10 Appendix 10

10.1 Introduction

This appendix gives two examples of cable sizing calculations in order to explain Chapter C of the book. Example one has been chosen to illustrate many of the techniques required or suggested in Chapter C, hence it's length. Example two is a little more straightforward.

Generally the procedure of Chapter C section C 4.1 will be followed as indicated on Figure C 4.1. For those that wish to find explanations to each stage of the calculation process, blue graphics have been included referring to the section numbers of Chapter C of the book.

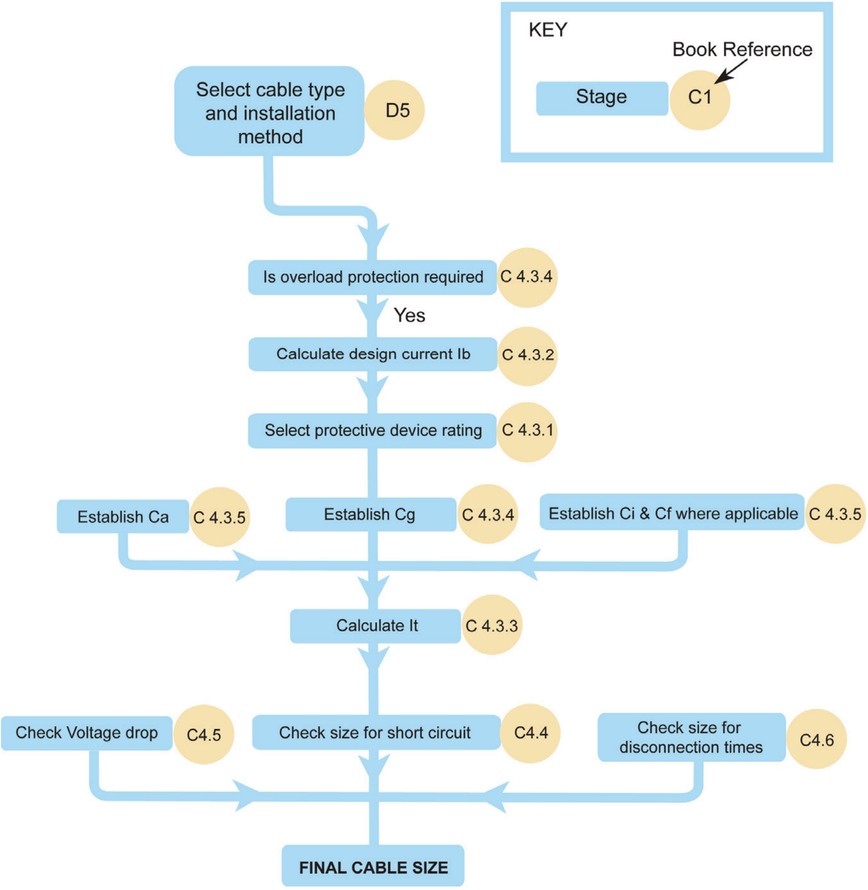

Figure C 4.1 Cable sizing stage diagram

10.2 Example 1

Consider a 50 kW, 3 phase load at 0.8 power factor. The load is to be supplied by a cable to be run underground for 50 m and clipped to cable tray for a further 50 m together with 6 other similar cables.

Overload protection is to be provided by a BS 88 fuse. The route length is 100 m and Z_e is given as 0.15 ohms.

The thermal resistivity of the soil along the underground part of the route has been confirmed as less than 2.5 K.m/W.

It is assumed that the grouped cables may be subject to simultaneous overload (note however that this is an unlikely situation).

10.2.1 Selection of cable type and installation method

Select cable type and installation method D5

As the cable is to be laid underground a steel wire armoured cable (with copper conductors) is to be used.

For half the route the cable is grouped with 6 other similar cables on a horizontal perforated cable tray otherwise run underground in a duct.

Overload protection is required.

