CONTROL AND PROTECTION

Safe Electrical Design

Topic 3-1

PROTECTION FOR SAFETY

ELECTRICAL RISKS

- The use of electrical equipment in industrial, commercial and domestic premises has risks associated with it.
- AS/NZS 3000 identifies three of those risks as:
  - **Shock current.** Shock current coming in contact with parts that are live in normal service
  - **Excessive temperatures.** Excessive temperatures likely to cause burns, fires and other injurious effects.
  - **Explosive atmospheres.** Equipment installed in areas where explosive gases or dusts may be present.

ELECTRIC SHOCK

- Electric Shock (at low voltages) effects mainly the lung and heart function depend mainly on:
- Severity of the effect depends mainly on:
  - AC or DC current
  - Magnitude of current
  - Duration of current
  - Path through body

TOUCH VOLTAGE/CURRENT

- To protect against faults from insulation failure the metal frame of an appliance is connected to earth.
- If the insulation within the appliance develops a fault, the active conductor may contact the conductive metal case. The role of the earth wire is:
  - Provide a low impedance path for current flow allowing the fuse or circuit breaker to function.
  - To try and keep the voltage of the appliance frame (The touch potential) at earth potential

TOUCH VOLTAGE/CURRENT

……(Cont'd)…..

- See **Figure PF-3-1-1** for an illustration of this.
- A way of avoiding this situation is to provide two effective layers of insulation between the live parts and the operator - this is known as double insulation.
- Double insulated appliances bear the following symbol:

TOUCH VOLTAGE/CURRENT

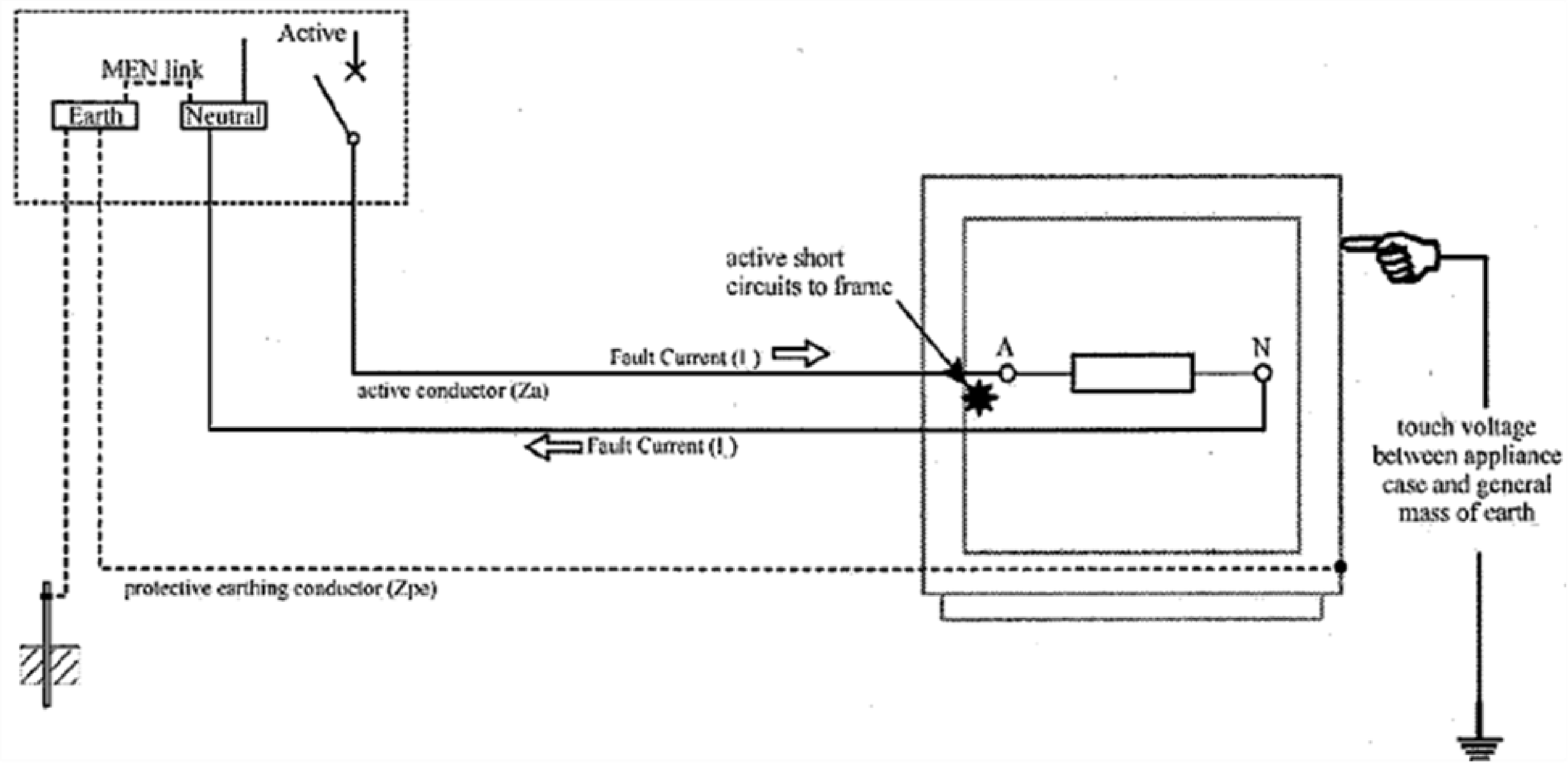


Fig. PF-3-1-1: Example of Touch Voltage

TOUCH VOLTAGE/CURRENT

…..(Cont'd)…..

- An effective earth system limits the touch voltage in an installation to a value less than the nominal supply voltage. It is important the circuit automatically disconnects from the supply when a fault could result in a touch voltage greater than 50V AC.

TOUCH VOLTAGE/CURRENT

….(Cont’d)….

- To determine the magnitude of touch voltage use the equation:

$$V_t = \frac{V_O \times Z_{PE}}{\left(Z_A + Z_{PE}\right)} \qquad \text{(E-3-1-1)}$$

Where:
V_t is touch voltage
V_0 is operating voltage
Z_A is impedance of active conductor
Z_{PE} is impedance of earthing conductor

CURRENT PATHS THROUGH THE HUMAN BODY

- Typical impedance values for various current paths through the human body are shown in **Fig PF-3-1-2** :

➢ Hand to hand	1000 ohms
➢ Hand to foot	1000 ohms
➢ Hand to both feet	750 ohms
➢ Hand to seat	500 ohms
➢ Both hands to seat	250 ohms

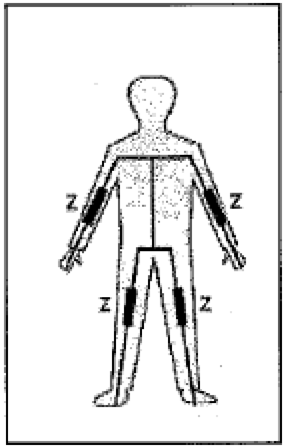


Fig. PF-3-1-2: Current Paths through the Human Body

CURRENT PATHS THROUGH THE HUMAN BODY

….(Cont’d)….

- Using the above values of body resistances the touch current for each path when coming in contact with 230V 50Hz AC source would be:

➢ Hand to hand	230 mA
➢ Hand to foot	230 mA
➢ Hand to both feet	307 mA
➢ Hand to seat	460 mA
➢ Both hands to seat	920 mA

PHYSIOLOGICAL EFFECTS OF ELECTRIC CURRENT THROUGH THE HUMAN BODY

- The effect of electric current on the human body is dependent on the magnitude of the current and the duration of the current.
- The following diagram (**Fig PF-3-1-3**) and accompanying table (**Table PT-3-1-1**) illustrate this:

