Engineering @ SP

SINGAPORE POLYTECHNIC SP

ET0050

ELECTRICAL INSTALLATION DESIGN

(Version 2.02)

School of Electrical & Electronic Engineering

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As a polytechnic for all ages
we prepare our learners to be
life ready, work ready, world ready
for the transformation of Singapore

The Singapore Polytechnic's Vision

Inspired Learner. Serve with Mastery. Caring Community.

A caring community of inspired learners committed to serve with mastery.

The SP CORE Values

- Self-discipline
- Personal Integrity
- Care & Concern
- Openness
- Responsibility
- Excellence

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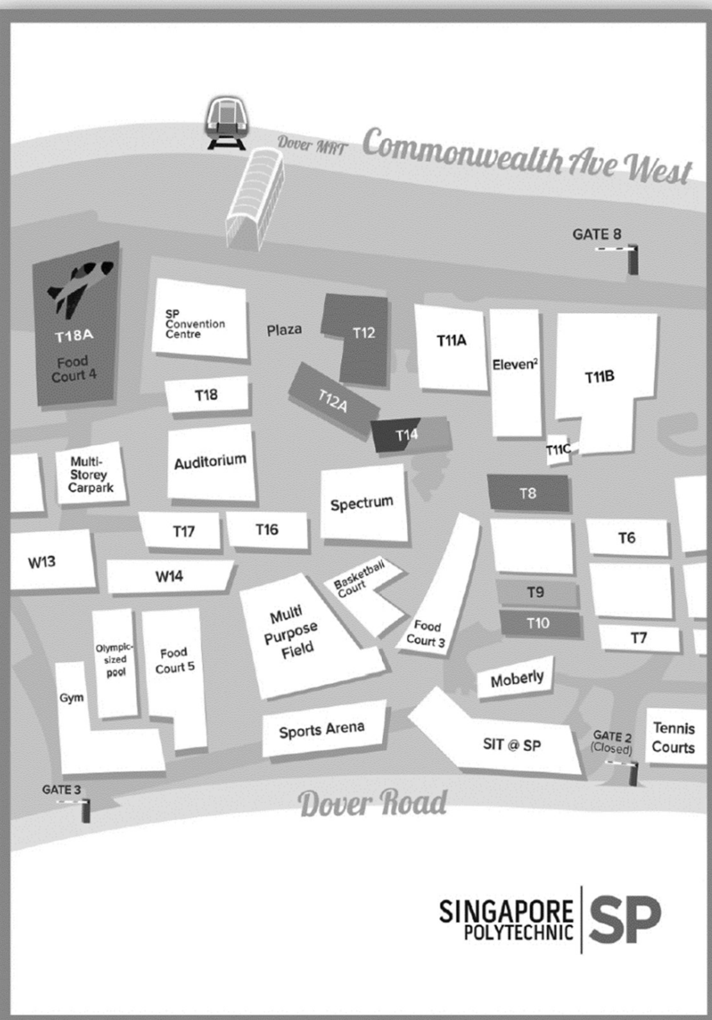
SINGAPORE POLYTECHNIC SP

SP | SCHOOL OF ELECTRICAL & ELECTRONIC ENGINEERING

Industry-Collaborated TECH HUB



T18A

T9 level 3 & T14 level 3

T14 level 3

T10 level 3

T8 level 2 & T12 level 1

T12/T12A level 2

T12 level 6

T8 level 2 & T12 level 1

Diploma in Aerospace Electronics

Aerospace Engineering Hub

Themed Project : Unmanned Aircraft Applications
Facilities : A320 Flight Simulator
Industries : Aerospace, Air Transport
Industry Partners : AIRBUS, Rolls-Royce
Industry Co-location Lab : ST Engineering Aerospace

Diploma in Computer Engineering

5G & AIoT Technology Hub

Themed Project : Smart Facility Management
Facilities : AIoT Nerve Centre, 5G Garage, SP Connected Solutions Lab
Industries : ICT & Media, Smart City
Industry Partners : ADVANTECH, CONTEC, D'CRYPT, ENVISION, HUAWEI, LINGJACK DIGITAL, unabiz
Industry Co-location Lab : BOSCH, ERICSSON, Singtel

Diploma in Engineering with Business

Technology to Business Hub

Themed Project : Technology To Business Venture
Facilities : IdeaBox, T2B Hub
Industries : Entrepreneurship & Start-up
Industry Co-location Lab : SPgroup, GEX VENTURES, APOL, BevEat, BitsGreat, OCTOPUS8, REAL IMPACT, SMARTDB, TOP TASTE, Vaster

Diploma in Electrical & Electronic Engineering

Robotics, Automation & Control Hub

Themed Project : Smart Workflow Solution for I4.0
Autonomous Mobile Robot/Robocup
Facilities : SP-SICK Smart Sensor Lab, SP-Rexroth I4.0 Innovation Lab
Industries : Logistics, Electronics (Manufacturing), Electronics & Chemicals (Manufacturing)
Industry Partners : ABB, BECKHOFF, SEW EURODRIVE, Weidmüller, ZEBRA
Industry Co-location Lab : rexroth A Bosch Company, SICK Sensor Intelligence.

Power & Sustainable Energy Hub

Themed Project : Net-zero Renewable Energy Vertical Farming
Facilities : High Voltage Training, LE & LET Training, Energy Efficiency Lab
Industries : Energy & Power
Industry Partners : CHNT, ebmpapst, sembcorp, SUNLIGHT A CHNT COMPANY

Semicon & Electronics Hub

Themed Project : Artificial Intelligence of Things using FPGA
Facilities : Nanofab & IC Design Labs, Infineon Innovation Lab
Industries : Semiconductor & Electronics
Industry Partners : SSIA
Industry Co-location Lab : ADVANTEST, Infineon

Biomedical Engineering Hub

Themed Project : Engaging Rehabilitation with Data Visualisation & Analytics
Facilities : Biomedical Engineering Lab
Industries : Healthcare
Industry Partners : GE Healthcare, GOLD LITE, Khoo Teck Puat Hospital, NATIONAL INSTRUMENTS

Autonomous & Transportation Systems Hub

Themed Project : 5G-enabled Autonomous Safety Vehicle
Autonomous Underwater Vehicle
Facilities : RSS Lab for RTT Training, Siemens Digital Experience Centre, SP-TIBCO Adv Mfg Analytics Lab
Industries : Smart Transport, Land Transport
Industry Partners : ST Engineering Land Systems, SMRT, SIIX, SUTD, GreenPower
Industry Co-location Lab : SIEMENS Ingenuity for life, TIBCO

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MODULE OVERVIEW

1 Introduction

Electrical Installation Design is a second year module for the Diploma in Electrical and Electronic Engineering Course. It will equip students with the practical knowledge and skills to design, operate and maintain an electrical installation. It provides the basic theoretical qualification for students aspiring to be a Licensed Electrical Technician in electrical installation.