10.2.2 Calculate design current Ib

Calculate design current Ib C 4.3.2

Using the equation in C 4.3.2

$$I_b = \frac{kW}{\sqrt{3}\ V_l \times pf} \times 1000 \text{ (amps) and hence,}$$

$$I_b = \frac{50}{\sqrt{3} \times 400 \times 0.8} \times 1000 \text{ (amps)} = 90.2 \text{ A}$$

where:

Ib is the design current of the circuit, (also for 3 phase denoted I_l the line current)

V_l is the line voltage also denoted U

p.f. is the power factor cos θ

kW is the load power in kilowatts

10.2.3 Select protective device rating

Select protective device rating C 4.3.1

Where overload protection is to be provided:

$I_n \geq I_b$

where:

≥ greater or equal to

I_b is the design current of the circuit

I_n is the nominal current or current setting of the protective device

The smallest protective device greater than 90.2 A is a 100 A overcurrent device BS 88 fuse; thus is selected at I_n = 100 A.

10.2.4 Establish Ca, Gg, Ci & Cc

Establish Ca C 4.3.5

Establish Cg C 4.3.4

Establish Ci & Cf where applicable C 4.3.5

As the cable has mixed installation methods the options are to carry out these calculations for both the buried portion and the portion run on tray and use the more onerous. However, from a quick glance at the various tables, the grouping factor or the cable with six other cables will be limiting and is used here.

C a is correction factor for ambient temperature, (Tables 4B1 and 4B2 of BS 7671: 2008),

No ambient temperature is given as is typically the case in practice as the assumption of a 30°C ambient is usual. This is higher than is likely, and is conservative for cable selection purposes.

Hence from Table 4B1 of BS 7671: 2008 Ca = 1

C g is correction factor for grouping (Table 4C of BS 7671: 2008)

From Table 4C1 (page 39 of this book) for a group of 7 cables single layer multicore on a perforated cable tray, Cg = 0.73

C i is correction factor for conductors surrounded by thermal insulation

The cables are not surrounded by insulation so Ci =1

C c is a correction factor for the installation conditions (Table 4B3) and for use when overload protection is being provided by overcurrent devices with fusing factors greater than 1.45 e.g. Cc = 0.725 for semi-enclosed fuses to BS 3036.

The fuse is BS 88 and the cable is not laid underground in this section of the cable route so Cc = 1

10.2.5 Calculate It

Calculate It C 4.3.3

This calculation is based on the more onerous portion of the cable grouped on a cable tray.

From section C 4.3.3,

$$I_t \geq \frac{I_n}{C_a\, C_g\, C_i\, C_c} \text{ and hence, } I_t \geq \frac{100}{1 \times 0.73 \times 1 \times 1} \geq 137 \text{ A.}$$

From Table 4D4A of BS 7671: 2008, column 7, the smallest cable suitable is a 70 mm^2 four core cable; note the lowest rating of the two installed conditions has to be used and in this case, column 7 has a rating of 143 amps.

10.2.6 Check size for volt drop

Check Voltage drop C4.5

Two calculations need to be carried out as the temperature of the cable will be different in each portion

i) For the part of the cable route where the cable is clipped to cable tray with 6 other cables

$$\text{Voltage drop in line to line voltage} = \frac{C_t \times (\text{mV/A/m}) \times L \times I_b}{1000}$$

(see C 4.5.3 and C 4.5.4 of this book and the equation from paragraph 6.2 of Appendix 4 to BS 7671: 2008).

Where:

$(\text{mV/A/m})_{3p}$ is the tabulated value of voltage drop in mV per amp per metre from the cable rating tables of Appendix 4 of BS 7671 for a three phase cable

L is the length of the circuit cable in metres

I_b is design current of the circuit A

$$C_t = \frac{230 + t_p - \left(C_a^2\, C_g^2 - \dfrac{I_b^2}{I_t^2}\right)(t_p - 30)}{230 + t_p}$$

Where:

t_p is the rated conductor operating temperature from the rating table

I_b is design current of the circuit

I_t is the tabulated current rating of the cable

From Table 4D4B column 4, the $(\text{mV/A/m})_{3p}$ is as follows:

