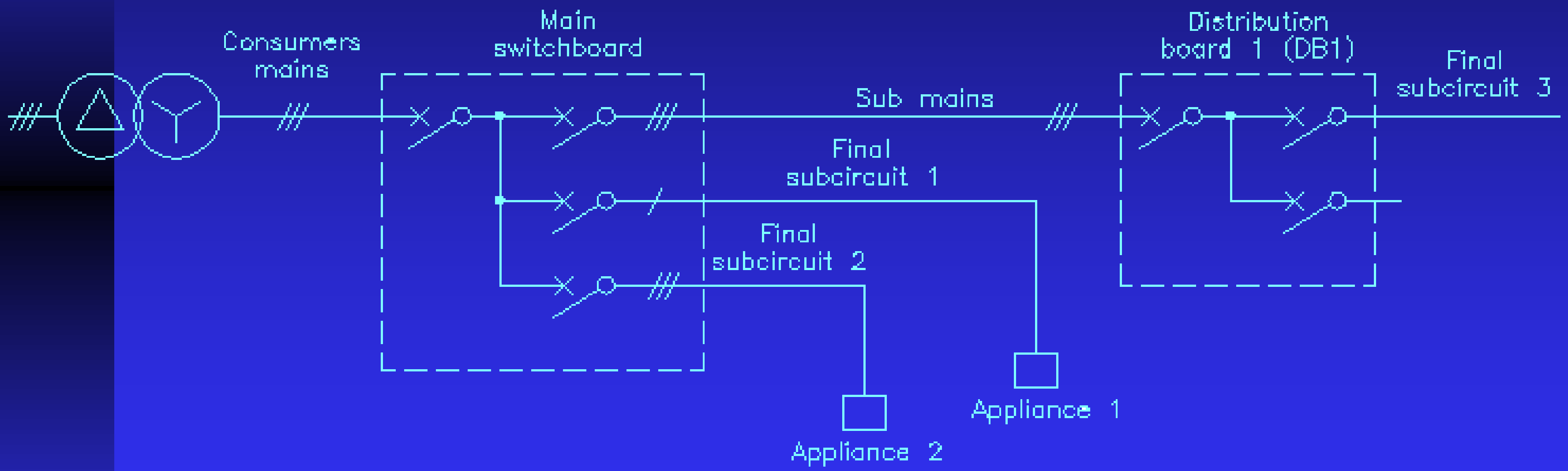
Electrical Fault Protection



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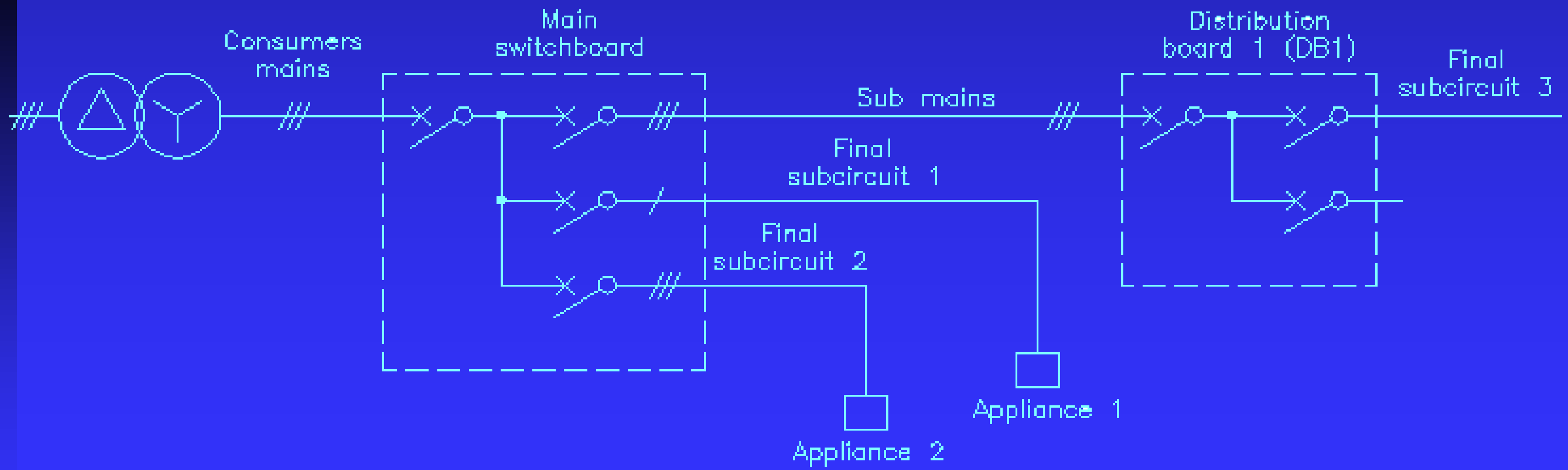
Wiring Systems

Electrical wiring systems must be installed in such a way that safe working limits are not exceeded. One of the main considerations is the maximum safe current.

If the maximum safe current in a circuit is exceeded it can result in damage to the cable and/or associated parts of the installation.



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Current Definitions

AS/NZS 3000 provides the following definitions relating to current:

Overcurrent – A current exceeding the rated value of electrical equipment. (Clause 1.4.90)

Current , fault – A current resulting from an insulation failure or from bridging of insulation. (Clause 1.4.41)

Current , overload– An overcurrent occurring in a circuit which is electrically sound. (Clause 1.4.42)

Current , short-circuit - A fault current resulting from a fault of negligible impedance between live conductors having a difference in potential under normal operating conditions. (Clause 1.4.43)

Protection of Wiring

The general requirements for the protection of wiring are:

Small overloads of short duration should not cause the protection to operate.