Electrical Installation Design (2nd Year)

3rd Year — Electrical Power and Distribution

2 Module Aims

This module will cover the basic knowledge and practical skills in the application and safe use of electrical energy and services in domestic, commercial and industrial buildings. The main topics to be covered include an overview of the power generation, transmission and distribution system, electrical safety and protection principles, analysis and design electrical systems based on the relevant codes of practices, and the principles on the testing and troubleshooting of electrical installation circuits. New technology in electrical installation, such as the KNX system, will also be covered.

3 Teaching Plan

Refer to the Blackboard for the detailed teaching plan

4 Method of Assessment

Refer to the Blackboard for the detailed method of assessment.

5 Resource Material

5.1 Textbook

There is no standard textbook that adequately covers the subject. However, students are provided with standard common notes to assist them in their study. They are strongly encouraged to purchase books for their use and/or borrow them from SP's Library.

5.2 Resources/References

Refer to the Blackboard for the supplementary Resources/References.

Chapter 1

Power Supplies and Distribution

Objectives

On successful completion of this chapter, you will be able to :

- Know the generation, transmission and distribution of electricity in Singapore.
- Learn the L.T and H.T supply voltages provided by the Supply Authority.
- Understand the single-phase and three-phase theories.
- Interpret single-line diagram

Overview

Electricity plays a very prominent role in the economy of our country and it has improved greatly our standards of living. It can be easily generated, transmitted and distributed to any user who requires it.

In Singapore, Singapore Power Ltd is responsible for the transmission and distribution of electricity. The voltage of supply is maintained at 400 v ± 6% while the frequency is maintained at 50 Hz ± 1%.

When a coil rotates in a uniform magnetic field, an emf is generated in that coil. This voltage is constantly varying in both magnitude and direction. This waveform is called an a.c. sine wave. Single-phase a.c. voltage is produced by single-phase a.c. generator or it can be obtained from the three-phase 4-wire supply. A single-phase source has a live and a neutral conductor. A three-phase a.c. source is produced by a three-phase generator at the power plant and it can be connected in star or delta formation.

A block diagram uses standard symbols or blocks to show the functional relation between stages of an electrical system. Its main purposes are: (i) to show the functional relationship between the stages, and (ii) to aid in the design and understanding of the functional stages to be used in the system.

A schematic diagram uses graphical symbols to show the functional relationship between circuit components of the stages of an electrical system. It is not drawn to any particular scale. Its main purposes are: (i) to aid in the analysis and design of an electrical system, and (ii) to convey information concerning the components such as part numbers, electrical values and functional relationship.

Single-line diagram is a diagram that graphically defines the equipment/components by using symbols to show the relationship between them and their circuit connections in an electrical system. The single-line can be used to represent the Live, Neutral and Earth for a single-phase system or the Brown, Black and Grey line for a three-phase system.

Resources and References

To supplement the learning of this chapter, the following resources/references can be harnessed:

- Tutorial 1
- Singapore Standard, SS638:2018
- Handbook on Application for Electricity Supply by Singapore Power
- Electrical Installation & Regulations by Michael Neidle
- Electrical distribution Engineering by Anthony J Pansini

1 Power Supplies and Distribution

1.1 Introduction

The Electricity Department of the Public Utilities Board (PUB) was originally responsible for the generation, transmission and distribution of electricity in the Republic of Singapore. In Oct 1995, the government corporatised the electricity and piped gas undertaking of PUB to facilitate competition in electricity generation and retails. The above tasks are now the responsibility of Singapore Power Ltd and the PUB undertakes the role of regulating the electricity and piped gas industries.

SP Services Ltd and PowerGrid Ltd are the two subsidiaries of Singapore Power Ltd. SP Services is the supplier of electricity and it receives request for electricity supply, offers terms and conditions of supply, arranges for supply connections and bills customers for consumption. PowerGrid develops, operates and maintains transmission and distribution facilities.

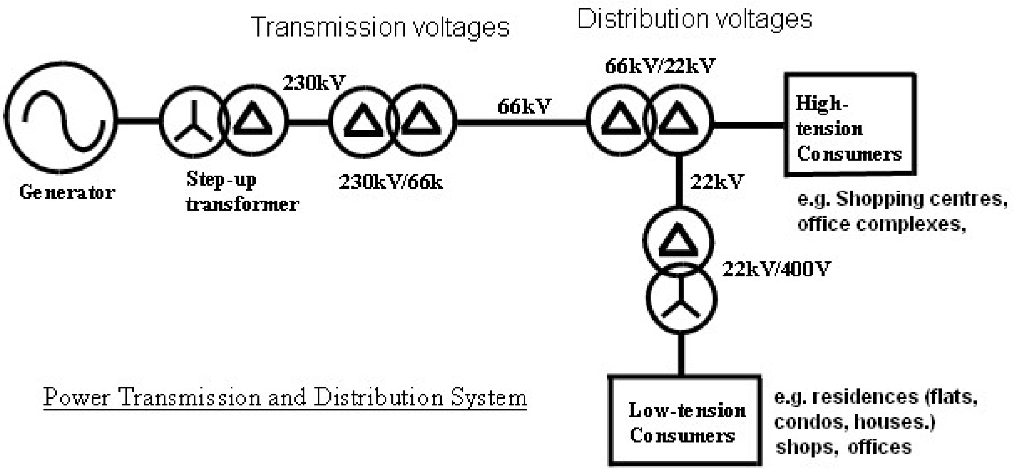
In April 2001, the Government restructured PUB into a comprehensive water authority and established a new statutory board called Energy Market Authority (EMA) of Singapore. EMA is responsible for regulating the electricity and gas industries and its Regulation Division is primarily responsible for: (i) ensuring consumer safety and compliance with prescribed codes and standards (ii) licensing of competent persons to carry out electrical and cable detection work (iii) ensuring security and reliability of supply through setting and regulating performance standards. Its subsidiary company Energy Market Company Ltd operates the wholesale electricity market. For further details, please access Blackboard>External Links>Power Supply>Energy Market Authority for Overview of Electricity Industry or EMA website at http://www.ema.gov.sg