$r = 0.55$, $x = 0.14$, $z = 0.57$

For simplicity using $z = 0.57$,

$$C_t = \frac{230 + 70 - \left(1^2 \times 0.73^2 - \frac{90^2}{207^2}\right)(70 - 30)}{230 + 70} = 0.95$$

$$\text{Voltage drop}_{\text{on tray}} = \frac{0.95 \times 0.57 \times 50 \times 90.2}{1000} = 2.44 \text{ volts}$$

This may now be reduced using the consideration of load power factor and temperature, see C 4.5.5

$$\text{Voltage drop}_{\text{on tray}}\ (\text{reduced}) = \frac{L\,I_b}{1000}\left[C_t \cos\phi\, (\text{mV/A/m})_r + \sin\phi\, (\text{mV/A/m})_x\right]$$

$$\text{Voltage drop}_{\text{on tray}}\ (\text{reduced}) = \frac{50 \times 90.2}{1000}\left[(0.97 \times 0.55 \times 0.8) + (0.6 \times 0.140)\right]$$

$= 2.30$ volts

Thus by using the 'power factor' voltage drop correction, the voltage drop has been reduced by some 40%.

ii) For the part of the cable route where the cable is run underground

For the underground section C_t is given by:

$$C_t = \frac{230 + 70 - \left(1^2 \times 1^2 - \frac{90^2}{143^2}\right)(70 - 30)}{230 + 70} = 0.920$$

$$\text{Voltage drop}_{\text{underground}} = \frac{L\,I_b}{1000}\left[C_t \cos\phi\, (\text{mV/A/m})_r + \sin\phi\, (\text{mV/A/m})_x\right]$$

$$\text{Voltage drop}_{\text{underground}} = \frac{50 \times 90.2}{1000}\left[(0.920 \times 0.55 \times 0.8) + (0.6 \times 0.140)\right]$$

$= 2.20$ volts

Now combining the voltage drop for the portion on the tray and that for the buried cable

Total voltage drop $= 2.30 + 2.20 = 4.50$ V

This is voltage drop in the line voltage, so percentage voltage drop is

$$\% \text{ voltage drop} = \frac{4.50}{400} \times 100 = 1.13\%, \text{ which is acceptable.}$$

Graphical estimation of the correction to voltage drop for conductor temperature as per section C 4.5.4 of the book

Manual calculations of Ct can be tedious and the graph in Figure C 4.5 provides a quick and convenient way of avoiding them. The graph can be used to correct tabulated (mV/A/m) values and can be applied to all cables under 16 mm^2 and to the tabulated resistive component, $(\text{mV/A/m})_r$, for larger cables. The graph is accurate where grouping factor is one and, for the buried cable portion, Cg, Ci and Cc are = 1. Thus, figure C 4.5, gives a reduction factor (equivalent to Ct) of 0.9; this is the same as the value calculated in (ii) above.