The protection must operate, even on a small overload, and if the overload persists long enough to cause overheating of the circuit conductors.

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

Overload protection is achieved by opening the circuit before overheating or deterioration of the protected wiring can occur.

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Coordination

AS/NZS 3000 Clause 2.5.3.1 requires coordination between conductors and protective devices.

The operating characteristics of a device protecting a cable against overload shall satisfy the following two conditions:

1. $I_B \leq I_N \leq I_Z$

2. $I_2 \leq (1.45 \times I_Z)$

Where:

I_B = Circuit maximum demand.
I_N = Nominal current of protective device.
I_Z = Current carrying capacity of cable.
I_2 = Current to operate protective device:
1.45 x I_N for circuit breakers or
1.6 x I_N for HRC fuses.

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Coordination

I_2	I_2	I_Z	I_N	I_B
Operation of HRC fuse	Operation of circuit breaker	Continuous current rating of cable	Nominal current rating of protective device	Maximum demand of circuit

1. $I_B \;\square\; I_N \;\square\; I_Z$
2. $I_2 \;\square\; (1.45 \text{ x } I_Z)$

Where:

I_B = Circuit maximum demand.
I_N = Nominal current of protective device.
I_Z = Current carrying capacity of cable.
I_2 = Current to operate protective device:
1.45 x I_N for circuit breakers or
1.6 x I_N for HRC fuses.

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Short-circuit Protection

Short-circuit fault protection is achieved by:

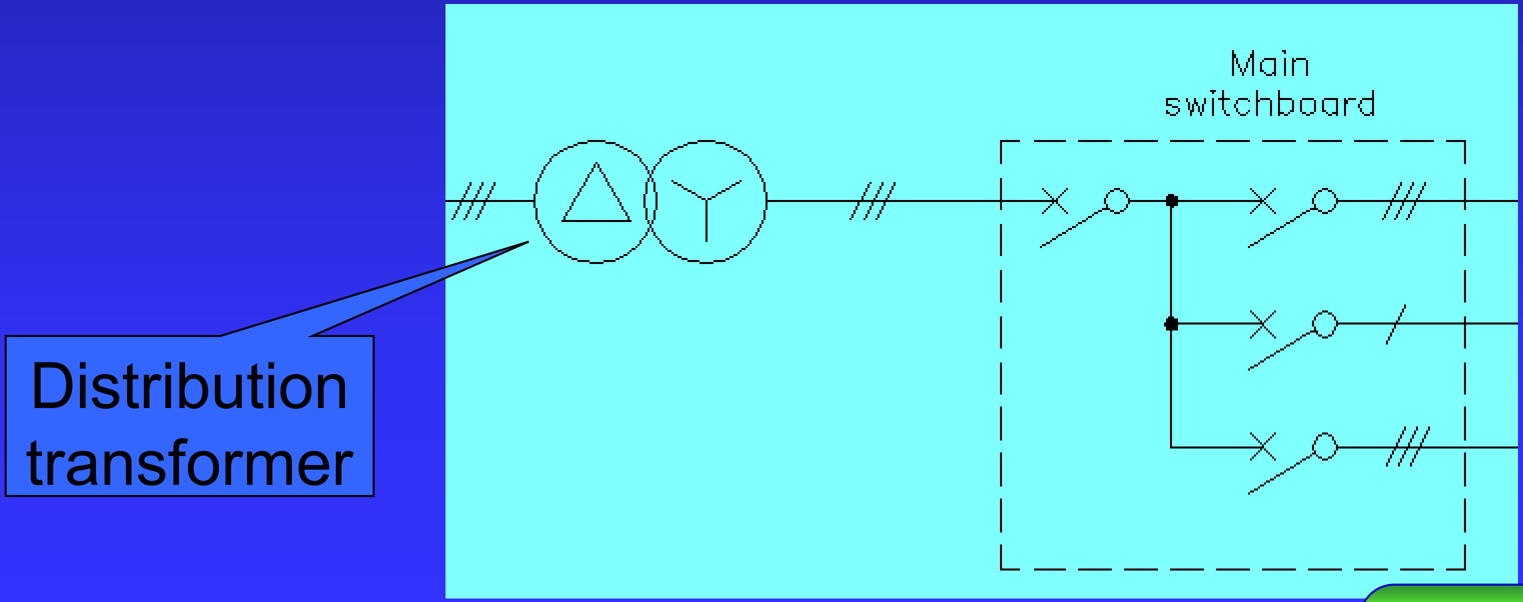
The action of the fuse or circuit breaker being fast enough to open the circuit before the let-through energy can attain a value that would cause damage by overheating, arcing or mechanical stress; and

The protective device being capable of opening the circuit, under these high fault current conditions, without damage to itself.

Short Circuit Current

In the case of a short circuit the only limit to the value of current in the circuit is the impedance of the faulty circuit, and the available short circuit energy.

This includes the impedance of the supply source, usually a distribution transformer provided by the network operator.



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Transformer Impedance

The impedance of a transformer is usually stated as the percentage of the primary-rated voltage that is necessary to cause full-load current in the secondary if the load terminals have a short across them.

A common transformer impedance value is 5 per cent. If 5 per 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 rated full load current will be present.

