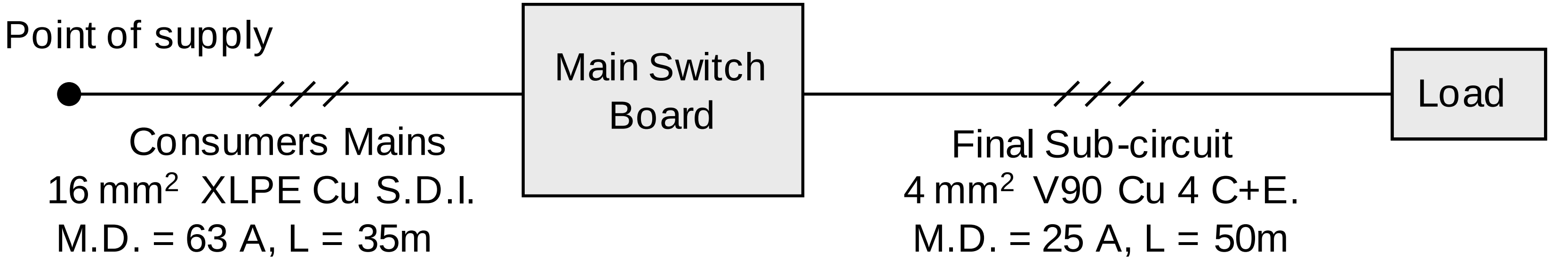
- where
- V_d = the actual voltage drop, in volts
- V_c = the value found from **Ref. R-6-D** tables in mV/A.m
- L = the route length of circuit, in metres
- I = the current to be carried by the cable, in amperes.

VOLTAGE DROP CALCULATIONS USING AS3008.1.1 (2009)

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

EXAMPLE Ex-6-4-1
Calculating V_d

Calculate the voltage drop for the installation



Solution to EXAMPLE Ex-6-4-1 Calculating V_d

For consumers mains:

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

For final sub-circuit:

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

Total voltage drop is 5.62 + 12.75 = 18.37V

- For detailed procedure in arriving at the above answer see Workbook Chapter 6, Topic 6-4

VOLTAGE DROP CALCULATIONS USING AS3008.1.1 (2009)

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.

VOLTAGE DROP CALCULATIONS USING AS3008.1.1 (2009)

Three Phase Installations with Single Phase Circuits

- If an installation is supplied by 3-phase and has 1-phase circuits within the installation, both 3 and 1 phase VDs 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

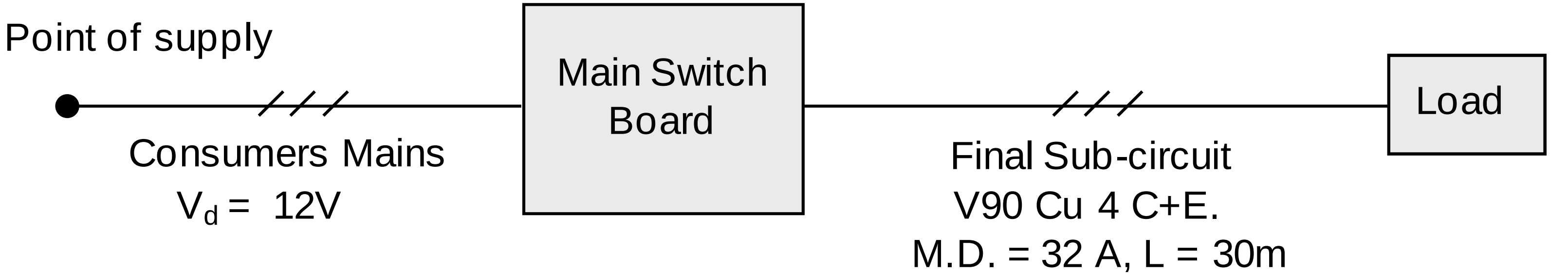
- Cable sizes are selected in order not to exceed a certain VD drop figure.
- Thus the following equation (as presented in previous Topic) is used to determine V_c and then Tables 40 to 51 of Ref R-6-D are consulted to select appropriate cable size