PHYSIOLOGICAL EFFECTS OF ELECTRIC CURRENT THROUGH THE HUMAN BODY

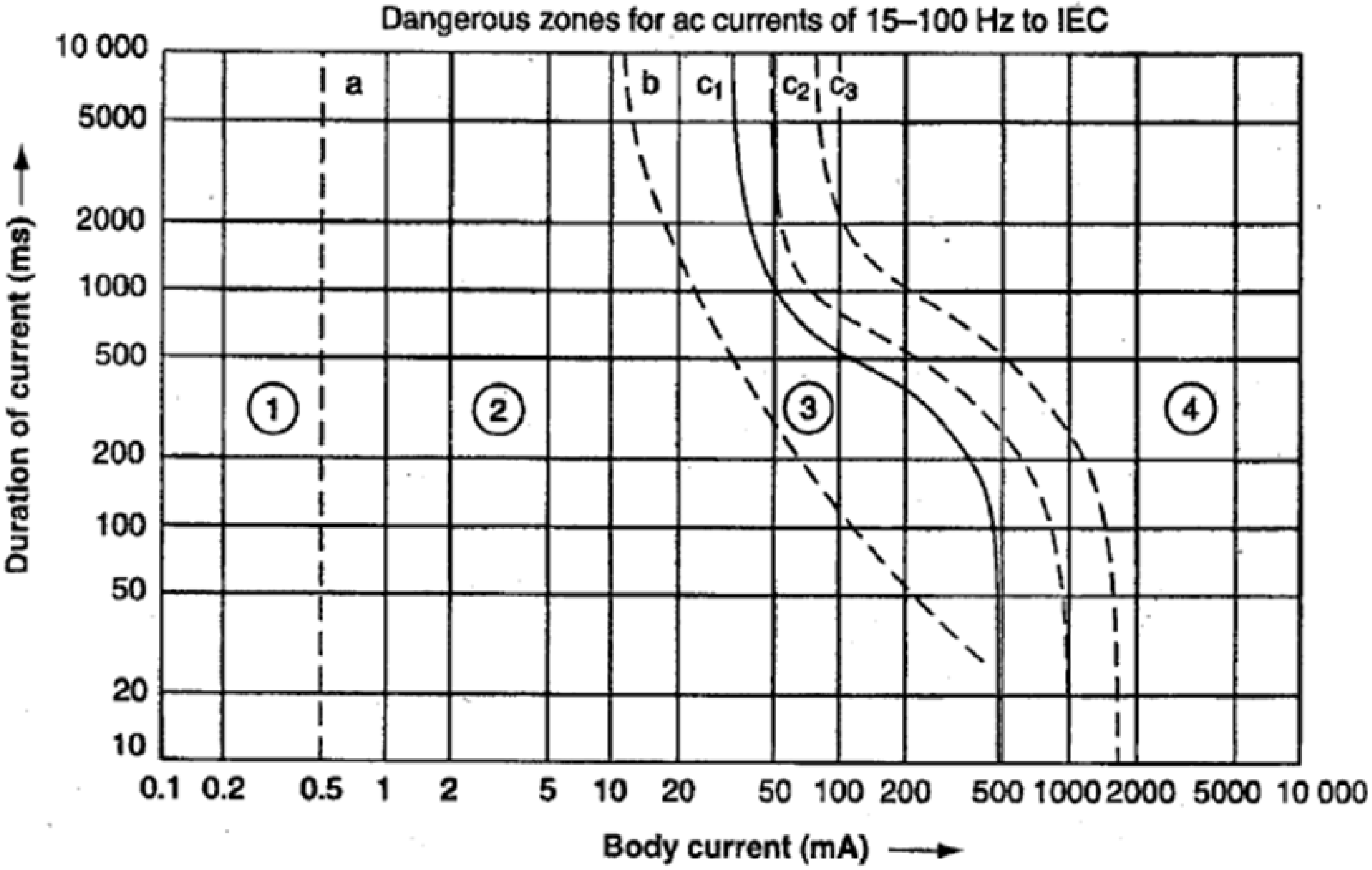


Fig PF-3-1-3 Time/current zones on the human body

PHYSIOLOGICAL EFFECTS OF ELECTRIC CURRENT THROUGH THE HUMAN BODY

Zone	Physiological effects
1	Usually no reaction
2	Usually no harmful physiological effects
3	Likelihood of muscular contractions and difficulty in breathing Possibility of cardiac arrest increasing with value of current and time
4	Effects of zone 3 C1 - probability of ventricular fibrillation 5% C2 - probability of ventricular fibrillation 50% C3 - probability of ventricular fibrillation >50% Further increases in current and/or time are likely to cause arrest & burns

Table PT-3-1-1 Time/current zones on the human body

PHYSIOLOGICAL EFFECTS OF ELECTRIC CURRENT THROUGH THE HUMAN BODY

Illustration

- If a current of 200mA is maintained through a human body for less than 50ms, the resultant locus on **Fig PF-3-1-3** remains in zone 2, which according to **Table PT-3-1-1** results in "*Usually no harmful physiological effects*". If the same current were maintained for more than 50ms the locus would cross into zone 3 (*likely muscular contractions and possible cardiac arrest*). Beyond about 400ms the locus traverses into zone 4 (*possibility of ventricular fibrillation*)

PROTECTION AGAINST THERMAL EFFECTS

- It is necessary to arrange installations so that there is no risk of ignition of flammable materials due to high temperature or electric arc in normal operation.
- Furthermore, there should be no risk of persons or livestock suffering burns during the normal operation of electrical equipment.

PROTECTION AGAINST THERMAL EFFECTS

- There are four effects of current flow. They are:
  - Magnetic
  - Physiological
  - Chemical, and
  - Heat
- When current flows through a conductor heat is generated.
- The amount of heat generated within a conductor is dependent on the load, length, cross-sectional area (CSA) and the type of material of the conductor.

PROTECTION AGAINST THERMAL EFFECTS

- If inappropriate (undersized) cables are used, the cables will overheat due to the I^2R losses of the conductors.
- If the temperature rises above the temperature rating of the cable, e.g., V75, V90, etc. then the cable's insulation will breakdown.
- The heat generated may start a fire

Topic 3-2

FAULT LOOP IMPEDANCE

INTRODUCTION

- Fault-loop impedance is the impedance of the fault-current loop (active to earth) starting and ending at the point of the earth fault.
- AS/NZS 3000 requires that each circuit is protected such that automatic disconnection of supply occurs within a 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 an electrical installation.

THE FAULT-LOOP

- The fault-loop in the MEN system comprises the following:
  - protective earthing conductor (PE), including the main earthing terminal, connection, or bar and MEN link
  - neutral return path, comprising the neutral conductor between the main neutral terminal or bar and the neutral point at the transformer
  - path through the neutral point of the transformer and the transformer winding
  - active conductor as far as the point of the fault

THE FAULT-LOOP

- The fault-loop can be divided into two parts:
  - conductors external to the installation
  - conductors within the installation
- The following diagram from fig B5 of **Ref R-3-C** details the fault-loop circuit.
- Fault loop impedance is obtained from the addition of all the individual impedances as follows:

$$Z_S = Z_{AB} + Z_{BC} + Z_{CD} + Z_{DE} + Z_{EF} + Z_{FG} + Z_{GH} + Z_{HA}$$

THE FAULT-LOOP

- Impedances upstream of the protective device are regarded as being external to the reference point i.e.

  $Z_{EXT} = Z_{AB} + Z_{BC} + Z_{CD} + Z_{FG} + Z_{GH} + Z_{HA}$
- Remainder are downstream and called 'internal' or Z_{INT}
- Therefore $Z_S = Z_{INT} + Z_{EXT}$
- At the instant a fault occurs, current will flow through the fault loop. Only the total system impedance (Zs) limits the magnitude of this current.