A distribution transformer having a full load current rating of 500 amps and an impedance of 5% would have a theoretical short circuit current of 20 x 500 or 10 000 amps.

$$\text{Short circuit current} = \text{Full load current} \times \frac{100}{\text{Impedance \%}}$$

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Prospective Fault-current Levels

The rated full load output current of a typical three-phase distribution transformer is given by the equation

$$I_{FL} = \frac{kVA \times 1000}{\sqrt{3} \times V_L}$$

So the rated full load current of a 500 kVA, 400/230 volt three phase distribution transformer with an impedance of 5% is:

$$I_{FL} = \frac{500 \times 1000}{\sqrt{3} \times 400}$$

= 721.69A

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Prospective Fault Current

The available short circuit current if the 400 volt 500 kVA transformer had an impedance of 5% would be:

$$I_{SC} = I_{FL} \times \frac{100}{Z\%}$$

$$= \frac{721.69 \times 100}{5}$$

= 14433.76 A

500 kVA 400 V
5% Impedance

I_{SC} = 14433.76 A

Impedance/Phase of Supply

If the available short circuit current of the 400 volt 500 kVA transformer was 14433.76 amps, the impedance per phase (Z_1) would be:

$$Z_{Phase} = \frac{E_{Phase}}{I_{SC}}$$

$$= \frac{230}{14433.76}$$

= 0.01593 ohms

500 kVA 400 V
5% Impedance

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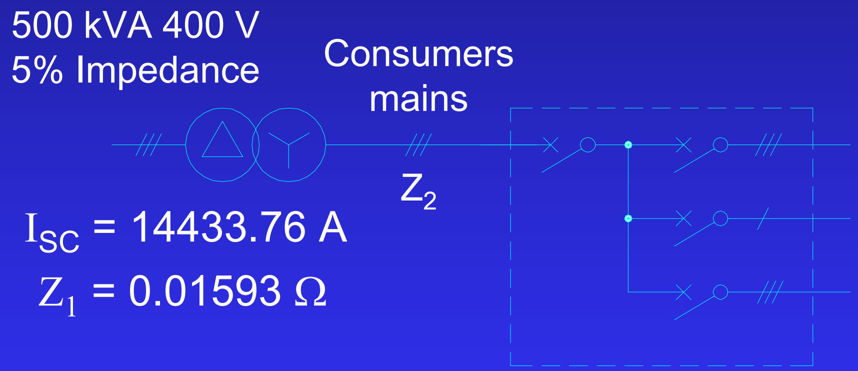
Cable Impedance

The prospective fault current (fault level) per phase at the main switchboard is limited by the impedance of the supply (Z_1) plus the impedance of the cables from the source to the switchboard (the consumers mains)(Z_2):

$$I_{Fault} = \frac{E_{Phase}}{Z_1 + Z_2}$$



I_{SC} = 14433.76 A

Z_1 = 0.01593 Ω

The impedance of the consumers mains can be found from relevant tables if the cable size, type and length are known.

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Fault Level at Main Switchboard

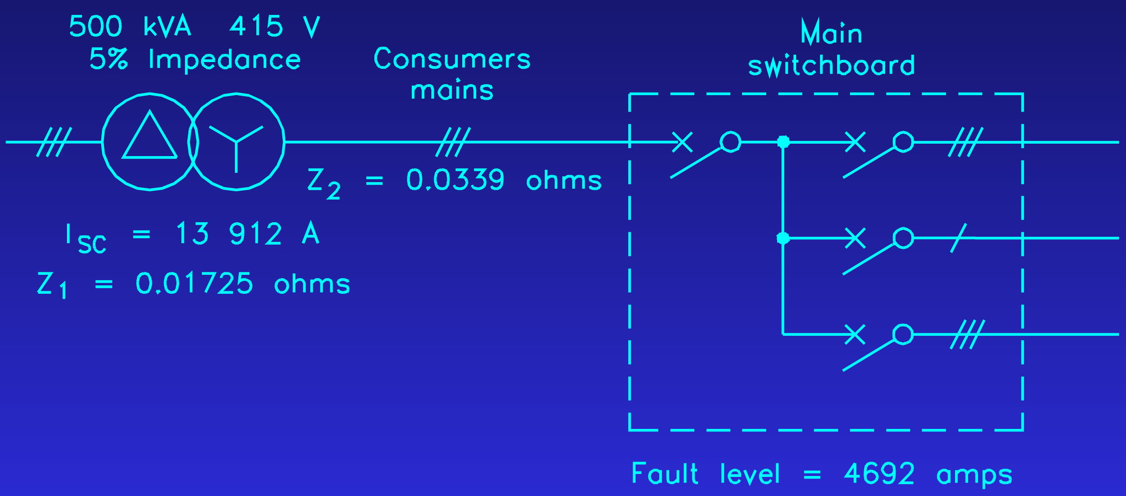
If the consumers mains consisted of 30 metres of 16 mm^2 copper TPS cable the impedance of the active conductor (Z_2) would be approximately 0.0339 ohms per phase (from a Table). The prospective fault current level at the main switchboard would be:

