VERIFICATION OF VIPCODA SOFTWARE BY USING STANDARD DESIGN PROCEDURE

SABARARIAH BINTI MOHAMMAD

A report submitted in partial fulfilment of the requirements for the degree of

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

ENDORSEMENT

“ I hereby declare that I have read through this report entitle “Verification of VipCoda software by using Standard Design Procedure” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

Signature: ....
Supervisor’s Name: DR. AMINUDIN BIN AMAN
Date: 23/6/2016 23/6/2016.

DECLARATION

I declare that this report entitle "Verification of VipCoda software by using Standard Design Procedure" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ....

Name: SABARIAH BINTI MOHAMMAD

Date: 23 JUNE 2016

ACKNOWLEDGMENT

Assalamualaikum w.b.t…

Firstly, I would like to give my thanks to Allah for giving me strength and ability to complete the project from beginning until the end. Without His permission, I would not finish my final year project in successful.

The special thank goes to my helpful supervisor, Dr. Aminudin bin Aman. The supervision and support that he gave truly help the progression and smoothness in order to complete my final year project. I really appreciate for all the guidance and advice that have been given for me.

My grateful thanks also go to my entire friend that never tired to support and help me to assemble the parts and gave suggestion about this research. Last but not least, many thanks to my beloved family for supporting and encourage me through out of this project. I have to appreciate the guidance given by other supervisor as well as panel especially to improve my report final year project to be a more better.

ABSTRACT

VipCoda is intelligent software that can be used to automatically assess and evaluate any submitted electrical network systematically within a short time. However, this software also has the constraint which is not providing step-by-step of guidance of electrical installation according to IEE Wiring Regulation (British Standard, BS 7671). This problem can be overcome by develop the step-by-step procedures to assist the VipCoda user according to BS 7671. To provide accurate and safe design procedure that follows BS 7671, literature study help in identify the suitable circuit breaker, sizing of cable, current rating and voltage drop. To verify the calculation of low voltage design with VipCoda results, a case study was conducted. The case study consists of two final DBs which is there are three type of load connected to each DB. It was conducted to verify calculation that follow BS 7671 with the VipCoda results. By comparing the results, only 2% error occurs in calculation. Therefore, it shows that the step-by-step procedure to assist the VipCoda user is reliable.

ABSTRAK

VipCoda adalah perisian pintar yang boleh digunakan untuk menilai secara automatik dan menilai mana-mana rangkaian elektrik dikemukakan secara sistematik dalam masa yang singkat. Walau bagaimanapun, perisian ini juga mempunyai kekangan yang mana tidak menyediakan langkah demi langkah panduan pemasangan elektrik mengikut IEE Wiring Regulation (British Standard, BS 7671).Masalah ini boleh diatasi dengan menyediakan prosedur langkah demi langkah untuk membantu pengguna VipCoda mengikut BS 7671.Untuk menyediakan prosedur reka bentuk yang tepat dan selamat merujuk BS 7671, kajian sastera membantu dalam mengenal pasti pemutus litar yang sesuai, saiz kabel, kedudukan arus, kejatuhan voltan. Untuk mengesahkan pengiraan reka bentuk voltan rendah dengan keputusan VipCoda, satu kajian kes telah dijalankan. Kajian ini terdiri daripada dua DB akhir yang terdapat tiga jenis beban disambungkan pada setiap DB. Ia telah dijalankan untuk mengesahkan pengiraan yang mengikuti BS 7671 dengan keputusan VipCoda. Dengan membandingkan keputusan, hanya 2% kesilapan berlaku dalam pengiraan. Oleh itu, ia menunjukkan bahawa prosedur langkah demi langkah untuk membantu pengguna VipCoda boleh dipercayai.

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LIST OF ABBREVIATIONS

BS - British Standard

CPC - Circuit Protective Conductor

DB - Distribution Board

MCB - Miniature Circuit Breakers

MCCB - Moulded Case Circuit Breaker

PVC - Polyvinyl Chloride

RCCB - Residual Current-Operated Circuit Breakers

SSO - Switch Socket Outlet

VipCoda - Visually Interactive Program for Consultant and Owner to Design and Assess

XLPE - Cross-Linked Polyethylene

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the electrical power system comprise of three important things which are generation, transmission and distribution energy in the form of electric current to the ultimate load. The distribution system consists of high voltage and low voltage. Normal voltages for high voltage are 33kV, 22kV and 11kV. From high voltage it will step down to low voltage power system, which are 240 V and 415 V. Voltage that normally used in industrial and commercial system should not exceed 1 kV [1].

The low-voltage is widely used in every industry in the society to connect the supply and marketing of the power energy and transfer the loss, comparing with the high-voltage grid. The low-voltage has characteristics as long circuitries, wide distribution, disordered layout, significant change, difficult management (due to many people engage in it), large loss and more accidents. Therefore, the authorities have to overcome these characteristics by following standard protective measures, properly installation and maintained. It is because to prevent persons from exposed to the risk of electric shock and being in contact with energized parts for a harmful length of time.

1.2 Project motivation

VipCoda is used to evaluate any submitted electrical network systematically within a short time. The current users of this visually interactive tool are Lakefront Residence Malaysia, Powerlite Engineering, Universiti Teknikal Malaysia Melaka (UTeM) and many more [2]. However, the VipCoda software alone will difficult to the new user such as UTeM because there are no step-by-step procedures that follow IEE wiring regulation (BS 7671). Therefore, this study will help the new user in design low voltage electrical installation according to standard design procedure BS 7671. This project is verified by VipCoda software results.

1.3 Problem Statement

In the design of low-voltage systems in buildings, safety of life and preservation of property are the first two important factors to be considered. The safety requirements should follow the established codes such as the IEE Wiring Regulations, CP5 or NEC [2][3][4]. Therefore, to make the proper design in low voltage installation the standard BS 7671 should be follow correctly. Recently, in advance technology there is software that can display the best installation for engineers which is VipCoda. VipCoda is intelligent software can automate the design process producing a sound and reliable. However, the constraint of VipCoda is not providing step-by-step of guidance of electrical installation. It wills difficult to the new user that needs guidance of electrical installation by following the standard BS 7671. To make proper and accurate guidance of low voltage installation, verification of VipCoda software with design calculation according to Standard BS 7671 was complied.

1.4 Project Objective

The objectives of this study are:

1. To examine the steps in low voltage design system according to BS 7671
2. To verify the calculation of low voltage design with VipCoda results
3. To develop the step-by-step verification procedures to assist the VipCoda user

1.5 Project Scope

The scopes of this research are:

i. The design for low voltage installation (240/415 V).
ii. The steps for design low voltage installation are following the British Standard (BS 7671).
iii. The type of load has been used in this study are normal load, motor load and lighting load.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Each circuit should be equipped with a circuit breaker for automatic interruption of supply in the event of overload current and fault current to provide adequate overcurrent protection. The important equipment in this study such as circuit breaker, cable, voltage drop will be discussed in the following sub-section. The current rating in each protective device is following the IEE Wiring Regulations (BS 7671).

2.2 Circuit Breaker

Circuit-breakers are the most important equipment in power systems. It is an interrupting device to use in normal operation and during faults. It is expected that circuit-breakers must be operated in any applications without problems. Without damaging of insulation, the circuit breaker must be able to interrupt short-circuit currents, capacitive currents and small inductive currents [5]. There are a few characteristic circuit breaker should be fulfil which is capable of being safely closed within the making capacity of the device. It also should safely open at any current up to the breaking capacity.

For selection of a circuit breaker, it is should follow the correct current rating, which is carry the required current without overheating. It also should have the correct voltage rating which is switch and isolate or disconnect the load from the source at the given system voltage. Lastly, circuit breaker should have the correct interrupting rating which is can interrupt any abnormally high operating current or short-circuit current likely to be encountered during operation [6]. The circuit breakers to be discussed are MCB, MCCB and RCCB. The details information of these circuit breakers is explained in the following sub-section.

2.2.1 Type of circuit breaker

Protective device is the equipment applied to electric power system to detect abnormal and intolerable conditions and to initiate appropriate corrective actions. The protective devices that use in this project are MCB, MCCB and RCCB. The sub-section below will explain the detail of the protective device that used.

2.2.1.1 Miniature Circuit Breakers (MCB)

MCB are available for single and three phases. The MCB are used for protection final circuits in domestic and commercials installations. Most MCBs are provided with two types of tripping mechanisms which is bi-metallic thermal trip and the electromagnetic of tripping. The current rating for this type of circuit breaker are 6, 8, 10, 15, 16, 20, 25, 32, 40, 50, 63, 80, 100 and 125 A [5]. For the standard values of rated short-circuit capacity are 1.5, 3, 4.5, 6 and 10 kA. For values above 10 kA, up to and including 25 kA, the preferred value is 20 kA. Figure 2.1 shows the example of MCB in the market.

Figure 2.1: MCB in the market [7]

2.2.1.2 Moulded Case Circuit Breaker MCCB

In low-voltage electrical equipment, MCCB is important belonging to the class of electrical protection. It has manual and automatically operation that can lose voltage, under voltage, overload and short circuit protection. It is used in low-voltage distribution circuit for motor or other electrical devices, and it takes in charge of make-on, carrying and breaking current in normal or abnormal conditions such as short circuit [8]. Figure 2.2 below shows the example of MCCB in the market.

Current rating: 10, 16, 20, 32, 40, 50, 63, 80, 100, 200, 300, 400, 630, 800 1250 A.
Rated voltage: 380, 400, 415 V.
Rated breaking capacity: 10, 20, 25, 35, 65, 85 kA (r.m.s)
Rated making capacity: 17, 44, 53, 63, 84, 143 kA (peak)

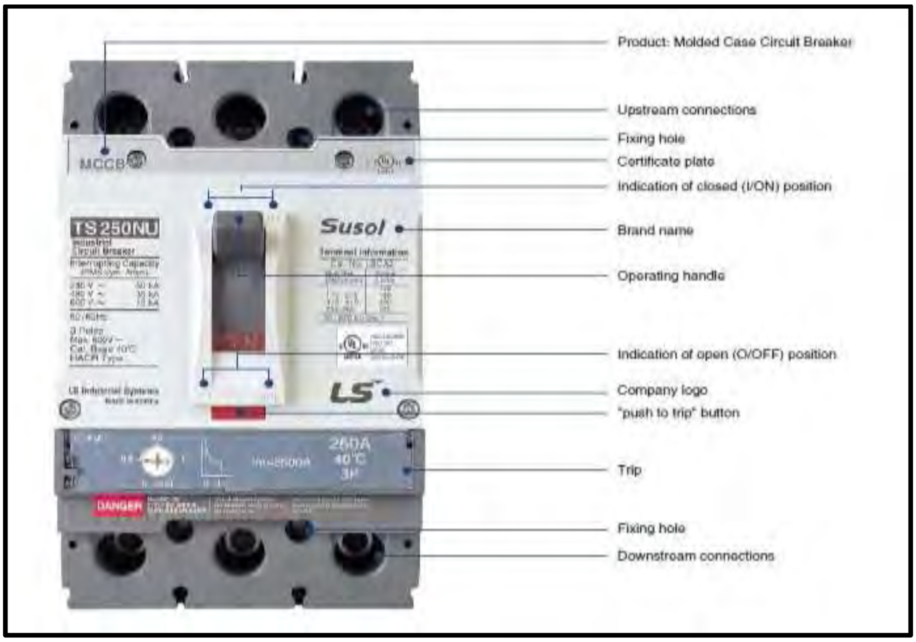


Figure 2.2: MCCB in the market [9]

2.2.1.3 Residual Current-Operated Circuit Breakers (RCCB)

RCCB are primarily designed to protect against ‘indirect contact’ electric shock. The term ‘indirect contact’ means the contact of the supply voltage indirectly through the touching of the exposed-conductive-part such as the metallic enclosures of electrical appliances, the metallic conduit, trunking or cable tray. During an earth fault, there is an earth fault current flowing from the live conductor through the exposed-conductive parts to earth, the exposed metalwork may be at a high potential relative to earth. Based on IEC 1008, RCCBs are specified as the following [10]. The example of RCCB in the market is shown in the Figure 2.3 below.

Preferred rated voltage

Single-phase, phase-to-neutral: 230 V
Three-phase, three-wire: 400 V
Three-phase, 4-wire: 400 V

Preferred rated current (IN)

10, 13, 16, 20, 25, 32, 40, 63, 80, 100, 125 A

Rated residual operating current (IΔN)

0.006, 0.01, 0.03, 0.1, 0.3, 0.5 A

Figure 2.3: RCCB in the market [11]

2.3 Installation Method

In the low installation of electrical network, there are many method of installation including trunking method, clip-direct, tray and many more. For the cable trunking, a manufactured enclosure for the protection of cables, normally of rectangular cross section which one side is removable or hinged. Figure 2.4 shows the trunking installation method in house. For cable tray, a cable support consisting of a continuous base with raised edges and no covering. A cable tray is considered to be non-perforated, where less than 30% of the material is removed from the base. The example of cable tray installation is as in Figure 2.5 below. For the clipped-direct, the installation method is Non-sheathed cables in conduit mounted on a wooden or masonry wall. The example clipped-direct installation is shown in Figure 2.6.

Figure 2.4: Cable trunking [12]

Figure 2.5: Cable tray [13]

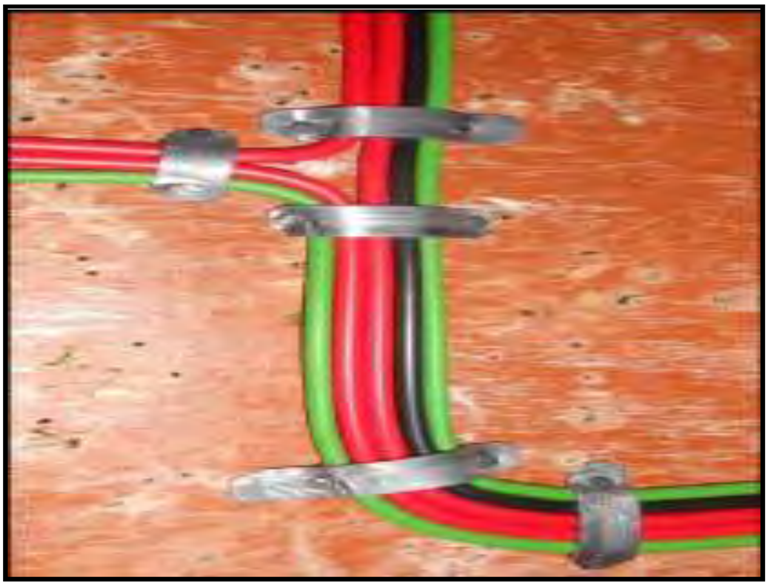


Figure 2.6: Clip direct [14]

2.4 Cable

A cable is length of insulated single conductor or two or more such conductors each provided with its own insulation which are laid up together. There are two type of insulation which is single-core and multi-core. The single-core cable is a cable that has only one insulated conductor with its own cable sheath while multi-core has multiple cores of insulated conductors within one common sheath. The example of single-core and multi-core is shown in Figure 2.7 and 2.8. The cable consists of conductor that provides electrical paths. The range standard metric cross-sectional area of conductors is 1.5mm2 to 1000mm2. Copper and aluminium are the two common types of material of conductor. The specific resistance of copper and aluminium at 70 C is 0.017 and 0.0283 Ω per mm2 per metre [5].

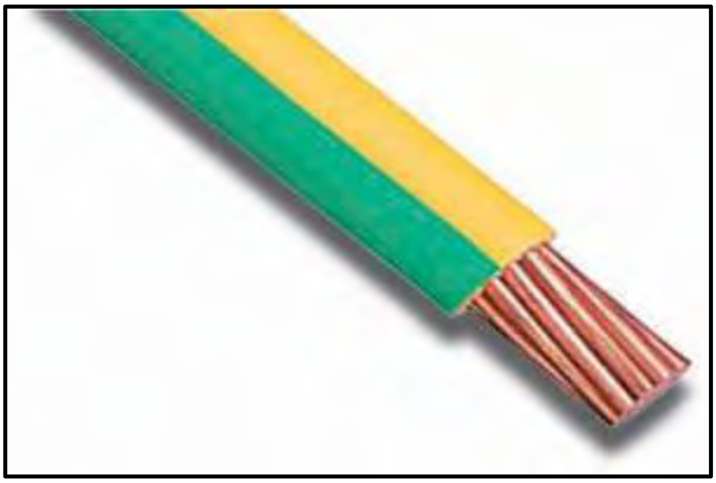


Figure 2.7: Single Core Cable [15]

Figure 2.8: Multi-core Cable [15]

2.4.1 Cable insulation

To prevent direct contact between individual conductors and earth, insulation surrounds each conductor is required. The type of insulation will depends on the voltage of the system, the operating temperature of conductors and the mechanical and environmental conditions affecting the cable during installation and operation. There are types of insulation materials which are polyvinyl chloride (PVC), rubber, cross-linked polyethylene (XLPE), powdered mineral, and oil impregnated paper tapes.

Low-voltage power cables are generally rated at 450/750 V or 600/1000 V regardless of the voltage used, be it 120 V, 230 V, 240 V or 400 V. The important thing of cable is current rating. It will be discussed in the sub-section 2.3.2.

2.4.2 Current rating of cable

The current rating of a cable is determined by a number of factors, namely ambient temperature, maximum allowable conductor temperature, conductor material, insulation material and installation methods.

To protect the cables from damage and for a reasonable service life, temperature at conductors of a cable are allowed to operate continuously depends on the insulation material used and the construction of the cable. The tabulated values of ambient temperature correction factor will ensure that excessive temperatures are not reached.

2.4.2.1 Ambient Temperature Correction Factor (Ca)

Correction factors for ambient temperature in determining the current carrying capacity of a cable are provided in Table 4C1 of IEE Regulation or CP5 [2][3]. For an ambient temperature higher than the specified temperature of 30°C, the rate of flow of heat out of the conductor will be lower than that of the specified condition. This will increase the conductor's operating temperature above the value permitted. This means that the current carrying capacity of the conductor has to be reduced to compensate for the reduction in the heat lost from the conductor. Table 2.1 shows the values of temperature correction factors for PVC cable.

Table 2.1: Temperature Correction Factors for PVC Cable [5]

Ambient Temperature °C	25	30	35	40	45	50
Correction Factor Ca	1.03	1.0	0.94	0.87	0.79	0.71

2.4.2.2 Grouping Correction Factor (Cg)

Cables will get hot when installed it is bundled together because they are carrying current. Those close to the edges of the enclosures will be able to release heat outward but will be restricted in losing heat inwards towards other hot cables. For the cables in the centre of the enclosure will difficult to lost heat and will thus increase the conductor temperature. Correction factors for groups of more than one circuit of a single-core cable, or more than one multi-core cable are summarised in Table 2.2.

Table 2.2: Grouping correction factors have to be applied. [5]

No. of circuits or multi-core cables	1	2	3	4	5	6
Bunched and clipped direct	1	0.8	0.7	0.65	0.6	0.57
Single layer clipped direct and touching	1	0.85	0.79	0.75	0.73	0.72
Single layer clipped direct and Spaced *	1	0.94	0.90	0.90	0.90	0.90

2.4.2.3 Thermal Insulation Correction Factor (Ci)

Many new buildings are now provided with better thermal insulating material for roofs and cavity walls to reduce the energy cost for heating, ventilation and air-conditioning (HVAC). It means to reduce the heat loss. As thermal insulation is designed to limit heat flow, a cable in contact with it will tend to become warmer than the preferred operation conditions. IEE Regulation 523-04 [2] recommends that for a single cable which is likely to be surrounded by thermally insulating material over a length of 0.5 m, the thermal correction factor (Ci) is 0.5 times the tabulated current carrying capacity for that cable clipped direct to a surface (method 1). If the surrounded length is less than 0.5 m, the correction factor (Ci) can be higher than 0.5 [5].