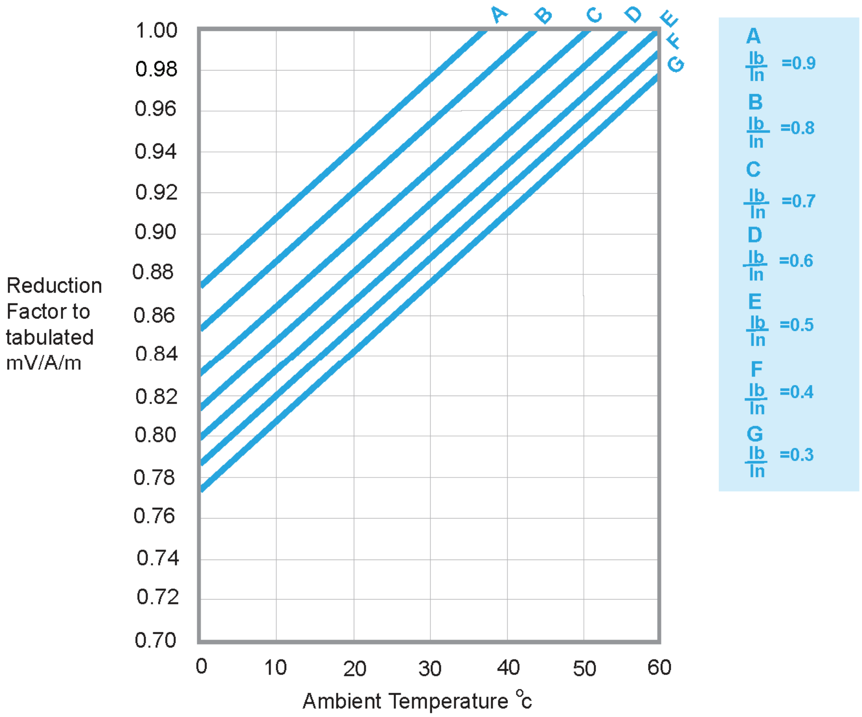

Figure C 4.5 Reduction factors for thermoplastic cables (PVC)

10.2.7 Check for short circuit

Check size for short circuit C4.4

As $I_b \leq I_n \leq I_z$ the phase conductors and neutral do not need a separate check for thermal withstand, see section C 4.4.2 of the book and regulation 434.5.2.

For the protective conductors, this does not need checking, see ECA recommendations C 5.3 of the book.

For completeness however, calculations based on BS 7671: 2008 are now provided.

i) the adiabatic equation of regulation 543

$$S \geq \frac{\sqrt{I^2 t}}{k}, \text{ or}$$

ii) meet the cross-sectional area requirements of Table 54.7.

The minimum size arising from these can be used; this will virtually always be by the adiabatic equation.

where:

S is the nominal cross-sectional area of the conductor in mm^2.

I is the value in amperes (rms for ac) of fault current for a fault of negligible impedance

t is the operating time of the disconnecting device in seconds corresponding to the fault current I amperes.

k is a factor taking account of the resistivity, temperature coefficient and heat capacity of the conductor material, and the appropriate initial and final temperatures, see Table 54.

(i) Size using the adiabatic equation

The fault current, I_f, is required and this is used to find a disconnection time using the protective device time current characteristic curve.

The fault current (in this case an earth fault current) is first calculated using the earth fault loop impedance. Strictly speaking calculations need to be carried out at the upstream and downstream ends of the cable but for illustration purposes, both will be carried out here (often a high loop impedance and lower fault current can let through more energy).

At distribution board outgoing terminals assuming a fault

$$I_f = \frac{U_0}{Z_e}$$

Note Z_e here is the earth fault loop impedance at the distribution board, in our simplified example it is also the external ELI.

$$I_f = \frac{230}{0.15} = 1533 \text{ amps,}$$

and from graph Figure 3.3B of BS 7671: 2008, disconnection time, $t = 0.1$ seconds. Note this figure would be lower if the British Standard or manufacturers data were used and the disconnection time would be 0.04 seconds, but we will proceed with 0.1 seconds. k from Table 54.4 is 51.

$$S \geq \frac{\sqrt{I^2 t}}{k} = \frac{\sqrt{1533^2\ 0.1}}{51} \geq 9.5 \text{ mm}^2$$

At load assuming a fault

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

Note Z_s here is the total earth fault loop impedance at the load end of the radial circuit. Using Table 4.5 of Appendix 4 of this book, the cable loop impedance, to be added to the external loop impedance is

$$\frac{R_1 + R_2 \text{ (ohms per km)} \times L}{1000} = \frac{2.19 \times 100}{1000} = 0.219 \text{ ohms}$$

Total ELI, $Z_s = Z_e + (R_1 + R_2) = 0.15 + 0.219 = 0.369$ ohms.

$$I_f = \frac{230}{0.369} = 623 \text{ amps,}$$

and from graph Figure 3.3B of BS 7671: 2008, disconnection time, $t = 2.8$ seconds.

$$S \geq \frac{\sqrt{I^2 t}}{k} = \frac{\sqrt{623^2\ 2.8}}{51} \geq 20.4\ \text{mm}^2$$

From Table 10.1, it can be seen that a 50 mm^2 4-core armoured cable, the csa of the armouring is 122 mm^2.