THE FAULT-LOOP

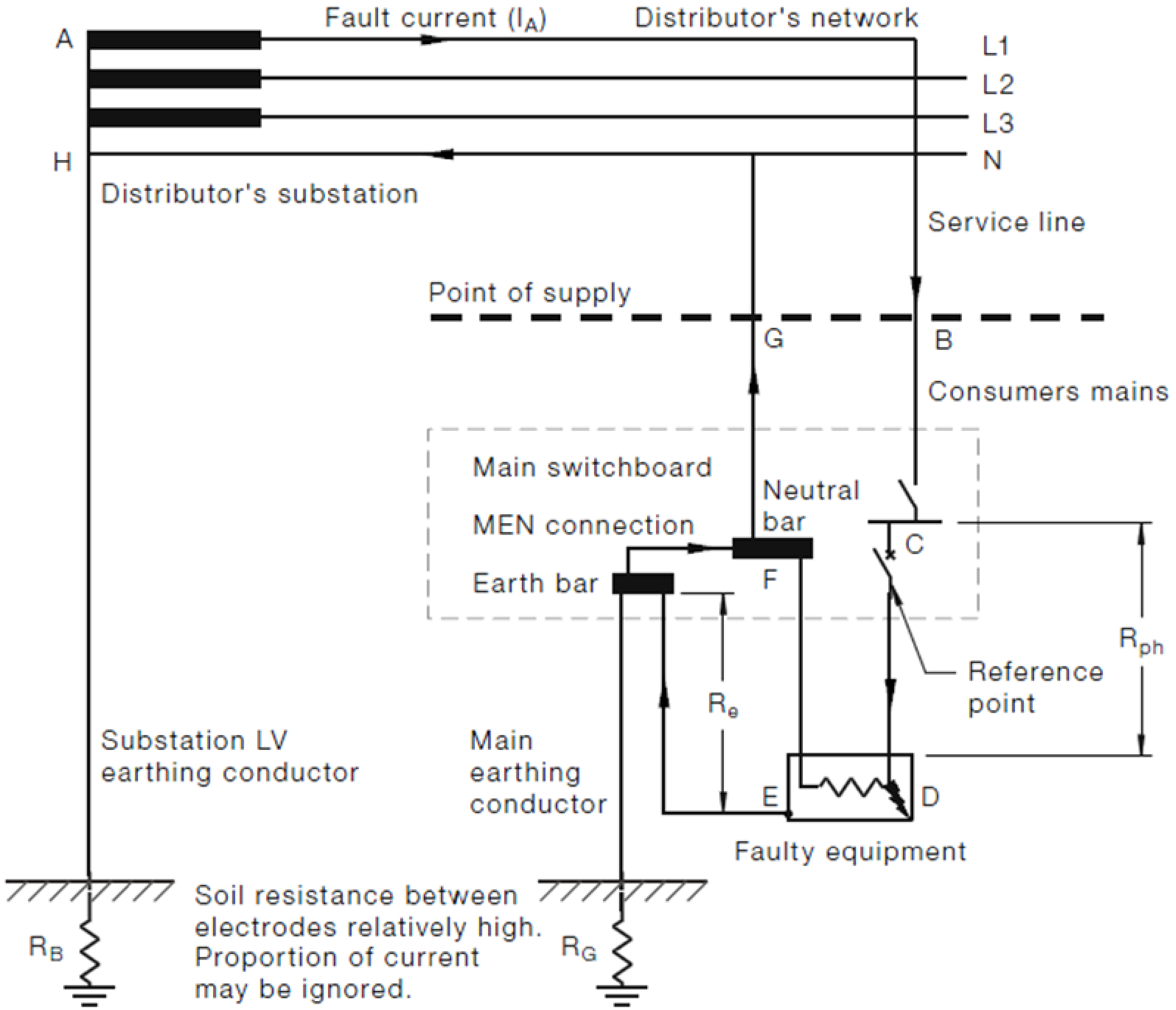


Fig F-3-2-1 Men System (Simplified)—Showing Fault Current (I_a) Path (Earth Fault-Loop)

Example of Measuring Fault-Loop Impedance At 230V (Supply Available)

A final sub-circuit supplies a load consisting of a 32A socket outlet and is protected by a 32A type C circuit breaker. To determine the fault-loop impedance of the final sub-circuit when supply is available, proceed as follows:

1. An instrument that has the facility for measuring and indicating low values of impedance is used
2. MEN connection is left intact
3. The most distant point of the circuit is identified.

Example of Measuring Fault-Loop Impedance At 230V (Supply Available)

4. A measurement is made between the active conductor and the protective earthing conductor. In this example let's say the reading obtained is 0.9Ω.
5. Table 8.1 of **Ref R-3-C** (reproduced below as **Fig F-3-2-2**) is used to determine the maximum fault-loop impedance for a 32A type C circuit breaker. In this example the maximum fault-loop impedance is $Z_S = 0.96\Omega$.
6. The measured value must be lower than 0.96Ω. The value obtained is 0.9Ω therefore it satisfies the requirement of **Ref R-3-C** .

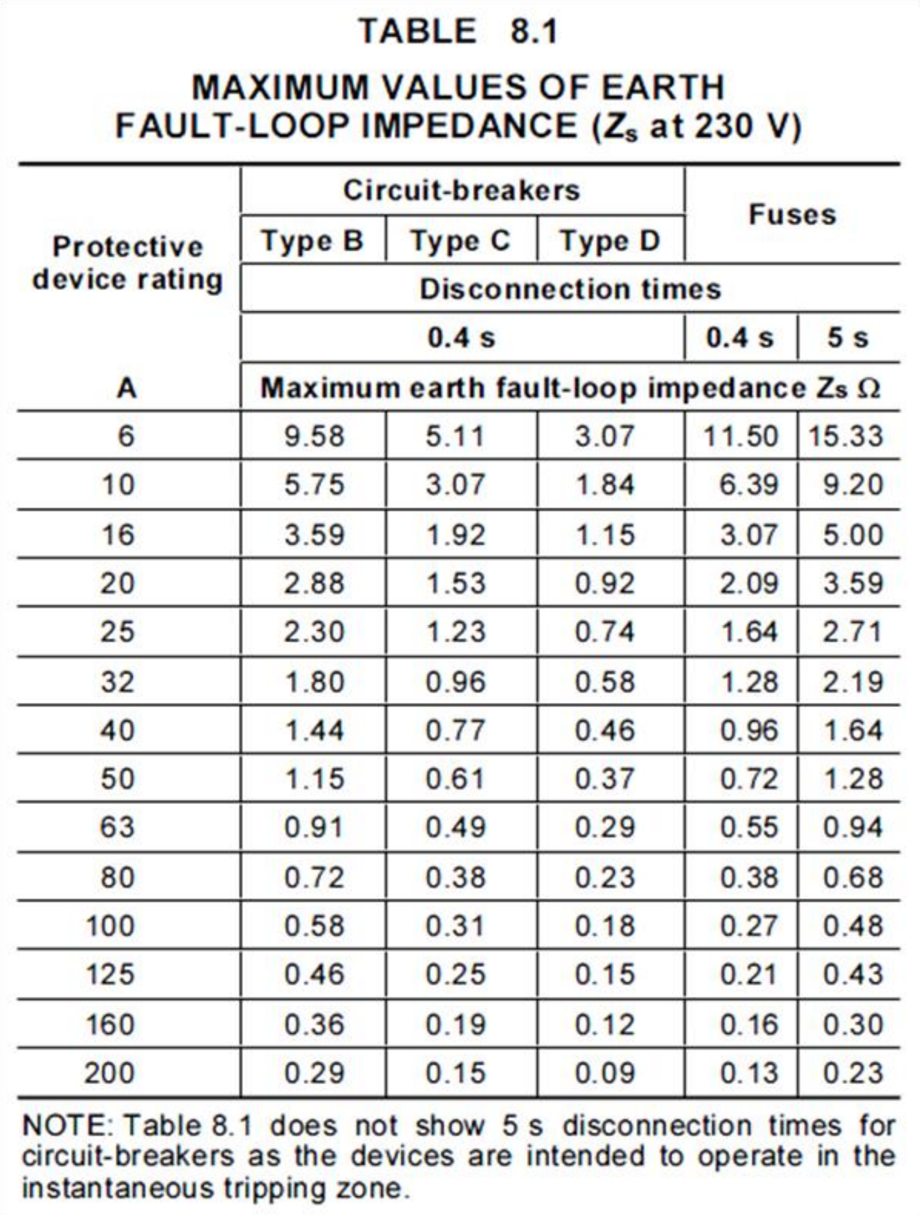


TABLE 8.1

MAXIMUM VALUES OF EARTH FAULT-LOOP IMPEDANCE (Z_s at 230 V)

Protective device rating	Circuit-breakers			Fuses	
	Type B	Type C	Type D		
	Disconnection times				
	0.4 s			0.4 s	5 s
A	Maximum earth fault-loop impedance Zs Ω				
6	9.58	5.11	3.07	11.50	15.33
10	5.75	3.07	1.84	6.39	9.20
16	3.59	1.92	1.15	3.07	5.00
20	2.88	1.53	0.92	2.09	3.59
25	2.30	1.23	0.74	1.64	2.71
32	1.80	0.96	0.58	1.28	2.19
40	1.44	0.77	0.46	0.96	1.64
50	1.15	0.61	0.37	0.72	1.28
63	0.91	0.49	0.29	0.55	0.94
80	0.72	0.38	0.23	0.38	0.68
100	0.58	0.31	0.18	0.27	0.48
125	0.46	0.25	0.15	0.21	0.43
160	0.36	0.19	0.12	0.16	0.30
200	0.29	0.15	0.09	0.13	0.23

NOTE: Table 8.1 does not show 5 s disconnection times for circuit-breakers as the devices are intended to operate in the instantaneous tripping zone.

Fig F-3-2-2 Copy of Table 8.1 from **Ref R-3-C**

THE FAULT-LOOP

The values in table 8.1 are obtained by the equation:

$$Z_S = \frac{U_O}{I_a}$$

Where:

Z_S Complete fault loop impedance

U_0 Nominal phase voltage (230V)

I_a Current causing automatic operation of the protective device (circuit breakers) are as follows:

Type B - 4 times rated current

Type C = 7.5 times rated current

Type D = 12.5 times rated current

Note: I_a values for fuses are approximate mean values from AS 60269

Example of Measuring Fault-Loop Impedance At 230V (Supply Not Available)

A final sub-circuit supplies a load consisting of 10A socket outlets and is protected by a 16A type C circuit breaker. To determine the fault-loop impedance of the final sub-circuit when supply is unavailable, the procedure is as follows:

1. The circuit breaker of the final sub-circuit under test is switched to OFF position.
2. A short length of conductor is used to bridge between the final sub-circuit active conductor downstream of the circuit protection device and the earth bar.

Example of Measuring Fault-Loop Impedance At 230V (Supply Not Available)

3. The furthermost socket outlet installed on the final sub-circuit is located.
4. A low-reading ohmmeter is used to measure the resistance between the active terminal, with the switch on the socket outlet in the ON position, and the earth terminal of the selected socket outlet. In this example let’s say the reading obtained is 0.75Ω.
5. Table 8.2 of **Ref R-3-C** (reproduced below as **Fig F-3-2-3**) is used to determine the maximum fault-loop impedance for a 16A type C circuit breaker. In this example the maximum fault-loop impedance is $R_{PHE}=1.22\Omega$ ($R_{PH}=0.61$ + $R_E=0.61$).

