Brunel University

ME5627 Electrical Services Design Assignment

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Programme: Renewable Energy Engineering MSc

The submission date for these assignments is the dates by which they should be uploaded to Brunel. Make sure you retain an electronic copy for reference in case of file corruption during submission. You should refer to your Course Handbook for general information on the submission of assignments.

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Submission Method: Submission electronically via Wiseflow by 23:59 on the date noted above (the link can be accessed through Blackboard Learn).

Useful data can be found with the lecture handouts. Additionally you should refer to BS 7671 (IET Wiring Regulations) and the IET Guidance Notes.

Read all of this part of the assignment carefully before you begin to ensure that you understand what is required.

Show all your calculations and justify all of your assumptions.

Introduction

In this Assignment you will undertake a design exercise for a commercial building. Data are provided from which you are to design parts of the electrical distribution. The building will have a public network supply with the following declared supply characteristics:

300 Ampere, 400/230 volt, TP&N, 50 Hz

Prospective short circuit current: 28 kA

TNCS, Earth fault loop impedance: 0.10 Ω

The incoming cable will terminate onto a main switchboard located on the ground floor. The Roof Distribution Board is fed from the Roof Plantroom Switchboard, but all other loads are fed radially from the main switchboard. The circuit details are shown in Table 1.

The following assumptions are to be made:

(i) All loads are three phase and operate at unity power factor.

(ii) The ambient temperature will not exceed 30°C.

(iii) Cables are not installed in contact with any thermal insulation.

You will also have to make assumptions about the layout of the distribution, and choose the cabling system.

Table 1 - Circuit Details

Circuit Ref.	Description	Route Length (m)	Design Current (A)	Protective Device Rating (A)
1	IT server room D.B.	100	80	160
2	Ground Floor D.B.	70	30	63
3	First Floor D.B.(East)	18	20	63
4	First Floor D.B. (West)	73	30	63
5	Lift Motor Room D.B.	85	55	63
6	Roof Plantroom Switchboard	95	100	125
7	Roof D.B. (fed from the Roof Plantroom Switchboard, ref 6)	20	40	63

Abbreviations:

D.B. distribution board.

TP&N three phase and neutral.

Assignment

1.)

(a) How do we ensure that the live conductors of a cable are protected against the effects of overload?

Answer We have to ensure that the current installed capacity of cable (I_z) is no less than the nominal current rating of the circuit protective devices (I_n). I_z can be determined by the following equation:

$I_z = I_t$ x rating factors of cable

Where: I_t is tabulated current capacity of cable and rating factors depend on the environment of the cable. For example: the ambient temperature (Ca), group of cable (Cg), etc. Furthermore, I_n has to be larger than our design current (I_b). Therefore, $I_z \geq I_n \geq I_b$, so that we can ensure our cables are protected against the effect of overload.

(b) What limitations do we need to impose on the volt drop in electrical distribution design?

Answer The limits for voltage drops to provide adequate voltage for any supply or load are shown in table 1 below, according to table 4Ab-Voltage drop, from Appendix 4.

	Lighting	Other uses
(i) Low voltage installations supplied directly from a public low voltage distribution system	3%	5%
(ii) Low voltage installations supplied directly from a private low voltage supply	6%	8%

Table 1 Voltage drop limits

(c) Why are we required to calculate the value of prospective short circuit current (PSCC) at points in the distribution system?

Answer We calculate the value of PSCC at points in the distribution system for choosing the suitable protective device for the circuit. Also, we calculate the PSCC value to ensure that circuit protective devices can withstand the worst case of short circuit (3 phase short circuit) because the PSCC value is going to be the maximum current value that may occur. The breaking capacity of the protective device must be at least equal to the PSCC.

(d) Why do we impose an upper limit on the earth fault loop impedance, Z_s, for each circuit?

Answer We impose an upper limit on the earth fault loop impedance (Z_s) low enough to ensure that the fault current is large enough in order to operate the protective device fast enough to prevent loss of life from an electric shock that might happen. In other words, we can say that we impose Z_s for protecting against electric shock.