2.5 Voltage drop

To ensure that the voltage applied to the electrical appliances is maintained within proper limits, a designer must have a working knowledge of voltage drop calculation. Most electrical appliances are designed to operate within a voltage tolerance of + 10%. The utility supply regulations normally ensure that the voltage variations at the supply intake are kept within +6% of the declared nominal voltage. The designer must therefore, ensure that the voltage drop from the supply intake to the terminals of any appliance does not exceed 4% of the declared nominal voltage. Thus, all electrical appliances can be operated safely and be fully functional within their design voltage tolerance of +10%. IEE Regulation 525-01 specifies that the voltage drop between the origin of the installation and the fixed current using equipment should not exceed 4% of the nominal voltage of the supply [2].

2.6 Earthing in low voltage

Earthing system is the most important thing in low voltage installation. The objectives of earthing are to protect human lives as well as provide safety to devices and appliances from leakage current. It is also can keep voltage as constant in the healthy phase (If fault occurs on any one phase). To protect electric system and buildings form lightning. It is because to avoid risk of fire in electrical installation systems.

For low-voltage system earthing, IEE Regulations define an electrical system as consisting of a single source of supply and an installation. System earthing refers to the earthing arrangement at the source of energy and at the installation. There are five types of earthing systems classified by a combination of two to four letters namely TT, TN-S, TN-C, TN-C-S and IT.

According to its earthing system, a low voltage distribution system may be identified. These are defined using the five letters T (direct connection to earth), N (neutral), C (combined), S (separate) and I (isolated from earth). The first letter denotes how the transformer neutral (supply source) is earthed while the second letter denotes how the metalwork of an installation (frame) is earthed. The third and fourth letters indicate the functions of neutral and protective conductors respectively. There are three possible configurations [1].

TT: transformer neutral earthed and frame earthed.
TN: transformer neutral earthed, frame connected to neutral.
IT: unearthed transformer neutral, earthed frame.
The TT and TN system are discussed in the following sub-sections.

2.6.1 TT system

In the TT system, firstly the source of supply is directly earthed (T). The installation earthing terminal that connected to the exposed-conductive parts is also earthed directly. Figure 2.1 shows the connection in the TT system.

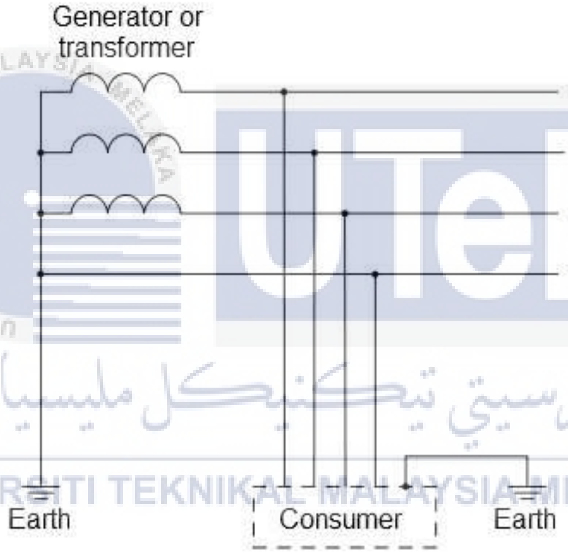


Figure 2.9: TT system [16]

To determine the value of earth fault current for TT system ($I_{EF,TT}$), the formula as follow:

$$I_{EF,TT} = \frac{V_{LL}/\sqrt{3}}{Z_S + Z_E + R_1 + R_{CPC} + R_B + R_A} = \frac{V_{LL}/\sqrt{3}}{Z_{EFL,TT}} \quad (2.1)$$

Where: Zs is the source impedance (i.e. RS + jXS), Z_E is the phase conductor impedance external to the installation (i.e. RE +jXE.), R1 is the phase conductor resistance of the installation, RCPC is the resistance of the circuit protective conductor, and R_B and R_A are the resistances of the earthing conductor and the earth electrode at the installation and at the source of supply respectively. $Z_{EFL,\ TT}$ is the earth fault loop impedance in the TT system.

The expose-conductive part and extraneous-conductive-parts are connected together at the installation's earthing terminal to provide an equipotential reference. Thus, during an earth fault, the voltage of exposed-conductive-parts with respect to the earth (usually known as touch voltage or shock voltage) is:

$$V_{shock,TT,Yes} = I_{EF,TT} \times R_{cpc} \qquad (2.2)$$

If an equipotential zone is not created without the main equipotential bonding, the touch voltage is:

$$V_{shock,TT,No} = I_{EF,TT} \times (R_{cpc} \times R_B) \qquad (2.3)$$

2.6.2 TNS System

For TNS system the source of supply is directly earthed (T). The exposed-conductive-parts connected to the installation's earthing terminal are earthed at the neutral point (N) of the supply source through a separate (S) protective conductor. Figure 2.2 shows the connection of TNS system consist of 3-phase line (L), neutral line (N), and protective conductor (PE) connected to the earth.

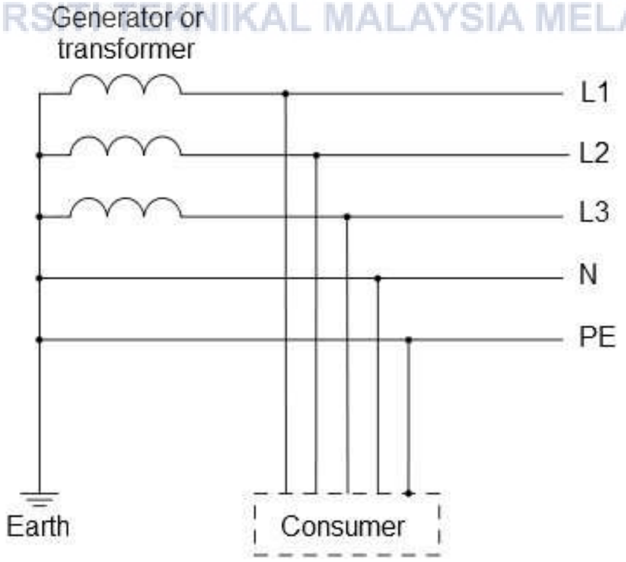


Figure 2.10: TNS system [16]

2.7 Visually Interactive Program for Consultant and Owner to Design and Assess electrical systems in building (VipCoda)

VipCoda provides a user friendly, visually interactive tool to automate the design process producing a sound and reliable design which meets the code of practice of CP5 (1998) and BS 7671:1992 [2][18] by utilizing the visually interactive window programming technique and facilities on database access. VipCoda can also be used to automatically assess and evaluate any submitted electrical network systematically within a short time. By utilizing the built-in database structure, all the design assumptions are automatically documented and stored together with the completed design network. Thus, it is also a comprehensive tool for training and upgrading engineers on how to design and assess an electrical network.

2.8 Summary of Literature Review

The important thing of literature review is tabulated in the Table 2.3

Table 2.3: Summary of Literature Review

Author Name	Title	Literature Review
M N John, et al. BSc FEng FIEE	IEE Wiring Regulations, 16th Edition. (BS 7671)	Safety of life and preservation of property are the first two important factors to be considered. The safety requirements should follow the established codes in IEE Wiring Regulations.
	IEE Wiring Regulation 525-01 16th Edition. (BS 7671)	Ensure that the voltage drop from the supply intake to the terminals of any appliance does not exceed 4%.
Teo Cheng Yu.	“Circuit Breakers”, Principles and Design of Low Voltage Systems, 2nd Edition.	There are eight steps of basic design procedure as shown in Figure 3 (flowchart).
Donald H.	“Basic circuit-breaker selection	For selection of circuit breaker, current

McCullough, et al.	criteria” IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems	carrying without overheating is required. (Correct current rating, I_N)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The purpose of the methodology to ensure that the project has guidelines and it can be done smoothly and well organized. This study was done in order to arrange step by step the low voltage installation.

3.2 Flowchart

The flowchart in Figure 3.1 described about overall activities of this study. Firstly start, process (theoretical study, 8 steps design procedure) and end. The flowchart in the figure is the sequence of the steps for low voltage installation that follow standard BS 7671.

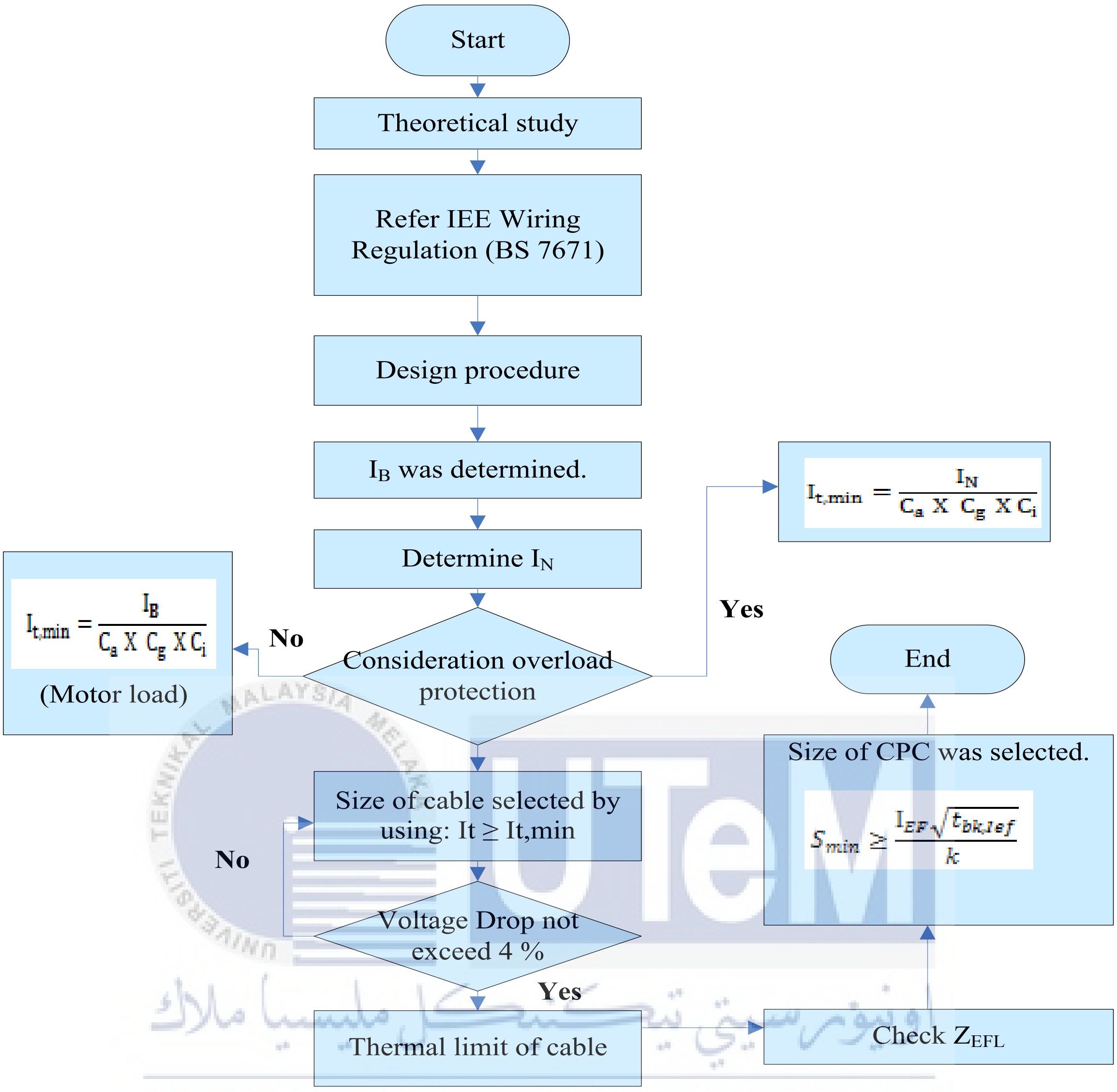


Figure 3.1: Flowchart for low voltage installation

3.3 Procedure of low voltage installation

The steps below consist of eight steps which are describing the verification of VipCoda software.

Step 1: Design current (I_B), was determined by calculation depends on the type of load connected. The detail calculation of I_B is attached in the Figure 4.42 to 4.44. It must consider the connected load, demand factor and coincidence factor.

Step 2: Type and current rating of protective device (I_N) was selected. I_N must be selected higher than value of design current (I_B), according to the available rating in the market; refer sub-section 2.2.1.1.

Step 3: Minimum tabulated current rating (It,min) was determined by:

$$I_{t,min} = \frac{I_N}{C_a \text{ X } C_g \text{ X } C_i} \quad \text{Or} \quad I_{t,min} = \frac{I_B}{C_a \text{ X } C_g \text{ X } C_i} \tag{3.1}$$

Refer sub-sections 2.4.2.1 to 2.4.2.3 for further information of C_a, C_g and C_i .

Step 4: Type of cable and the current rating was selected such that
It,min ≤ It ; It : tabulated current rating

Step 5: Check voltage drop within 4% from supply intake to individual appliances. If the voltage drop exceeds 4%, repeat step 4.

Step 6: Thermal limit of cable was selected by the following equation:

$$t_{cable,max} = \frac{k^2 S^2}{I_{F,}\ 3\emptyset} \tag{3.2}$$

Step 7: For TN system, check for earth fault loop impedance ($Z_{EFL,TN}$) such that during an earth fault, the protective device will disconnect supply within the specified time of either 0.4s or 5 s.

Step 8: Select the minimum size of CPC (S_{min}) such that:

$$S_{min} \geq \frac{I_{EF}\sqrt{t_{bk,Ief}}}{k} \tag{3.3}$$

For TT system check for:

$$RaIa < 50 \text{ V} \tag{3.4}$$

Ia: the current causing the automatic disconnection of the protective device within 5s.
Ra : resistances of the earth electrode and the CPC.

3.4 Protection of TT system

For installation of TT system, every exposed-conductive-part shall be connected via the main earthing terminal to a common earth electrode. Thus, one or both of the protective devices below should be used: i) a residual current device ii) an overcurrent protective device.

The earth fault loop current impedance in the TT system is usually higher than TN system. It is affected the value of earth fault current may not be high enough to operate the overcurrent protective device to disconnect the circuit. However, the use of RCCB is more suitable. Other than that, the shock voltage shall be limited so that not more than 50 V by satisfied the following condition:

$$R_a \text{ x } I_a \ll 50 \text{ V} \tag{3.4}$$

Where:

Ra: Sum of the earth electrode and protective conductor(s) connecting it to exposed-conductive-part.

Ia: Current causing the automatic operation of the protective device within 5 s:

When the protective device is a residual current device, Ia is the rated residual operating current In.

3.5 Protection of TNS system

For an installation which is part of a TN system, each exposed-conductive-part shall be connected to the main earthing terminal which shall be connected to the earth point of the supply source. One or both of the following two types of protective devices shall be used

(i) An overcurrent protective device,

(ii) A residual current device.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will shows the steps in low voltage design system according to BS 7671 and verified with the VipCoda results. Firstly, the sub-chapter below will shows the overall results of a DB 2 followed by specific result which are classify according to the type of load.

4.2 Overview of this project

This studied about low voltage installation in a single storey building that has two shops operated by the utility. Each shop has a final DB serving a floor area of 14m x 10m which are T11 and T12. There is a main DB (M1) connecting to two final DBs (T11 and T12) as shown in Figure 4.1. The connected loads of each shop as follows:

i) <u>Shop 1 (T11)</u>

- 20 units of 40-W fluorescent lighting.
- 28 units of 13-A socket outlets with an average connected load of 300 W for each socket outlet at power factor 0.9.
- One 3-Phase 11-kW star-delta motor.
- One 3-Phsae 15-kW direct-on-line motor.

ii) Shop 2 (T12)

- 20 units of 40-W fluorescent lighting.
- 28 units of 13-Asocket outlets with an average connected load of 300 W for each socket outlet at power factor 0.9.
- One 3-Phase 11-kW star-delta motor.
- One 3-Phase 15-kW direct-on-line motor.

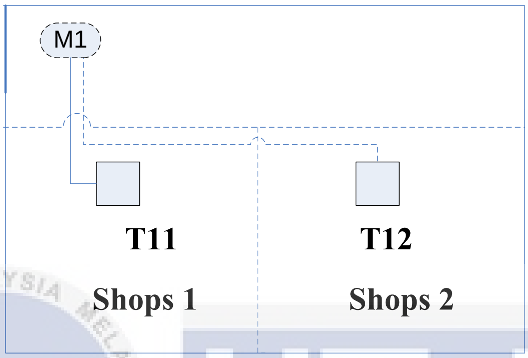


Figure 4.1: Electrical network in single-storey building

The connection at final DBs T11 and T12 was depicted more detail in the Figure 4.2 and 4.3.

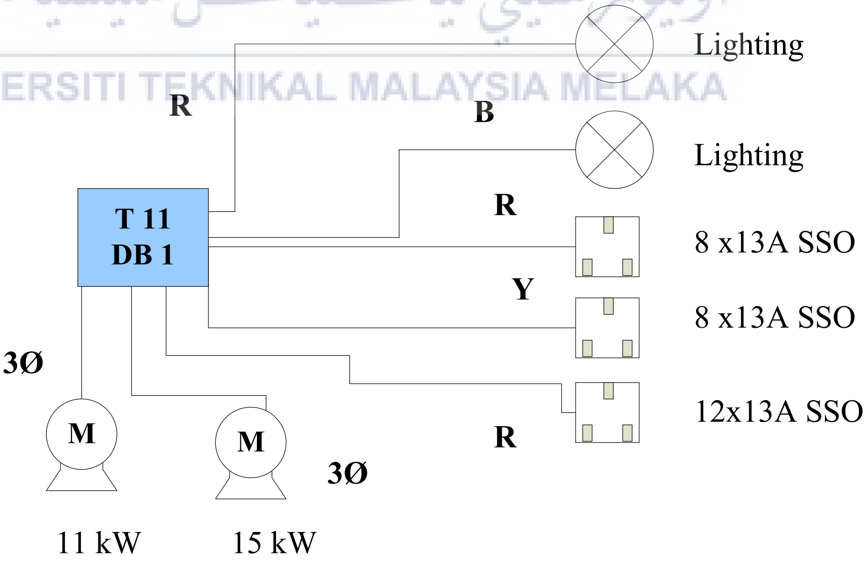


Figure 4.2: Final DB T11 connection

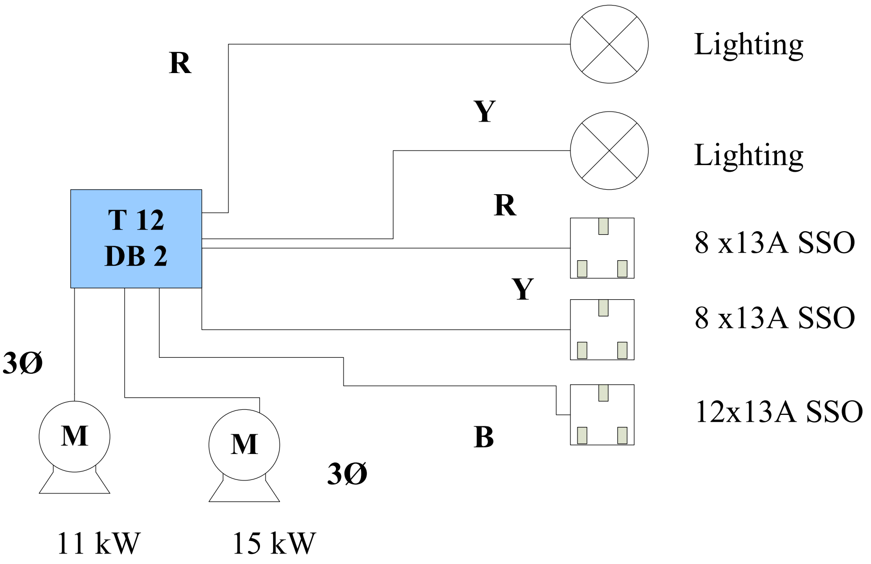


Figure 4.3: Final DB T12 connection

For the detailed information of connected load are tabulated in Table 4.1 and 4.2. Each of loads has their own type of cable, insulation method, installation method, power factor, efficiency and condition of Ambient Temperature Correction Factor (C_a), Grouping Correction Factor (C_g) and Thermal Insulation Correction Factor (C_i). Information in Table 4.3 is used in to calculate of main DB circuit and it is shows in sub-section 4.3.4 and 4.4.4.