500 kVA 400 V
5% Impedance

$$I_{Fault} = \frac{E_{Phase}}{Z_1 + Z_2}$$

$$= \frac{230}{0.01593 + 0.0339}$$

= 4615 A



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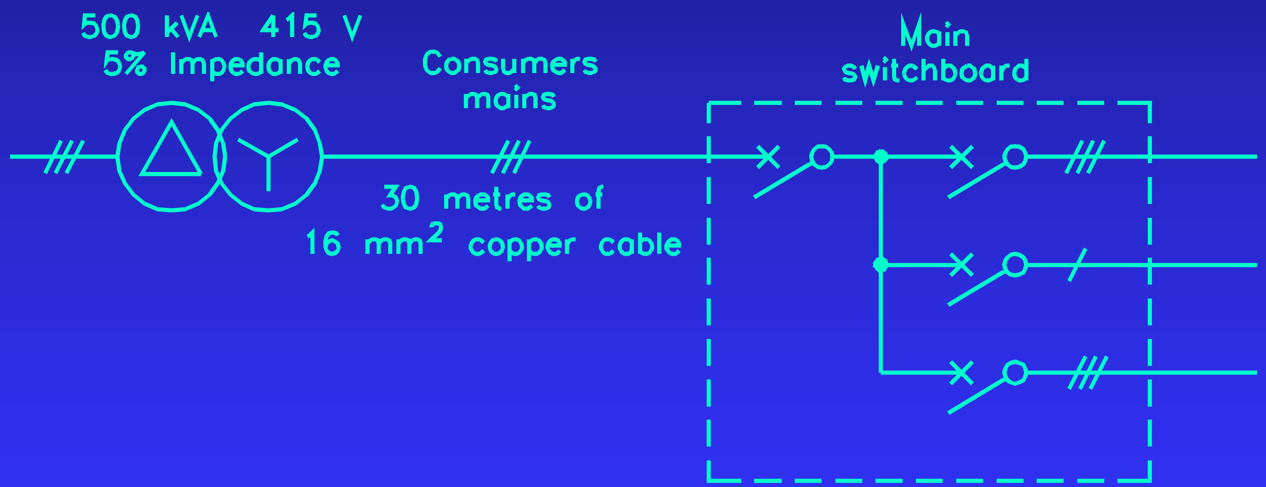
Circuit Breaker Rating

Since the prospective fault current at the main switchboard is 4615 amps, the circuit breakers on the main switchboard need to rated at a short circuit current above this value. A rating of 8 kA would be suitable.



Circuit breaker rating = 8 kA

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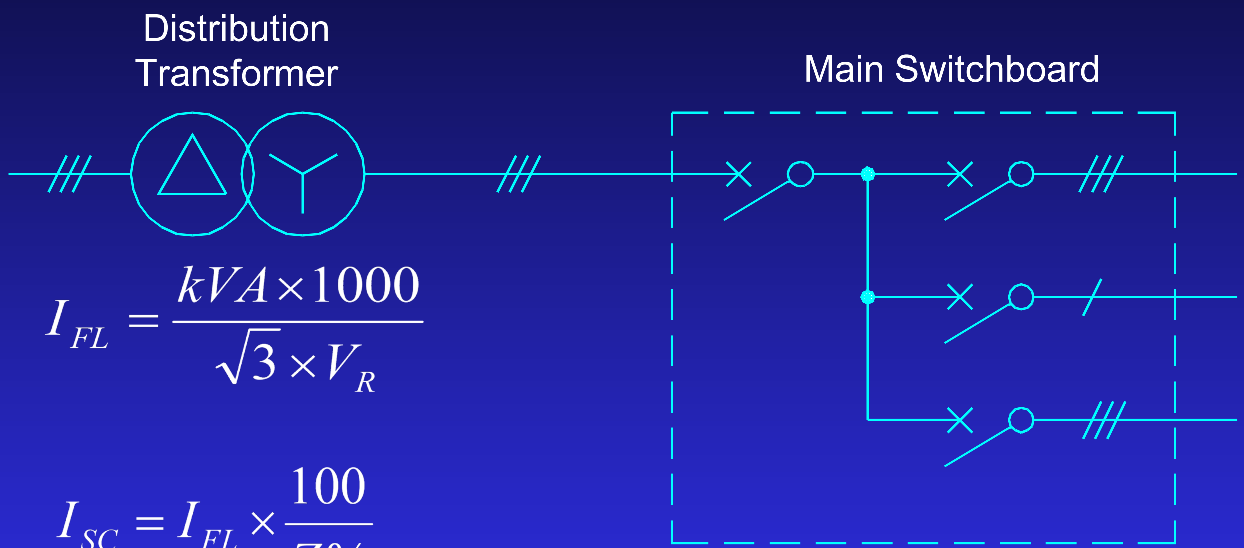
Calculator