(e) How do we ensure that the circuit protective conductor is protected against the effects of fault current?

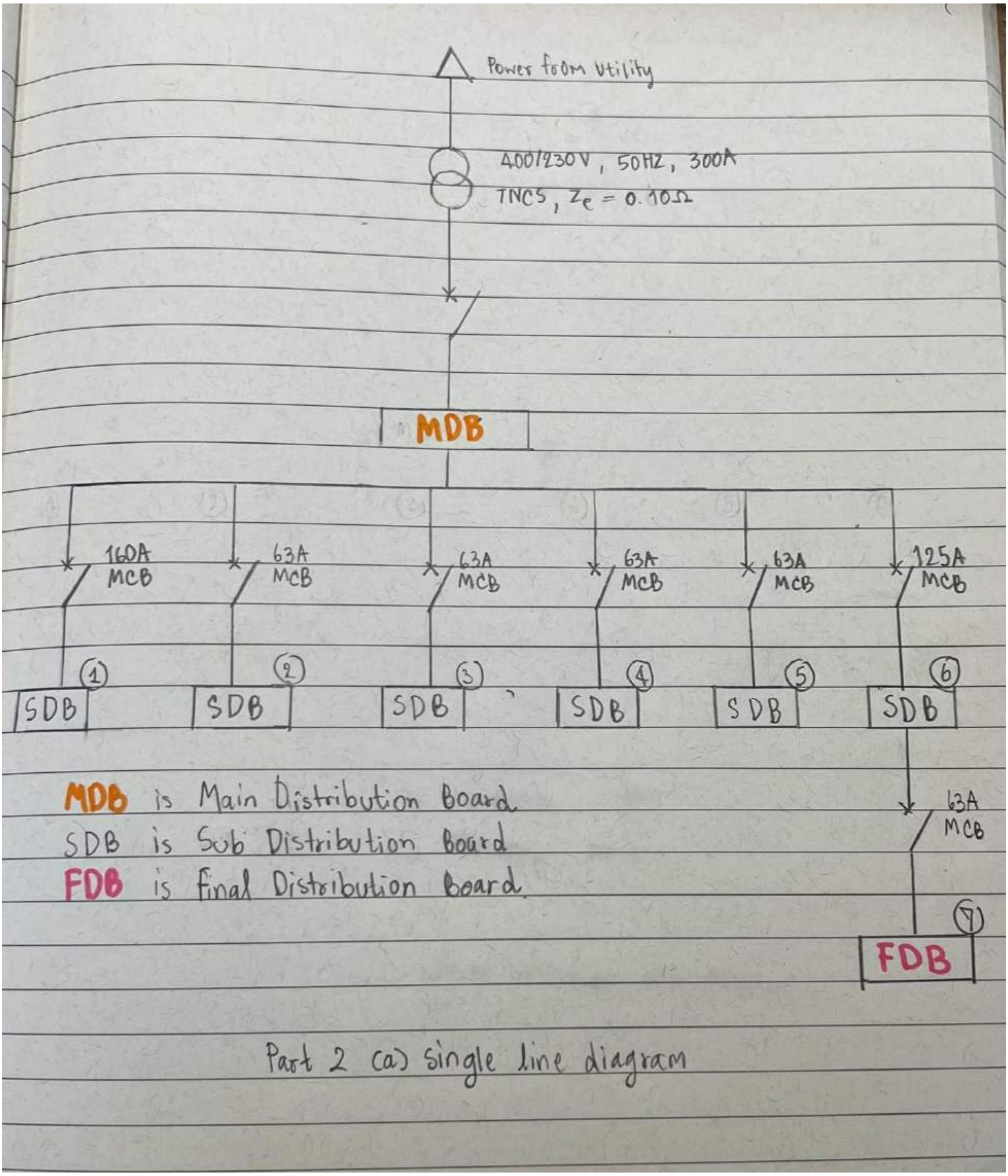
Answer We have to impose the total energy let-through of our protective device (I^2t) of no more than the maximum ($k^2 S^2$) as shown in the adiabatic equation below, to ensure that the CPC is protected against the effect of fault current.