Table 4.1: Connected load to the DB 1 (T11) at the shop 1

Ph	**Description of load**	**Cable type & insulation/ Installation method**	**Length(M)**	**p.f.**	**n**	**C_a**	**C_g**	**C_i**
R	10 x 40W FLU FTG	CU/PVC/TRUNKING/MC	10	0.85	-	0.94	0.65	1.0
B	10 x 40W FLU FTG	CU/PVC/CLIPPED/1C	30	0.85	-	0.94	0.65	1.0
R	8 X 300W SSO	CU/PVC/TRUNKING/1C	10	0.9	-	0.94	0.65	1.0
Y	8 X 300W SSO	CU/PVC/CLIPPED/MC	30	0.9	-	0.94	0.65	1.0
R	12 X 300W SSO	CU/PVC/TRUNKING/MC	20	0.9	-	0.87	0.7	1.0
R, y,b	11KW MOTOR(SD)	CU/PVC/TRUNKING/MC	20	0.8	0.9	0.94	0.7	1.0
R, y,b	15KW MOTOR (DOL)	CU/XLPE/TRAY/1C	40	0.8	0.9	0.87	0.7	1.0

Table 4.2: Connected load to the DB 2 (T12) at the shop 2

Ph	**Description of load**	**Cable type & insulation/ Installation method**	**Length(M)**	**p.f.**	**n**	**C_a**	**C_g**	**C_i**
R	10 x 40W FLU FTG	CU/PVC/TRUNKING/MC	10	0.85	-	0.94	0.65	1.0
Y	10 x 40W FLU FTG	CU/PVC/CLIPPED/1C	30	0.85	-	0.94	0.65	1.0
R	8 X 300W SSO	CU/PVC/TRUNKING/1C	10	0.9	-	0.94	0.65	1.0
Y	8 X 300W SSO	CU/PVC/CLIPPED/MC	30	0.9	-	0.94	0.65	1.0
B	12 X 300W SSO	CU/PVC/TRUNKING/MC	20	0.9	-	0.87	0.7	1.0
R,y,b	11KW MOTOR(SD)	CU/PVC/TRUNKING/MC	20	0.8	0.9	0.94	0.7	1.0
R,y,b	15KW MOTOR(DOL)	CU/XLPE/TRAY/1C	40	0.8	0.9	0.87	0.7	1.0

Table 4.3 Main DB Specification

Ph	**Description of load**	**Cable type & insulation/ Installation method**	**Length (M)**	**C_a**	**C_g**	**C_i**	**Volt Tol(%)**
R,y,b	T 11	CU/PVC/TRUNKING/MC	18	0.94	0.8	1.0	1
R,y,b	T 12	CU/PVC/TRUNKING/MC	18	0.94	0.8	1.0	1
Demand Factor: 0.9							

4.3 Overall Result for DB 2

This sub-chapter will display the overall results of VipCoda software for the 7 loads that connected to DB 2 as shown in the Figure 4.4. The sub-section below will shows detail step-by-step procedures in design of lighting load, socket load, motor load according to the BS 7671 standards for DB 1 and DB 2.

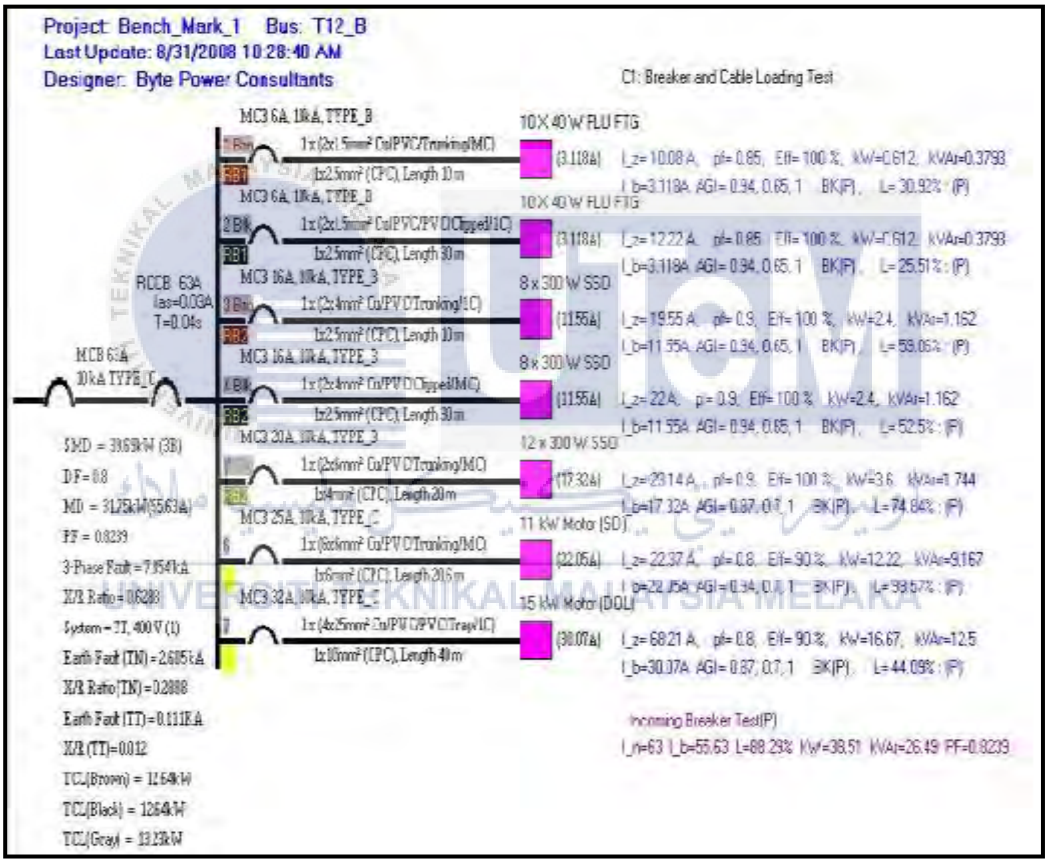


Figure 4.4: Overall result for DB

4.3.1 Result of lighting load

This sub-section present the steps according to the BS 7671 for design lighting load with the data stated in the previous chapter which is Table 4.1. There are two lighting load connected at this DB which are at the Red and Yellow phase.

4.3.1.1 Red Phase

The connected load for this phase is 10 units of fluorescent lamp with 40W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load: 10 x 40W fluorescent lighting

$$I_B = \frac{P \times 1.8}{V}$$

$$I_B = \frac{40 \times 10 \times 1.8}{230.9} = 3.118\ A$$

$I_N = 6$ A; 6A is chosen due to the available circuit breaker that bigger than I_B. Refer sub-section 2.2.1.1 for details.

$$I_{t.min} = \frac{6}{0.94 \times 0.65 \times 1} = 9.82\ A$$

Since the installation method is enclosed in trunking, a 1.5 mm^2, multi-core, pvc-insulated copper conductor non-armoured cable with $I_t = 16.5$A and mv/A/m of 29 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

For the overload protection, the calculation as follow:

$I_Z = I_t \times C_a \times C_g \times C_i$

$I_Z = 16.5 \times 0.94 \times 0.65 \times 1$

$I_Z = 10.08$ A

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\ I_Z$

Since $I_N = 6$ A; $I_Z = 10.08$ A, the condition in i) is adequate. For condition ii) :

$I_2 = 1.45\ I_N$ $\qquad$ $8.7 \leq 1.45\ I_Z$

$I_2 = 1.45\ (6)$ $\qquad$ $8.7 \leq 1.45\ (10.08)$

$I_2 = 8.7$ A $\qquad$ $8.7\ A \leq 14.62\ A$

For Overload protection = $\frac{1.45\ \mathrm{I_Z} - \mathrm{I_2}}{1.45\ \mathrm{I_Z}}$ x 100% = $\frac{14.62-8.7}{14.62}$ x 100% = 40.49%

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

Voltage drop = $\frac{\mathrm{r\ cos\emptyset + sin\emptyset}}{1000}$ x $\mathrm{I_b}$ x length

Voltage drop = $\frac{29 \mathrm{\ x\ } 0.85}{1000}$ x 3.118 x 10 = 0.77 V @ 0.33%

Circuit Loading, L = $\frac{\mathrm{I_B}}{\mathrm{I_t\ X\ C_a\ X\ C_g\ X\ C_i}} = \frac{3.118}{16.5\mathrm{\ X\ }0.94\mathrm{\ X\ }0.65\mathrm{\ X\ }1}$ = 30.9%

Active connected load, CLa = 40 x 1.8 x 10 x 0.85= 0. 612 kW

Reactive connected load, $\mathrm{CL_r}$ = 40 x 1.8 x 10 x 0.85 x tan ($\cos^{-1}$ 0.85) = 0.379 kVar

Estimated 3-phase short current: $\mathrm{I_{F,3-phase}}$= 732.5 A

From time-current characteristic curve of Type B MCB. T_bk = 0.01s;

Thermal limitation: $\mathrm{t_{cable,max}} = \frac{\mathrm{k^2\ S^2}}{\mathrm{I_F^2}} = \frac{115^2 \mathrm{x\ } 1.5^2}{732.5^2}$ = 0.05546s

For the short circuit protection, SC_P_Yes = $\frac{\mathrm{t_{cable,max}} - \mathrm{T\_bk}}{\mathrm{t_{cable,max}}}$ x 100% = $\frac{0.05546-0.01}{0.05546}$ x 100% = 81.97%

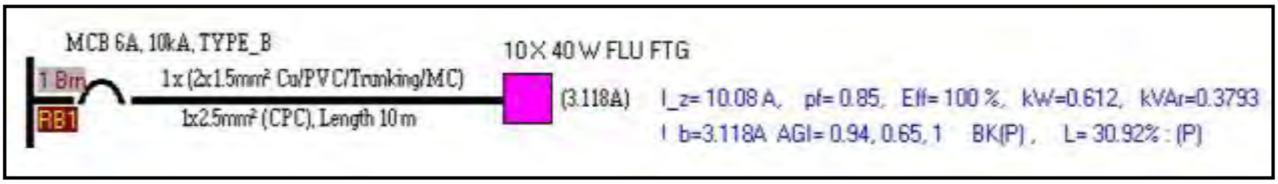
Estimated Earth fault current: $\mathrm{I_{EF}}$= 99.53 A;

From time-current characteristic curve of Type B MCB. T_bk = 0.01s;

$\mathrm{t_{CPC,max}} = \frac{\mathrm{k^2\ S^2}}{\mathrm{I_{EF}^2}} = \frac{115^2 \mathrm{x\ } 2.5^2}{99.53^2}$ = 8.344s

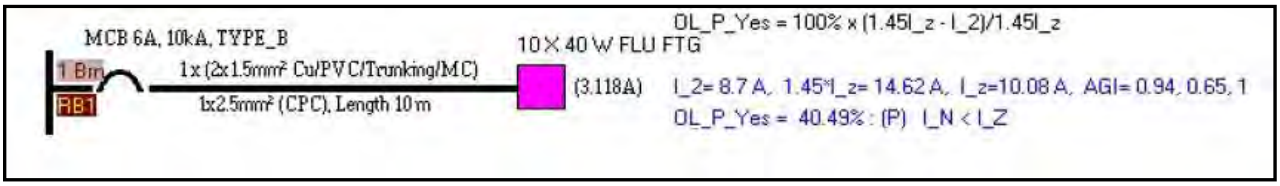
For the CPC protection, CPC_P_Yes = $\frac{\mathrm{t_{CPC,max}} - \mathrm{T\_bk}}{\mathrm{t_{CPC,max}}}$ x 100% = $\frac{8.344-0.01}{8.344}$ x 100% = 99.88%

The calculation of $\mathrm{I_B}$, $\mathrm{I_Z}$, CLa, $\mathrm{CL_r}$, L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.5 to Figure 4.9 below.



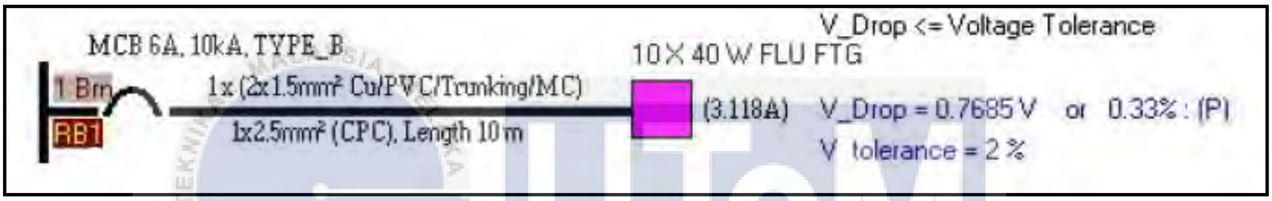
```
I_z= 10.08 A,   pf= 0.85,  Eff= 100 %,  kW=0.612,  kVAr=0.3793
I_b=3.118A  AGI= 0.94, 0.65, 1   BK(P) ,   L= 30.92% : (P)
```

Figure 4.5: Breaker and cable loading test



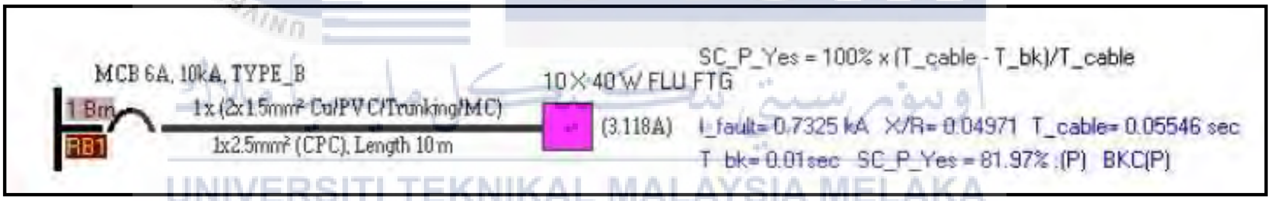
```
OL_P_Yes = 100% x (1.45I_z - I_2)/1.45I_z
I_2= 8.7 A,  1.45*I_z= 14.62 A,  I_z=10.08 A,  AGI= 0.94, 0.65, 1
OL_P_Yes =  40.49% : (P)   I_N < I_Z
```

Figure 4.6: Overload Protection test



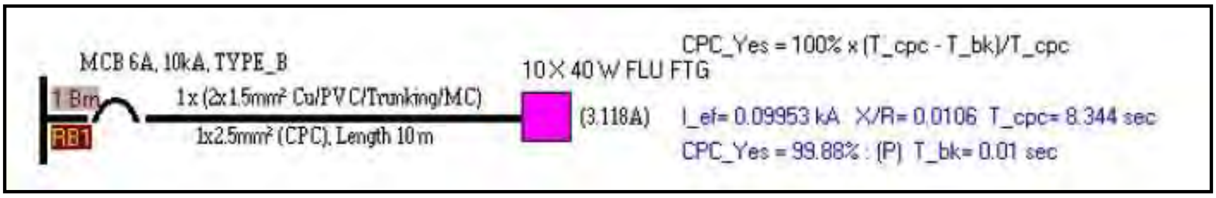
```
V_Drop <= Voltage Tolerance
V_Drop = 0.7685 V   or   0.33% : (P)
V_tolerance = 2 %
```

Figure 4.7: Voltage drop test



```
SC_P_Yes = 100% x (T_cable - T_bk)/T_cable
I_fault= 0.7325 kA   X/R= 0.04971   T_cable= 0.05546 sec
T_bk= 0.01sec   SC_P_Yes = 81.97% :(P)   BKC(P)
```

Figure 4.8: Short circuit protection test



```
CPC_Yes = 100% x (T_cpc - T_bk)/T_cpc
I_ef= 0.09953 kA   X/R= 0.0106   T_cpc= 8.344 sec
CPC_Yes = 99.88% : (P)   T_bk= 0.01 sec
```

Figure 4.9: Earth fault and CPC test

4.3.1.2 Yellow Phase

The connected load for this phase is 10 units of fluorescent lamp with 40W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 10 x 40 W fluorescent lighting

$$I_B = \frac{40 \text{ x } 10 \text{ x } 1.8}{230.9} = 3.118 \text{ A}$$

$I_N = 6$ A; 6A is chosen due to the available circuit breaker that bigger than I_B. Refer sub-section 2.2.1.1 for details.

$$I_{t.min} = \frac{6}{0.94 \text{ x } 0.65 \text{ x } 1} = 9.82 \text{ A}$$

Since the installation method is clipped direct to surface, a 1.5 mm^2, single-core, pvc-insulated copper conductor non-armoured cable with $I_t = 20$A, and mv/A/m of 29 is selected from Table 4D1A because of It,min ≤ It. Refer Appendix A for Table 4D1A.

For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

$I_Z = 20 \text{ x } 0.94 \text{ x } 0.65 \text{ x } 1$

$I_Z = 12.22$ A

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\ I_Z$

Since $I_N = 6$ A; $I_Z = 10.08$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$ $\quad 8.7 \leq 1.45\ I_Z$

$I_2 = 1.45\ (6)$ $\quad 8.7 \leq 1.45\ (12.22)$

$I_2 = 8.7$ A $\quad 8.7 \text{ A} \leq 17.72 \text{ A}$

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z} \text{ x } 100\% = \frac{17.72-8.7}{17.72} \text{ x } 100\% = 50.9\%$

Voltage drop = $\frac{r\ \cos\emptyset + \sin\emptyset}{1000} \text{ x } I_b \text{ x length}$

Voltage drop = $\frac{29 \text{ x } 0.85}{1000} \text{ x } 3.118 \text{ x } 30 = 2.31$ V @ 1.00%

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{3.118}{20 \text{ X } 0.94 \text{ X } 0.65 \text{ X } 1} = 25.51\%$

CLa = 40 x 1.8 x 10 x 0.85= 0.612 kW

CLr = 612 x tan ($\cos^{-1} 0.85$) = 0.379 kVar

Estimated 3-phase short current: $I_{F,3-phase} = 258$ A

From time-current characteristic curve of Type B MCB. T_bk = 0.01s;

Estimated Earth fault current: I_{EF}= 82.77 A;

From time-current characteristic curve of Type B MCB. T_bk = 0.01s;

Thermal limitation: $t_{cable,max} = \frac{k^2 S^2}{I_F^2} = \frac{115^2 x\, 1.5^2}{258^2}$ = 0.4470 s

For the short circuit protection, SC_P_Yes = $\frac{t_{cable,max} - T\_bk}{t_{cable,max}}$ x 100% = $\frac{0.4470-0.01}{0.4470}$ x 100% = 97.76%

$t_{CPC,max} = \frac{k^2 S^2}{I_{EF}^2} = \frac{115^2 x\, 2.5^2}{82.77^2}$ = 12.07 s

For the CPC protection, CPC_P_Yes = $\frac{t_{CPC,max} - T\_bk}{t_{CPC,max}}$ x 100% = $\frac{12.07-0.01}{12.07}$ x 100% = 99.92%

The calculation of I_B, I_Z, CLa, CL_r , L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.10 to Figure 4.14 below.