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

EXAMPLE Ex-6-4-2

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 to EXAMPLE Ex-6-4-2
Cable Selection Based on Voltage Drop

a) FSC allowable volt drop is **8V**
b) maximum permissible value of V_c is **8.333 mV/A.m**
c) minimum cable size is **6 mm²**

- For detailed procedure in arriving at the above answer see Workbook Chapter 6, Topic 6-4

EXAMPLE Ex-6-4-3
MAXIMUM LENGTH OF CABLE BASED ON VD

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:** V_c, from Table 42 is 15.6mV/A.m
- Then from

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

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

Topic 6-5

CABLE SELECTION BASED ON EARTH FAULT LOOP IMPEDANCE REQUIREMENTS

INTRODUCTION

- VD 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 (PE) conductor is usually smaller than the active or neutral conductors; its impedance will be higher than that of the active or neutral conductors.

INTRODUCTION

- Under earth fault conditions the combined impedance of the fault path from active to PE 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 PE 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.

INTRODUCTION

- 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”.
- AS/NZS 3000:2007 requires **fault protection** (protection from indirect contact with live parts).

INTRODUCTION

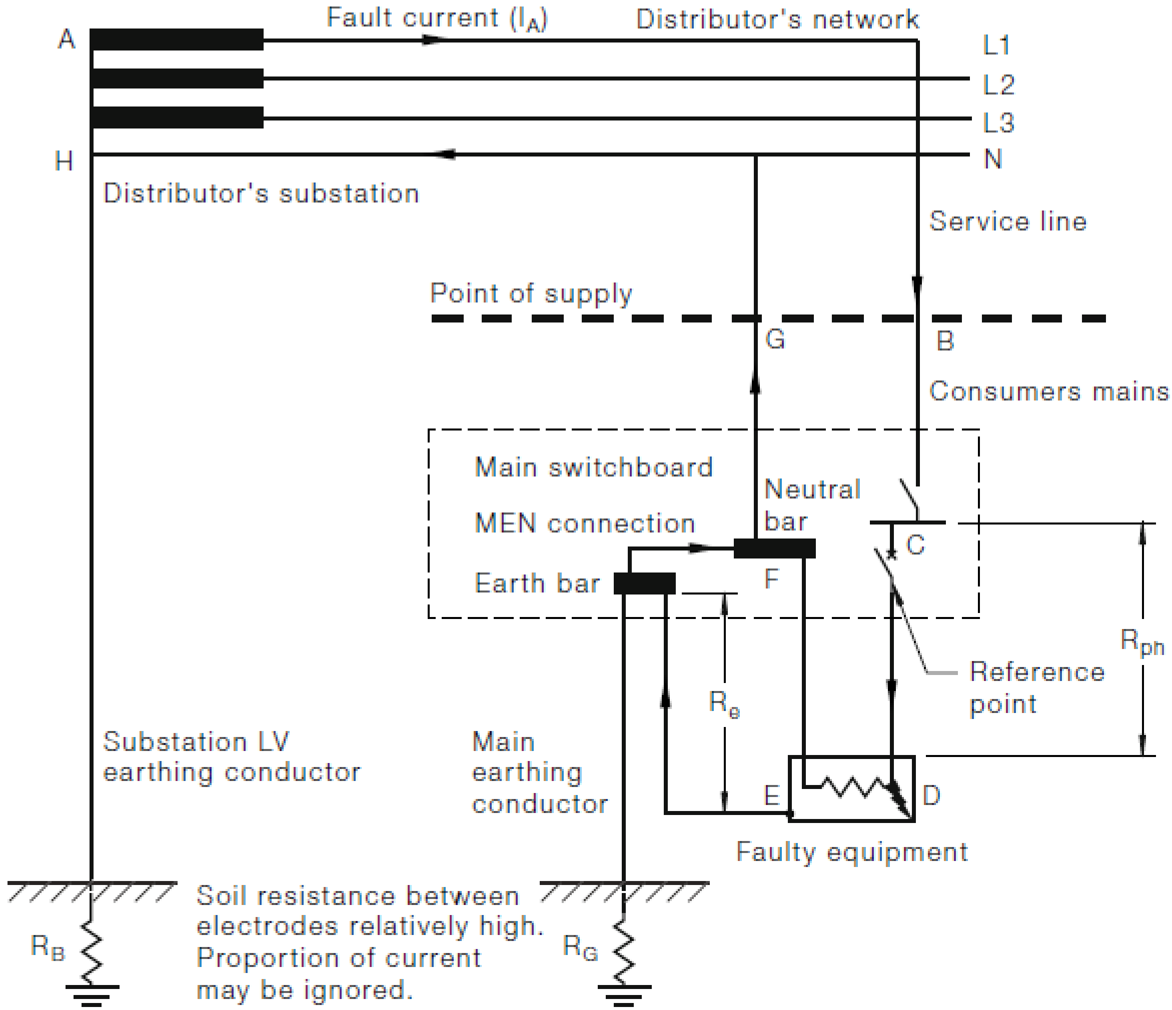
- The most commonly used method for providing this protection is automatic disconnection of supply.
- Automatic disconnection of the supply (AS/NZS 3000:2007) shall be achieved by:-
  - provision of a system of earthing in which exposed conductive parts are connected to protective earthing conductors, and;
  - automatic disconnection of the fault by an over-current protective device or an RCD within the disconnection time.