Adiabatic equation: $I^2t \leq k^2S^2$

Where: I is the fault current (Amps), t is the duration of fault (seconds), S is the conductor cross-sectional area (mm^2)

2.)

a) Draw a single-line schematic diagram of the electrical distribution.



b) For both of the circuits ref. 6 and 7 state your choice of the type of:

Circuit protective device - **MCB Type B**
Cabling system - **XLPE, Sheathed multicore cable on a ladder (Method E)**
Circuit protective conductor - **Copper**

c) Calculate the cable sizes for circuits 6 and 7, demonstrating how you have satisfied each of the requirements from question 1.
**Figure from intake switch to circuit 6

c1) Cable sizing for circuit 6
Data given

I_b	100A
I_n	125A
Z_e	0.10Ω
Cable length	95m
C_a	1
C_i	1
Power factor	Unity

For the installation reference method E, Thermosetting sheathed multicore cable on a ladder (6 cable on one layer ladder). Cable group rating factor (C_g) is 0.79.

TABLE 4C1 – Rating factors for one circuit or one multicore cable or for a group of circuits, or a group of multicore cables, to be used with current-carrying capacities of Tables 4D1A to 4J4A

Item	Arrangement (cables touching)	Number of circuits or multicore cables												To be used with current-carrying capacities, Reference Method
		1	2	3	4	5	6	7	8	9	12	16	20	
1.	Bunched in air, on a surface, embedded or enclosed	1.00	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.45	0.41	0.38	A to F
2.	Single layer on wall or floor	1.00	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70	0.70	0.70	0.70	C
3.	Single layer multicore on a perforated horizontal or vertical cable tray system	1.00	0.88	0.82	0.77	0.75	0.73	0.73	0.72	0.72	0.72	0.72	0.72	E
4.	Single layer multicore on cable ladder system or cleats etc.	1.00	0.87	0.82	0.80	0.80	0.79	0.79	0.78	0.78	0.78	0.78	0.78	

Therefore: $I_t = \frac{In}{CaCiCgCdCs} = \frac{125}{1x1x0.79x1x1} = 158.3A$

To ensure that the live conductors of a cable are protected against the overcurrent, the cable carrying capacity must be at least equal to tabulated current ($I_z \geq I_t$)

TABLE 4E2A – Multicore 90 °C thermosetting insulated and thermoplastic sheathed cables, non-armoured (COPPER CONDUCTORS)

CURRENT-CARRYING CAPACITY (amperes):

Ambient temperature: 30 °C
Conductor operating temperature: 90 °C

Conductor cross-sectional area	Reference Method A (enclosed in conduit in thermally insulating wall etc.)		Reference Method B (enclosed in conduit on a wall or in trunking etc.)		Reference Method C (clipped direct)		Reference Method E (free air or on a perforated cable tray etc, horizontal or vertical)	
	1 two-core cable*, single-phase AC or DC	1 three- or four-core cable*, three-phase AC	1 two-core cable*, single-phase AC or DC	1 three- or four-core cable*, three-phase AC	1 two-core cable*, single-phase AC or DC	1 three- or four-core cable*, three-phase AC	1 two-core cable*, single-phase AC or DC	1 three- or four-core cable*, three-phase AC
1	2	3	4	5	6	7	8	9
(mm^2)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1	14.5	13	17	15	19	17	21	18
1.5	18.5	16.5	22	19.5	24	22	26	23
2.5	25	22	30	26	33	30	36	32
4	33	30	40	35	45	40	49	42
6	42	38	51	44	58	52	63	54
10	57	51	69	60	80	71	86	75
16	76	68	91	80	107	96	115	100
25	99	89	119	105	138	119	149	127
35	121	109	146	128	171	147	185	158
50	145	130	175	154	209	179	225	192
70	183	164	221	194	269	229	289	246
95	220	197	265	233	328	278	352	298