(i) Size using Table 54.7, then

$$\text{Minimum area of protective conductor} \geq \frac{k_1}{k_2} \times \frac{S}{2}$$

from Table 54.2 of BS 7671: 2008

$$\text{Minimum area of protective conductor} \geq \frac{115}{51} \times \frac{70}{2} \geq 78.9\ \text{mm}^2$$

Table 10.1 Gross cross-sectional area of armour wires for two-core, three-core and four-core 600/1000 V cables having steel-wire armour to BS 6436

Nominal area of conductor	Cross-sectional area of round armour wires						
	Cables with stranded copper conductors				Cables with solid aluminium conductors		
	2 -core (mm^2)	3-core (mm^2)	4-core (mm^2)	4-core (reduced neutral) (mm^2)	2 -core (mm^2)	3-core (mm^2)	4-core (mm^2)
1.5	15	16	17	-	-	-	-
2.5	17	19	20	-	-	-	-
4	21	23	35	-	-	-	-
6	24	36	40	-	-	-	-
10	41	44	49	-	-	-	-
16	46	50	72	-	42	46	66
25	60	66	76	76	54	62	70
35	66	74	84	82	58	68	78
50	74	84	122	94	66	78	113
70	84	119	138	135	74	113	128
95	122	138	160	157	109	128	147
120	131	150	220	215	-	138	201
150	144	211	240	235	-	191	220
185	201	230	265	260	-	215	245
240	225	260	299	289	-	240	274
300	250	289	333	323	-	265	304
400	279	319	467	452	-	-	-

10.2.8 Check for disconnection times

Check size for disconnection times C4.6

To check disconnection times you need to confirm that the total circuit earth fault loop impedance, ELI is less than that required by Chapter 41 of the regulations. We have designated the design ELI as Z_{41}.

So, $Z_s \leq Z_{41}$

From Table 41.4 of BS 7671: 2008 or from Appendix 3 of this book, the maximum design ELI, $Z_{41} \leq 0.42$ ohms.

$$Z_s = Z_e + L\,(r_1 + r_2)$$

where:

Z_e is the impedance in ohms of the source

r_1 is the resistance in ohms per metre of the line conductor

r_2 is the resistance in ohms per metre of the protective conductor

L is the length of the cable in metres

The value of $r_1 + r_2$ for steel wire armoured cables are given in tables in Appendix 4, Table 4.5 and for a 50 mm^2 four core cable neglecting reactance and correction for temperature, is

$$r_1 + r_2 = \frac{1.47 \times 100}{1000} = 0.147 \text{ ohms,}$$

and the total ELI = 0.15 + 0.147 = 0.297 ohms.

Therefore the actual designed ELI is less than the 0.42 Ω given in Table 41.4 of BS 7671: 2008.

It is noted that these values have been calculated using resistances of copper at 20°C, and an allowance has to be made for the final temperature of the conductors.

The new Appendix 14 of BS 7671: 2008 suggests a correction factor of 0.8. This however does not take into account that the cable will not be at its maximum operating temperature. A quick estimate of the reduction effect of this can be made using Figure C 4.5 of this book, but using

$$\frac{I_b}{I_z},$$

where I_z is the tabulated current carrying capacity.

Thus, using BS 7671: 2008 correction factor, the maximum ELI is 0.42 + 0.8 = 0.336 and the cable ELI is within this value.

10.3 Example 2

This example is a radial circuit supplying luminaires of length 40 m. The circuit cable to be enclosed in 50 mm by 50 mm trunking with 8 other single phase circuits. The load I_b is estimated to be 10 A and a 20 A type B circuit breaker is to be used to avoid unwanted tripping on switch due to inrush. The client has required a protective conductor to be run in the trunking Z_e is 0.4 ohm.