Depending on customer's load requirements, electricity supply will be provided as follows:

(1) 230V, 50 Hz, single phase, 2-wire, up to 23 kVA, 100A
(2) 400V, 50 Hz, 3 phase, 4-wire, up to max 5000kVA (400V/230V)
(3) 22,000V, 50 Hz, 3 phase, 3-wire, 2000kVA up to 30,000 kVA
(4) 66,000V, 50 Hz, 3 phase, 3-wire, greater than 30,000 kVA

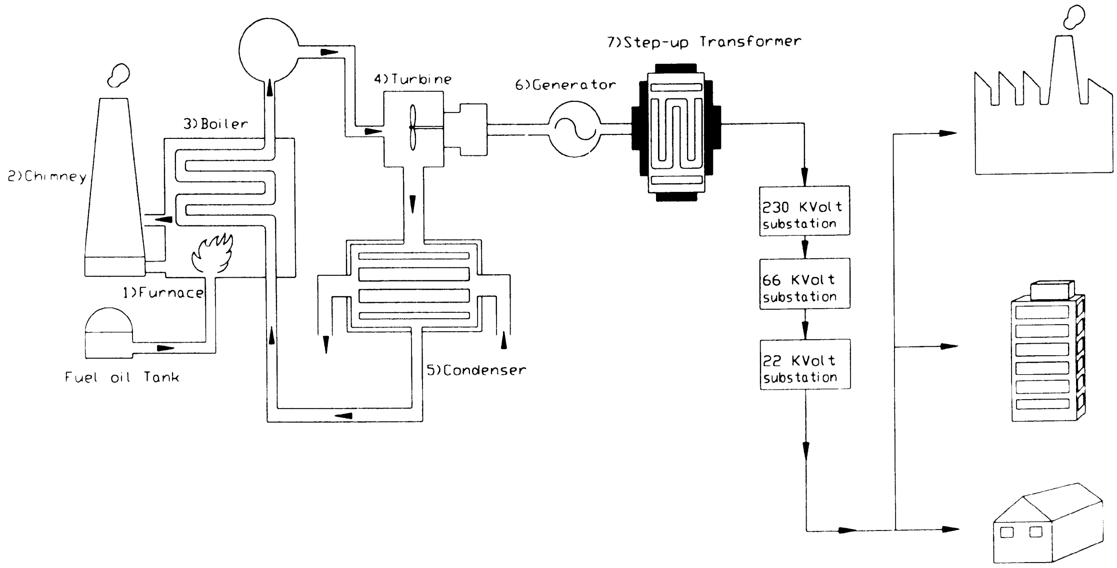
The *voltage* of supply is maintained within +/- *6%* and the *frequency*, within +/- *1%*.

Figure below is a schematic showing how power is transmitted and distributed to the high-tension and low-tension consumers in Singapore.



Power Transmission and Distribution System

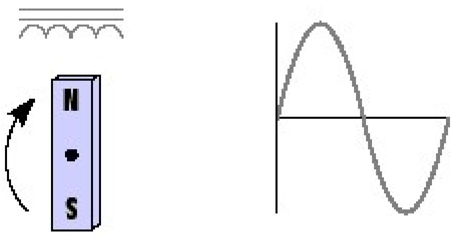
How electricity is brought to you



1) Furnace Fuel oil pumped into the furnace where it is burned. Air is also fed into the furnace to help the oil burn at a very high temperature.	2) Chimney After the dust is removed by the electrostatic precipitator, waste gas from the furnace is dispersed through the chimney.	3) Boiler Heat produced by burning oil in the furnace boils the water in the boiler turning it into steam.	4) Turbine Steam from the boiler is used to rotate the shaft in the turbine.
5) Condenser In the condenser, steam from the turbine passes between numerous tubes containing cold sea water and condenses into water. The water is returned to the boiler.	6) Generator This is where electricity is generated.	7) Step-up Here electricity that is generated is raised to a high voltage so that it can be economically transmitted to a wide area through sub-station.	8) Substation Transformer with high and low voltage winding step down the voltage of electricity to a level suitable for use.

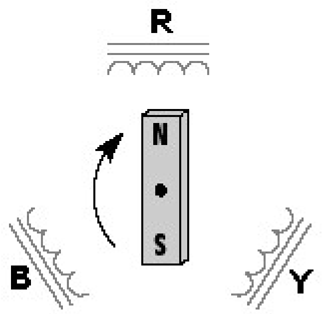
1.3 Three-phase AC Voltage

A single-phase alternating voltage can be produced by rotating a magnetic field through the conductors of a stationary coil, as shown in the figure below:



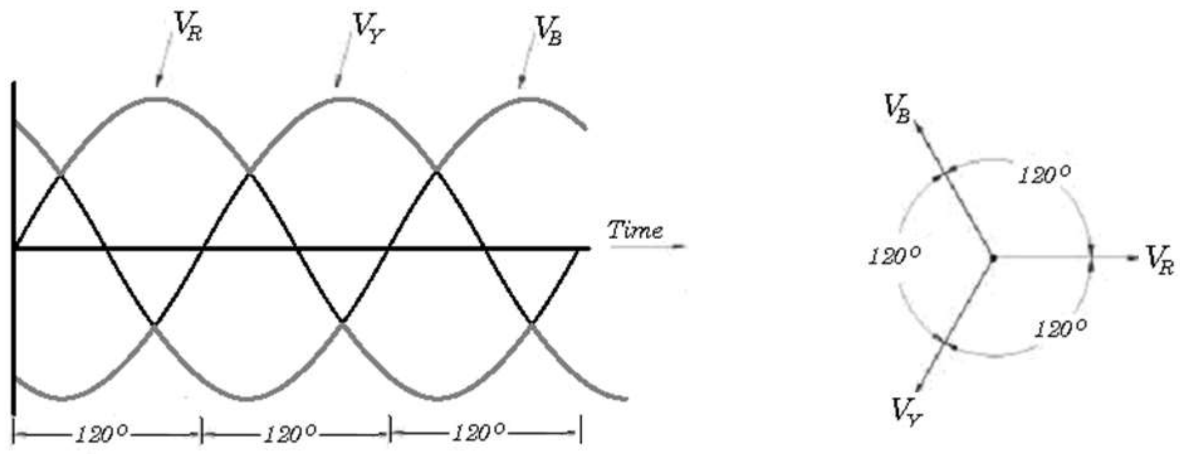
***Production of single-phase voltage*.**

Since alternate polarities of the magnetic field cut through the conductors of the stationary coil, the induced voltage will change polarity at the same speed as the rotation of the magnetic field. The alternator just described is a single-phase alternator because it produces only one AC voltage.



***Production of three-phase voltages*.**

If three separate coils are spaced 120° apart, three voltages 120° out of phase with each other will be produced when the magnetic field cuts through the coils. This is the manner in which a three-phase voltage is produced.

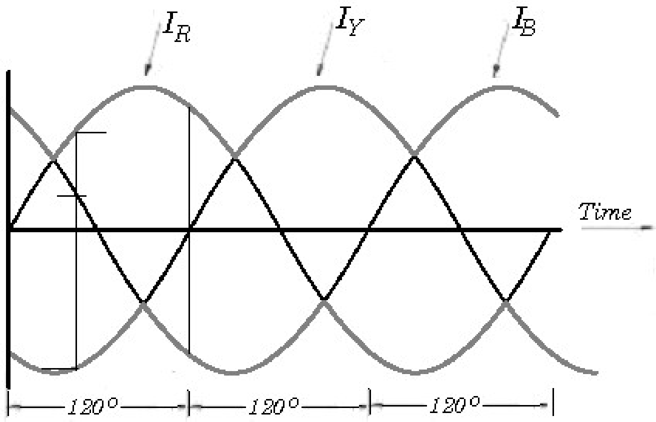


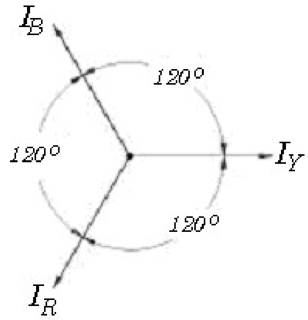
This is the method adopted for the commercial generation of A.C. voltages.

The phase difference of 120° is not between voltage and current but between any two of the three windings.

In this part of the course, we will only be looking at balanced three-phase supply. At unity power factor, the current waveform will be similar to the voltage waveform, i.e. the sine waves will start and finish at the same period of time. One interesting point is that the three current as can be seen from the current waveform, will sum to zero.

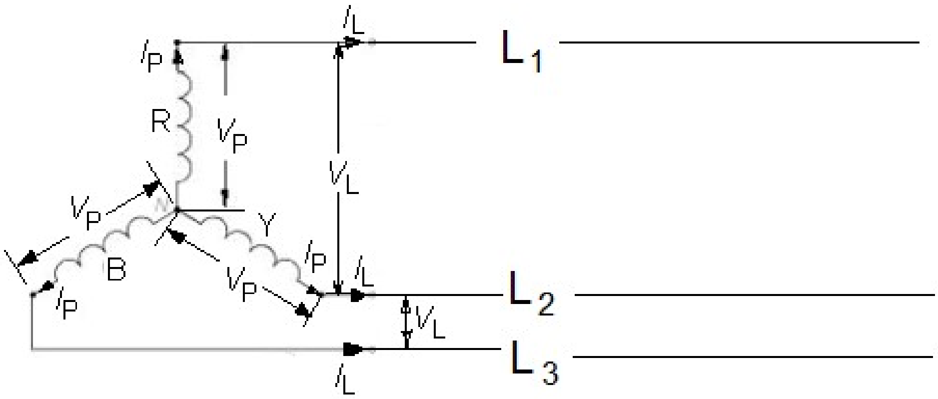
i.e. $\sin\Phi + \sin(\Phi - 120^o) + \sin(\Phi - 240^o) = 0$





At every point in time the vector sum of the three current is zero.

For a typical 400V/230V three-phase supply, the three windings are interconnected to form a star connection.



Star Connection

From the star connection diagram, it can be seen that the phase current, I_p, is equal to the line current, I_L.

To obtain the line voltage, V_L, in terms of the phase voltage, the two phase voltages V_P that are 120° out of phase had to be added up vectorially.

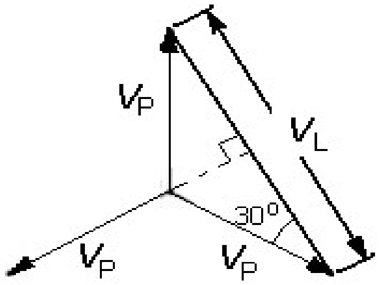
From the geometry of the phasor diagram,

$\cos 30° = ½\, V_L / V_P$

Therefore $V_L = 2 \times (\cos 30°) \times V_P$

and $\cos 30° = (\sqrt{3})/2$

$V_L = \sqrt{3} \times V_p$



Phase and Line voltage

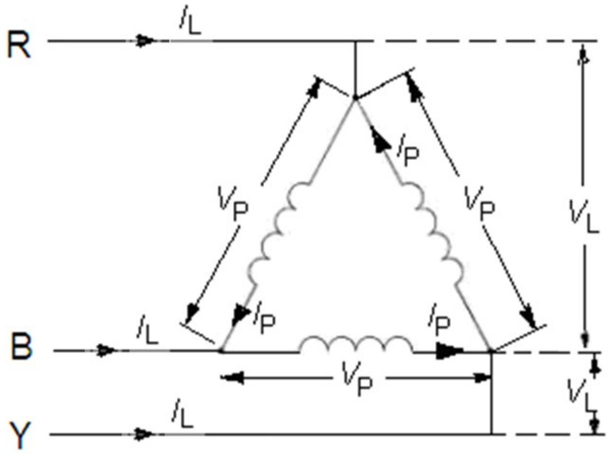
Hence for star-connection, the line voltage is equal to 1.732 times the phase voltage.