Equation Summary



$$I_{FL} = \frac{kVA \times 1000}{\sqrt{3} \times V_R}$$

$$I_{SC} = I_{FL} \times \frac{100}{Z\%}$$

$$Z_{Phase} = \frac{E_{Phase}}{I_{SC}}$$

I_B □ I_N □ I_Z

I_2 □ $(1.45 \text{ x } I_Z)$

$$I_{Fault} = \frac{E_{Phase}}{Z_1 + Z_2}$$

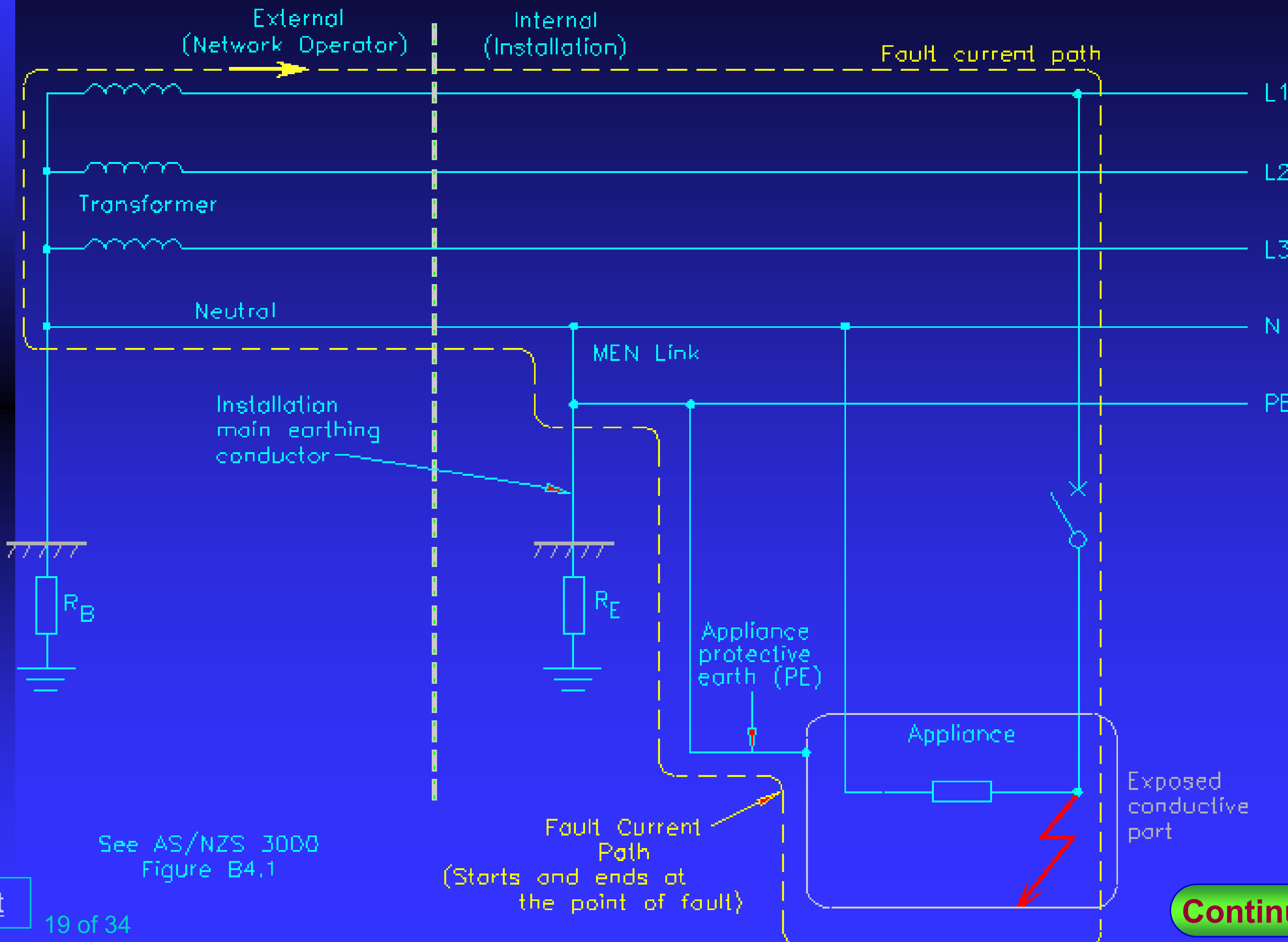
Fault Loop Impedance

Fault-loop impedance is the impedance of the conductors in the series path taken by the current in the event of a fault between an active conductor and an earth fault, 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. See Clause 1.5.5.3.(c)

This condition is satisfied when the fault-loop impedance is sufficiently low to allow enough current to flow in the fault-loop to cause the circuit protection device to operate within the specified time, thus limiting the touch voltage as required by Clause 5.7.1.

Fault Current Path (MEN)



See AS/NZS 3000
Figure B4.1

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Disconnection Times

The maximum disconnection time for 230/240 V supply voltage shall not exceed the following (See AS/NZS 3000 Clauses 1.5.5.3.(d) & 5.7.2):

(a) 0.4 seconds for final subcircuits that supply—

(i) socket-outlets having rated currents not exceeding 63 A; or

(ii) hand-held Class I equipment; or

(iii) portable equipment intended for manual movement during use.

(b) 5 seconds for other circuits including submains and final subcircuits supplying fixed or stationary equipment.

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Circuit Breaker Mean Tripping Time

The maximum value of fault loop impedance (Z_S) can be calculated for circuits protected by circuit breaker using manufacturers' information relating to the approximate mean tripping current for the circuit breaker.

The mean tripping current for circuit breakers can be taken as:

Type B = 4 times rated current
Type C = 7.5 times rated current (e.g. general purpose loads)
Type D = 12.5 times rated current (e.g. high inductive loads)

See AS/NZS 3000 Clause B4.5 and Table 8.1

Fault Loop Impedance Equation

The fault loop impedance (Z_S) for a circuit breaker can be calculated using the following equation:

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

U_O (The nominal supply voltage)

I_a (The mean tripping current)

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Fault Loop Impedance Calculation

A 240 volt final sub-circuit supplies a load consisting of a 10 A socket outlet protected by a 16 A, Type C, 8 kA circuit breaker. Determine the maximum internal fault loop impedance of the circuit, if the supply is not available.

$$Z_S = \frac{U_O}{I_a} = \frac{240}{16 \times 7.5} = 2.0 \text{ ohms}$$

For 240V Rphe = Zs x 0.64 = 2 x 0.64 = 1.28 ohms

See AS/NZS 3000 Clause B4.5 and Table 8.1.