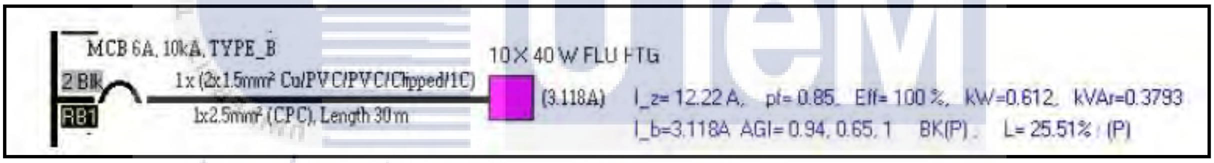


Figure 4.10: Breaker and cable loading test

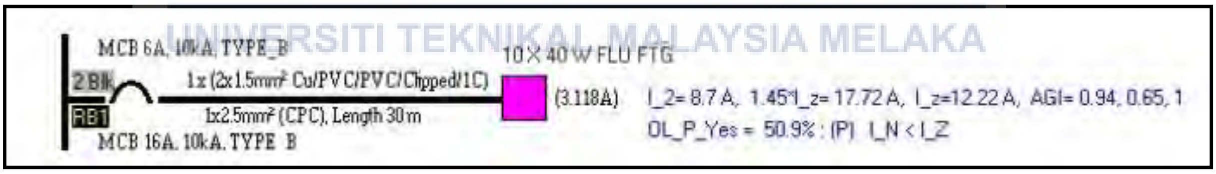


Figure 4.11: Overload Protection test

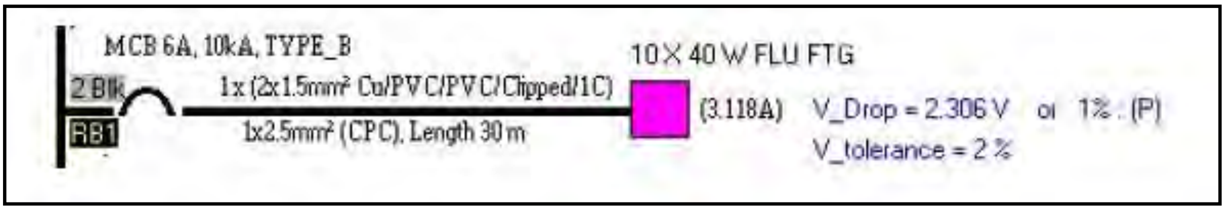
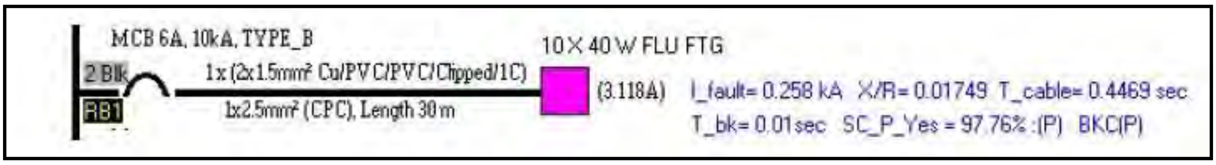


Figure 4.12: Voltage drop test



MCB 6A, 10kA, TYPE_B

2 Blk

RB1

1x (2x1.5mm² Cu/PVC/PVC/Clipped/1C)

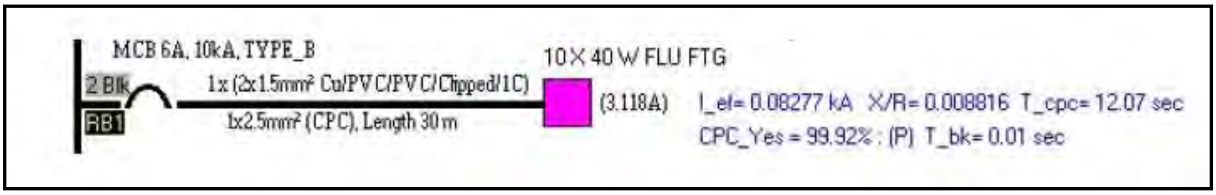
1x2.5mm² (CPC), Length 30 m

10X 40 W FLU FTG

(3.118A) I_fault= 0.258 kA X/R= 0.01749 T_cable= 0.4469 sec

T_bk= 0.01sec SC_P_Yes = 97.76% :(P) BKC(P)

Figure 4.13: Short circuit protection test



MCB 6A, 10kA, TYPE_B

2 Blk

RB1

1x (2x1.5mm² Cu/PVC/PVC/Clipped/1C)

1x2.5mm² (CPC), Length 30 m

10X 40 W FLU FTG

(3.118A) I_ef= 0.08277 kA X/R= 0.008816 T_cpc= 12.07 sec

CPC_Yes = 99.92% : (P) T_bk= 0.01 sec

Figure 4.14: Earth fault and CPC test

4.3.2 Result of Socket outlet load

This sub-section present the steps according to the BS 7671 for design socket outlet load with the data stated in the previous chapter which is Table 3.1. There are three socket outlet connected to this DB which are at the Red, Yellow and Blue phase.

4.3.2.1 Red phase

The connected load for this phase is 8 units of socket outlet (SSO) with 300W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 8 x 300 W

$$I_B = \frac{300 \text{ x } 8}{230.9 \text{ x } 0.9} = 11.55$$

I_B=11.55 A; I_N = 16 A type B MCB is selected; 16A is chosen due to the available circuit breaker that bigger than I_B. Refer sub-section 2.2.1.1 for details.

$$I_{t.min} = \frac{16}{0.94 \text{ x } 0.65 \text{ x } 1} = 26.19 \text{ A}$$

Since the installation method is enclosed in trunking, a 4.0 mm^2, single-core, pvc-insulated copper conductor non-armoured cable with I_t = 32A, Iz=19.55 A and mv/A/m of 11 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A. For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

$I_Z = 32 \text{ x } 0.94 \text{ x } 0.65 \text{ x } 1$

$I_Z = 19.55$ A

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\ I_Z$

Since I_N = 16 A; I_Z = 19.55 A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$	$23.2 \leq 1.45\ I_Z$
$I_2 = 1.45\ (16)$	$23.2 \leq 1.45\ (19.55)$
$I_2 = 23.2$ A	$23.2 \leq 28.35$ A

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z} \text{ x } 100\% = \frac{28.35-23.2}{28.35} \text{ x } 100\% = 18.16\%$

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

Voltage drop = $\frac{r \cos\emptyset + \sin\emptyset}{1000} \text{ x } I_b \text{ x length}$

Voltage drop = $\frac{11 \text{ x } 0.9}{1000} \text{ x } 11.55 \text{ x } 10 = 1.143$ V @ 0.49%

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{11.55}{32 \text{ X } 0.94 \text{ X } 0.65 \text{ X } 1} = 59.06\%$

Active connected load, CL_a = 8 x 300 = 2.4 kW

Reactive connected load, CL_r = 2.4 kW x tan ($\cos^{-1}$ 0.9) = 1.16 kVar

Estimated 3-phase short current: $I_{F,3-\text{phase}}$ = 1701 A

From time-current characteristic curve of Type 1 MCB. T_bk = 0.01s;

Thermal limitation: $t_{\text{cable,max}} = \frac{k^2\ S^2}{I_F^2} = \frac{115^2 \text{x } 4^2}{1701^2} = 0.07316\text{s}$

For the short circuit protection, SC_P_Yes = $\frac{t_{\text{cable,max}} - \text{T\_bk}}{t_{\text{cable,max}}} \text{ x } 100\% = \frac{0.07316-0.01}{0.07316} \text{ x } 100\% = 86.33\%$

Estimated Earth fault current: I_{EF}= 103.6 A;

From time-current characteristic curve of Type B MCB. T_bk = 0.02s;

$$t_{CPC,max} = \frac{k^2\,S^2}{I_F^2} = \frac{115^2 x\, 2.5^2}{103.6^2} = 7.707s$$

For the CPC protection, CPC_P_Yes $= \frac{t_{CPC,max} - T\_bk}{t_{CPC,max}}$ x 100% $= \frac{7.707-0.02}{7.707}$ x 100% = 99.74%

The calculation of I_B, I_Z, CLa, CL_r , L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.15 to Figure 4.19 below.

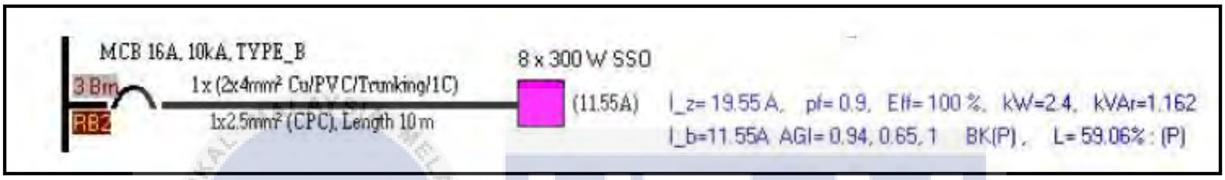


Figure 4.15: Breaker and cable loading test

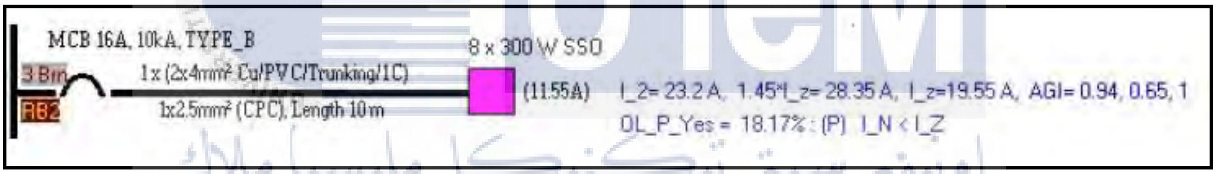


Figure 4.16: Overload Protection test

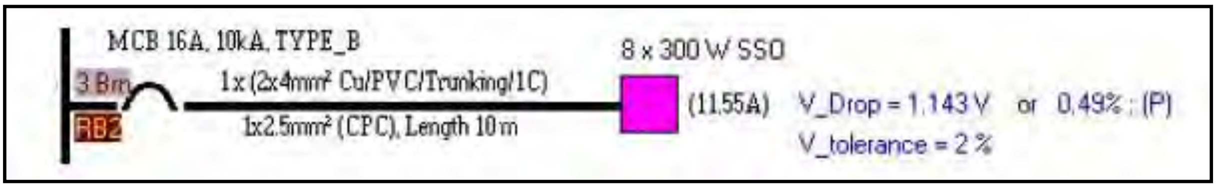


Figure 4.17: Voltage drop test

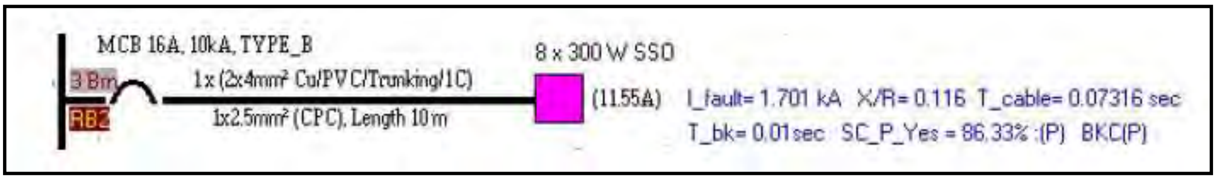


Figure 4.18: Short circuit protection test

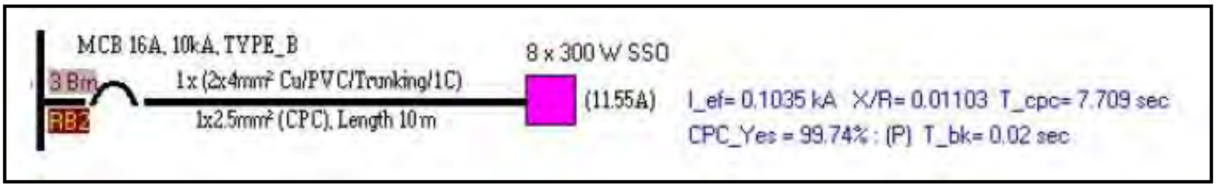


Figure 4.19: Earth fault and CPC test

4.3.2.2 Yellow phase (SSO)

The connected load for this phase is 8 units of socket outlet (SSO) with 300W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 8 x 300 W SSO;

$I_B = \frac{300 \times 8}{230.9 \times 0.9} = 11.55$ A

$I_B = 11.55$ A; $I_N = 16$ A MCB is selected; 16A is chosen due to the available circuit breaker that bigger than I_B. Refer sub-section 2.2.1.1 for details.

$$I_{t.min} = \frac{16}{0.94 \times 0.65 \times 1} = 26.19 \text{ A}$$

Since the installation method is clipped direct to surface, a 2.5 mm^2, multi-core, pvc-insulated copper conductor non-armoured cable with $I_t = 27$A, and mv/A/m of 18 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

Voltage drop = $\frac{r \cos\emptyset + \sin\emptyset}{1000}$ x I_b x length

Voltage drop = $\frac{18 \times 0.9}{1000}$ x 11.55 x 30 = 5.613 V @ 2.43% (exceeds 2%)

Re-select the next cable size of 4.0 mm^2 with $I_t = 36$ A and a mv/A/m of 11 and re-computed voltage drop is 3.43V, which is voltage drop is less than 2%.

Voltage drop = $\frac{11 \times 0.9}{1000}$ x 11.55 x 30 = 3.43 V @ 1.48%

For the overload protection, the calculation as follow:

$I_Z = I_t \times C_a \times C_g \times C_i$

$I_Z = 36 \times 0.94 \times 0.65 \times 1$

$I_Z = 22$ A

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\, I_Z$

Since $I_N = 16$ A; $I_Z = 19.55$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\, I_N$	$23.2 \leq 1.45\, I_Z$
$I_2 = 1.45\,(16)$	$23.2 \leq 1.45\,(22)$
$I_2 = 23.2$ A	$23.2\text{ A} \leq 31.89\text{ A}$

For Overload protection = $\frac{1.45\, I_Z - I_2}{1.45\, I_Z} \times 100\% = \frac{31.89-23.2}{31.89} \times 100\% = 27.26\%$

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

$CL_a = 8 \times 300 = 2.4$ kW

$CL_r = 2.4\text{ kW} \times \tan(\cos^{-1} 0.9) = 1.16$ kVar

Circuit Loading, $L = \frac{I_B}{I_t \,X\, C_a \,X\, C_g \,X\, C_i} = \frac{11.55}{36 \,X\, 0.94 \,X\, 0.65 \,X\, 1} = 52.5\%$

Estimated 3-phase short current: $I_{F,3-phase} = 650$ A; $t_{cable,max} = 0.5$ s (T_bk =0.01 s)

$t_{cable,max} = \frac{k^2\, S^2}{I_F^2} = \frac{115^2 x\, 4^2}{650^2} = 0.5$s

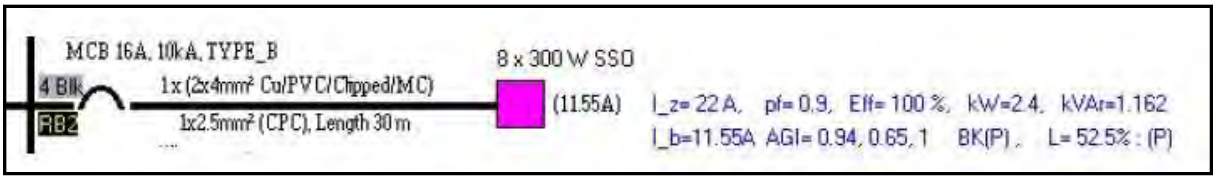
For the short circuit protection, SC_P_Yes = $\frac{t_{cable,max} - T\_bk}{t_{cable,max}} \times 100\% = \frac{0.5-0.01}{0.5} \times 100\% = 98\%$

Estimated Earth fault current: $I_{EF} = 91.6$ A ; $t_{CPC} = 9.85$ s (T_bk =0.03 s)

$t_{CPC,max} = \frac{k^2\, S^2}{I_F^2} = \frac{115^2 x\, 2.5^2}{91.6^2} = 9.85$ s

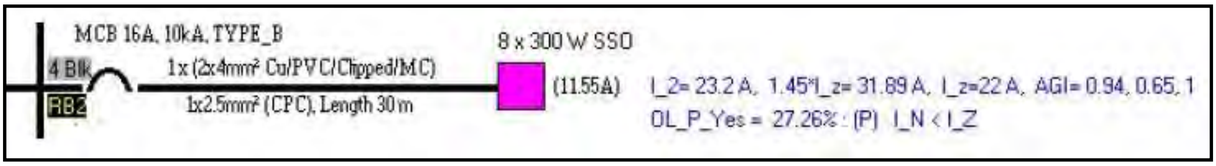
For the CPC protection, CPC_P_Yes = $\frac{t_{CPC,max} - T\_bk}{t_{CPC,max}} \times 100\% = \frac{9.85-0.03}{9.85} \times 100\% = 99.70\%$

The calculation of I_B, I_Z, CLa, CL_r, L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.20 to Figure 4.24 below.



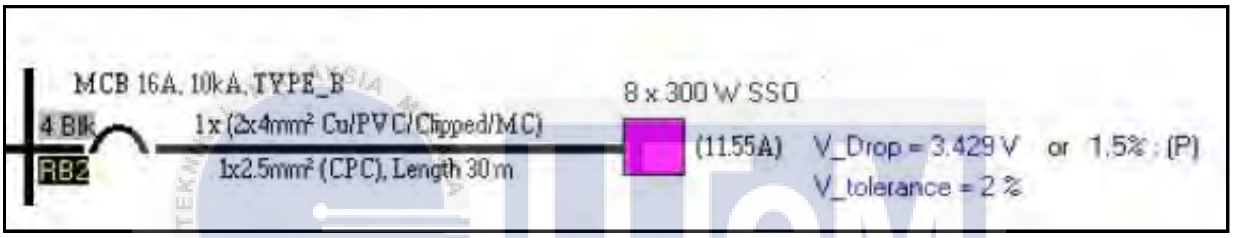
I_z= 22 A, pf= 0.9, Eff= 100 %, kW=2.4, kVAr=1.162
I_b=11.55A AGI= 0.94, 0.65, 1 BK(P), L= 52.5% : (P)

Figure 4.20: Breaker and cable loading test



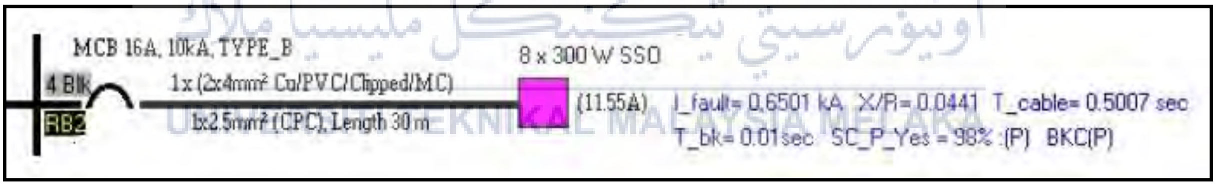
I_2= 23.2 A, 1.45*I_z= 31.89 A, I_z=22 A, AGI= 0.94, 0.65, 1
OL_P_Yes = 27.26% : (P) I_N < I_Z

Figure 4.21: Overload Protection test



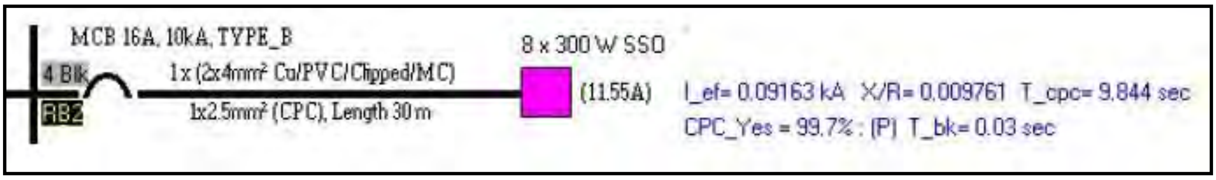
V_Drop = 3.429 V or 1.5% : (P)
V_tolerance = 2 %

Figure 4.22: Voltage drop test



I_fault= 0.6501 kA X/R= 0.0441 T_cable= 0.5007 sec
T_bk= 0.01sec SC_P_Yes = 98% :(P) BKC(P)

Figure 4.23: Short circuit protection test



I_ef= 0.09163 kA X/R= 0.009761 T_cpc= 9.844 sec
CPC_Yes = 99.7% : (P) T_bk= 0.03 sec

Figure 4.24: Earth fault and CPC test

4.3.2.3 Blue Phase (SSO)

The connected load for this phase is 12 units of socket outlet (SSO) with 300W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 12 x 300 W SSO;

$$I_B = \frac{300 \text{ x } 12}{230.9 \text{ x } 0.9} = 17.32 \text{ A}$$

I_B = 17.32 A; I_N = 20 A MCB is selected; 20A is chosen due to the available circuit breaker that bigger than I_B. Refer sub-section 2.2.1.1 for details.

$$I_{t.min} = \frac{20}{0.87 \text{ x } 0.7 \text{ x } 1} = 32.84 \text{ A}$$

Since the installation method is enclosed in trunking, a 6 mm^2, multi-core, pvc-insulated copper conductor non-armoured cable with I_t = 38A, and mv/A/m of 7.3 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

I_Z = 38 x 0.87 x 0.7 x 1

I_Z = 23.14 A

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\ I_Z$

Since I_N = 20 A; I_Z = 23.14 A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$	$29 \leq 1.45\ I_Z$
$I_2 = 1.45\ (20)$	$29 \leq 1.45\ (23.14)$
$I_2 = 29$ A	$29 \text{ A} \leq 33.56 \text{ A}$

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z} \text{ x } 100\% = \frac{33.56-92}{33.56} \text{ x } 100\% = 13.58\%$

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

Voltage drop = $\frac{\text{r } \cos\emptyset + \sin\emptyset}{1000} \text{ x } I_b \text{ x length}$

Voltage drop = $\frac{7.3 \text{ x } 0.9}{1000}$ x 17.32 x 20 = 2.28 V @ 0.99 %

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{17.32}{38 \text{ X } 0.87 \text{ X } 0.7 \text{ X } 1}$ = 74.84%

CL_a = 12 x 300 = 3.6 kW

CL_r = 3.6 kW x tan ($\cos^{-1}$ 0.9) = 1.74 kVar

Estimated 3-phase short current: $I_{F,3-phase}$= 1346 A; $t_{cable,max}$ = 0.5 s (T_bk =0.01 s)

$t_{cable,max} = \frac{k^2 \text{ } S^2}{I_F^2} = \frac{115^2 \text{x } 6^2}{1346^2}$ = 0.263 s

For the short circuit protection, SC_P_Yes = $\frac{t_{cable,max} - \text{T\_bk}}{t_{cable,max}}$ x 100% = $\frac{0.263-0.01}{0.263}$ x 100% = 96.2%

Estimated Earth fault current: I_{EF}= 101.8 A; t_{CPC} = 20.42 s (T_bk =0.04 s)

$t_{CPC,max} = \frac{k^2 \text{ } S^2}{I_F^2} = \frac{115^2 \text{x } 4^2}{101.8^2}$ = 20.42 s

For the CPC protection, CPC_P_Yes = $\frac{t_{CPC,max} - \text{T\_bk}}{t_{CPC,max}}$ x 100% = $\frac{20.42-0.04}{20.42}$ x 100% = 99.80%

The calculation of I_B, I_Z, CLa, CL_r , L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.25 to Figure 4.29 below.