Three-phase power = three times the power in each phase winding

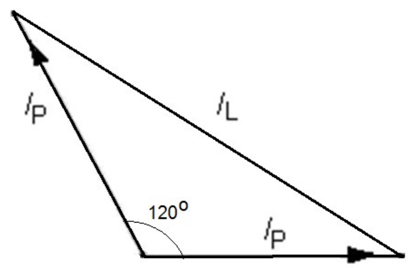
$= 3 \times V_P \times I_P \times \cos \Phi = \sqrt{3}\sqrt{3} \times V_P \times I_P \times \cos \Phi$

$= \sqrt{3} \times V_L \times I_L \times \cos \Phi = \sqrt{3} V_L I_L \cos \Phi$

By similar reasoning to the above, for delta connection,



Delta connection



$V_L = V_P$

$I_L = \sqrt{3}\, I_P$

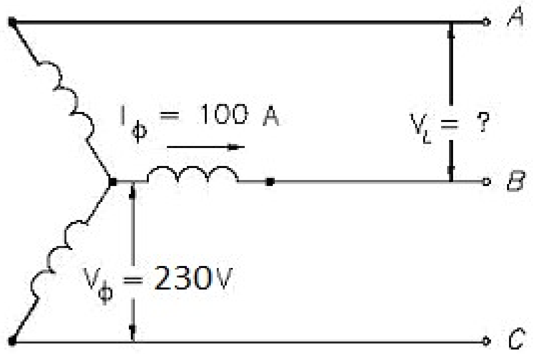
$P = \sqrt{3}\, V_L I_L \cos Ø$

Note: power factor = cosØ e.g. power factor is 0.85, cosØ = 0.85 not cos0.85

Three-phase power, whether star or delta connected, is obtained by identical equation.

Note : All voltages, currents unless otherwise stated are rms.

E.g.1 Each phase of a star connected 3-phase AC generator supplies a 100A current at a phase voltage of 230V and a power factor of 0.9 lagging, as shown below:



Find: Line voltage, V_L and total power, PT

Solution:

$V_L = \sqrt{3}$ Vp
= (1.732)(230) = 398.4 volts

$P_T = \sqrt{3}\ V_L\ I_L \cos Ø$
= (1.732)(398.4)(100)(0.9) = 62.1 kW

We had discuss that when the loads are balanced, the vector sum of the three phase currents is zero, therefore the neutral wire carries no current under balanced load. Under slightly unbalanced load, the neutral wire will carry a small amount of the resultant current. **Hence, for a three-phase supply which is essentially balanced, a single neutral wire will be needed hence resulting in savings of 1/3 of wiring cost**, where three single-phase supply are used.

Three-phase equipment (motors, transformers, etc.) weighs less than single-phase equipment of the same power rating. They have a wide range of voltages and can be used for single-phase loads. **Three-phase equipment is smaller in size, weighs less, and is more efficient than single-phase equipment.**

E.g. 2 A three-phase induction motor is connected to a three phase, 400V ac supply. When the motor is running on full load the current in each line is 12A and the power factor is 0.8 lagging, determine the power consumed by the motor on full load.

P = $\sqrt{3}\ V_L\ I_L \cos Ø$
= $\sqrt{3}$ x 400 x 12 x 0.8 = 6,651W or 6.65 kW

A three-phase supply may be provided using either a three-wire or a four-wire system. A three-wire system is one in which only the three line conductors are used. In Singapore, only high voltages (6.6 kV and 22 kV) and extra high voltage (66 kV) are supplied by three-wire system.

E.g. 3 A 3-phase star-connected motor is rated 400V, 50Hz, output power 25kW, pf 0.88, and efficiency 80%. Determine the line current drawn by the motor and also the impedance of one winding of the motor. Hence determine the line current when the windings are reconnected in delta.

Using $P = \sqrt{3}V_L I_L \cos\phi$

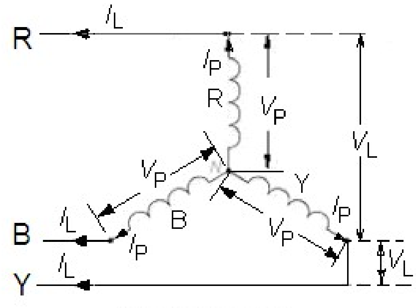
Line current I_L = 25000/(1.732x400x0.8x0.88)

= 51.26A

Phase current = I_L (star connected)

Impedance of one winding Z = V/I = 231/51.26

= 4.51ohms

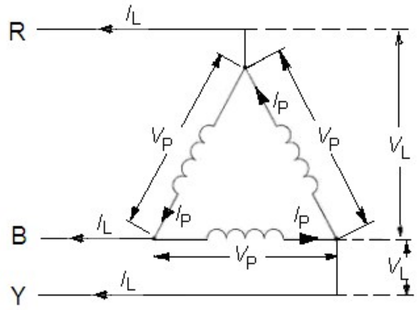


Reconnected in Δ, cannot use $P = \sqrt{3}V_L I_L \cos\phi$ as 25kW is rated for star connection.

How?

Use basic ohm's law $I_P = V_P/Z$ = 400/4.51 = 88.7A

$I_L = \sqrt{3}I_P = \sqrt{3} \times 88.7$ = <u>153.6A</u>



Low voltage at 400V is supplied using the four-wire system. In the four-wire system is one in which the three line conductors and an extra conductor connected to the star point of the supply is used. This additional conductor is usually earthed at the supply end and is known as the neutral conductor. It can be seen that single-phase loads can be connected between any line conductor and the neutral conductor, while three phase loads can be connected to the three line conductors.

Most electrical appliances (e.g. refrigerators, kettle, television, VCR, iron, fluorescent lighting) used in Singapore operate on 220V to 240V single phase ac (RMS).