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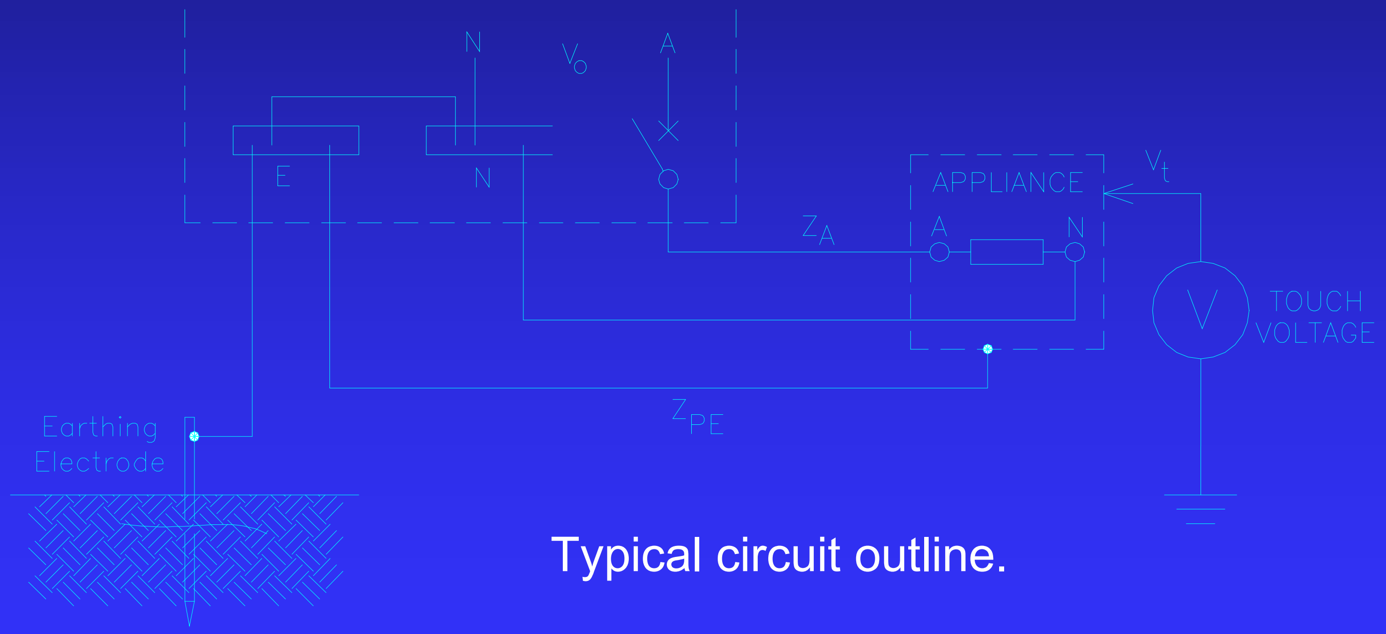
Maximum Circuit Lengths - Table B1

Table B5.1 of AS/NZS 3000 contains maximum circuit lengths, above which the impedance of the conductors will limit the magnitude of the short-circuit current to a level below that required to operate the protective device protecting the circuit in sufficient time (within 0.4 seconds) to ensure safety against indirect contact.

The maximum circuit lengths in Table B1 are based on a nominal phase voltage of 230 volts. For 240 volt circuits the maximum length can be determined by multiplying the value in the table by 1.04.

Touch Voltage

AS/NZS 3000 Clause 1.5.5.3(b) specifies that in the event of a fault between a live part and an exposed conductive part which could give rise to a prospective touch voltage exceeding 50 V a.c. or 120 V ripple-free d.c., a protective device shall automatically disconnect the supply to the circuit or electrical equipment concerned.



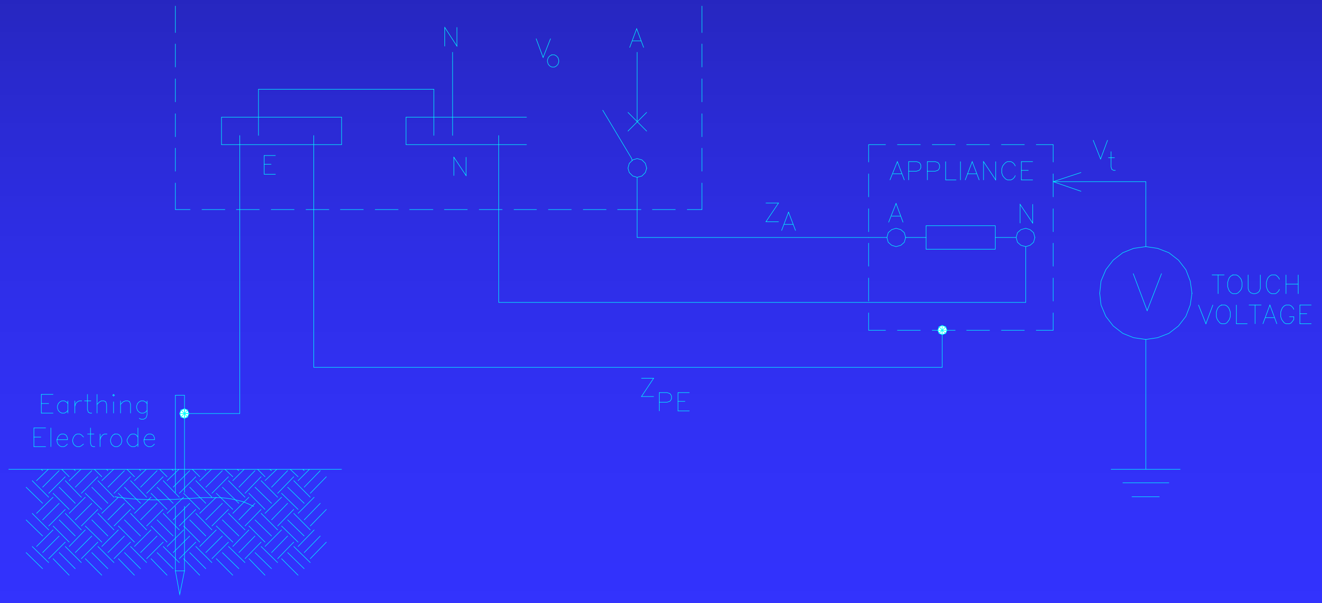
Typical circuit outline.