10.3.1 Cable type and installation method

Select cable type and installation method D5

Single core 70°C thermoplastic insulated cable without sheath enclosed in trunking is selected.

10.3.2 Calculate design current Ib

Calculate design current Ib C 4.3.2

$I_b = 10$ A

10.3.3 Calculate protective device rating

Select protective device rating C 4.3.1

To avoid unwanted tripping the device rating is selected to be 20 A, $I_n = 20$ A

10.3.4 Establish Ca, Gg, Ci & Cc

Establish Ca C 4.3.5

Establish Cg C 4.3.4

Establish Ci & Cf where applicable C 4.3.5

C a is the rating factor for ambient temperature, (Table 4B1 of BS 7671),

No ambient temperature is given, as is typically the case in practice. The assumption of a 30°C ambient is usual and is conservative for cable selection purposes.

Hence from Table 4B1 of BS 7671: 2008 Ca = 1

Cg is the rating factor for grouping

BS 7671: 2008 Appendix 4 includes revised information for grouping factors calculations. This includes a new table of grouping factors for buried cables.

It also includes a new generic method for calculating grouping factors for circuits with different size as follows:

$$F = \frac{1}{\sqrt{n}}$$

where F is the group reduction factor and n is the number of circuits.

$$\text{Using } F = \frac{1}{\sqrt{n}} = \frac{1}{\sqrt{9}} = 0.33$$

10.3.5 Calculate It

Calculate It C 4.3.3

This would require a cable of tabulated rating

Using Equation 2 given in C 4.3.3:

$$I_t \geq \frac{I_n}{C_a C_g} \text{ (Equation 2)}$$

Note that for many examples, the thermal insulation (C_i) and semi-enclosed fuse factor (C_c) are not used and have been ignored here. Thus,

$$I_t \geq \frac{I_n}{C_a C_g} \geq \frac{20}{1 \times 0.333 \times 1 \times 1} \geq 60$$

These formulae will give a lower group factor than BS 7671 tables 4C1 to 4C5 as these tables assume that cables in the group are of the same size (and requiring a higher I_t).

Table 4C1 (see C 4.33.4 of this book) gives a grouping factor = 0.5

$$I_t \geq \frac{20}{1 \times 0.5 \times 1 \times 1} \geq 40 \text{ (amps)}$$

The procedure (see section C 4.3.4 in this book) for applying grouping factors is to use either the factor from BS 7671 Tables 4C1 to 4C2 or use the following method:

Compare the formulae

$$I_t \geq \sqrt{I_n^2 + 0.48 I_b^2 \left(\frac{1 - C_g^2}{C_g^2}\right)} \text{ (Equation 3)}$$

with

$$I_t \geq \frac{I_b}{C_g} \text{ (Equation 4)}$$

using the larger value (note these equation numbers are from this book, Chapter C).

In our example Equation 3 is

$$I_t \geq \frac{1}{1 \times 1}\sqrt{\frac{20^2}{1^2} + 0.48 \times 10^2 \left(\frac{1 - 0.5^2}{0.5^2}\right)} = 23.3 \text{ amps}$$

and Equation 4 is

$$I_t \geq \frac{10}{0.5} \geq 20 \text{ amps.}$$

Thus an I_t equal or greater than 23.3 amps is to be selected. From Table 4D1A a 2.5 mm^2 cable is adequate.

In summary, for circuits that are not fully loaded, the use of this (Equation 4) method produces a lower I_t than the grouping factor method using Tables 4C1 to 4C5 from BS 7671.

In summary the procedures are summarised as:

- If a quick size method is required use BS 7671 Tables 4C1 to 4C5 and Equation 2,

  $$I_t \leq \frac{I_n}{C_a C_g}$$

  and do no more or,
- Calculate I_t using Equation 4 and Equation 3, using the larger I_t value.

To make life even easier and to save application of the second bullet point above which can be tiresome, the following look up table in Figure C 4.3 can be used instead and applied to Equation 2 (do not use where the protective device is a semi-enclosed fuse).