Example of Measuring Fault-Loop Impedance At 230V (Supply Not Available)

6. As the measured value is 0.75 and the maximum is 1.22 the circuit satisfies the requirement of **Ref R-3-C**.
7. The temporary bridging conductor of Step 1 is removed.

THE FAULT-LOOP

Determining Maximum Circuit Lengths

- When the length and CSA of conductors are not known it may be assumed that there will always be 80% or more of the nominal phase voltage available at the position of the circuit protective device.
- Therefore Z_{int} should be not greater than 0.8 Z_S and may be expressed as follows:

$$Z_{\text{int}} = \frac{0.8U_O}{I_a}$$

Determining Maximum Circuit Lengths

- Expressing this equation in terms of circuit length:

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

Where:

L_{max} = max. route length (m)— (see Table B1 of **Ref R-3-C**)

U_0 = nominal phase volts (230 V)

ρ = resistivity at normal working temp. (Ω-mm^2/m)

= 22.5×10^{-3} for copper

= 36×10^{-3} for aluminium

THE FAULT-LOOP

Determining Maximum Circuit Lengths

I_a = trip current setting for the instantaneous operation of a circuit-breaker; or the current that assures operation of the protective fuse concerned, in the specified time

S_{ph} = CSA of the active conductor of the circuit concerned in mm^2

S_{pe} = CSA of the protective earthing conductor concerned in mm^2

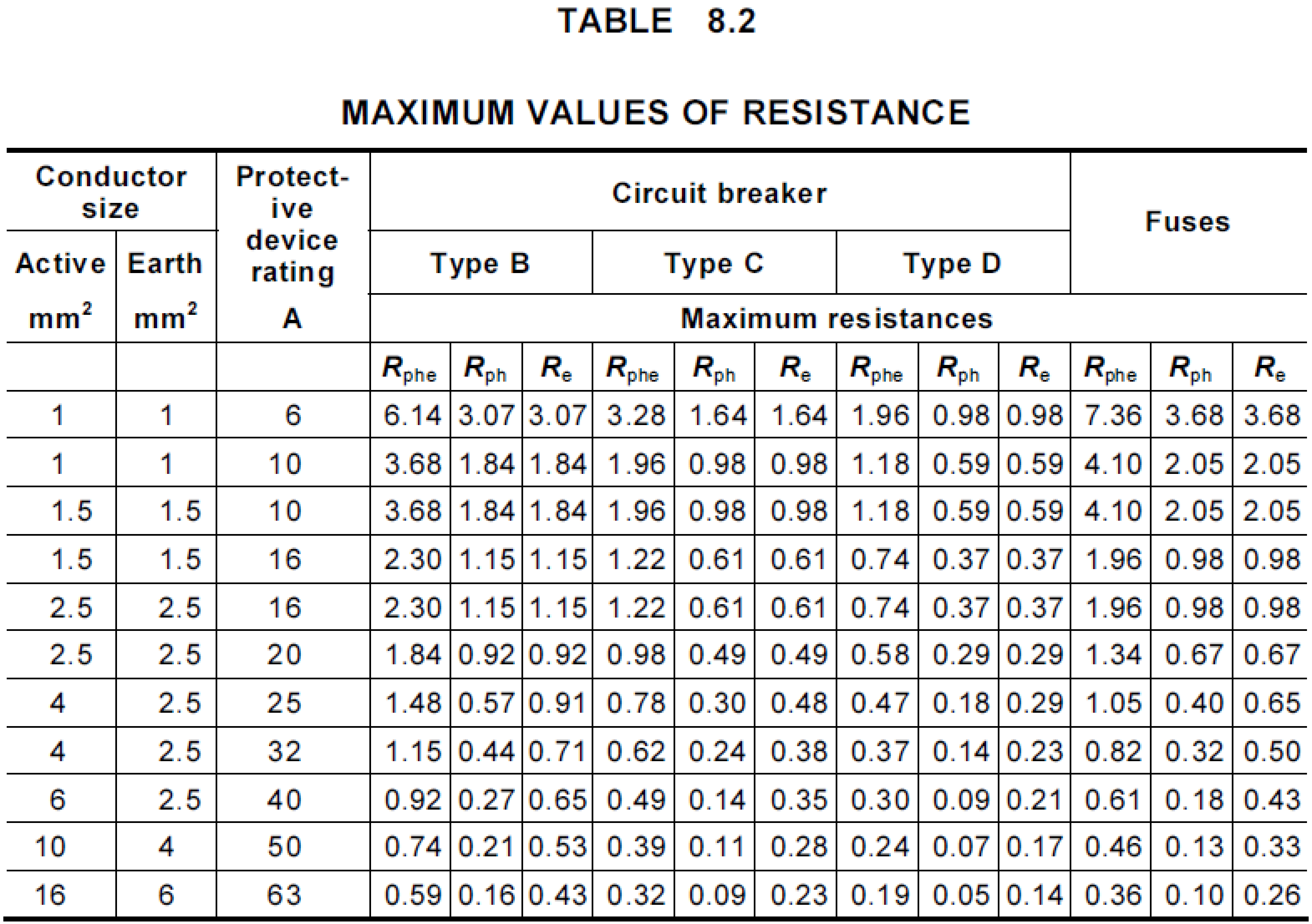


TABLE 8.2

MAXIMUM VALUES OF RESISTANCE

Conductor size		Protective device rating	Circuit breaker									Fuses		
Active	Earth		Type B			Type C			Type D					
mm^2	mm^2	A	Maximum resistances											
			R_{phe}	R_{ph}	R_e	R_{phe}	R_{ph}	R_e	R_{phe}	R_{ph}	R_e	R_{phe}	R_{ph}	R_e
1	1	6	6.14	3.07	3.07	3.28	1.64	1.64	1.96	0.98	0.98	7.36	3.68	3.68
1	1	10	3.68	1.84	1.84	1.96	0.98	0.98	1.18	0.59	0.59	4.10	2.05	2.05
1.5	1.5	10	3.68	1.84	1.84	1.96	0.98	0.98	1.18	0.59	0.59	4.10	2.05	2.05
1.5	1.5	16	2.30	1.15	1.15	1.22	0.61	0.61	0.74	0.37	0.37	1.96	0.98	0.98
2.5	2.5	16	2.30	1.15	1.15	1.22	0.61	0.61	0.74	0.37	0.37	1.96	0.98	0.98
2.5	2.5	20	1.84	0.92	0.92	0.98	0.49	0.49	0.58	0.29	0.29	1.34	0.67	0.67
4	2.5	25	1.48	0.57	0.91	0.78	0.30	0.48	0.47	0.18	0.29	1.05	0.40	0.65
4	2.5	32	1.15	0.44	0.71	0.62	0.24	0.38	0.37	0.14	0.23	0.82	0.32	0.50
6	2.5	40	0.92	0.27	0.65	0.49	0.14	0.35	0.30	0.09	0.21	0.61	0.18	0.43
10	4	50	0.74	0.21	0.53	0.39	0.11	0.28	0.24	0.07	0.17	0.46	0.13	0.33
16	6	63	0.59	0.16	0.43	0.32	0.09	0.23	0.19	0.05	0.14	0.36	0.10	0.26

Fig PF-3-2-3 Copy of Table 8.2 from **Ref R-3-C**

Topic 3-3

FAULT PROTECTION DEVICES

ENPRA101A – Engineering Practices

highered.tafensw.edu.au

INTRODUCTION

- All electrical circuits must have conductors of adequate size to carry normal and fault current loads without damaged or degradation from heating.
- All electric current conductors are required to be insulated to prevent current flow between conductors or between conductors and earth.

INTRODUCTION

- The purposes of electric power system protection devices are:
  - To detect excessive current levels in power system conductors
  - To detect excessive current flows to earth due to insulation failure

INTRODUCTION

- Electrical protection is a primary control for many of the electrical key risk areas and is used to minimise the risk of:
  - Electrocution
  - Death or injury from electric shock
  - Electrical burns (including burns from radiation, current flow, and plasma. It also includes arc blast injuries)
  - Fires
  - Explosions due to gas or catastrophic failure of electrical enclosures.

PROTECTION AGAINST OVER-CURRENT OVERLOAD AND SHORT-CIRCUIT CURRENT

- Maximum safe working currents for electrical wiring are specified in AS/NZS 3008.1.1.
- If specified current limits are exceeded, the resulting abnormal conditions could produce overheating of conductors and subsequent failure of wire insulation as well as risk to personnel from:
    - fire.
    - arcing during a high-energy fault
    - shock due to leakage current, to parts that are normally at earth potential or isolated from earth.