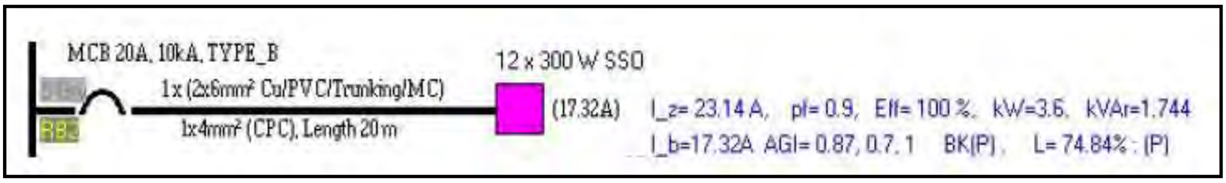


Figure 4.25: Breaker and cable loading test

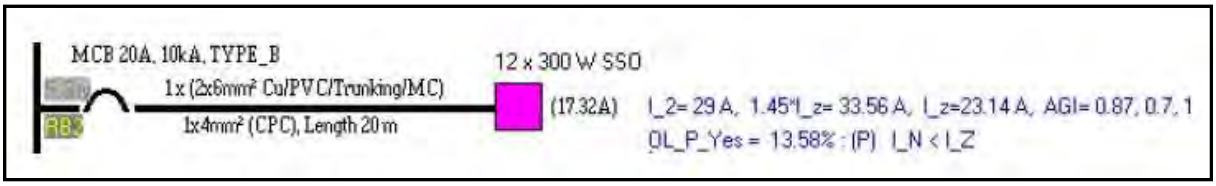


Figure 4.26: Overload Protection test

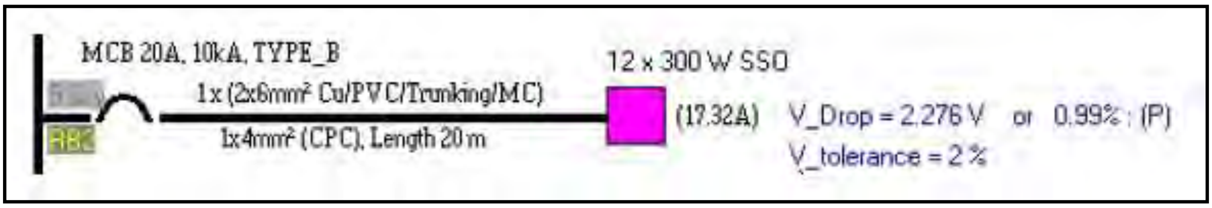


Figure 4.27: Voltage drop test

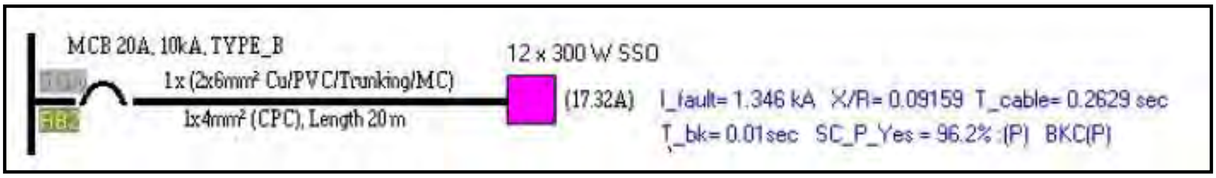


Figure 4.28: Short circuit protection test

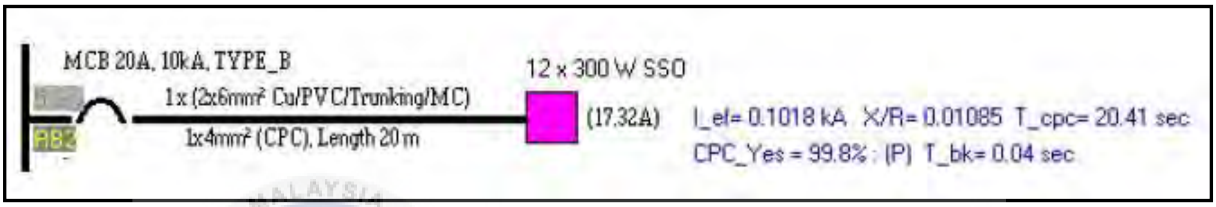


Figure 4.29: Earth fault and CPC test

4.3.3 Result of Motor load

This sub-section present the steps according to the BS 7671 for 11kW star-delta motor and15 kW direct-online motor starter load with the specific data stated in the previous chapter which is Table 3.1.

4.3.3.1 11 kW Motor (Star-Delta)

The connected load for this 3-phase is a star delta motor with 11 kW power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

$$I_B = \frac{\text{Net output of Motor}}{\sqrt{3}\ \text{X}\ 400\ \text{X Eff X Pf}} = \frac{11\ \text{X}\ 10^3}{\sqrt{3}\ \text{X}\ 400\ \text{X}\ 0.9\ \text{X}\ 0.8} = 22.05\ \text{A};$$

I_N = 25 A; 25A is chosen due to the available circuit breaker that bigger than I_B. Refer sub-section 2.2.1.1 for details.

$$I_{t,min} = \frac{22.05}{0.94\ \text{X}\ 0.7\ \text{X}\ 1} = 33.51\ \text{A}$$

Since the installation method is on trunking, a 6 mm2, multi-core, pvc-insulated copper conductor non-armoured cable with It = 34A, and mv/A/m of 6.4 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

$I_Z = 34 \text{ x } 0.94 \text{ x } 0.7 \text{ x } 1$

$I_Z = 22.37 \text{ A}$

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\, I_Z$

Since $I_N = 25$ A; $I_Z = 22.37$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\, I_N$	$36.25 \leq 1.45\, I_Z$
$I_2 = 1.45\,(25)$	$36.25 \leq 1.45\,(22.37)$
$I_2 = 36.25$ A	$36.25 \text{ A} \leq 32.44 \text{ A}$

For Overload protection = $\frac{1.45\, I_Z - I_2}{1.45\, I_Z} \text{ x } 100\% = \frac{32.44-36.25}{32.44} \text{ x } 100\% = -11.75\%$

A negative value of Overload protection implies that the circuit is not adequate against overload current protection. However, this is acceptable because the motor starter has a built-in overload relay.

Voltage drop = $\frac{\text{r} \cos\emptyset + \sin\emptyset}{1000} \text{ x } I_b \text{ x length}$

Voltage drop = $\frac{6.4 \text{ x } 0.8}{1000} \text{ x } 22.05 \text{ x } 20 = 2.3 \text{ V @ } 1\ \%$

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{22.05}{34 \text{ X } 0.94 \text{ X } 0.7 \text{ X } 1} = 98.56\%$

CLa = $\frac{11 \text{ kW}}{0.9} = 12.22$ kW

CLr = 12.22 kW x tan $(\cos^{-1} 0.8) = 9.17$ kVar

Based on the 3-phase short circuit current of 2.259 kA, the calculated critical time (tcable,max) is 0.0933s. Since the operating time (tbk,3-phase,F) of the 25-A MCB is 0.01 s, this circuit satisfies the requirement of thermal limitation.

Estimated 3-phase short current: $I_{F,3-\text{phase}} = 2259$ A; $t_{\text{cable,max}} = 0.0932$ s (T_bk =0.01 s)

$t_{\text{cable,max}} = \frac{k^2\, S^2}{I_F^2} = \frac{115^2 \text{x } 6^2}{2259^2} = 0.0933 \text{ s}$

For the short circuit protection, SC_P_Yes = $\frac{t_{\text{cable,max}} - \text{T\_bk}}{t_{\text{cable,max}}}$ x 100% = $\frac{0.0933-0.01}{0.0933}$ x 100% = 89.28%

Estimated Earth fault current: I_{EF}= 103.3 A; t_{CPC} = 44.62 s (T_bk =30 s),

$$t_{\text{CPC,max}} = \frac{k^2\,S^2}{I_F^2} = \frac{115^2 \text{x}\, 6^2}{103.3^2} = 44.62 \text{ s}$$

For the CPC protection, CPC_P_Yes = $\frac{t_{\text{CPC,max}} - \text{T\_bk}}{t_{\text{CPC,max}}}$ x 100% = $\frac{44.62-30}{44.62}$ x 100% = 32.76%

Based on the earth phase current 103.3 A, the calculated critical time (t_cpc) is 44.6 s. since the operating time (t_bk) of the 25-A MCB is 30 s, this circuit satisfies the requirement of thermal limitation of CPC.

The motor starting current is four time the full load current which is 88 A during the first 15. As the operating time of the 25-A type C MCB is 40 s, this circuit satisfies the requirement for motor starting.

The calculation of I_B, I_Z, CLa, CL_r , L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.30 to Figure 4.34 below.

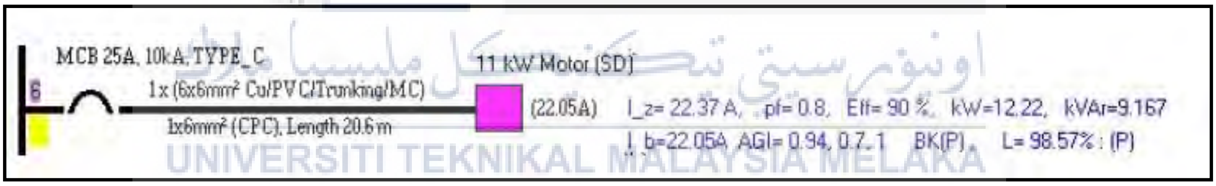


Figure 4.30: Breaker and cable loading test

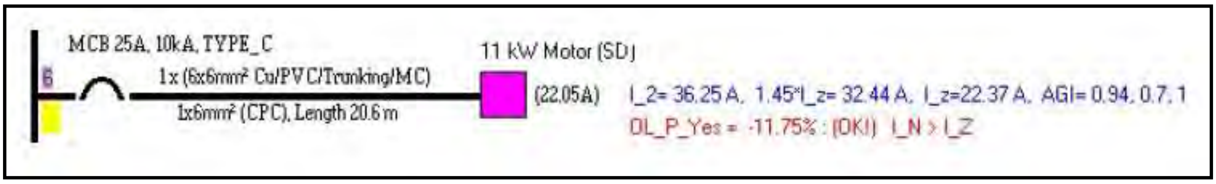
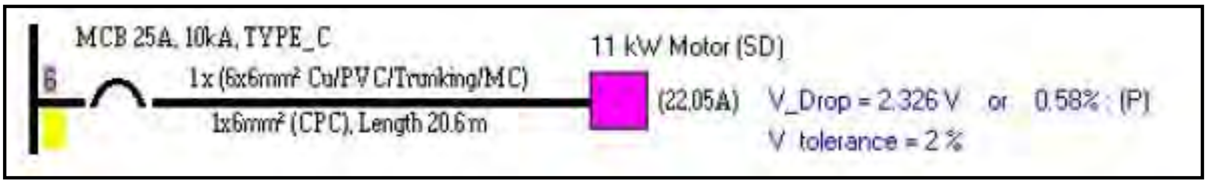


Figure 4.31: Overload Protection test



MCB 25A, 10kA, TYPE_C

1x (6x6mm² Cu/PVC/Trunking/MC)

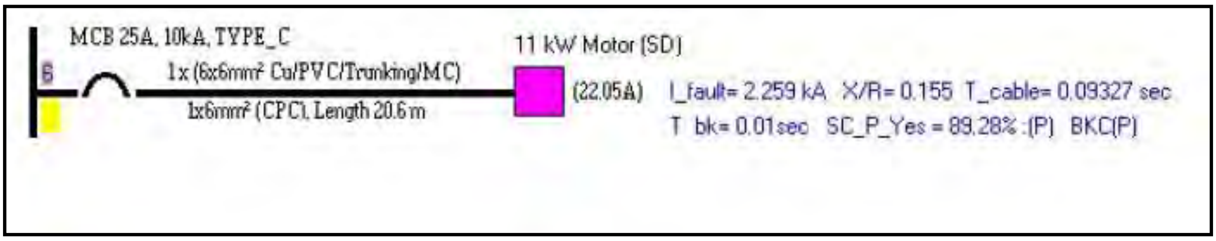
1x6mm² (CPC), Length 20.6 m

11 kW Motor (SD)

(22.05A) V_Drop = 2.326 V or 0.58% : (P)

V tolerance = 2 %

Figure 4.32: Voltage drop test



MCB 25A, 10kA, TYPE_C

1x (6x6mm² Cu/PVC/Trunking/MC)

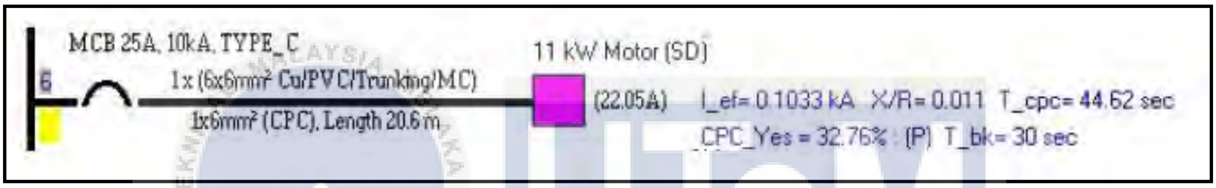
1x6mm² (CPC), Length 20.6 m

11 kW Motor (SD)

(22.05A) I_fault= 2.259 kA X/R= 0.155 T_cable= 0.09327 sec

T bk= 0.01sec SC_P_Yes = 89.28% :(P) BKC(P)

Figure 4.33: Short circuit protection test



MCB 25A, 10kA, TYPE_C

1x (6x6mm² Cu/PVC/Trunking/MC)

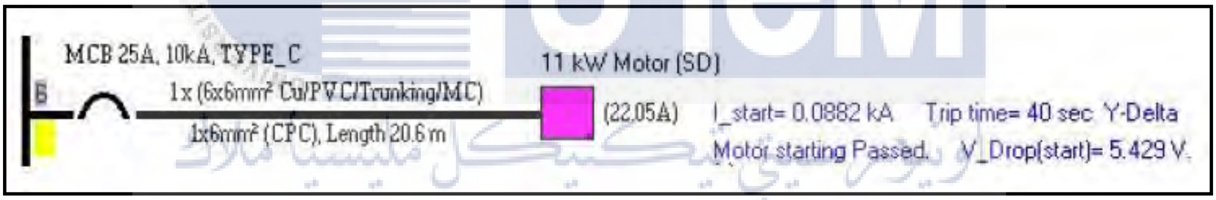
1x6mm² (CPC), Length 20.6 m

11 kW Motor (SD)

(22.05A) I_ef= 0.1033 kA X/R= 0.011 T_cpc= 44.62 sec

CPC_Yes = 32.76% : (P) T_bk= 30 sec

Figure 4.31: Earth fault and CPC test



MCB 25A, 10kA, TYPE_C

1x (6x6mm² Cu/PVC/Trunking/MC)

1x6mm² (CPC), Length 20.6 m

11 kW Motor (SD)

(22.05A) I_start= 0.0882 kA Trip time= 40 sec Y-Delta

Motor starting Passed. V_Drop(start)= 5.429 V.

Figure 4.34: Motor starting test

4.3.3.2 15-kW Motor (DOL)

The connected load for this 3-phase is a start delta motor with 15 kW power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

$I_B = \frac{\text{Net output of Motor}}{\sqrt{3}\ \text{X}\ 400\ \text{X Eff X Pf}} = \frac{15\ \text{X}\ 10^3}{\sqrt{3}\ \text{X}\ 400\ \text{X}\ 0.9\ \text{X}\ 0.8} = 30.07$ A;

I_N = 32 A; 32A is chosen due to the available circuit breaker that bigger than I_B. Refer sub-section 2.2.1.1 for details.

$I_{t,min} = \frac{30.07}{0.87 \text{ X } 0.7 \text{ X } 1} = 49.38$ A

$I_{starting}$ = 30.07 x 7 = 210.49 A

The motor starting current is seven times of the full load current which is 210 A during the first 10 s. As the operating time of the 32 A type 1 MCB for a current of 210 A is 0.01s, the next available rating of 32 A Type 3 MCB is selected. The operating time of the 32 A Type 3 MCB is 10 s, which is 10 s, which is critically acceptable.

Since the installation method is on tray, a 25 mm^2, single-core, pvc-insulated copper conductor non-armoured cable with I_t = 112 A, is selected from Table 4D1A because of It,min ≤ It. Refer Appendix A for Table 4D1A.

For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

I_Z = 112 x 0.87 x 0.7 x 1

I_Z = 68.21 A

i) $I_N \le I_Z$

ii) $I_2 \le 1.45 I_Z$

Since I_N = 32 A; I_Z = 68.21 A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45 I_N$ $\quad$ 46.40 A ≤ 1.45 I_Z

I_2 = 1.45 (32) $\quad$ 46.40 A ≤ 1.45 (68.21)

I_2 = 46.40 A $\quad$ 46.40 A ≤ 98.90 A

For Overload protection = $\frac{1.45 I_Z - I_2}{1.45 I_Z} \text{ x } 100\% = \frac{98.90-46.40}{98.90} \text{ x } 100\% = 53.08\%$

A positive value of Overload protection implies that the circuit is adequate against overload current protection. However, this is acceptable because the motor starter has a built-in overload relay.