Touch Voltage Equation

If the details of the circuit are known the touch voltage (V_t) can be calculated using the equation:

$$\text{Touch voltage} = \frac{V_o \times Z_{PE}}{(Z_A + Z_{PE})}$$

Where:
V_o = Voltage at protective device
Z_{PE} = Impedance of protective earth
Z_A = Impedance of active



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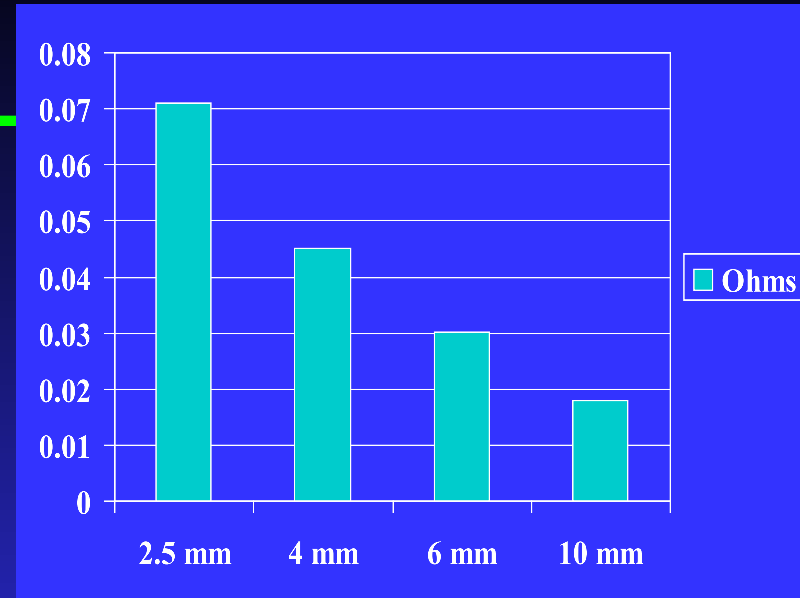
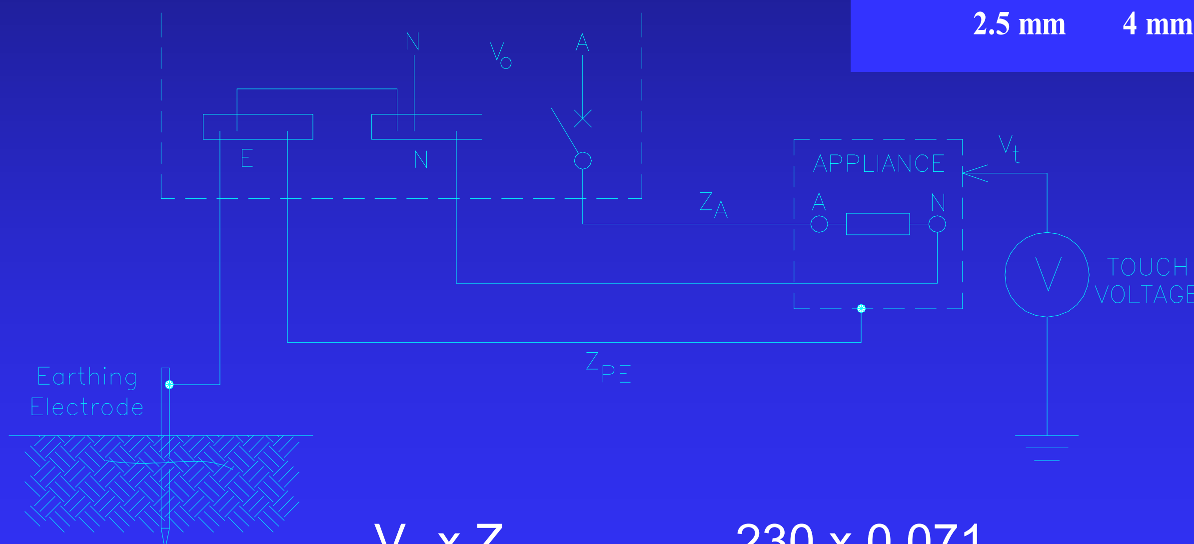
Touch Voltage Calculation

Approximate impedance per 10 metres



An appliance is installed with a 4 mm^2 copper active conductor (0.0452 ohms) and has a 2.5 mm^2 earthing conductor (0.071 ohms). Calculate the touch voltage if the supply voltage is 230 volts a.c.



$$\text{Touch voltage} = \frac{V_o \times Z_{PE}}{(Z_A + Z_{PE})} = \frac{230 \times 0.071}{(0.0452 + 0.071)} = 140.53 \text{ V}$$