E.g. 4 An electric fan rated 75W at 220V single phase ac with power factor of 0.8. What is the operating current? What will be the current if the supply voltage is increased to 260V?

$P = V I \cos\varnothing$ (notice no √3 in front of the formula)

$I_L = P/(V \cos\varnothing)$ = 75/(220 x 0.8) = 0.426A.

We cannot apply the same formula using V_L = 260V because the fan is not rated 75W at 260V. However the impedance of the fan and the power factor remains unchanged, hence by finding impedance Z, we can then find the operating current.

Z =V/I = 220/0.426 = 516.4 ohms

Hence when V=260V, I = V/Z = 260/516.4 = 0.503A

This 0.503A is about 20% more than the rated current of 0.426A This would cause overheating of the copper winding resulting in insulation failure after prolong use.

Generally all electrical appliances are designed to operate within ± 10% of rated voltage but not ± 20%.

E.g. 5 A 5 kW single phase motor operating on full load has an efficiency of 82% and power factor of 0.8 lagging. The supply voltage is 230V 50 Hz. What is current taken by the motor?

Efficiency = Output power/Input power

5kW for motor is always the output power.

Therefore input power P = Output Power/ Efficiency = 5000/0.82 = 6097W

Using $P = V\ I\ \cos Ø$

$I = P/(V \cos Ø) = 6097/(230 \times 0.8) = 33.14A$

In most offices and in some residential (home) places, three phase supply at 400V is used. This is mainly used to power three phase motors which are more efficient than single phase motors. All other loads such as computers, lightings, refrigerators, kettles, water heaters, etc are connected to the single phase 230V (which is part of the 400V three phase supply).

E.g. 6 The following loads are connected between line and neutral in a 400V three-phase, 4-wire system. Red phase to neutral 8 kW at unity power factor, yellow phase to neutral 5 kW at unity power factor, blue phase to neutral 5 kW at unity factor. Find the neutral current.

Phase voltage = 400/√3 = 231V.

Red phase current = (Load in kW)/(Vp *power factor) = 8000/(231*1) = 34.63A

Yellow phase current = 5000/231 = 21.65A

Blue phase current = 5000/231 = 21.65A

As these currents are of different phase angles, they have to be added up vectorially.

i.e. $I_N = I_r + I_y + I_b = 34.63\angle 0^o + 21.65\angle 120^o + 21.65\angle 240^o$

$= 12.98\angle 0^o + 21.65\angle 0^o + 21.65\angle 120^o + 21.65\angle 240^o$

$= 12.98\angle 0^o$. $(21.65\angle 0^o + 21.65\angle 120^o + 21.65\angle 240^o=0)$

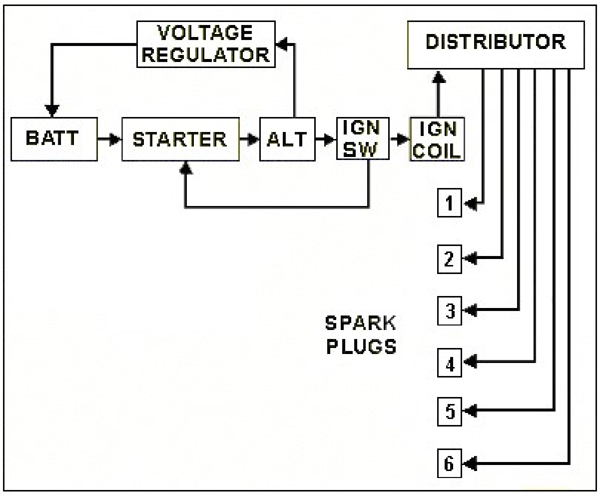
1.4 Electrical Drawings and Single-line Diagram

There are three types of electrical drawings:

i) block diagram
ii) schematic diagram and
iii) single-line diagram

1.4.1 Block Diagram

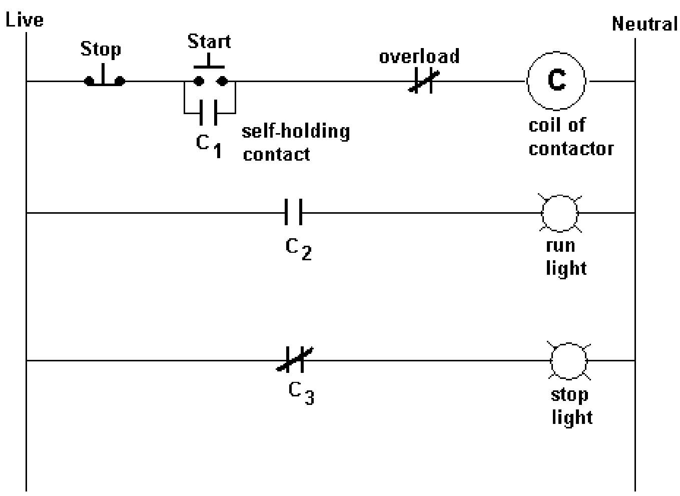
A block diagram is used primarily to present a general description of a system and its functions. This type of diagram is generally used in conjunction with text material. A block diagram shows the major components of a system and the interconnections of these components. All components are shown in block form, and each block is labeled for identification purposes.



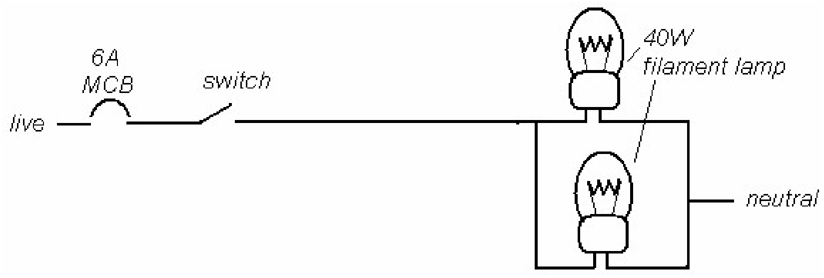
Example of block diagram of car electrical supply

1.4.2 Schematic Diagram

The schematic diagram shows, by means of graphic symbols, the electrical connections and functions of a specific circuit arrangement. The schematic diagram is used to trace the circuit and its functions without regard to the actual physical size, shape, or location of the component devices or parts. The schematic diagram is the most useful of all the diagrams in knowing the overall system operation.