Voltage drop = $\frac{r \cos\emptyset + \sin\emptyset}{1000} \text{ x } I_b$ x length

Voltage drop = $\frac{(1.5 \text{ x } 0.8)+(0.25 \text{ x } 0.6)}{1000}$ x 30.07 x 40 = 1.624 V @ 0.4 %

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{30.07}{112 \text{ X } 0.87 \text{ X } 0.7 \text{ X } 1}$ = 44.09 %

$CL_a = \frac{15 \text{ kW}}{0.9}$ = 16.67 kW

CL_r = 16.67 kW x tan ($\cos^{-1}$ 0.8) = 12.5 kVar

Estimated 3-phase short current: $I_{F,3-\text{phase}} = 3650$ A; $t_{cable,max} = 0.6204$ s (T_bk =0.01 s)

$$t_{cable,max} = \frac{k^2\,S^2}{I_F^2} = \frac{115^2 x\, 25^2}{3650^2} = 0.6204 \text{ s}$$

For the short circuit protection, $SC\_P\_Yes = \frac{t_{cable,max} - T\_bk}{t_{cable,max}} \text{ x } 100\% = \frac{0.6204-0.01}{0.6204} \text{ x } 100\% = 98.39\%$

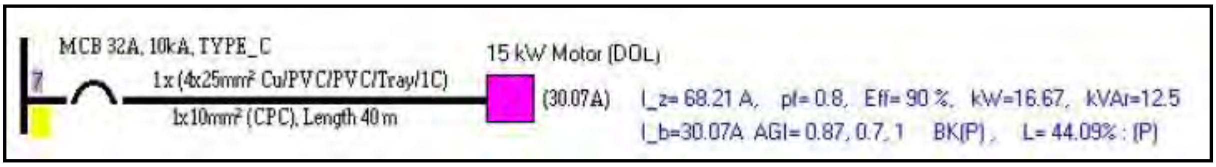
Estimated Earth fault current: $I_{EF} = 104.6$ A; $t_{CPC} = 44.62$ s (T_bk =50 s),

$$t_{CPC,max} = \frac{k^2\,S^2}{I_F^2} = \frac{115^2 x\, 10^2}{104.6^2} = 120.9 \text{ s}$$

For the CPC protection, $CPC\_P\_Yes = \frac{t_{CPC,max} - T\_bk}{t_{CPC,max}} \text{ x } 100\% = \frac{120.9-50}{120.9} \text{ x } 100\% = 58.62\%$

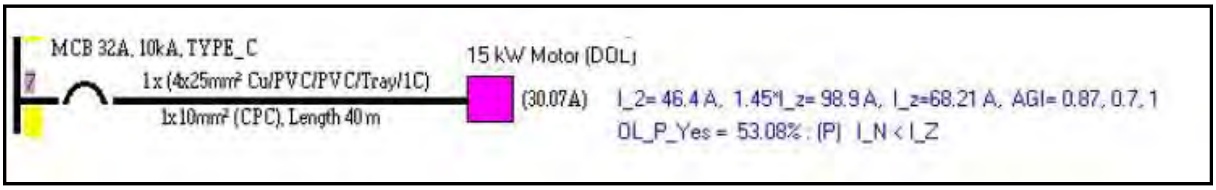
Since $t_{cable,max}$ is greater than $t_{bk,3\text{-Phase},\ F,}$ it satisfies the requirement of thermal limitation of the cable. It also satisfies the requirement of overload protection since the operating time of the MCB at 1.45 $I_{Z\ is}$ 60 s which is less than 2 hours. Based on earth fault current of 105 A, the calculated critical time (t_cpc) is 121 s. Since the operating time (t_bk) of the 32-A Type C MCB is 500 s, this circuit satisfies the requirement of thermal limitation of CPC.

The calculation of I_B, I_Z, CLa, CL_T, L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.35 to Figure 4.40 below.



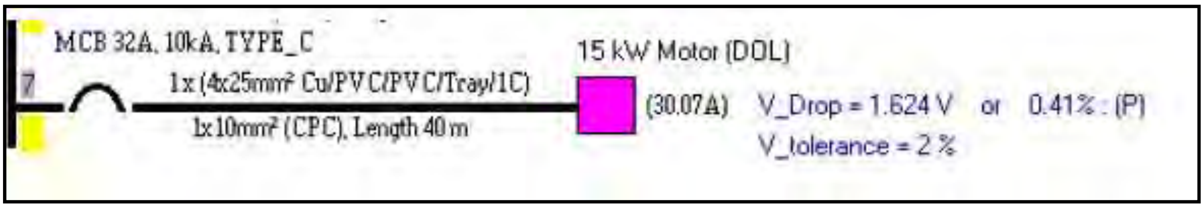
I_z= 68.21 A, pf= 0.8, Eff= 90 %, kW=16.67, kVAr=12.5
I_b=30.07A AGI= 0.87, 0.7, 1 BK(P), L= 44.09% : (P)

Figure 4.35: Breaker and cable loading test



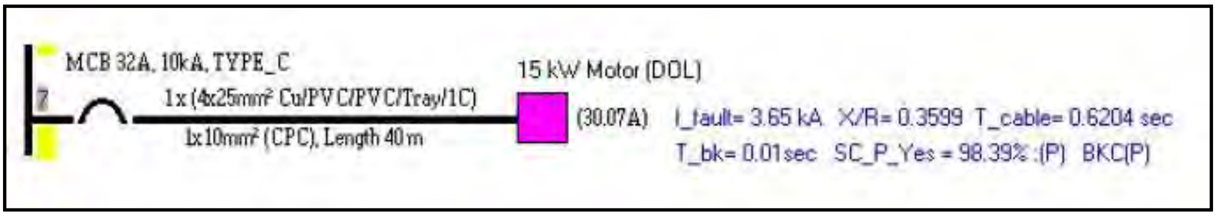
I_2= 46.4 A, 1.45*I_z= 98.9 A, I_z=68.21 A, AGI= 0.87, 0.7, 1
OL_P_Yes = 53.08% : (P) I_N < I_Z

Figure 4.36: Overload Protection test



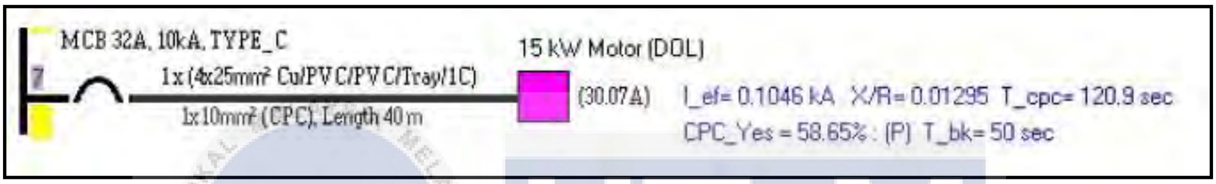
V_Drop = 1.624 V or 0.41% : (P)
V_tolerance = 2 %

Figure 4.37: Voltage drop test



I_fault= 3.65 kA X/R= 0.3599 T_cable= 0.6204 sec
T_bk= 0.01sec SC_P_Yes = 98.39% :(P) BKC(P)

Figure 4.38: Short circuit protection test



I_ef= 0.1046 kA X/R= 0.01295 T_cpc= 120.9 sec
CPC_Yes = 58.65% : (P) T_bk= 50 sec

Figure 4.39: Earth fault and CPC test

I_start= 0.21 kA Trip time= 10 sec DOL
Motor starting Passed. V_Drop(start)= 11.99 V.

Figure 4.40: Motor starting test

4.3.4 Incoming to Final DB T12

Total active connected load:

TCL_a (red) = 0.612 kW + 2.4 kW + $\frac{12.22\text{ kW}}{3} + \frac{16.67\text{ kW}}{3}$ = 12.642 kW

TCL_a (yellow) = 0.612 kW + 2.4 kW + $\frac{12.22\text{ kW}}{3} + \frac{16.67\text{ kW}}{3}$ = 12.642 kW

TCL_a (Blue) = 3.6 kW + $\frac{12.22\text{ kW}}{3} + \frac{16.67\text{ kW}}{3} = 13.23\text{ kW}$

Total reactive connected load:

TCL_r(red) = 0.379 kVar + 1.16 kVar + $\frac{9.17\text{ kVar}}{3} + \frac{12.5\text{ kVar}}{3} = 8.762\text{ kVar}$

$\text{TCL}_r\text{(yellow)} = 0.379\text{ kVar} + 1.16\text{ kVar} + \frac{9.17\text{ kVar}}{3} + \frac{12.5\text{ kVar}}{3} = 8.762\text{ kVar}$

$\text{TCL}_r\text{ (Blue)} = 1.74\text{ kVar} + \frac{9.17\text{ kVar}}{3} + \frac{12.5\text{ kVar}}{3} = 8.963\text{ kVar}$

In determining the maximum current of the design current of the incoming circuit, since TCL_a (Blue) has the highest $\text{TCL}_{a,}$ the TCL_a of FDB T12 is:

3 X 13.23 kW = 39.69 kW

The power factor is calculated based on [TCL_a(red) + TCL_a(yellow) + TCL_a(Blue)] {i.e. 38.514 kW} and [TCL_r(red) + TCL_r(yellow) + TCL_r (Blue)] {i.e 26.488 kVar}

Power factor = $\cos(\tan^{-1}(\frac{26.488}{38.514}) = 0.8239$

Based on the given deman factor of 0.8. The maximum current or the design current of the incoming circuit is

$I_B = \frac{\text{TCLa}}{\sqrt{3}\text{ X }400\text{ X }\cos\theta}$ x DF

$I_B = \frac{39.69\text{ X }10^3}{\sqrt{3}\text{ X }400\text{ X }0.8239}\text{ X }0.8 = 55.63\text{ A}$

A MCCB and RCCB with I_N = 63 A is selected.

It,min = $\frac{63}{0.94\text{ X }0.8\text{ X }1} = 83.78\text{ A}$

Since the installation method is on trunking, a 35 mm2, multi-core, pvc-insulated copper conductor non-armoured cable with It = 99 A, and mv/A/m of 6.4 is selected from Table 4D2A because of It,min ≤ It.

Circuit Loading, L = $\frac{I_B}{I_t\text{ X }C_a\text{ X }C_g\text{ X }C_i} = \frac{55.63}{99\text{ X }0.94\text{ X }0.8\text{ X }1} = 74.72\%$

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

$I_Z = 99 \text{ x } 0.94 \text{ x } 0.8 \text{ x } 1$

$I_Z = 74.45$ A

The calculation of I_B, I_Z, L, I_N and size of cable for main DB 1 and DB 2 are verified by VipCoda software in the Figure 4.39. This verification is including for DB 1 and DB 2 which is the verified calculation for DB 1 in the sub-section below.

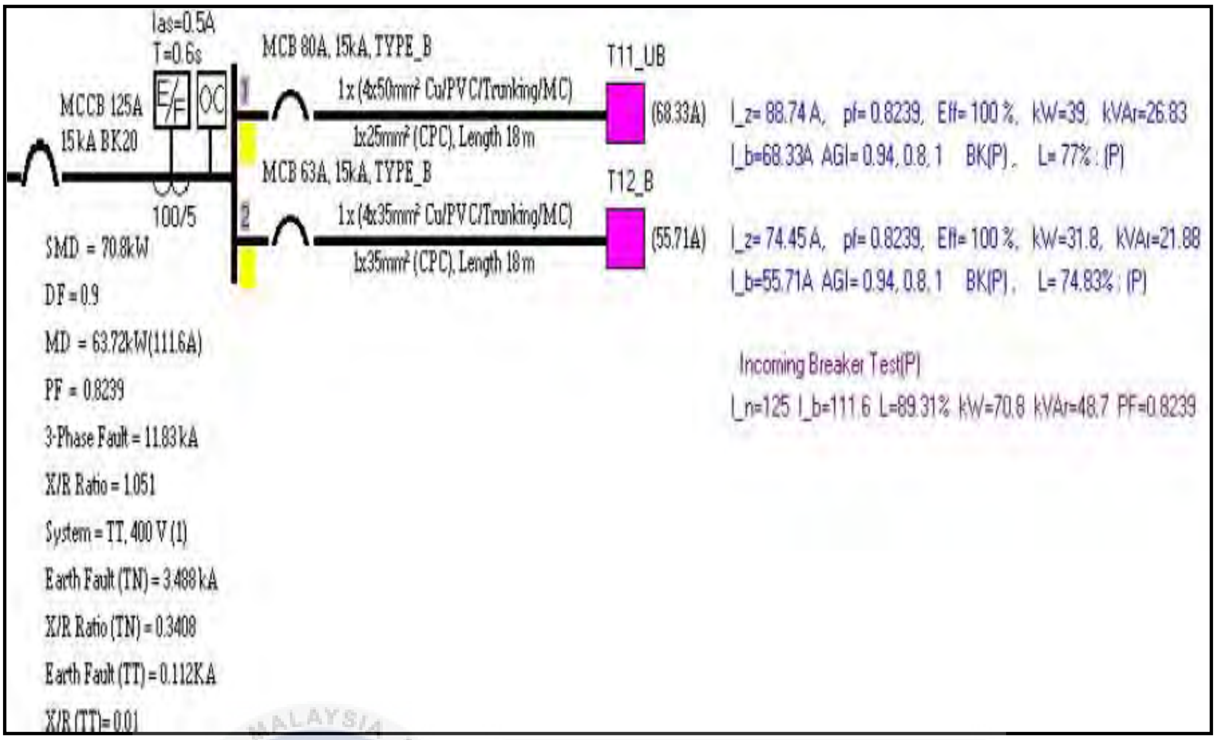


Figure 4.41: Completed design of main DB

4.4 Overall Result for DB 1

The results of calculation for this connected load at DB 1 are same with the VipCoda result at DB 2 due to the connected load at this DB 1 is duplicate from DB 2.

4.4.1 Result of Lighting Load

This sub-section present the steps according to the BS 7671 for design lighting load with the data stated in the previous chapter which is Table 3.1. There are two lighting load connected at this DB which are at the Red and Yellow phase.

4.4.1.1 Red Phase

The connected load for this phase is 10 units of fluorescent lamp with 40W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load: 10 x 40W fluorescent lighting

$$I_B = \frac{\text{P x 1.8}}{\text{V}}$$

$$I_B = \frac{\text{40 x 10 x 1.8}}{230.9} = 3.118\text{ A}$$

$$I_N = 6\text{ A};$$

$$I_{t.min} = \frac{6}{\text{0.94 x 0.65 x 1}} = 9.82\text{ A}$$

Since the installation method is enclosed in trunking, a 1.5 mm^2, multi-core, pvc-insulated copper conductor non-armoured cable with $I_t = 16.5A$ and mv/A/m of 29 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

$I_Z = 16.5 \text{ x } 0.94 \text{ x } 0.65 \text{ x } 1$

$I_Z = 10.08$ A

iii) $I_N \leq I_Z$

iv) $I_2 \leq 1.45\ I_Z$

Since $I_N = 6$ A; $I_Z = 10.08$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$	$8.7 \leq 1.45\ I_Z$
$I_2 = 1.45\ (6)$	$8.7 \leq 1.45\ (10.08)$
$I_2 = 8.7$ A	$8.7\text{ A} \leq 14.62\text{ A}$

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z} \text{ x } 100\% = \frac{14.62-8.7}{14.62} \text{ x } 100\% = 40.49\%$

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

Voltage drop = $\frac{\text{r } \cos\varnothing + \sin\varnothing}{1000}$ x I_b x length

Voltage drop = $\frac{29 \text{ x } 0.85}{1000}$ x 3.118 x 10 = 0.77 V @ 0.33%

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{3.118}{16.5 \text{ X } 0.94 \text{ X } 0.65 \text{ X } 1}$ = 30.9%

Active connected load, CLa = 40 x 1.8 x 10 x 0.85= 0. 612 kW

Reactive connected load, CL_r = 40 x 1.8 x 10 x 0.85 x tan ($\cos^{-1}$ 0.85) = 0.379 kVar

Estimated 3-phase short current: $I_{F,3-\text{phase}}$= 732.5 A

From time-current characteristic curve of Type 1 MCB. T_bk = 0.01s;

Thermal limitation: $t_{\text{cable,max}} = \frac{k^2 \, S^2}{I_F^2} = \frac{115^2 \text{x } 1.5^2}{732.5^2}$ = 0.05546s

For the short circuit protection, SC_P_Yes = $\frac{t_{\text{cable,max}} - \text{T\_bk}}{t_{\text{cable,max}}}$ x 100% = $\frac{0.05546-0.01}{0.05546}$ x 100% = 81.97%

Estimated Earth fault current: I_{EF}= 99.53 A;

From time-current characteristic curve of Type B MCB. T_bk = 0.01s;

$t_{\text{CPC,max}} = \frac{k^2 \, S^2}{I_{EF}^2} = \frac{115^2 \text{x } 2.5^2}{99.53^2}$ = 8.344s

For the CPC protection, CPC_P_Yes = $\frac{t_{\text{CPC,max}} - \text{T\_bk}}{t_{\text{CPC,max}}}$ x 100% = $\frac{8.344-0.01}{8.344}$ x 100% = 99.88%

4.4.1.2 Blue Phase

The connected load for this phase is 10 units of fluorescent lamp with 40W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 10 x 40 W fluorescent lighting

$$I_B = \frac{40 \text{ x } 10 \text{ x } 1.8}{230.9} = 3.118 \text{ A}$$

I_N = 6 A;

$$I_{t.min} = \frac{6}{0.94 \text{ x } 0.65 \text{ x } 1} = 9.82 \text{ A}$$

Since the installation method is clipped direct to surface, a 1.5 mm^2, single-core, pvc-insulated copper conductor non-armoured cable with $I_{t\,=}$ 20A, and mv/A/m of 29 is selected from Table 4D1A because of It,min ≤ It. Refer Appendix A for Table 4D1A.

For the overload protection, the calculation as follow:

$I_Z = I_t \times C_a \times C_g \times C_i$

$I_Z = 20 \times 0.94 \times 0.65 \times 1$

$I_Z = 12.22$ A

iii) $I_N \leq I_Z$

iv) $I_2 \leq 1.45\ I_Z$

Since $I_N = 6$ A; $I_Z = 10.08$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$ $\quad$ $8.7 \leq 1.45\ I_Z$

$I_2 = 1.45\ (6)$ $\quad$ $8.7 \leq 1.45\ (12.22)$

$I_2 = 8.7$ A $\quad$ $8.7\ \text{A} \leq 17.72\ \text{A}$

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z} \times 100\% = \frac{17.72-8.7}{17.72} \times 100\% = 50.9\%$

Estimated 3-phase short current: $I_{F,3-phase} = 258$ A

From time-current characteristic curve of Type 1 MCB. T_bk = 0.01s;

Thermal limitation: $t_{cable,max} = \frac{k^2\ S^2}{I_F^2} = \frac{115^2 \times 1.5^2}{258^2} = 0.4470$ s

For the short circuit protection, SC_P_Yes = $\frac{t_{cable,max} - T\_bk}{t_{cable,max}} \times 100\% = \frac{0.4470-0.01}{0.4470} \times 100\% = 97.76\%$

Estimated Earth fault current: $I_{EF} = 82.77$ A;

From time-current characteristic curve of Type B MCB. T_bk = 0.01s;

$t_{CPC,max} = \frac{k^2\ S^2}{I_{EF}^2} = \frac{115^2 \times 2.5^2}{82.77^2} = 12.07$ s

For the CPC protection, CPC_P_Yes = $\frac{t_{CPC,max} - T\_bk}{t_{CPC,max}} \times 100\% = \frac{12.07-0.01}{12.07} \times 100\% = 99.92\%$

The calculation of I_B, I_Z, CLa, CL_r , L, Voltage drop, Overload protection, Short circuit protection, CPC protection is verified by VipCoda software in the Figure 4.2 to Figure 4.6 below.

Voltage drop = $\frac{r\ \cos\emptyset + \sin\emptyset}{1000} \times I_b \times \text{length}$

Voltage drop = $\frac{29 \times 0.85}{1000} \times 3.118 \times 30 = 2.31$ V @ 1.00%

Circuit Loading, L = $\frac{I_B}{I_t \times C_a \times C_g \times C_i} = \frac{3.118}{20 \times 0.94 \times 0.65 \times 1} = 25.51\%$

CLa = 40 x 1.8 x 10 x 0.85= 0.612 kW

CLr = 612 x tan ($\cos^{-1}$ 0.85) = 0.379 kVar

4.4.2 Result of Socket outlet load

This sub-section present the steps according to the BS 7671 for design socket outlet load with the data stated in the previous chapter which is Table 3.1. There are three socket outlet connected to this DB which are at the Red, Yellow and Blue phase.