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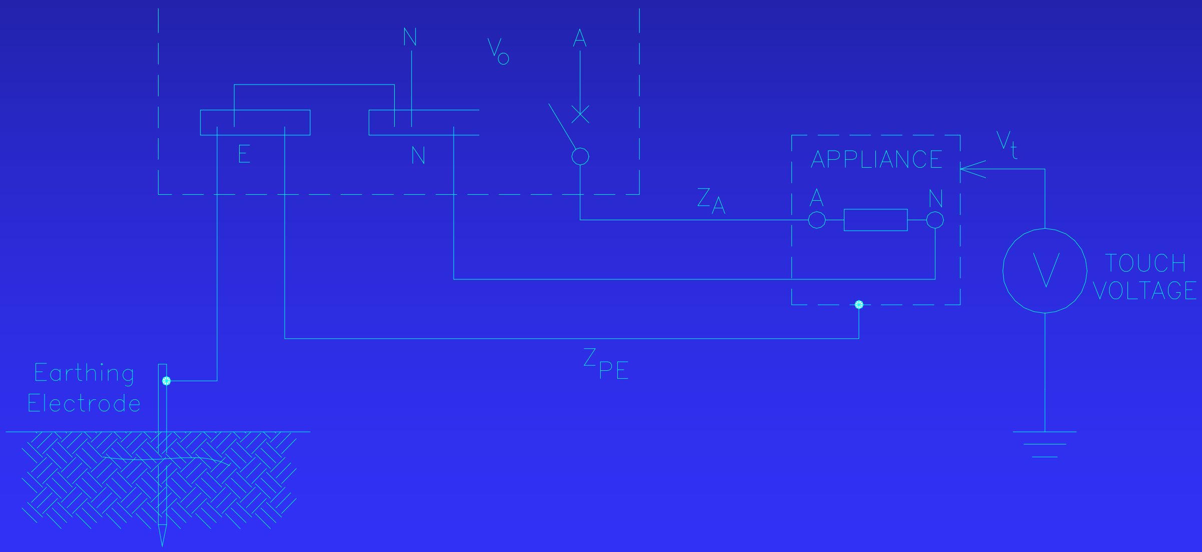
Touch Voltage Limit

The circuit protection device must automatically disconnect the supply if a fault occurs which could result in a touch voltage greater than 50 V a.c. or 120 V d.c. (AS/NZS 3000 Clause 1.5.5.3(b))



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Short Circuit Current

AS/NZS 3000 Clause 2.5.1 requires that general protective devices shall be provided to interrupt any short-circuit current flowing in the conductors before such a current can cause danger due to thermal and mechanical effects produced in conductors and connections.

Short Circuit Disconnect Time

For short circuits of duration up to 5 seconds the time in which a given short-circuit current will raise the conductors from the highest permissible temperature in normal duty to the limit temperature may, as an approximation, be calculated from the following equation:

$$t = \frac{K^2 . S^2}{I^2}$$

See AS/NZS 3000 Clause 2.5.4.5 (b)

Where

t = duration in seconds

K = a factor dependent on the material of the conductor, the insulation and the initial and the final temperatures.
See AS/NZS 3008.1.1 Table 51. A typical value of K is 111.

S = cross-sectional area of the conductor in mm^2

I = effective short-circuit current (A r.m.s)

Short Circuit Current

An equation to calculate the current required to disconnect the circuit in a given time can be determined by transposition:

$$t = \frac{K^2 . S^2}{I^2} \quad \text{so} \quad I = \sqrt{\frac{K^2 . S^2}{t}}$$

Where

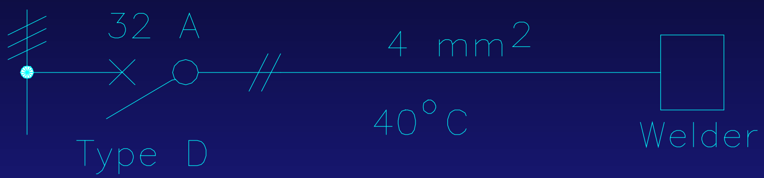
t = duration in seconds

K = a factor dependent on the material of the conductor, the insulation and the initial and the final temperatures.
See AS/NZS 3008.1.1 Table 51. A typical value of K is 111.

S = cross-sectional area of the conductor in mm^2

I = effective short-circuit current (A r.m.s)

Overload Current Calculation



A single phase final subcircuit supplies a 415 volt welding transformer from a 4 mm^2 V75 TPI copper active conductor with a 2.5 mm^2 copper protective earthing conductor. Determine the maximum overload current that could flow in the circuit if the associated 32 A, Type D, 8 kA circuit breaker is to operate within 4.5 seconds. The ambient temperature is 40 degrees C.

$$I = \sqrt{\frac{K^2 . S^2}{t}} \qquad = \sqrt{\frac{111^2 . 4^2}{4.5}}$$

= 209.3 amps

See AS/NZS 3000:2000 Clause 2.5.4.5 (b)

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Reference Summary

AS/NZS 3000 Clause 1.5	Protection against dangers and damage
AS/NZS 3000 Clause 1.4.37	Current , fault.
AS/NZS 3000 Clause 1.4.38	Current, overload
AS/NZS 3000 Clause 1.4.39	Current, short circuit 2.5.4
AS/NZS 3000 Clause 1.4.95	Touch voltage.

AS/NZS 3000 Clause 2.5.3.1 Coordination between conductors and protective devices.

AS/NZS 3000 Clause 2.5.1	General (Protection against overcurrent).
AS/NZS 3000 Clause B4.5	Calculation of fault loop impedance.
AS/NZS 3000 Table B1	Maximum circuit lengths.
AS/NZS 3008.1.1 Table 51	Values of constant K.

Australian Electrical Wiring, Vol 2, Pethebridge and Neeson, 6th Ed, McGraw-Hill

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That is the end of this presentation.

Thank you for your participation.

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