PROTECTION AGAINST OVER-CURRENT OVERLOAD AND SHORT-CIRCUIT CURRENT

- The heating effect in a conductor is proportional to the square of the current and can be found from:

$H = I^2Rt$

Where:

H = heat produced in joules

I = conductor current in amperes

R = resistance of conductor in ohms

T = time for which current flows in seconds

PROTECTION AGAINST OVER-CURRENT OVERLOAD AND SHORT-CIRCUIT CURRENT

- Circuit protection must be capable of interrupting a fault current before it can rise to a dangerous value.
- Circuit protection, be it a fuse or a circuit breaker, must also be able to disconnect the supply to the fault without damage to itself.
- To achieve this, the design of a protective device must have adequate 'short-circuit capacity‘
- For circuit breakers this is known as 'breaking capacity'
- For fuses the term is 'rupturing capacity’

PROTECTION AGAINST OVER-CURRENT OVERLOAD AND SHORT-CIRCUIT CURRENT

- The requirements for the protection of wiring are:
    - The protective device should be capable of carrying its rated current continuously without overheating or deterioration.
    - Small overloads of short duration should not cause the protection to operate.
    - The protection must operate, even on a small overload if the overload persists long enough to cause overheating of the circuit conductors.

PROTECTION AGAINST OVER-CURRENT OVERLOAD AND SHORT-CIRCUIT CURRENT

- The protection must open the circuit before damage caused by fault currents can occur.
- Protection must be 'discriminative' in that only the faulty circuit is isolated and other circuits remain operative and unaffected.
- **Overload protection** is achieved by opening the circuit before overheating or deterioration of the protected wiring can occur.

PROTECTION AGAINST OVER-CURRENT OVERLOAD AND SHORT-CIRCUIT CURRENT

- This 'overload' action is relatively long, the time varying inversely with the square of the current, as an example a typical circuit breaker might trip in:
    - 2 hours on 125 per cent overload, and
    - 3 seconds on 600 per cent overload
- **Short-circuit fault protection** is achieved by:
    - The action of the fuse or circuit breaker being fast enough to open the circuit before the let-through energy (I^2t) can attain a value that would cause damage by overheating, arcing or mechanical stress; and

PROTECTION AGAINST OVER-CURRENT OVERLOAD AND SHORT-CIRCUIT CURRENT

….(cont’d)….

  - The protective device being capable of opening the circuit, without damage to itself.

- The action in this case is explosive and comparatively violent, when high values of energy must be dissipated in a very short time.
- For more details on general requirements of *Protection Against Overcurrent* see Clause 2.5.1 of AS/NZS 3000:2007

OVERLOAD PROTECTION - COORDINATION OF PROTECTIVE DEVICES

- AS/NZS 3000:2007 specifies that the current rating of a device protecting cables against overload current:
  - shall not exceed the current-carrying capacity of the protected cables, and
  - Shall not be less than the maximum demand of the protected circuit.

NOTE: the current-carrying capacity of a cable is the current that the conductors can carry continuously without overheating the cable.

OVERLOAD PROTECTION - COORDINATION OF PROTECTIVE DEVICES

The requirement for the coordination between conductors and protective devices is outlined in Clause 2.5.3 of AS/NZS 3000:2007, as follows:

- T*he operating characteristics of a device protecting a conductor against overload shall satisfy the following two conditions:*
- $I_B \leq I_N \leq I_Z$ *(2.1)*
- *and*
- $I_2 \leq 1.45 \leq I_Z$ *(2.2)*

OVERLOAD PROTECTION - COORDINATION OF PROTECTIVE DEVICES

Where:

I_B *current that the circuit conductors would be expected to carry continuously without deterioration (maximum demand)*

I_N *nominal rating of the protective device*

I_Z *continuous current-carrying capacity of the conductor (see AS/NZS 3008.1 series)*

I_2 *current ensuring effective operation of the protective device and may be taken as equal to either:*

- *a) the operating current in conventional time for circuit-breakers (*$1.45I_N$*); or*
- *b) the fusing current in conventional time for fuses (*$1.6\ I_N$ *for fuses in accordance with the AS/NZS 60269 series)*

OVERLOAD PROTECTION - COORDINATION OF PROTECTIVE DEVICES

- *To satisfy equation (2.2), the nominal current I_N of a fuse should not exceed 90% of I_Z (1.45/1.6 = 0.9), therefore:*
  - *For circuit-breakers….. Equation 2.1 applies*
  - *For HRC fuses…..* $I_B \leq I_N \leq 0.9 I_Z$ *(2.3)*
- If an overload occurs, the temperature of the cable supplying the load rises (see **Fig. PF-3-3-1**).
- The protective device must operate to open the circuit before the maximum-permitted operating temperature of the cable is exceeded.

OVERLOAD PROTECTION - COORDINATION OF PROTECTIVE DEVICES

- **Fig. PF-3-3-1** shows that the protection must be temperature-sensitive, the tripping time being less for high ambient temperatures than for low ones.
- In Australia, maximum cable temperature is usually based on an ambient temperature maximum of 40°C.
- As an example, in **Fig. PF-3-3-1** the dotted line shows that with an ambient temperature of 27°C a current of 35A will cause the cable to attain a temperature of 60°C in 220 seconds.

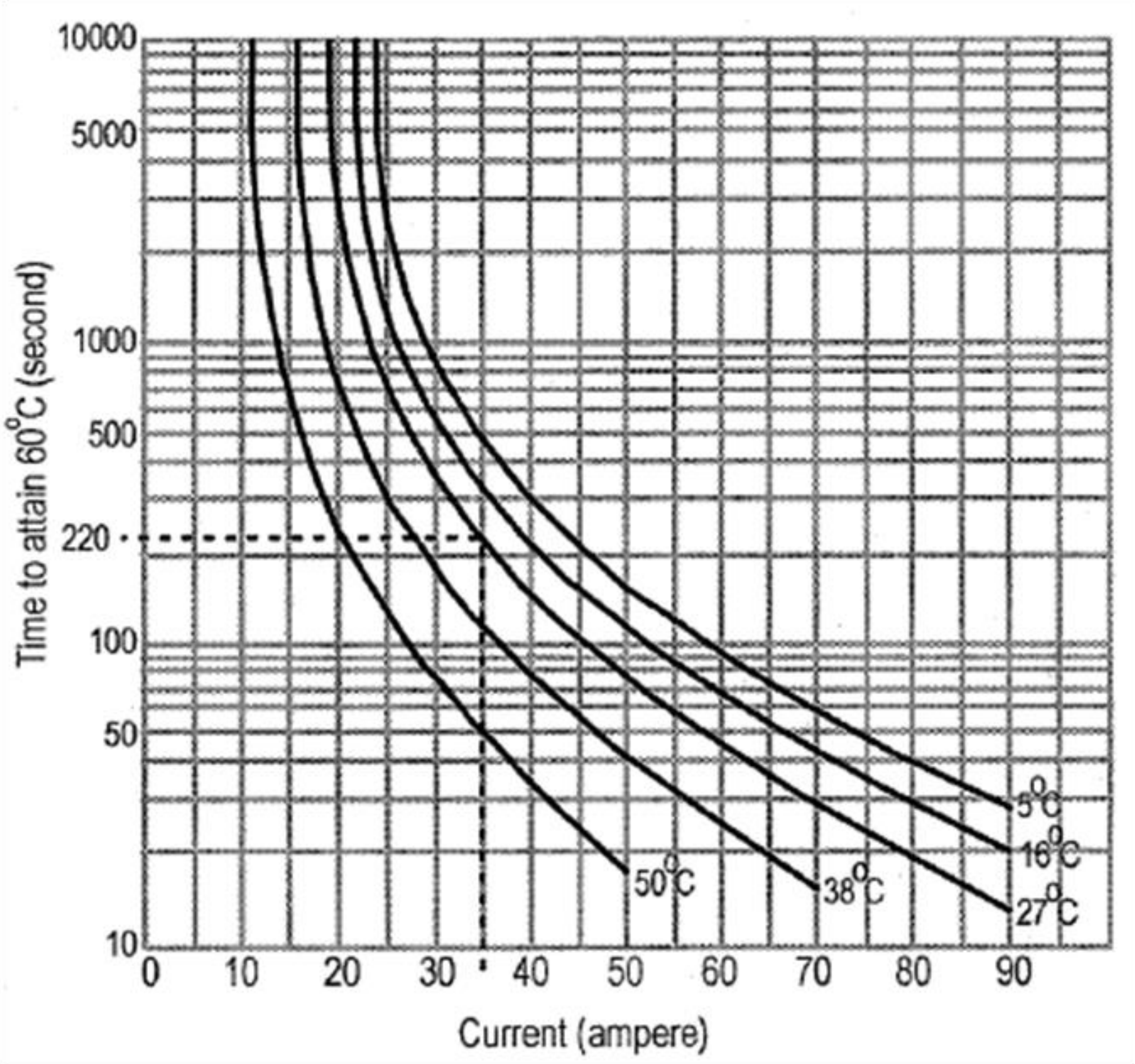


Fig. PF-3-3-1 Typical heating curves for cable in conduit

SHORT CIRCUIT PROTECTION

- In a short circuit, the only limit to current is the impedance of the faulty circuit (including the impedance of the supply source e.g. a transformer), and the available short-circuit energy.
- Energy distributors will generally advise fault levels at the termination of their cabling.
- If the short circuit occurs close to the source of supply, the only limit to the current is the source impedance

SHORT CIRCUIT PROTECTION

- The impedance of a transformer is usually stated as the percentage of the primary-rated voltage that is necessary to cause rated secondary current to flow in a short circuited secondary.
- A common transformer impedance value is 5%.
- This %Z represents the amount of voltage needed to make rated current flow in the secondary under short circuit conditions.