Example of motor DOL schematic diagram



Example of schematic diagram of lighting circuit

1.4.3 Single-line Diagram

It is relatively easy and simple to design and draw a schematic diagram of a lighting circuit or the schematic diagram of a motor starting circuit.

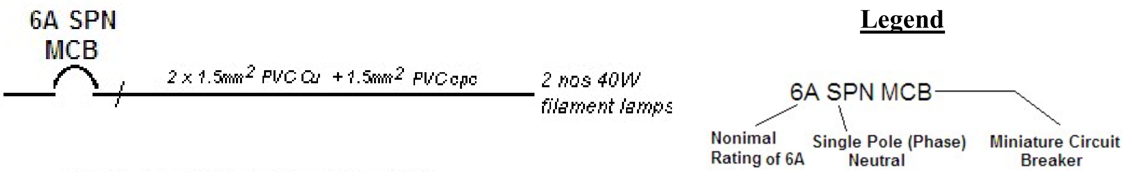
However, if all the electrical connections in a building were to be represented by schematic diagrams, there would not be enough space in the drawing plan.

A way, therefore, has to be found to show how the electrical system in an electrical installation is connected. The diagram should show the electrical connection from the main supply cable to all of the installation distribution panels and electrical loads. A single-line diagram is used.

*A **single*** **or** ***one-line diagram*** of a distribution system is a simple and easy-to-read diagram showing power supplies, loads, and major components in the distribution system.

A single-line diagram uses symbols rather than label blocks to represent components and shows all components in a single line.

There are standard symbols in the Singapore Standards CP83 Part2: 2020, which are closely followed for electrical single-line diagrams in Singapore. However not all components are represented in the CP83. It is therefore acceptable to see components represented in symbols, which can be interpreted from the legend of the drawing. Descriptions in words are usually added along the line or components to give an accurate description of the item.

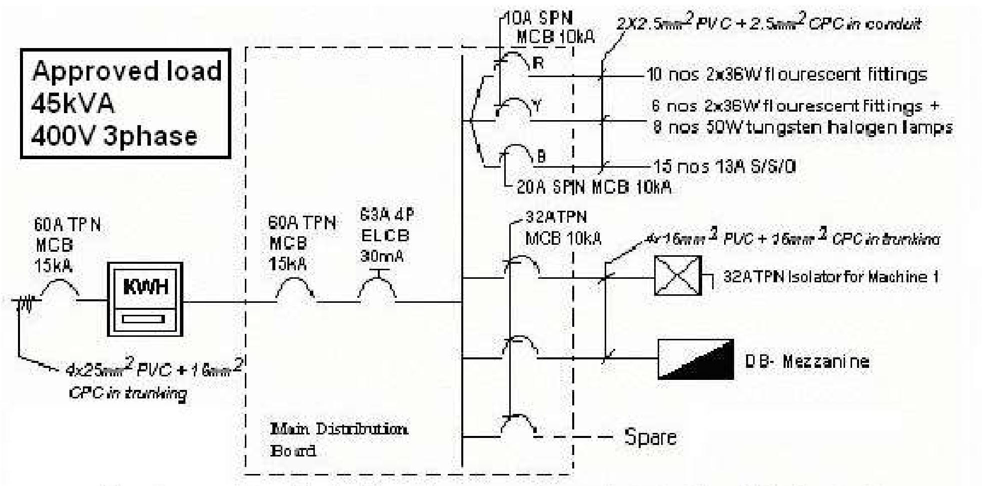


Single-line diagram of lighting circuit

In the above example of the single-line diagram of the lighting circuit, the load connected is described in words (*2 nos 40W filament lamps*). The solid line after the symbol of the 6A SPN MCB is used to represent the live, neutral and cpc cable. To avoid ambiguity, the cable sizes are described in words alongside the line. Notice the difference between the single line diagram and the schematic diagram for the same lighting circuit. In the schematic diagram the functional connections are shown, whereas the single-line diagram shows the type of equipment that is being connected, no functional connection!

A good single-line diagram will show:

- the mains (supply) cable size and the method of installation,
- the main distribution board and type of protective devices used
- and the sub-circuits connecting sub-distribution boards
- or final circuits connecting electrical loads and equipment.

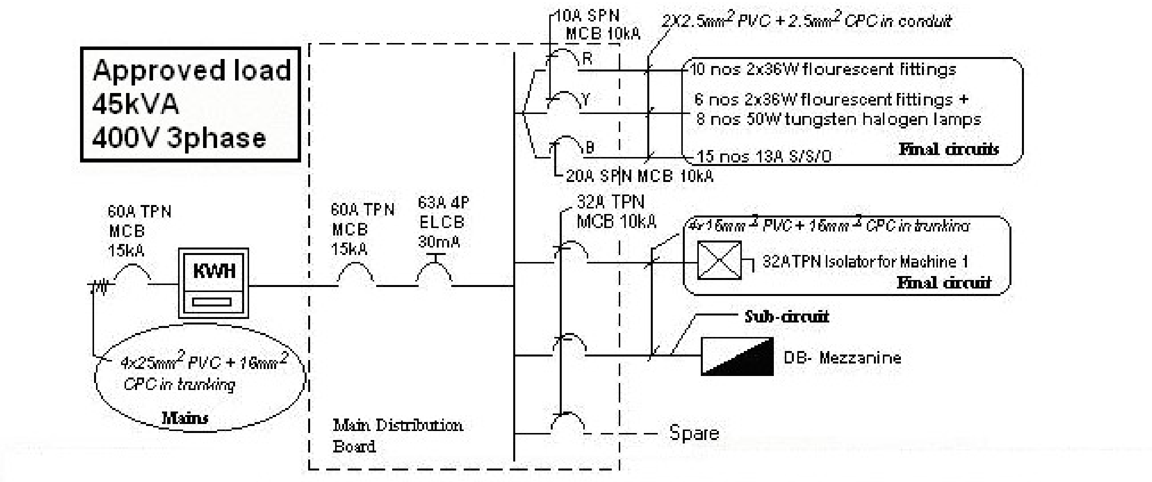


Example of complete single-line diagram of an electrical installation taking supply at 400V