INTRODUCTION

- 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 PE 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.

INTRODUCTION

- The earth fault-loop in an MEN system is as shown in figure B5 of AS/NZS 3000:2007, reproduced below as **Fig. PF-6-5-1**
  - 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.



NOTE: Although supply from a distribution system is shown, the same principle applies where the substation forms part of the electrical installation.

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

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

CABLE IMPEDANCE TABLES IN AS/NZS 3008.1.1

- 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.

CABLE IMPEDANCE TABLES IN AS/NZS 3008.1.1

- 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 kilometre (Ω/km). To calculate the A.C. resistance of a given conductor use the equation;

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

CABLE IMPEDANCE TABLES IN AS/NZS 3008.1.1

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)

EXAMPLE Ex-6-5-1
Determining R_C from Tables

Calculate the A.C. resistance of a single conductor in the following cable:

10 mm^2 4C+E V90 (Cu) cable, 45m long

Solution:

From Ref R-6-D, Table 35, Column 4, for 10mm^2 cable

$R_C = 2.33\Omega/km$

Therefore:

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

EARTH LOOP IMPEDANCE CALCULATIONS

- Any circuit protected by an RCD satisfies the requirements of earth fault loop impedance.
- RCDs that protect light and power circuits must have a rated residual current of not greater than 30mA (AS/NZS 3000:2007 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.

EARTH LOOP IMPEDANCE CALCULATIONS

- Type ‘S’ RCDs which have a rated residual current in the range of 100 to 300mA (AS/NZS 3000:2007 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 RCDs:
  - **Residential (domestic) installations**
    - Socket outlets
    - Lighting points
    - Directly connected hand-held electrical equipment

EARTH LOOP IMPEDANCE CALCULATIONS

- **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.
- This is done in miniature circuit breakers (MCBs) by the magnetic trip mechanism.
- If the fault current is too low the circuit breaker will trip by the thermal mechanism.

DISCONNECTION TIMES

- 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 AS/NZS 3000:2007 specify time in which automatic disconnection of supply must occur.

DISCONNECTION TIMES

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.