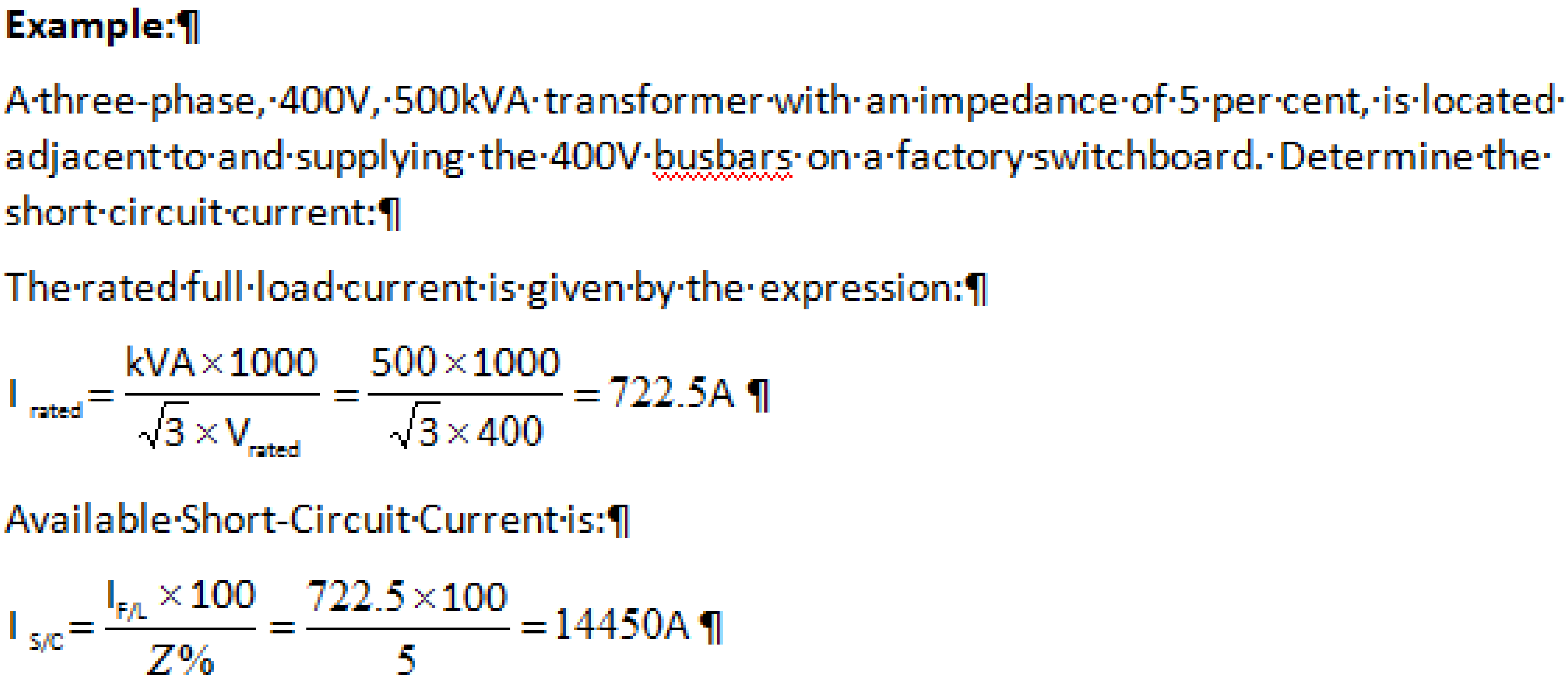
SHORT CIRCUIT PROTECTION

- Thus if 5% cent of supply voltage will produce full load current, then, with a secondary short circuit and normal supply voltage of 100 per cent, twenty times the full load current will be present, i.e. :

$$\text{short circuit current} = (\text{full load current}) \times \frac{100}{5}$$

- The increasing current demand of modern installations results in an increase in the capability of the supply source to deliver high values of short-circuit current.

SHORT CIRCUIT PROTECTION



Example:

A three-phase, 400V, 500kVA transformer with an impedance of 5 per cent, is located adjacent to and supplying the 400V busbars on a factory switchboard. Determine the short circuit current:

The rated full load current is given by the expression:

$$I_{rated} = \frac{kVA \times 1000}{\sqrt{3} \times V_{rated}} = \frac{500 \times 1000}{\sqrt{3} \times 400} = 722.5A$$

Available Short-Circuit Current is:

$$I_{S/C} = \frac{I_{F/L} \times 100}{Z\%} = \frac{722.5 \times 100}{5} = 14450A$$

NOTE: In the above example, at any point in the circuit, other than at the point of supply, the current is less than the above value, due to the impedance of the circuit between the source and the fault.

SHORT CIRCUIT PROTECTION

- The most severe short-circuit is a three-phase fault at the supply terminals, and calculations are usually based on this.
- A fault between two phases reduces the fault current to about 87%, while current due to a phase to neutral fault reduces it to about 50% per cent.
- A short to earth on the MEN system is the equivalent of a phase to neutral fault. Current is reduced due to the impedance of the earthing system between the fault and the neutral link.

PROSPECTIVE SHORT-CIRCUIT CURRENT

- The interrupting capacity of the protection must be adequate to enable the interruption of the highest value of current available at the point of installation of the protection.
- Clause 2.5.2 of AS/NZS 3000:2007, stipulates that the protection must be installed at the commencement of the circuit, which is usually at the main switchboard or at a distribution board.

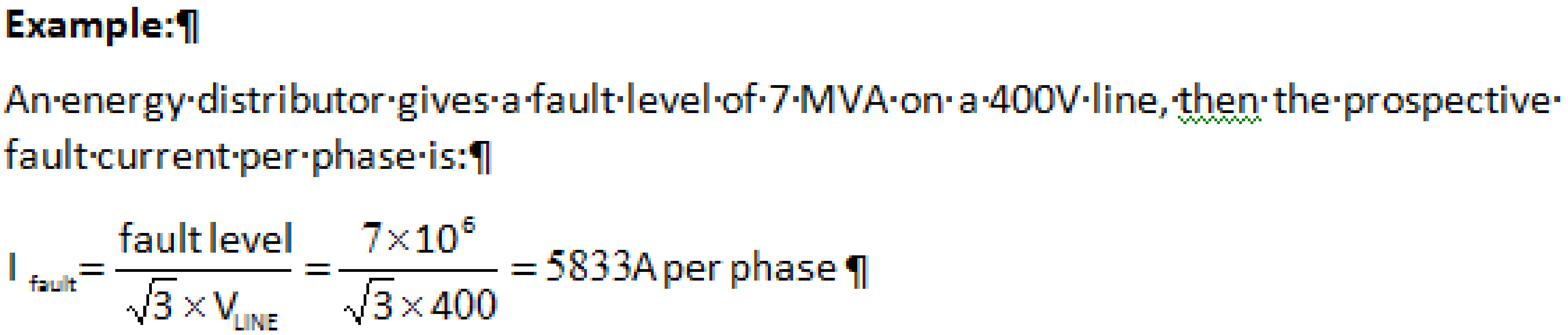
PROSPECTIVE SHORT-CIRCUIT CURRENT

- The fault current, usually termed 'prospective short-circuit current', must be interrupted before the temperature of conductors reaches the admissible limit.
- Temperature limits for cables under short-circuit conditions are given in the AS/NZS 3008.1 series Section 5.

PROSPECTIVE SHORT-CIRCUIT CURRENT

- Clause 2.5.4.1 of AS/NZS 3000:2007 requires that the prospective short-circuit current be determined at every relevant point of an electrical installation, the relevant points being mainly where a protective device is installed.
- Any estimation of fault level must commence at the source of supply.
- There are various ways estimating fault levels. The following example is applicable If the rating of the transformer is known.

PROSPECTIVE SHORT-CIRCUIT CURRENT



Example:

An energy distributor gives a fault level of 7 MVA on a 400V line, then the prospective fault current per phase is:

$$I_{\text{fault}} = \frac{\text{fault level}}{\sqrt{3} \times V_{\text{LINE}}} = \frac{7 \times 10^{6}}{\sqrt{3} \times 400} = 5833\text{A per phase}$$

- If the transformer's rating is not known, information must be obtained from the energy distributor and is usually stated as amperes per phase or total MVA fault capacity at any point on the line.

PROSPECTIVE SHORT-CIRCUIT CURRENT

- If the supply source is other than a transformer (an alternator for example), the characteristics of the supply source must be known to permit calculations.
- As an example a 500kVA 11kV/400V transformer with 5% impedance will have:
  - Fault capacity of 10MVA
  - Fault current of 14433A at 400V
- Switchboards close to the transformer will absorb nearly all the fault energy available and need to be designed accordingly.