From table 4E2A in BS7671 the selected cable is 50 mm^2 with cable current capacity (I_z) of 192A (192A > 158.3A)

Voltage drop (V_d)
The voltage drop in the cable can be determined from the following equation:

$V_d = I_b R \cos\theta + I_b X \sin\theta$

Where: R is the cable resistance per cable length (mv/A/m)
X is the cable reactance per cable length (mv/A/m)

From the course book (page 132) the influence of reactance (X) only becomes important for large cables (>16mm^2) and, for these the IET regulations separate the volt drop data into 'R', 'X' element. If, however, we overlook the power factor and simply use the combined 'Z' elements for volt drop, we will overestimate circuit voltage drop.

From table 4E2A (given below) in BS7671. The values of R, X and Z for XLPE of 50 mm^2 are 0.86, 0.135 and 0.87, respectively. From the data given: Ib = 100A, L = 95m, cosθ = 1 (unity), sinθ = 0

Therefore, the voltage drop of the cable is given by:

Vd = (100A x 0.86 mv/A/m x 95m) + 0 = 8.17V

%Vd = $\frac{8.17}{230}$ x 100% = 3.55% (less than 5% so the cable is adequate)

TABLE 4E2B

VOLTAGE DROP (per ampere per metre): Conductor operating temperature: 90 °C

Conductor cross-sectional area	Two-core cable, DC	Two-core cable, single-phase AC			Three- or four-core cable, three-phase AC		
1	2	3			4		
(mm^2)	(mV/A/m)	(mV/A/m)			(mV/A/m)		
1	46	46			40		
1.5	31	31			27		
2.5	19	19			16		
4	12	12			10		
6	7.9	7.9			6.8		
10	4.7	4.7			4.0		
16	2.9	2.9			2.5		
		r	x	z	r	x	z
25	1.85	1.85	0.160	1.90	1.60	0.140	1.65
35	1.35	1.35	0.155	1.35	1.15	0.135	1.15
50	0.98	0.99	0.155	1.00	0.86	0.135	0.87
70	0.67	0.67	0.150	0.69	0.59	0.130	0.60
95	0.49	0.50	0.150	0.52	0.43	0.130	0.45

Prospective short circuit current (PSCC) calculation
We need to know the maximum short circuit current that may occur in order to verify our protective device will definitely be able to handle the current.

PSCC can be determined thus: PSCC = $\frac{Phase\ Voltage}{total\ phase\ impedance\ (Zo)}$

Intake PSCC = 28kA therefore:

Total source impedance = $\frac{230V}{28kA}$ = 8.22 mΩ

The worst case (maximum PSCC) occurs when the cable impedance is lowest (i.e. when the cable is cold). Therefore, data for 20°C needs to be used.

From BS7671, XLPE at 20C; R = 1.15 mΩ/m, X is negligible.
For 95m; R = 1.15 mΩ/m x 95m = 109.25 mΩ

The total phase impedance = $\sqrt{R^2 + Z^2}$ = $\sqrt{109.25^2 + 8.22^2}$ = 109.59 $\simeq$ 109.6 mΩ

Therefore, PSCC at the D.B = $\frac{230V}{109.6m\Omega}$ = 2098A $\simeq$ 2.1kA

So the protective device at circuit 6 (Roof Plantroom Switchboard) must have breaking capacity at least 2.1kA. For MCB Type B 125A has breaking capacity of $\leq$ 25kA so the protective device can withstand the worst case of a short circuit.