DISCONNECTION TIMES

- The total earth fault loop impedance (Z_S) is calculated by: (AS/NZS 3000:2007 section B4.5);

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

Where:

Z_s = the total 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

DISCONNECTION TIMES

Figure PF-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 PF-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

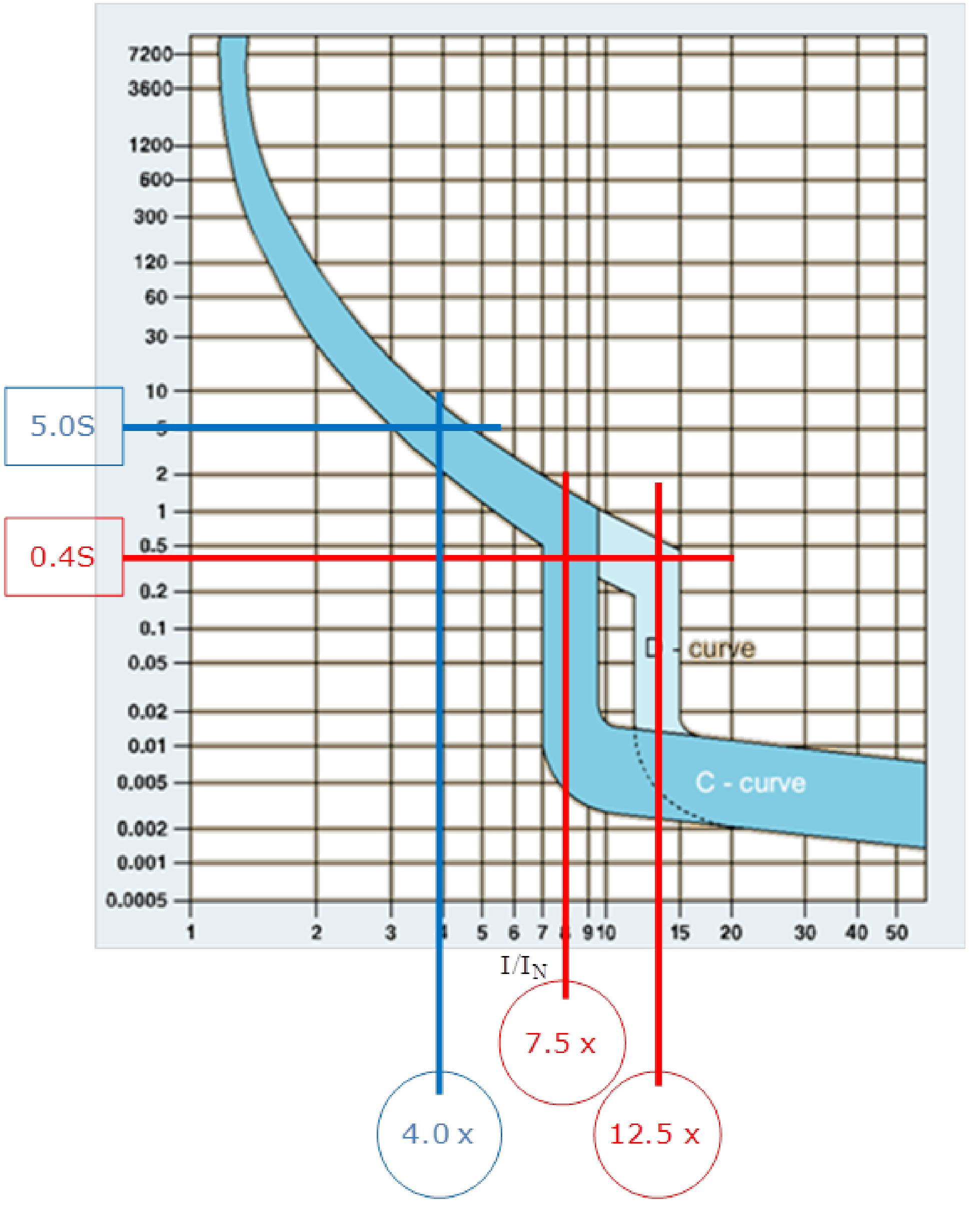


Figure PF-6-5-2
Clipsal 6 and 10 kA M.C.B. characteristic curve

DISCONNECTION TIMES

- When designing circuits for a 5 s disconnection time, the circuit protection manufacturer's data must be used.
- Calculations and table data in AS/NZS 3000:2007 refers to a 0.4 second disconnection time.
- The value of 4 x in **figure PF-6-5-2** is the current required to operate the circuit breaker within 5 s.
- 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..