PROSPECTIVE SHORT-CIRCUIT CURRENT

- There is a reduction of fault levels with switchboards further away from their source of supply due to impedance of feeder cables.
- Manufacturers need to consider requirements for switchboards to pass 'type approval' tests with respect to fault-current capability.
- Venting and modular design may be used to contain explosions caused by high fault currents.

EXAMPLE Ex-3-3-1

A 500kVA 11000:400/230V 5% impedance transformer connected through a large consumer's mains to a main switchboard that feeds a distribution board through a sub-main originating at the main switchboard. The impedance of the consumer mains is given as 0.004Ω and that of the sub-mains as 0.026Ω. Calculate the fault level at the main switchboard and the distribution board

Solution to EXAMPLE Ex-3-3-1

The prospective short-circuit current for a 500kVA transformer is

$$I_{\text{fault}} = \frac{\text{TX VA rating}}{\sqrt{3} \times V_{\text{LINE}}} \times \frac{100}{\%Z} = \frac{500 \times 10^{3}}{\sqrt{3} \times 400} \times \frac{100}{5} = 14433\ \text{A}$$

Therefore, the impedance/phase of supply (Z_1) is:

$$Z_1 = \frac{V}{I_{SC}} = \frac{230}{14433} = 0.01594\ \Omega$$

Let impedance of consumer mains be Z_2 and sub-mains Z_3

Solution to EXAMPLE Ex-3-3-1

Then fault level at main switchboard is:

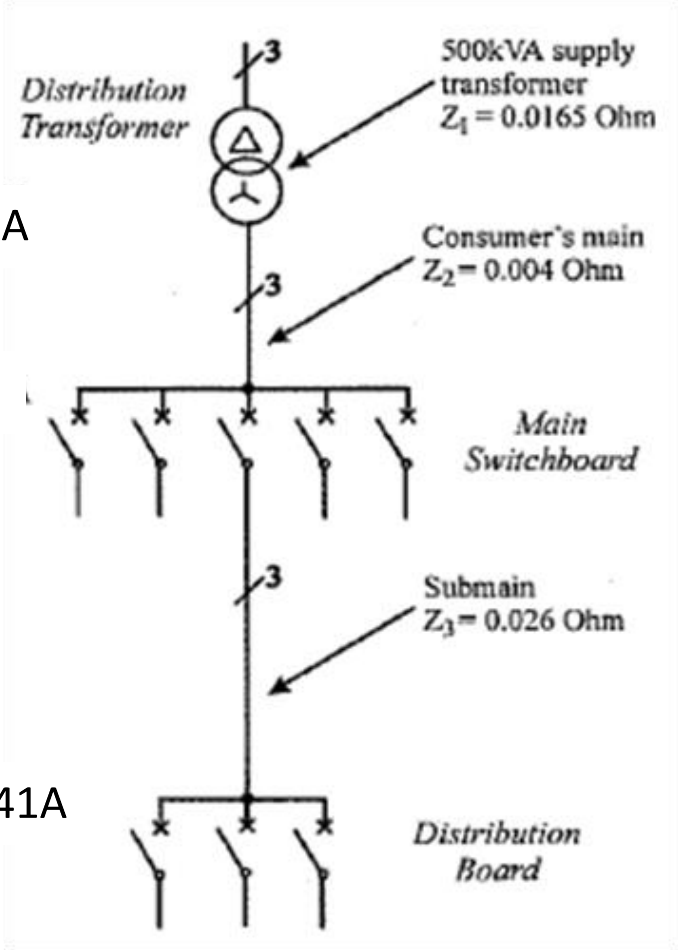
$$\mathrm{I}_{\mathrm{FAULT}} = \frac{\mathrm{V}}{\mathrm{Z}_1 + \mathrm{Z}_2} = \frac{230}{0.01594 + 0.004} = 11435\ A$$

Fault level at distribution board is:

$$\mathrm{I}_{\mathrm{FAULT}} = \frac{\mathrm{V}}{\mathrm{Z}_1 + \mathrm{Z}_2 + Z_3} = \frac{230}{0.01594 + 0.004 + 0.026} = 5006\,\mathrm{A}$$

The fault levels calculated above are summarized in the following diagram

Solution to EXAMPLE Ex-3-3-1



Fault level 14433A

Fault level 11435A

Fault level 4941A

Fig PF-3-3-2 Decreasing Fault Levels with Distance from Source

PROSPECTIVE SHORT-CIRCUIT CURRENT

- In the above example the protective equipment needs to have a rating sufficient to clear the indicated values of short-circuit current.
- Any busway feed-in to the circuit needs to be included and the manufacturers should supply appropriate impedance figures.
- If the installation comprises many motors, the energy stored in their magnetic fields could also contribute to fault current, to the extent of approximately four times their rated current.

PROSPECTIVE FAULT-CURRENT LEVELS FROM TABLES AND GRAPHS

- In practice, fault levels are usually determined by consulting the appropriate tables and graphs where, by cross-reference, the values can be 'read off’.
- Tables and graphs of the like shown in Figures **PF-3-3-3** and **PF-3-3-4** can be obtained from manufacturers.

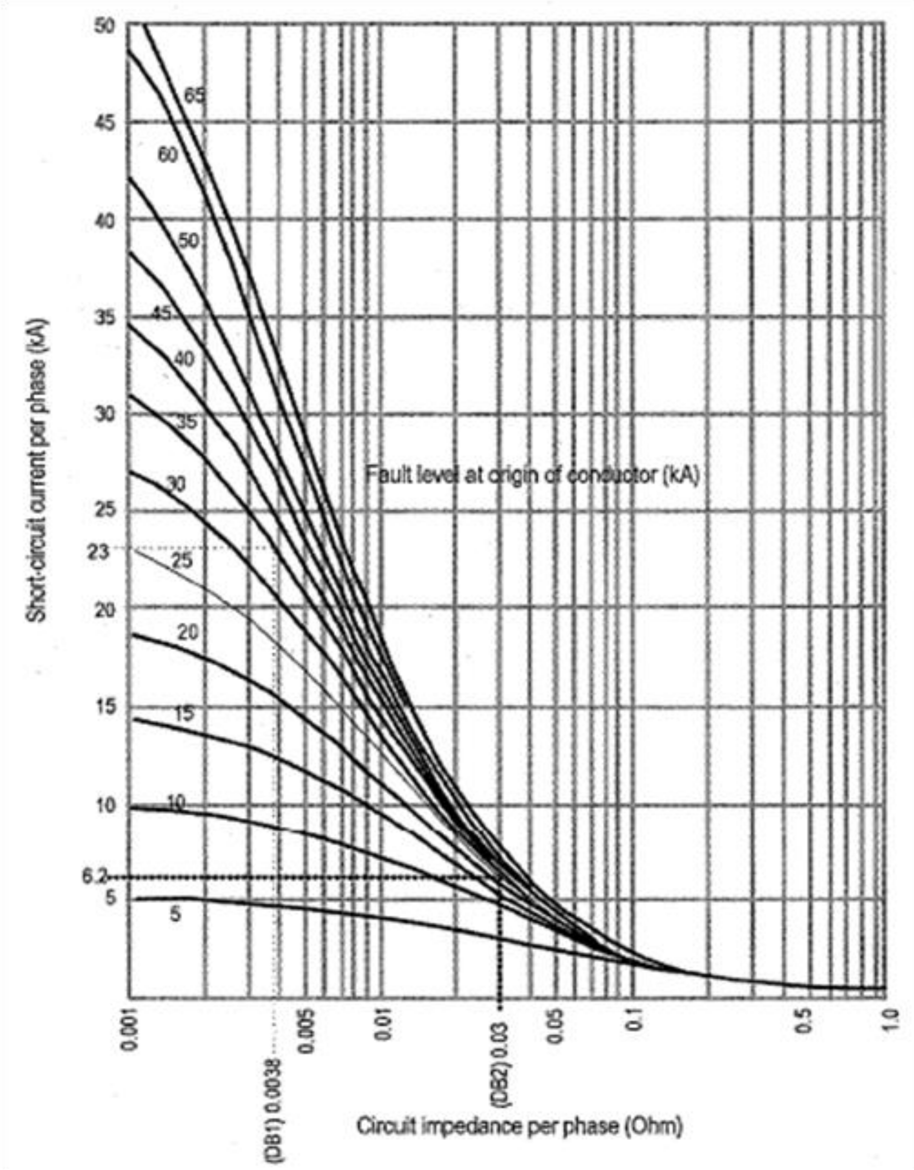
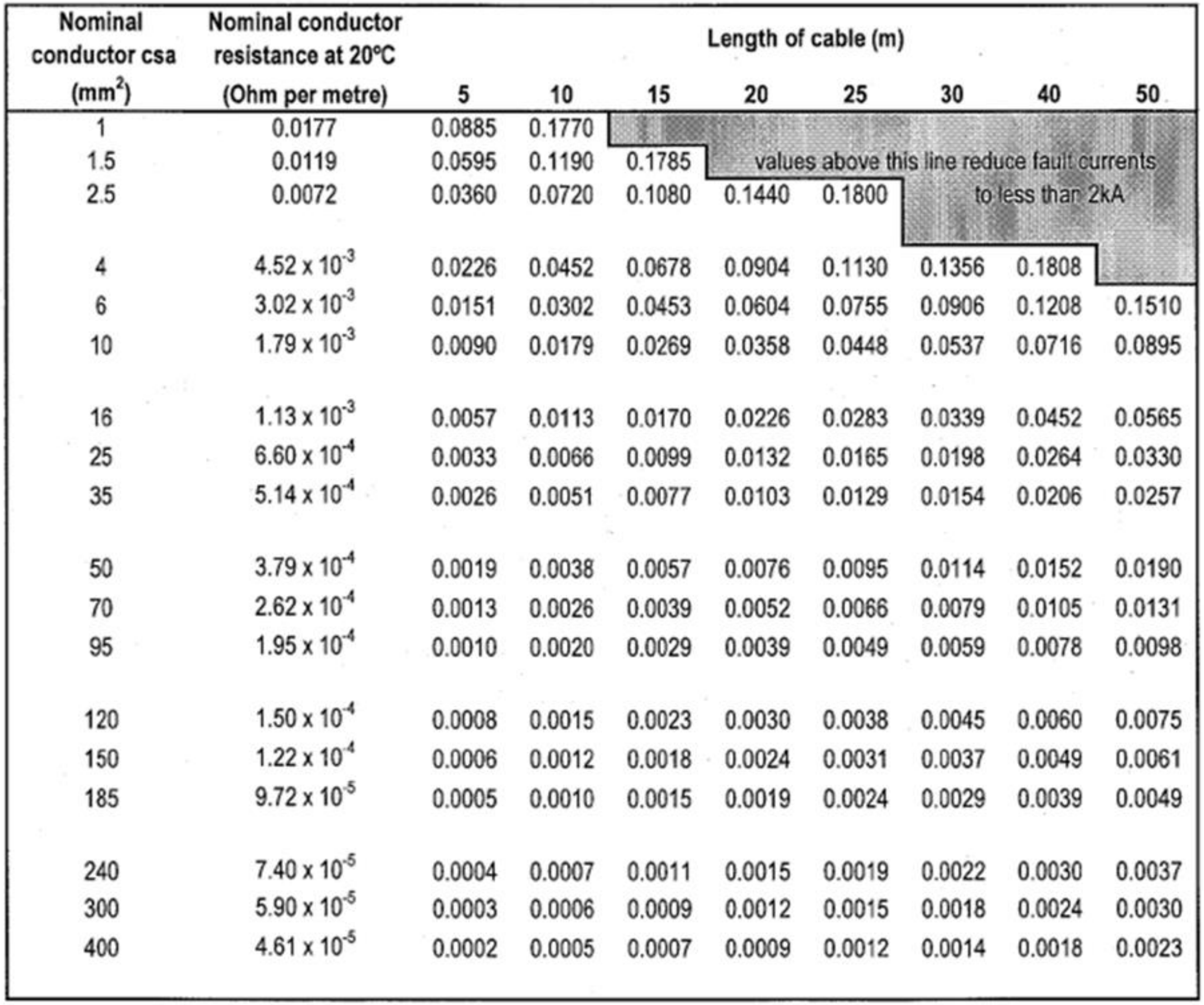