Characteristics of cb	BS EN 60898-1	BS EN 60947-2
Current ratings, In	6 - 125 A	0.5 - 6,300 A
Short-circuit breaking capacity, Icn	≤ 25 kA	≤ 150 kA
Impulse withstand voltage, Uimp	4 kV	6 kV or 8 kV
Tripping characteristics	B,C,D	B,C,D,K,Z,MA
Pollution Level	2	3
Typical uses	Household and similar installations, retail premises, schools, offices	Commercial and industrial installations

Earth Fault Loop Impedance calculation (Z_s)

Z_s can be calculated from the following equation:

$Z_s = Z_e + (R_1+R_2)$ or $Z_e + (R_1+R_2) \times L \times F$

Where:

Ze is the earth fault loop impedance external to the circuit concern
R_1 is the resistance of the line conductor from the origin of the circuit to the point of utilisation
R_2 is the resistance of the protective conductor from the origin of the circuit to the point of utilisation
F is the temperature correction factor to take into account the final operating temperature

Table I3 shows the values of R_1+R_2 (mΩ/m) from the On-Site-Guide in Appendix I. Assume the cross sectional area of the protective conductor is $25mm^2$. The line conductor cross sectional area is $50mm^2$. The value of R_1+R_2 for $50mm^2$ line conductor and $25mm^2$ protective conductor at 20°C is 1.114 mΩ/m (for copper conductor).

F can be found in Appendix I table I3 from On-Site-Guide. Which is 1.28 for XLPE with copper conductor.

Given data: Z_e = 0.10Ω, L = 95m, R_1+R_2 at 20°C = 1.114 mΩ/m, F = 1.28
R_1+R_2 = 1.114 mΩ/m x 95m = 105.83mΩ = 0.10583Ω
Z_s At 20°C; Z_s = 0.10Ω + 0.10583Ω = 0.20583Ω ≃ 0.206Ω
Z_s At 90°C; Z_s = 0.10Ω + (0.10583x1.28)Ω = 0.23546Ω ≃ 0.236Ω

Table 41.3 from BS7671 shows the maximum Z_s for circuit breakers. For MCB Type B 125A, the maximum Z_s is 0.35Ω. Calculated Z_s must be less than the maximum Z_s to ensure that the fault current is large enough in order to operate the protective device fast enough. And 0.236Ω ≤ 0.35Ω so the selection of the line conductor and protective conductor can handle the electric shock.

Table I3 Multipliers to be applied to Table I1 to calculate conductor resistance at maximum operating temperature (note 3) for standard devices (note 4)

Conductor installation	Conductor insulation		
	70 °C Thermoplastic (PVC)	90 °C Thermoplastic (PVC)	90 °C Thermosetting
Not incorporated in a cable and not bunched (note 1)	1.04	1.04	1.04
Incorporated in a cable or bunched (note 2)	1.20	1.28	1.28

Table I1 Values of resistance/metre or $(R_1 + R_2)$/metre for copper and aluminium conductors at 20 °C

Cross-sectional area (mm²)		Resistance/metre or $(R_1 + R_2)$/metre (mΩ/m)	
Line conductor	Protective conductor	Copper	Aluminium
1	–	18.10	
1	1	36.20	
1.5	–	12.10	
1.5	1	30.20	
1.5	1.5	24.20	
2.5	–	7.41	
2.5	1	25.51	
2.5	1.5	19.51	
2.5	2.5	14.82	
4	–	4.61	
4	1.5	16.71	
4	2.5	12.02	
4	4	9.22	
6	–	3.08	
6	2.5	10.49	
6	4	7.69	
6	6	6.16	
10	–	1.83	
10	4	6.44	
10	6	4.91	
10	10	3.66	
16	–	1.15	1.91
16	6	4.23	–
16	10	2.98	–
16	16	2.30	3.82
25	–	0.727	1.20
25	10	2.557	–
25	16	1.877	–
25	25	1.454	2.40
35	–	0.524	0.87
35	16	1.674	2.78
35	25	1.251	2.07
35	35	1.048	1.74
50	–	0.387	0.64
50	25	1.114	1.84
50	35	0.911	1.51