EXAMPLE Ex-6-5-2

Calculating Z_s (Total earth fault loop impedance)

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:

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

TOTAL EARTH FAULT LOOP IMPEDANCE (Z_S)

- The maximum value of total earth fault loop impedance (Z_S) can also be found using table 8.1 of AS/NZS 3000:2007.
- 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 Ex-6-5-3

Determining Earth Fault Impedance from Tables

Determine the total earth fault loop impedance for the following:

- A 25A socket outlet in data room protected by a 25A type C circuit breaker

Solution:

- From Clause 1.5.5.3(d) of AS/NZS 3000:2007 Socket Outlet is less than 63A, therefore 0.4s disconnect time applies
- From table 8.1 of AS/NZS 3000:2007, $Z_s = 1.23\Omega$

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 PF-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 PF-6-5-1, that at least 80% of the nominal supply voltage (230V) is available under earth fault conditions.

INTERNAL EARTH FAULT LOOP IMPEDANCE (Z_{int})

- 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: (AS/NZS 3000:2007 section B5.2.1);

INTERNAL EARTH FAULT LOOP IMPEDANCE (Z_{int})

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

Where:

Z_{int} = **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 Ex-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:

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

INTERNAL EARTH FAULT LOOP IMPEDANCE (Z_{int})

- 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.
- In most cases if the cable has been selected correctly based on CCC and VD the earth fault loop impedance will not be an issue.
- Normally VD is the most significant factor that limits the length of a cable. Long cables which are lightly loaded however can be an issue.

EXAMPLE Ex-6-5-5
EARTH FAULT LOOP IMPEDANCE

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

b) 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 to EXAMPLE Ex-6-5-5 EARTH FAULT LOOP IMPEDANCE

a)

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

b)

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 AS/NZS 3000:2007 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 RCD 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.

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 AS/NZS 3000:2007 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 (AS/NZS 3000:2007 section B5.2.2);

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

CALCULATION OF MAXIMUM LENGTH OF CONDUCTORS BASED ON EARTH FAULT LOOP IMPEDANCE

Where:

L_{max} = maximum route length in metres

U_0 = 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), (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

EXAMPLE Ex-6-5-6
MAXIMUM LENGTH OF CONDUCTORS

Use Section B5.2.2 of AS/NZS 3000:2007 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 to EXAMPLE Ex-6-5-6 MAXIMUM LENGTH OF CONDUCTORS

- Note that from Table 5.1 of AS/NZS 3000:2007 the earth conductor size for a $4mm^2$ 2C+E is $2.5\ mm^2$
- Note resistivity of copper is $22.5 \times 10^{-3}\ \Omega\text{-mm}^2/m$
- Note I_a is 7.5 x 25

$$L_{max} = \frac{0.8U_0 S_{ph} S_{pe}}{I_a \rho (S_{ph} + S_{pe})} = \frac{0.8 \times 230 \times 4 \times 2.5}{7.5 \times 25 \times 22.5 \times 10^{-3} (4 + 2.5)} = 67m$$

CALCULATION OF MAXIMUM LENGTH OF CONDUCTORS BASED ON EARTH FAULT LOOP IMPEDANCE

- 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).
- See Example **X-6-5-7** (Chapter 6, Topic 6-5) in Workbook for analysis of a situation where both current carrying capacity and voltage drop comply with AS/NZS 3000:2007 requirements, but the earth fault loop impedance does not.


END