4.4.2.1 Red phase

The connected load for this phase is 8 units of socket outlet (SSO) with 300W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 8 x 300 W

$$I_B = \frac{300 \text{ x } 8}{230.9 \text{ x } 0.9} = 11.55$$

I_B=11.55 A; I_N = 16 A type B MCB is selected;

$$I_{t.min} = \frac{16}{0.94 \text{ x } 0.65 \text{ x } 1} = 26.19 \text{ A}$$

Since the installation method is enclosed in trunking, a 4.0 mm^2, single-core, pvc-insulated copper conductor non-armoured cable with I_t = 32A, Iz=19.55 A and mv/A/m of 11 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

I_Z = 32 x 0.94 x 0.65 x 1

I_Z = 19.55 A

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\ I_Z$

Since I_N = 16 A; I_Z = 19.55 A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$ $\qquad$ $23.2 \leq 1.45\ I_Z$

$I_2 = 1.45\ (16)$ $\qquad$ $23.2 \leq 1.45\ (19.55)$

$23.2\text{A} \leq 28.35 \text{ A}$

$I_2 = 23.2$ A

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z}$ x 100% = $\frac{28.35-23.2}{28.35}$ x 100% = 18.16%

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

Voltage drop = $\frac{r\ \cos\emptyset + \sin\emptyset}{1000}$ x I_b x length

Voltage drop = $\frac{11 \text{ x } 0.9}{1000}$ x 11.55 x 10 = 1.143 V @ 0.49%

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{11.55}{32 \text{ X } 0.94 \text{ X } 0.65 \text{ X } 1}$ = 59.06%

Active connected load, CL_a = 8 x 300 = 2.4 kW

Reactive connected load, CL_r = 2.4 kW x tan ($\cos^{-1}$ 0.9) = 1.16 kVar

Estimated 3-phase short current: $I_{F,3-phase}$= 1701 A

From time-current characteristic curve of Type 1 MCB. T_bk = 0.01s;

Thermal limitation: $t_{cable,max} = \frac{k^2\ S^2}{I_F^2} = \frac{115^2 \text{x } 4^2}{1701^2}$ = 0.07316s

For the short circuit protection, SC_P_Yes = $\frac{t_{cable,max} - T\_bk}{t_{cable,max}}$ x 100% = $\frac{0.07316-0.01}{0.07316}$ x 100% = 86.33%

Estimated Earth fault current: I_{EF}= 103.6 A;

$t_{CPC,max} = \frac{k^2\ S^2}{I_F^2} = \frac{115^2 \text{x } 2.5^2}{103.6^2}$ = 7.707s

From time-current characteristic curve of Type B MCB. T_bk = 0.02s;

For the CPC protection, CPC_P_Yes = $\frac{t_{CPC,max} - T\_bk}{t_{CPC,max}}$ x 100% = $\frac{7.707-0.02}{7.707}$ x 100% = 99.74%

4.4.2.2 Yellow phase (SSO)

The connected load for this phase is 8 units of socket outlet (SSO) with 300W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 8 x 300 W SSO;

$$I_B = \frac{300 \text{ x } 8}{230.9 \text{ x } 0.9} = 11.55$$

I_B = 11.55 A; I_N = 16 A type 1 MCB is selected;

$$I_{t.min} = \frac{16}{0.94 \text{ x } 0.65 \text{ x } 1} = 26.19 \text{ A}$$

Since the installation method is clipped direct to surface, a 2.5 mm^2, multi-core, pvc-insulated copper conductor non-armoured cable with I_t = 27A, and mv/A/m of 18 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

Voltage drop = $\frac{r \cos\emptyset + \sin\emptyset}{1000}$ x I_b x length

Voltage drop = $\frac{18 \text{ x } 0.9}{1000}$ x 11.55 x 30 = 5.613 V @ 2.43% (exceeds 2%)

Re-select the next cable size of 4.0 mm^2 with I_t = 36 A and a mv/A/m of 11 and re-computed voltage drop is 3.43V, which is voltage drop is less than 2%.

Voltage drop = $\frac{11 \text{ x } 0.9}{1000}$ x 11.55 x 30 = 3.43 V @ 1.48%

For the overload protection, the calculation as follow:

$I_Z = I_t$ x C_a x C_g x C_i

I_Z = 36 x 0.94 x 0.65 x 1

I_Z = 22 A

iii) $I_N \leq I_Z$

iv) $I_2 \leq 1.45\ I_Z$

Since I_N = 16 A; I_Z = 19.55 A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$ $23.2 \leq 1.45\ I_Z$

I_2 = 1.45 (16) $23.2 \leq 1.45\ (22)$

I_2 = 23.2 A $23.2 \text{ A} \leq 31.89 \text{ A}$

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z}$ x $100\% = \frac{31.89 - 23.2}{31.89}$ x $100\% = 27.26\%$

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

CL_a = 8 x 300 = 2.4 kW

CL_r = 2.4 kW x tan ($\cos^{-1}$ 0.9) = 1.16 kVar

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{11.55}{36 \text{ X } 0.94 \text{ X } 0.65 \text{ X } 1}$ = 52.5%

Estimated 3-phase short current: $I_{F,3-phase}$= 650 A; $t_{cable,max}$ = 0.5 s (T_bk =0.01 s)

$t_{cable,max} = \frac{k^2 \, S^2}{I_F^2} = \frac{115^2 x \, 4^2}{650^2}$ = 0.5s

For the short circuit protection, SC_P_Yes = $\frac{t_{cable,max} - \text{T\_bk}}{t_{cable,max}}$ x 100% = $\frac{0.5-0.01}{0.5}$ x 100% = 98%

Estimated Earth fault current: I_{EF}= 91.6 A ; t_{CPC} = 9.85 s (T_bk =0.03 s)

$t_{CPC,max} = \frac{k^2 \, S^2}{I_F^2} = \frac{115^2 x \, 2.5^2}{91.6^2}$ = 9.85 s

For the CPC protection, CPC_P_Yes = $\frac{t_{CPC,max} - \text{T\_bk}}{t_{CPC,max}}$ x 100% = $\frac{9.85-0.03}{9.85}$ x 100% = 99.70%

4.4.2.3 Red Phase (SSO)

The connected load for this phase is 12 units of socket outlet (SSO) with 300W power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

Connected load = 12 x 300 W SSO;

$$I_B = \frac{300 \text{ x } 12}{230.9 \text{ x } 0.9} = 17.32 \text{ A}$$

I_B = 17.32 A; I_N = 20 A type 1 MCB is selected;

$$I_{t.min} = \frac{20}{0.87 \text{ x } 0.7 \text{ x } 1} = 32.84 \text{ A}$$

Since the installation method is enclosed in trunking, a 6 mm^2, multi-core, pvc-insulated copper conductor non-armoured cable with I_t = 38A, and mv/A/m of 7.3 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

For the overload protection, the calculation as follow:

$I_Z = I_t \times C_a \times C_g \times C_i$

$I_Z = 38 \times 0.87 \times 0.7 \times 1$

$I_Z = 23.14$ A

iii) $I_N \leq I_Z$

iv) $I_2 \leq 1.45\ I_Z$

Since $I_N = 20$ A; $I_Z = 23.14$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$ $\qquad 29 \leq 1.45\ I_Z$

$I_2 = 1.45\ (20)$ $\qquad 29 \leq 1.45\ (23.14)$

$I_2 = 29$ A $\qquad 29\text{ A} \leq 33.56\text{ A}$

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z} \times 100\% = \frac{33.56-92}{33.56} \times 100\% = 13.58\%$

A positive value of Overload protection implies that the circuit is adequately protected against overload current, and a higher percentage means that the circuit is more unlikely to be overloaded.

Voltage drop = $\frac{r\ \cos\emptyset + \sin\emptyset}{1000} \times I_b \times \text{length}$

Voltage drop = $\frac{7.3 \times 0.9}{1000} \times 17.32 \times 20 = 2.28$ V @ 0.99 %

Circuit Loading, L = $\frac{I_B}{I_t \times C_a \times C_g \times C_i} = \frac{17.32}{38 \times 0.87 \times 0.7 \times 1} = 74.84\%$

$CL_a = 12 \times 300 = 3.6$ kW

$CL_r = 3.6$ kW x tan $(\cos^{-1} 0.9) = 1.74$ kVar

Estimated 3-phase short current: $I_{F,3-\text{phase}} = 1346$ A; $t_{\text{cable,max}} = 0.5$ s (T_bk =0.01 s)

$t_{\text{cable,max}} = \frac{k^2\ S^2}{I_F^2} = \frac{115^2 \times 6^2}{1346^2} = 0.263$ s

For the short circuit protection, SC_P_Yes = $\frac{t_{\text{cable,max}} - T\_bk}{t_{\text{cable,max}}} \times 100\% = \frac{0.263-0.01}{0.263} \times 100\% = 96.2\%$

Estimated Earth fault current: $I_{EF} = 101.8$ A; $t_{CPC} = 20.42$ s (T_bk =0.04 s)

$t_{\text{CPC,max}} = \frac{k^2\ S^2}{I_F^2} = \frac{115^2 \times 4^2}{101.8^2} = 20.42$ s

For the CPC protection, CPC_P_Yes = $\frac{t_{\text{CPC,max}} - T\_bk}{t_{\text{CPC,max}}} \times 100\% = \frac{20.42-0.04}{20.42} \times 100\% = 99.80\%$.

4.4.3 Result of Motor load

This sub-section present the steps according to the BS 7671 for 11kW star-delta motor and15 kW direct-online motor starter load with the specific data stated in the previous chapter which is Table 3.1.

4.4.3.1 11 kW Motor (Star-Delta)

The connected load for this 3-phase is a star delta motor with 11 kW power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

$I_B = \frac{\text{Net output of Motor}}{\sqrt{3}\ \text{X}\ 400\ \text{X Eff X Pf}} = \frac{11\ \text{X}\ 10^3}{\sqrt{3}\ \text{X}\ 400\ \text{X}\ 0.9\ \text{X}\ 0.8} = 22.05$ A;

$I_N = 25$ A; It,min = $\frac{22.05}{0.94\ \text{X}\ 0.7\ \text{X}\ 1} = 33.51$ A

Since the installation method is on trunking, a 6 mm2, multi-core, pvc-insulated copper conductor non-armoured cable with It = 34A, and mv/A/m of 6.4 is selected from Table 4D2A because of It,min ≤ It. Refer Appendix C for Table 4D2A.

For the overload protection, the calculation as follow:

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

$I_Z = 34 \text{ x } 0.94 \text{ x } 0.7 \text{ x } 1$

$I_Z = 22.37$ A

iii) $I_N \leq I_Z$

iv) $I_2 \leq 1.45\ I_Z$

Since $I_N = 25$ A; $I_Z = 22.37$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\ I_N$	$36.25 \leq 1.45\ I_Z$
$I_2 = 1.45\ (25)$	$36.25 \leq 1.45\ (22.37)$
$I_2 = 36.25$ A	36.25 A ≤ 32.44 A

For Overload protection = $\frac{1.45\ I_Z - I_2}{1.45\ I_Z} \text{ x } 100\% = \frac{32.44-36.25}{32.44} \text{ x } 100\% = -11.75\%$

A negative value of Overload protection implies that the circuit is not adequate against overload current protection. However, this is acceptable because the motor starter has a built-in overload relay.

Voltage drop = $\frac{\text{r } \cos\emptyset + \sin\emptyset}{1000}$ x I_b x length

Voltage drop = $\frac{6.4 \text{ x } 0.8}{1000}$ x 22.05 x 20 = 2.3 V @ 1 %

Circuit Loading, L = $\frac{I_B}{I_t \text{ X } C_a \text{ X } C_g \text{ X } C_i} = \frac{22.05}{34 \text{ X } 0.94 \text{ X } 0.7 \text{ X } 1}$ = 98.56%

CLa = $\frac{11 \text{ kW}}{0.9}$ = 12.22 kW

CLr = 12.22 kW x tan ($\cos^{-1}$ 0.8) = 9.17 kVar

Based on the 3-phase short circuit current of 2.259 kA, the calculated critical time (tcable,max) is 0.0933s. Since the operating time (tbk,3-phase,F) of the 25-A MCB is 0.01 s, this circuit satisfies the requirement of thermal limitation.

Estimated 3-phase short current: $I_{F,3-\text{phase}}$= 2259 A; $t_{\text{cable,max}}$ = 0.0932 s (T_bk =0.01 s)

$t_{\text{cable,max}} = \frac{k^2 \, S^2}{I_F^2} = \frac{115^2 \text{x } 6^2}{2259^2}$ = 0.0933 s

For the short circuit protection, SC_P_Yes = $\frac{t_{\text{cable,max}} - \text{T\_bk}}{t_{\text{cable,max}}}$ x 100% = $\frac{0.0933-0.01}{0.0933}$ x 100% = 89.28%

Estimated Earth fault current: I_{EF}= 103.3 A; t_{CPC} = 44.62 s (T_bk =30 s),

$t_{\text{CPC,max}} = \frac{k^2 \, S^2}{I_F^2} = \frac{115^2 \text{x } 6^2}{103.3^2}$ = 44.62 s

For the CPC protection, CPC_P_Yes = $\frac{t_{\text{CPC,max}} - \text{T\_bk}}{t_{\text{CPC,max}}}$ x 100% = $\frac{44.62-30}{44.62}$ x 100% = 32.76%.

4.4.3.2 15-kW Motor (DOL)

The connected load for this 3-phase is a start delta motor with 15 kW power consumption. Calculation below shows how to get the value of design current, I_B. Next, for current rating, I_N must be selected higher than I_B.

$I_B = \frac{\text{Net output of Motor}}{\sqrt{3} \text{ X } 400 \text{ X Eff X Pf}} = \frac{15 \text{ X } 10^3}{\sqrt{3} \text{ X } 400 \text{ X } 0.9 \text{ X } 0.8}$ = 30.07 A;

$I_N = 32$ A; $I_{t,min} = \frac{30.07}{0.87 \times 0.7 \times 1} = 49.38$ A

$I_{starting} = 30.07 \times 7 = 210.49$ A

The motor starting current is seven times of the full load current which is 210 A during the first 10 s. As the operating time of the 32 A type 1 MCB for a current of 210 A is 0.01s, the next available rating of 32 A Type 3 MCB is selected. The operating time of the 32 A Type 3 MCB is 10 s, which is 10 s, which is critically acceptable.

Since the installation method is on tray, a 25 mm^2, single-core, pvc-insulated copper conductor non-armoured cable with $I_t = 112$ A, is selected from Table 4D1A because of It,min ≤ It. Refer Appendix A for Table 4D1A.

For the overload protection, the calculation as follow:

$I_Z = I_t \times C_a \times C_g \times C_i$

$I_Z = 112 \times 0.87 \times 0.7 \times 1$

$I_Z = 68.21$ A

i) $I_N \leq I_Z$

ii) $I_2 \leq 1.45\, I_Z$

Since $I_N = 32$ A; $I_Z = 68.21$ A, the condition in i) is adequate. For condition ii)

$I_2 = 1.45\, I_N$	$46.40\text{ A} \leq 1.45\text{ IZ}$
$I_2 = 1.45\,(32)$	$46.40\text{ A} \leq 1.45\,(68.21)$
$I_2 = 46.40$ A	$46.40\text{ A} \leq 98.90$ A

For Overload protection $= \frac{1.45\, I_Z - I_2}{1.45\, I_Z} \times 100\% = \frac{98.90 - 46.40}{98.90} \times 100\% = 53.08\%$

A positive value of Overload protection implies that the circuit is adequate against overload current protection. However, this is acceptable because the motor starter has a built-in overload relay.

Voltage drop $= \frac{r\ \cos\emptyset + \sin\emptyset}{1000} \times I_b \times$ length

Voltage drop $= \frac{(1.5 \times 0.8) + (0.25 \times 0.6)}{1000} \times 30.07 \times 40 = 1.624$ V @ 0.4 %

Circuit Loading, $L = \frac{I_B}{I_t \times C_a \times C_g \times C_i} = \frac{30.07}{112 \times 0.87 \times 0.7 \times 1} = 44.09$ %

$CL_a = \frac{15\text{ kW}}{0.9} = 16.67$ kW

$CL_r = 16.67\text{ kW} \times \tan(\cos^{-1} 0.8) = 12.5$ kVar

Estimated 3-phase short current: $I_{F,3-phase} = 3650$ A; $t_{cable,max} = 0.6204$ s (T_bk =0.01 s)

$t_{\text{cable,max}} = \frac{k^2\,S^2}{I_F^2} = \frac{115^2 \text{x}\, 25^2}{3650^2} = 0.6204$ s

For the short circuit protection, SC_P_Yes = $\frac{t_{\text{cable,max}} - \text{T\_bk}}{t_{\text{cable,max}}}$ x 100% = $\frac{0.6204-0.01}{0.6204}$ x 100% = 98.39%

Estimated Earth fault current: I_{EF}= 104.6 A; t_{CPC} = 44.62 s (T_bk =50 s)

$t_{\text{CPC,max}} = \frac{k^2\,S^2}{I_F^2} = \frac{115^2 \text{x}\, 10^2}{104.6^2} = 120.9$ s

For the CPC protection, CPC_P_Yes = $\frac{t_{\text{CPC,max}} - \text{T\_bk}}{t_{\text{CPC,max}}}$ x 100% = $\frac{120.9-50}{120.9}$ x 100% = 58.62%

Since $t_{\text{cable,max}}$ is greater than $t_{\text{bk,3-Phase, F,}}$ it satisfies the requirement of thermal limitation of the cable. It also satisfies the requirement of overload protection since the operating time of the MCB at 1.45 $I_{Z\text{ is}}$ 60 s which is less than 2 hours. Based on earth fault current of 105 A, the calculated critical time (t_cpc) is 121 s. Since the operating time (t_bk) of the 32-A Type C MCB is 500 s, this circuit satisfies the requirement of thermal limitation of CPC.

4.4.4 Incoming to FDB T11 B

Total active connected load:

TCL_a (red) = 0.612 kW + 2.4 kW + 3.6 kW + $\frac{12.22\ kW}{3} + \frac{16.67\ kW}{3}$ = 16.242 kW

TCLa (yellow) = 2.4 kW + $\frac{12.22\ kW}{3} + \frac{16.67\ kW}{3}$ = 12.03 kW

TCLa (Blue) = 0.612 kW + $\frac{12.22\ kW}{3} + \frac{16.67\ kW}{3} = 10.242\ kW$

Total reactive connected load:

TCLr(red) = 0.379 kVar + 1.16 kVar + 1.74 kVar + $\frac{9.17\ kVar}{3} + \frac{12.5\ kVar}{3} = 10.502\ kVar$

TCLr(yellow) = 1.16 kVar + $\frac{9.17\ kVar}{3} + \frac{12.5\ kVar}{3} = 8.383\ kVar$

TCLr (Blue) = 0.379 kVar + $\frac{9.17\ kVar}{3} + \frac{12.5\ kVar}{3}$ = 7.602 kVar

In determining the maximum current of the design current of the incoming circuit, since TCL_a (Red) has the highest $\text{TCL}_{a,}$ the TCL_a of FDB T11 is:

3 X 16.242 kW = 48.726 kW

The power factor is calculated based on [TCL_a (red) + TCL_a(yellow) + TCL_a (Blue)] {i.e. 38.514 kW} and [TCL_r(red) + TCL_r(yellow) + TCL_r (Blue)] {i.e 26.488 kVar}

Power factor = $\cos(tan^{-1}(\frac{26.488}{38.514}) = 0.8239$

Based on the given deman factor of 0.8. The maximum current or the design current of the incoming circuit is

$I_B = \frac{\text{TCLa}}{\sqrt{3}\ \text{X}\ 400\ \text{X} \cos\theta}\ \text{x DF}$

$I_B = \frac{48.726\ \text{X}\ 10^3}{\sqrt{3}\ \text{X}\ 400\ \text{X}\ 0.8239}\ \text{X}\ 0.8 = 68.29\ \text{A}$

A MCCB and RCCB with I_N = 80 A is selected.

$\text{It,min} = \frac{80}{0.94\ \text{X}\ 0.8\ \text{X}\ 1} = 106.38\ \text{A}$

Since the installation method is on trunking, a 50 mm2, multi-core, pvc-insulated copper conductor non-armoured cable with It = 118A, and mv/A/m of 6.4 is selected from Table 4D2A because of It,min ≤ It.