TABLE 41.3 –
Maximum earth fault loop impedance (Z_S) for circuit-breakers with U_0 of 230 V, for operation giving compliance with the 0.4 s disconnection time of Regulation 411.3.2.2 and 5 s disconnection time of Regulation 411.3.2.3 (for RCBOs see also Regulation 411.4.204)

(a) Type B circuit-breakers to BS EN 60898 and the overcurrent characteristics of RCBOs to BS EN 61009-1

Rating (amperes)	3	6	10	16	20	25	32	40	50	63	80	100	125	I_n
Z_s (ohms)	14.57	7.28	4.37	2.73	2.19	1.75	1.37	1.09	0.87	0.69	0.55	0.44	0.35	230 x 0.95/(5I_n)

Thermal constraint verification
This calculation is a check to ensure that the cross-section of the CPC is sufficient to allow it to withstand the energy let-through of the Circuit Protective Device (CDP) under earth fault conditions.

Adiabatic equation: $t = \frac{S^2K^2}{I^2}$ or $S = \frac{\sqrt{I^2t}}{K}$

Where:

t is the duration in seconds

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

I is the effective fault current, in amperes, expressed for AC as the RMS value, due account being taken of the current limiting effect of the circuit impedances

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. For common materials, the values of k are shown in Table 43.1or table 54.2-54.6 from BS7671

From table 43.1 from BS7671 for copper conductor (XLPE), k = 143

Determine the disconnection time (t), how long the circuit can handle the fault current of 1.12kA.

For circuit 6 the fault current can be determined by the following equation:

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

Where:

U_o = nominal line voltage = 230V
Z_s = earth fault loop impedance
Z_s At 20°C; $Z_s \simeq 0.206\Omega$
Z_s At 90°C; $Z_s \simeq 0.236\Omega$

Therefore:

At 20°C $I_f = \frac{230V}{0.206\Omega}$ = 1116.5A ≃ 1.12kA
At 90°C $I_f = \frac{230V}{0.236\Omega}$ = 975A

Calculate the disconnection time

From the calculations above; S = 25mm^2, I_f at 20°C = 1.12kA, k = 143

$$t = \frac{S^2K^2}{I^2} = \frac{25^2\ x\ 143^2}{(1.12x1000)^2} = 10s$$

This means that the circuit can withstand the fault current of 1.12kA for 10 seconds before the live conductor starts softening and becoming damaged. The thermoplastic insulation will start to suffer, so it must turn off within 10 seconds.

TABLE 43.1 –
Values of k for common materials, for calculation of the effects of fault current for disconnection times up to 5 seconds

	Conductor insulation							
	Thermoplastic				Thermosetting		Mineral insulated	
	90 °C		70 °C		90 °C	60 °C	Thermoplastic sheath	Bare (unsheathed)
Conductor cross-sectional area	≤ 300 mm²	> 300 mm²	≤ 300 mm²	> 300 mm²				
Initial temperature	90 °C		70 °C		90 °C	60 °C	70 °C	105 °C
Final temperature	160 °C	140 °C	160 °C	140 °C	250 °C	200 °C	160 °C	250 °C
Copper conductor	k = 100	k = 86	k = 115	k = 103	k = 143	k = 141	k = 115	k = 135/115[a]
Aluminium conductor	k = 66	k = 57	k = 76	k = 68	k = 94	k = 93		
Tin soldered joints in copper conductors	k = 100	k = 86	k = 115	k = 103	k = 100	k = 122		