Fig. PF-3-3-3 Prospective short-circuit currents



Nominal conductor csa (mm^2)	Nominal conductor resistance at 20°C (Ohm per metre)	Length of cable (m)							
		5	10	15	20	25	30	40	50
1	0.0177	0.0885	0.1770						
1.5	0.0119	0.0595	0.1190	0.1785					
2.5	0.0072	0.0360	0.0720	0.1080	0.1440	0.1800			
4	4.52×10^{-3}	0.0226	0.0452	0.0678	0.0904	0.1130	0.1356	0.1808	
6	3.02×10^{-3}	0.0151	0.0302	0.0453	0.0604	0.0755	0.0906	0.1208	0.1510
10	1.79×10^{-3}	0.0090	0.0179	0.0269	0.0358	0.0448	0.0537	0.0716	0.0895
16	1.13×10^{-3}	0.0057	0.0113	0.0170	0.0226	0.0283	0.0339	0.0452	0.0565
25	6.60×10^{-4}	0.0033	0.0066	0.0099	0.0132	0.0165	0.0198	0.0264	0.0330
35	5.14×10^{-4}	0.0026	0.0051	0.0077	0.0103	0.0129	0.0154	0.0206	0.0257
50	3.79×10^{-4}	0.0019	0.0038	0.0057	0.0076	0.0095	0.0114	0.0152	0.0190
70	2.62×10^{-4}	0.0013	0.0026	0.0039	0.0052	0.0066	0.0079	0.0105	0.0131
95	1.95×10^{-4}	0.0010	0.0020	0.0029	0.0039	0.0049	0.0059	0.0078	0.0098
120	1.50×10^{-4}	0.0008	0.0015	0.0023	0.0030	0.0038	0.0045	0.0060	0.0075
150	1.22×10^{-4}	0.0006	0.0012	0.0018	0.0024	0.0031	0.0037	0.0049	0.0061
185	9.72×10^{-5}	0.0005	0.0010	0.0015	0.0019	0.0024	0.0029	0.0039	0.0049
240	7.40×10^{-5}	0.0004	0.0007	0.0011	0.0015	0.0019	0.0022	0.0030	0.0037
300	5.90×10^{-5}	0.0003	0.0006	0.0009	0.0012	0.0015	0.0018	0.0024	0.0030
400	4.61×10^{-5}	0.0002	0.0005	0.0007	0.0009	0.0012	0.0014	0.0018	0.0023

values above this line reduce fault currents to less than 2kA

Fig. PF-3-3-4 Cable Impedance (Ohms) for Copper

EXAMPLE Ex-3-3-2

An energy distributor states that a prospective short-circuit current of 35kA is to be assumed at a point of supply at a main switchboard, which feeds a main distribution board (DB1) through 25m of 120mm^2 cable. This distribution board supplies another distribution board (DB2) through 45m of 25mm^2 cable. Calculate the fault level at DB2

Solution to EXAMPLE Ex-3-3-2

Fault level at point of supply = 35kA

Impedance of 25m of $120mm^2$ cable (from Table in **Fig. PF-3-3-4**) = 0.0038Ω

Fault level at DB1 (from **Fig. PF-3-3-3**) = 23 kA

Impedance of 45m of 25 mm^2 cable (from Table in **Fig. PF-3-3-4**) = 0.029Ω

Fault level at DB2 (from **Fig. PF-3-3-3**) fault level at origin of conductor is 23 kA; a point between the 20 kA and the 25 kA curves is estimated at = 6.2 kA.

PROSPECTIVE FAULT-CURRENT LEVELS (ENERGY DISTRIBUTOR)

- The NSW Service and Installation Rules (Ref **R-3-F**) provide prospective short-circuit currents at the point of supply as follows:

➢ Suburban residential areas	10 kA
➢ Commercial and industrial areas	25 kA
➢ Installations on railway land	6 kA

OPERATION TIME OF PROTECTIVE DEVICE

- The protection provided for short circuits is different to overload protection
- Overload current is quite moderate compared with the high currents under short-circuit conditions.
- On overload, the protection operating time is relatively long, and high-speed operation would be a disadvantage because overloads of short duration are permissible (eg motor starting).

OPERATION TIME OF PROTECTIVE DEVICE

- The time taken to clear a short circuit must be such that the stresses due to the heavy currents are kept within safe bounds. These stresses are due to:
  - the magnetic forces between current-carrying paths
  - the rapid heating of parts due to the fault energy
  - damage caused by arcing at the fault
- Thus short circuit faults must be cleared (isolated from the supply) before the current can reach its first maximum or peak value.

OPERATION TIME OF PROTECTIVE DEVICE

- Not only must the device clear the fault but it must also have the capacity to do so (rupturing or breaking capacity) without damage to itself.
- To achieve this, the operation time must be such as to limit the fault energy to a value that the device is capable of clearing.

TEMPERATURE RISE IN CONDUCTORS DURING SHORT CIRCUIT

- All short-circuit currents shall be interrupted before the temperature of the conductors reaches the admissible limit. Section 5 of AS/NZS 3008.1.1 table 52 & 53 gives the maximum temperature limits for conductors with varying insulation. The equation defining these limits is
- $I^2t = K^2S^2$ or $t = \frac{K^2S^2}{I^2}$

TEMPERATURE RISE IN CONDUCTORS DURING SHORT CIRCUIT

- Where:

  t = duration in seconds

  K = factor dependent on the material of the conductor, the insulation and the initial and the final temperatures (value of K obtained from table 52 of AS/NZS3008.1.1)

  S = CSA of conductor in mm^2

  I = effective short-circuit current

Thank you- IQY Technical College