Circuit Loading, $L = \frac{I_B}{I_t\ \text{X}\ C_a\ \text{X}\ C_g\ \text{X}\ C_i} = \frac{68.29}{118\ \text{X}\ 0.94\ \text{X}\ 0.8\ \text{X}\ 1} = 76.96\%$

$I_Z = I_t \text{ x } C_a \text{ x } C_g \text{ x } C_i$

$I_Z = 118 \text{ x } 0.94 \text{ x } 0.8 \text{ x } 1$

$I_Z = 88.74$ A

4.5 Manual for low voltage installation

In this sub-section, the user can see the summarize of the steps in the electrical installation according to the BS 7671. The procedures for three types of load that normally use in building has been simplified in the flowcharts below. The flowchart in the figure 4.42 is use to design lighting load. For the figure 4.43 which is the standard for the normal load electrical installation. The user can follow the stated formula whether for single phase or three phase. For the third flowchart in the figure 4.44 is a standard for the motor load installation. The user can easily follow the steps in the flowchart to get the best electrical design network.

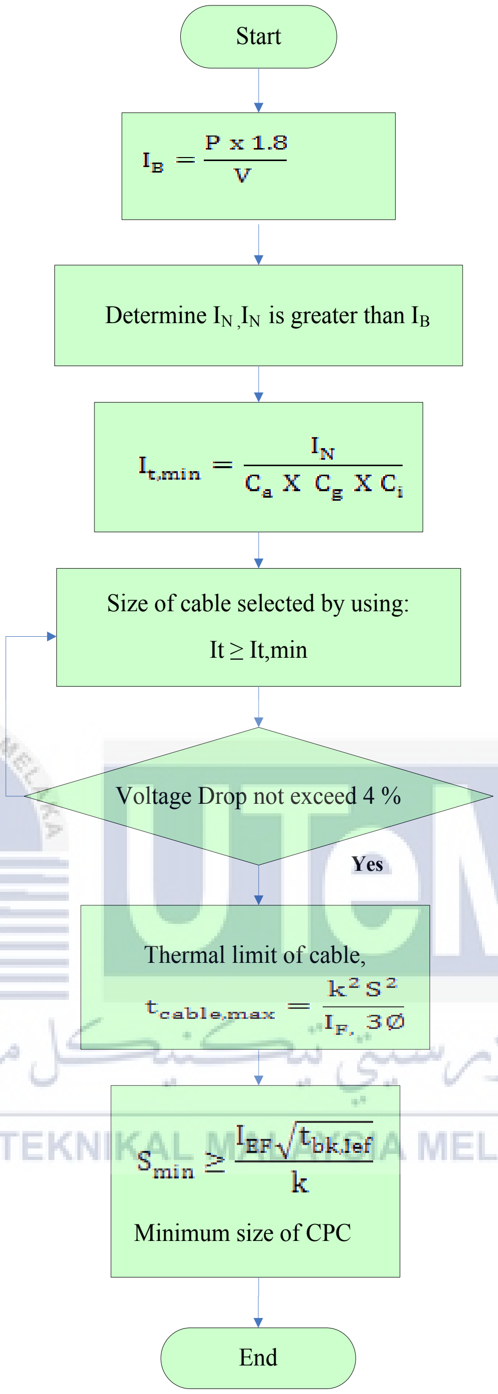


Figure 4.42: Standard Procedure for lighting load

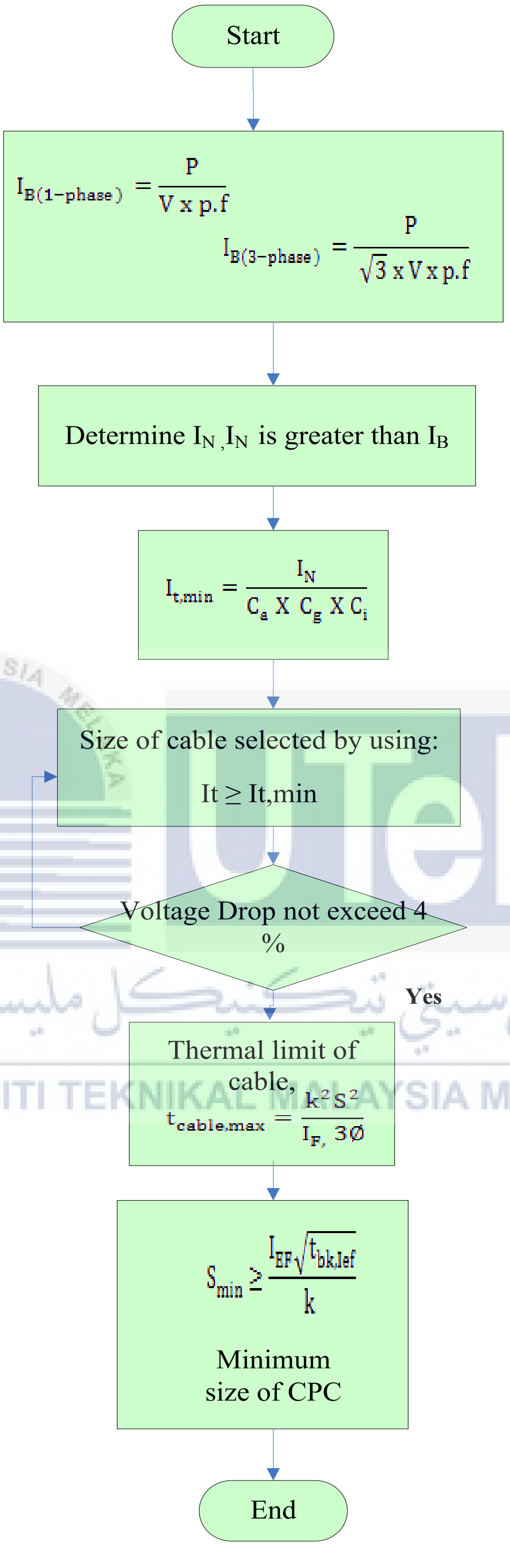


Figure 4.43: Standard Procedure for normal load

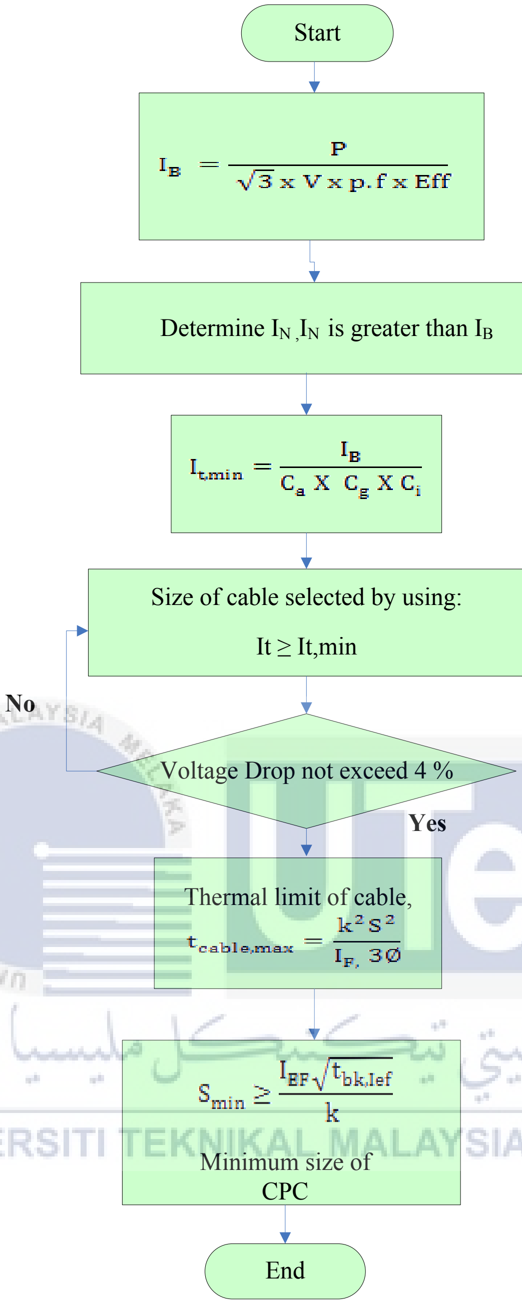


Figure 4.44: Standard Procedure for motor load

CHAPTER 5

CONCLUSION

5.0 Conclusion

VipCoda is the intelligent software that wills benefits consultant and electrical engineer. However, there is constraint of VipCoda software which is not providing step-by-step of guidance of electrical installation. It wills difficult to the new user that needs guidance of electrical installation by following the standard BS 7671.

This problem can be solving by conducting this project which is examine the steps in low voltage design system according to BS 7671. The user has to follow 8 steps of standard design procedure BS 7671 in sub-section 3.2 to ensure the electrical design is the proper and safe design.

Next, calculation of low voltage design which is connected load in the shops as tabulated in Figure 3.1 and 3.2 was verified with VipCoda results in Chapter 4. The calculation results of each load connected to the DB 1 and DB 2 which are I_B, I_N, I_Z, Voltage drop, Size of cable, Overload protection, CPC protection was verified with VipCoda results. However, there are small error occur in the verification with VipCoda results which is in range 2 % error.

Lastly, this project will ease to the new user by providing the step-by-step procedures to assist the VipCoda user. The simple manual in the Figure 4.40 to 4.42 will help the new user that needs accurate guidance of electrical installation by following the standard BS 7671 but this project only appropriate for only three types of loads which are lighting load, normal load (1-phase and 3-phase) and motor load.

For recommendation, this study can be proceeds with double-storey house which is have more complex circuit. It is because many final DB should be added in connection to the main DB. Furthermore, the researcher should add more case studies with the different type of loads connected to the DB.

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APPENDIX A

TABLE 4D1A

Single-core 70 °C thermoplastic (pvc) insulated cables, non-armoured, with or without sheath
(COPPER CONDUCTORS)

Ambient temperature: 30 °C
Conductor operating temperature: 70 °C

CURRENT-CARRYING CAPACITY (amperes):

Conductor cross-sectional area	Reference Method 4 (enclosed in conduit in thermally insulating wall etc.)		Reference Method 3 (enclosed in conduit on a wall or in trunking etc.)		Reference Method 1 (clipped direct)		Reference Method 11 (on a perforated cable tray horizontal or vertical)		Reference Method 12 (free air) Horizontal flat spaced	Reference Method 12 (free air) Vertical flat spaced	Reference Method 12 (free air) Trefoil
	2 cables, single-phase a.c. or d.c.	3 or 4 cables, three-phase a.c.	2 cables, single-phase a.c. or d.c.	3 or 4 cables, three-phase a.c.	2 cables, single-phase a.c. or d.c. flat and touching	3 or 4 cables, three-phase a.c. flat and touching or trefoil	2 cables, single-phase a.c. or d.c. flat and touching	3 or 4 cables, three-phase a.c. flat and touching or trefoil	2 cables, single-phase a.c. or d.c. or 3 cables three-phase a.c.	2 cables, single-phase a.c. or d.c. or 3 cables three-phase a.c.	3 cables trefoil, three phase a.c.
1	2	3	4	5	6	7	8	9	10	11	12
(mm²)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1	11	10.5	13.5	12	15.5	14	-	-	-	-	-
1.5	14.5	13.5	17.5	15.5	20	18	-	-	-	-	-
2.5	19.5	18	24	21	27	25	-	-	-	-	-
4	26	24	32	28	37	33	-	-	-	-	-
6	34	31	41	36	47	43	-	-	-	-	-
10	46	42	57	50	65	59	-	-	-	-	-
16	61	56	76	68	87	79	-	-	-	-	-
25	80	73	101	89	114	104	126	112	146	130	110
35	99	89	125	110	141	129	156	141	181	162	137
50	119	108	151	134	182	167	191	172	219	197	167
70	151	136	192	171	234	214	246	223	281	254	216
95	182	164	232	207	284	261	300	273	341	311	264
120	210	188	269	239	330	303	349	318	396	362	308
150	240	216	300	262	381	349	404	369	456	419	356
185	273	245	341	296	436	400	463	424	521	480	409
240	320	286	400	346	515	472	549	504	615	569	485
300	367	328	458	394	594	545	635	584	709	659	561
400	-	-	546	467	694	634	732	679	852	795	656
500	-	-	626	533	792	723	835	778	982	920	749
630	-	-	720	611	904	826	953	892	1138	1070	855
800	-	-	-	-	1030	943	1086	1020	1265	1188	971
1000	-	-	-	-	1154	1058	1216	1149	1420	1337	1079

APPENDIX B

TABLE 4D1B

VOLTAGE DROP (per ampere per metre): Conductor operating temperature: 70 °C

Conductor cross-sectional area	2 cables d.c.	2 cables, single-phase a.c.									3 or 4 cables, three-phase a.c.											
		Reference Methods 3 &4 (enclosed in conduit etc. in or on a wall)			Reference Methods 1 & 11 (clipped direct or on trays, touching)			Reference Method 12 (spaced*)			Reference Methods 3 &4 (enclosed in conduit etc. in or on a wall)			Reference Methods 1, 11 & 12 (in trefoil)			Reference Methods1 &11 (flat and touching)			Reference Method 12 (flat spaced*)		
1	2	3			4			5			6			7			8			9		
(mm^2)	(mV/A/m)	(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)			(mV/A/m)		
1	44		44			44			44			38			38			38			38	
1.5	29		29			29			29			25			25			25			25	
2.5	18		18			18			18			15			15			15			15	
4	11		11			11			11			9.5			9.5			9.5			9.5	
6	7.3		7.3			7.3			7.3			6.4			6.4			6.4			6.4	
10	4.4		4.4			4.4			4.4			3.8			3.8			3.8			3.8	
16	2.8		2.8			2.8			2.8			2.4			2.4			2.4			2.4	
		r	x	z	r	x	z	r	x	z	r	x	z	r	x	z	r	x	z	r	x	z
25	1.75	1.80	0.33	1.80	1.75	0.20	1.75	1.75	0.29	1.80	1.50	0.29	1.55	1.50	0.175	1.50	1.50	0.25	1.55	1.50	0.32	1.55
35	1.25	1.30	0.31	1.30	1.25	0.195	1.25	1.25	0.28	1.30	1.10	0.27	1.10	1.10	0.170	1.10	1.10	0.24	1.10	1.10	0.32	1.15
50	0.93	0.95	0.30	1.00	0.93	0.190	0.95	0.93	0.28	0.97	0.81	0.26	0.85	0.80	0.165	0.82	0.80	0.24	0.84	0.80	0.32	0.86
70	0.63	0.65	0.29	0.72	0.63	0.185	0.66	0.63	0.27	0.69	0.56	0.25	0.61	0.55	0.160	0.57	0.55	0.24	0.60	0.55	0.31	0.63
95	0.46	0.49	0.28	0.56	0.47	0.180	0.50	0.47	0.27	0.54	0.42	0.24	0.48	0.41	0.155	0.43	0.41	0.23	0.47	0.40	0.31	0.51
120	0.36	0.39	0.27	0.47	0.37	0.175	0.41	0.37	0.26	0.45	0.33	0.23	0.41	0.32	0.150	0.36	0.32	0.23	0.40	0.32	0.30	0.44
150	0.29	0.31	0.27	0.41	0.30	0.175	0.34	0.29	0.26	0.39	0.27	0.23	0.36	0.26	0.150	0.30	0.26	0.23	0.34	0.26	0.30	0.40
185	0.23	0.25	0.27	0.37	0.24	0.170	0.29	0.24	0.26	0.35	0.22	0.23	0.32	0.21	0.145	0.26	0.21	0.22	0.31	0.21	0.30	0.36
240	0.180	0.195	0.26	0.33	0.185	0.165	0.25	0.185	0.25	0.31	0.17	0.23	0.29	0.160	0.145	0.22	0.160	0.22	0.27	0.160	0.29	0.34
300	0.145	0.160	0.26	0.31	0.150	0.165	0.22	0.150	0.25	0.29	0.14	0.23	0.27	0.130	0.140	0.190	0.130	0.22	0.25	0.130	0.29	0.32
400	0.105	0.130	0.26	0.29	0.120	0.160	0.20	0.115	0.25	0.27	0.12	0.22	0.25	0.105	0.140	0.175	0.105	0.21	0.24	0.100	0.29	0.31
500	0.086	0.110	0.26	0.28	0.098	0.155	0.185	0.093	0.24	0.26	0.10	0.22	0.25	0.086	0.135	0.160	0.086	0.21	0.23	0.081	0.29	0.30
630	0.068	0.094	0.25	0.27	0.081	0.155	0.175	0.076	0.24	0.25	0.08	0.22	0.24	0.072	0.135	0.150	0.072	0.21	0.22	0.066	0.28	0.29
800	0.053		-		0.068	0.150	0.165	0.061	0.24	0.25		-		0.060	0.130	0.145	0.060	0.21	0.22	0.053	0.28	0.29
1000	0.042		-		0.059	0.150	0.160	0.050	0.24	0.24		-		0.052	0.130	0.140	0.052	0.20	0.21	0.044	0.28	0.28

NOTE: * Spacings larger than those specified in Method 12 (see Table 4A1) will result in larger voltage drop.

APPENDIX C

TABLE 4D2A
Multicore 70 °C thermoplastic (pvc) insulated and thermosetting insulated cables, non-armoured
(COPPER CONDUCTORS)

Ambient temperature: 30 °C
Conductor operating temperature: 70 °C

CURRENT-CARRYING CAPACITY (amperes):

Conductor cross-sectional area	Reference Method 4 (enclosed in an insulated wall, etc.)		Reference Method 3 (enclosed in conduit on a wall or ceiling, or in trunking)		Reference Method 1 (clipped direct)		Reference Method 11 (on a perforated cable tray) or Reference Method 13 (free air)	
	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.
1	2	3	4	5	6	7	8	9
(mm^2)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1	11	10	13	11.5	15	13.5	17	14.5
1.5	14	13	16.5	15	19.5	17.5	22	18.5
2.5	18.5	17.5	23	20	27	24	30	25
4	25	23	30	27	36	32	40	34
6	32	29	38	34	46	41	51	43
10	43	39	52	46	63	57	70	60
16	57	52	69	62	85	76	94	80
25	75	68	90	80	112	96	119	101
35	92	83	111	99	138	119	148	126
50	110	99	133	118	168	144	180	153
70	139	125	168	149	213	184	232	196
95	167	150	201	179	258	223	282	238
120	192	172	232	206	299	259	328	276
150	219	196	258	225	344	299	379	319
185	248	223	294	255	392	341	434	364
240	291	261	344	297	461	403	514	430
300	334	298	394	339	530	464	593	497
400	-	-	470	402	634	557	715	597

APPENDIX D

TABLE 4D2B

VOLTAGE DROP (per ampere per metre): Conductor operating temperature: 70 °C

Conductor cross-sectional area 1	Two-core cable, d.c. 2	Two-core cable, single-phase a.c. 3			Three- or four-core cable, three-phase a.c. 4		
(mm²)	(mV/A/m)	(mV/A/m)			(mV/A/m)		
1	44	44			38		
1.5	29	29			25		
2.5	18	18			15		
4	11	11			9.5		
6	7.3	7.3			6.4		
10	4.4	4.4			3.8		
16	2.8	2.8			2.4		
		r	x	z	r	x	z
25	1.75	1.75	0.170	1.75	1.50	0.145	1.50
35	1.25	1.25	0.165	1.25	1.10	0.145	1.10
50	0.93	0.93	0.165	0.94	0.80	0.140	0.81
70	0.63	0.63	0.160	0.65	0.55	0.140	0.57
95	0.46	0.47	0.155	0.50	0.41	0.135	0.43
120	0.36	0.38	0.155	0.41	0.33	0.135	0.35
150	0.29	0.30	0.155	0.34	0.26	0.130	0.29
185	0.23	0.25	0.150	0.29	0.21	0.130	0.25
240	0.180	0.190	0.150	0.24	0.165	0.130	0.21
300	0.145	0.155	0.145	0.21	0.135	0.130	0.185
400	0.105	0.115	0.145	0.185	0.100	0.125	0.160