Fig 3A4 – Type B circuit-breakers to BS EN 60898 and RCBOs to BS EN 61009-1

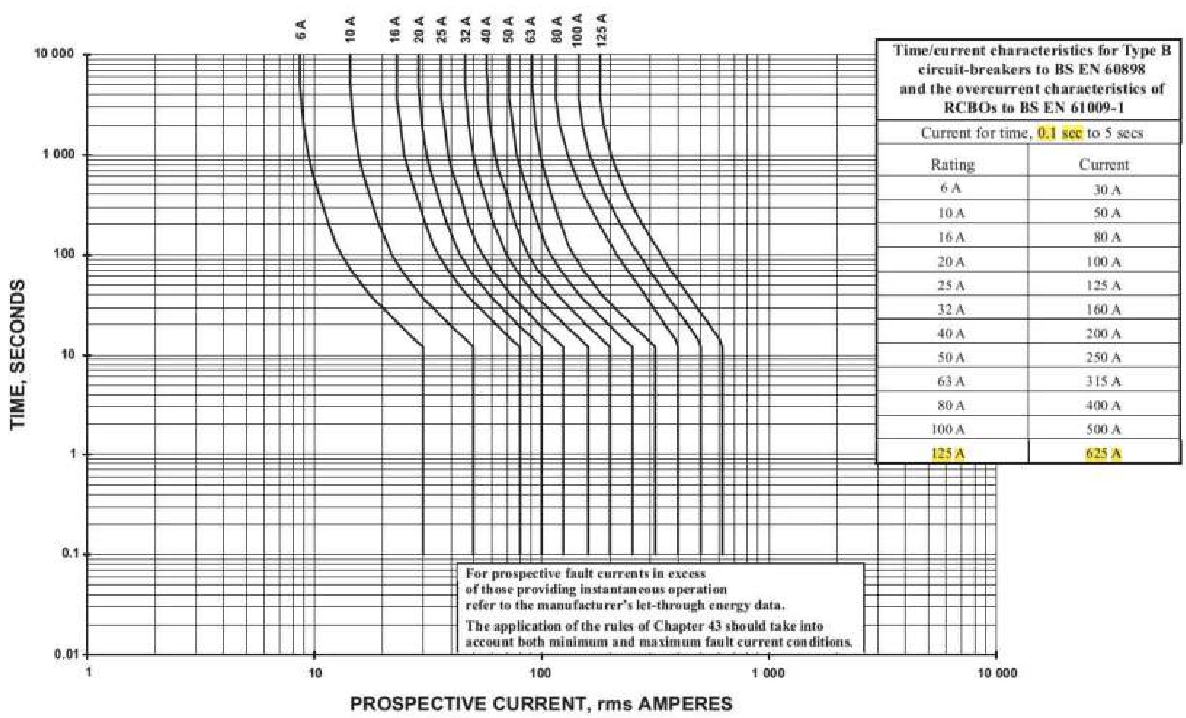


Figure 3A4 in Appendix 3 from BS7671, MCB Type B 125A will trip in 0.1 seconds. So our circuit will cut off long before 10 seconds (before damage starts).

Protective conductor verification

From the calculations above: I_f at 20°C = 1.12kA, k = 143

The disconnection time (t) can be found in Fig 3A4; for MCB Type B 125A will need 625A to operate the device and have a disconnection time of 0.1 seconds.

Therefore: $S = \frac{\sqrt{I^2 t}}{K} = \frac{\sqrt{1120^2\ x\ 0.1}}{143} = 2.4767mm^2 \simeq 2.5mm^2$

The cross sectional area of the CPC has to be larger than $2.5mm^2$ in order to trip within 0.1 seconds when a fault current of 1.12kA occurs. For this case, the cross sectional area of the CPC of the circuit is $25mm^2$ so the CPC is protected against the fault current.

Finally, to verify the thermal constraint using the following equation:

$I^2 t \leq K^2 S^2$

To ensure that the CPC is protected against the effect of fault current, the amount of let through energy ($I^2 t$) has to be less than the amount of the energy that the cable can withstand ($K^2 S^2$).

From the calculations above: I = 1.12kA, t = 10s, K = 143 and S = $25mm^2$

So the design conditions are satisfied:

$I^2 t \leq K^2 S^2$

$1120^2 \text{ x } 10 \leq 143^2 \text{ x } 25^2$

$12{,}544{,}000 \leq 12{,}780{,}625$

The let-through energy is less than the energy that the cable can handle, so our XLPE $50mm^2$ with CPC of 25 mm^2 cross-sectional area is adequate.