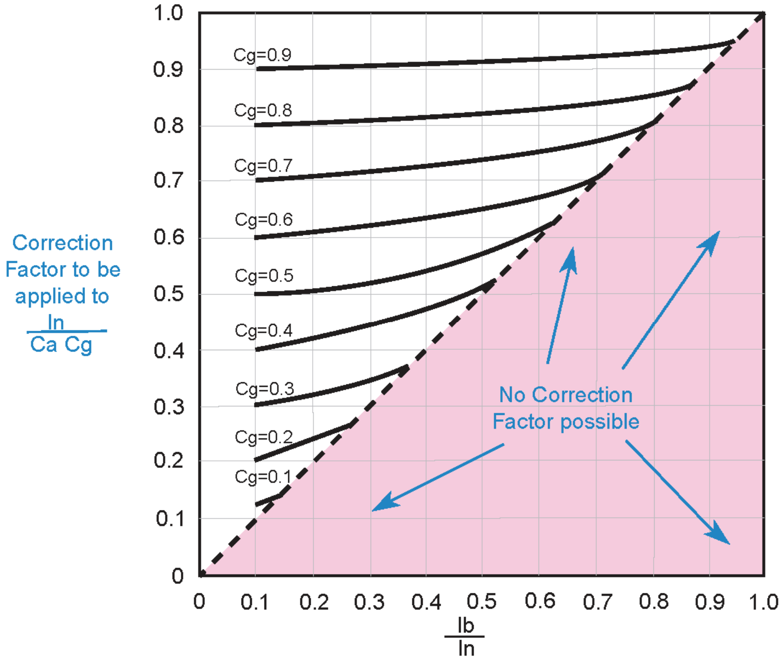

Figure C 4.3 Reduction formulae for circuits not fully loaded

Applying the table to the last example

$$\frac{I_b}{I_n} = \frac{10}{20} = 0.5$$

C_g is 0.5 and Figure C 4.3, the reduction factor that can be used with Equation 2 is approximately 0.58.

This would give a cable I_t

$$I_t \geq \frac{I_n}{C_a\, C_g} \times \text{Figure C 4.3 factor} \geq \frac{20}{0.5} \times 0.58 \geq 23.2 \text{ amps}$$

You can see the speed of using Figure C4.3 and the result is very close to the longer calculation above.

10.3.6 Check size for volt drop

Check Voltage drop C4.5

Using the simple volt drop calculation for 2.5 mm^2 cable of length 60 m with a load I_b of 10A, from Table 4E1B (mV/A/m) is 16mV/A/m

$$\text{Voltage drop} = \frac{(\text{mV/A/m}) \times L \times I_b}{1000} = \frac{15 \times 40 \times 10}{1000} = 6 \text{ volts}$$

The suggested 3% limit, in light of other values, of 230 V is 6.9 V, so this voltage drop may be acceptable.

10.3.7 Check for disconnection times

Check size for disconnection times C4.6

To check disconnection times we need to confirm that:

$$Z_s \leq Z_{41.4}$$

From Table 41.3 of BS 7671: 2008 Z_{41} = 2.3 ohms

$$Z_s = Z_e + L\,(r_1 + r_2)$$

Where:

Z_e is the impedance in ohms of the source

r_1 is the resistance in ohms per metre of the line conductor

r_2 is the resistance in ohms per metre of the protective conductor

L is the length of the cable in metres

From Table 4.2 of this book (Appendix 4), for 2.5 mm^2 line and protective conductor

$r_1 + r_2$ at 20°C is 14.82 mΩ/m.

$$\text{Hence } Z_s = Z_e + L\,(r_1 + r_2) = 0.4 + \frac{14.82 \times 40}{1000} = 0.99 \text{ ohms}$$

Correcting for conductor temperature of 70°C (see Table 4.6, Appendix 4 of this book), correction factor = 1.197

Thus the ELI will be 1.2 ohms which is less than that required by Chapter 41.

10.3.8 Check for short circuit withstand

Check size for short circuit C4.4

Not necessary no reduced area protective conductors used.