Explanation of terms	**_10A SPN MCB 10kA_** – 10Amperes Single Pole and Neutral Miniature Circuit Breaker with short circuit breaking capacity of up to 10 kiloAmperes
kVA – kiloVolt Ampere ***60A TPN MCB 15kA*** – 60Amperes Triple Pole and Neutral Miniature Circuit Breaker with short circuit breaking rating of up to 15 kiloAmperes ***KWH*** – KiloWatt Hour meter ***63A 4P ELCB 30mA*** – 63 Amperes 4 Poles Earth Leakage Circuit Breaker with 30mA tripping current	***4x25mm² PVC + 16mm² CPC in trunking*** – 4 numbers of 25mm² PVC insulated copper cable + 16mm² Circuit Protective Conductor installed in trunking

In order to better identify circuits branching off from the main distribution board and the supply cable, different names are used for the different cables. The supply cable is called the mains. The circuits branching off the main distribution board are call sub-mains or sub-circuits. However circuits for feeding any equipment (such as machine or, motor), lighting or switched socket outlets or isolators are called final circuits. It is quite common to find final circuits and sub-circuits originating from the same distribution board.

In the above example, the mains, sub-circuit and final circuits are marked below for easy identification.



Example of complete single-line diagram of an electrical installation taking supply at 400V

Explanation of terms	***Submains*** – the submains are outgoing cables from the Distribution Board providing supply to another distribution board.
<u>Mains</u> – the Mains are the incoming cable providing supply (electricity) to the installation also called the incoming cable ***Main Distribution Board*** – where the incoming supply cable is connected, consist of busbars, circuit breakers, etc. This is where all other distribution boards in the installation are connected to.	***Final circuit*** – the final circuit is an outgoing cable from the Distribution Board providing supply to electrical equipment such as motor, lighting, switched socket outlets, etc

Chapter 2

Types of Protective Devices, Cables, Wiring Systems

Objectives

On successful completion of this chapter, you will be able to:

- Know the various types of fuses, circuit breakers, cables and wiring systems.
- Learn the types and characteristics of the cables.
- Know the various methods to install cables.
- Learn the SS638:2108 requirements on Cables, Conductors and Wiring Materials.
- Learn the characteristics and working principles of the protective devices such as fuses and miniature circuit breakers.

Overview

The range of types of cables used in electrical work is very wide: from heavy lead-sheathed and armoured paper-insulated cables to the domestic flexible cable use to connect a hair-drier to the electrical supply.

Commercial and industrial electrical installations are, nowadays, generally comprehensive and complex systems employing a variety of trunking and conduit types, cable trays, cable and accessories. A wiring system is an assembly of parts used in formation of one or more electric circuits. It consists of cables, wiring accessories, fittings, conduits, trunking etc. Before any electrical installation is begun, some careful thought must be given to the factors or conditions which decide the type of wiring system.

Resources and References

To supplement the learning of this chapter, the following resources/references can be harnessed:

- Tutorial 2/MCQ posted in Blackboard
- KNX.org Websites
- Singapore Standard, SS638:2018
- Electrical Installation & Regulations by Michael Neidle
- Advanced Electrical Installation Work by Trevor Linsley

Chapter 2

Types of Protective Device, Cable, Wiring Systems and KNX Technology

2.1 Protective Device

Some of the protective devices are:

a) Fuse
b) Miniature Circuit Breaker (MCB)
c) Moulded Case Circuit Breaker (MCCB)
d) Air Circuit Breaker (ACB)
e) Oil Circuit Breaker (OCB)
f) Vacuum Circuit Breaker (VCB)

2.1.1 Fuses

Fuses operate because the fuse element is the 'weak link' in the circuit, so that overcurrent will melt it and break the circuit. The time taken for the fuselink to break the circuit can be obtained from the time/current characteristic curve as given in Fig.3A1 to Fig.3A3 of Appendix 3 of SS638.

When the current is very much greater than the rated value (usually associated with a fault rather than with an overload), operation takes very little time. For small overloads, where the current is not much greater than the rated value, the operating time for the fuse is prolonged. This is often refers to as the adiabatic or Inverse time lag characteristic.

A graph with linear axes would be very large is both short time/high current and longtime/low current ends of the operating curve for the device were to be easily read. To overcome this problem, logarithmic scales are used.

Fuses are still used extensively in the utility's LV network for cable protection; as backup protection in the industrial installation for a circuit breaker that has inadequate breaking capacity, and for protection in various types of electrical appliances. The main advantage of the fuse is its ability to interrupt very large short-circuit currents safely within its breaking capacity and in a much shorter time than that of a circuit breaker. The other advantage is its lower capital cost as compared to a circuit breaker of a similar rating and breaking capacity. The disadvantages of using fuses are obviously that once a fuse has operated, it has to be replaced by the correct type; and that fuses generates heat, dissipates power and may also result in a voltage drop.

2.1.2 Fuse Terminology

Fuse: A device for breaking a circuit by means of a fuse element designed to melt when an over current flows for a sufficient time.

Fuse Base: Fixed part of a base provided with terminals for connection to the external circuit. The fuse base comprises all the parts necessary for insulation.

Fuse Base Contact: A conducting part of a fuse base connected to a terminal and designed to engage with a fuse carrier contact or fuse link contact.

Fuse Carrier: The moveable part a fuse designed to carry the fuse link.

Fuse Holder: The combination of fuse base with its fuse carrier.

Cartridge Fuse Link: A device comprising fuse element or several fuse elements connected in parallel enclosed in a cartridge usually filled with an arc extinguishing medium and connected to terminations.

Fuse Element: A part of a fuse designed to melt when the fuse operates.

Switch Fuse: A switch in which one or more poles have a fuse in series in a composite unit.

Fuse Switch: A switch in which a fuse link or a fuse carrier with the fuse link forms the moving contact of the switch.

Fuse Rating: Nominal rating of the fuse (the current which the fuse will carry continuously without overheating).

Fusing Current: Current causing operation of device.

Fusing factor: Fusing current/fuse rating.

Rupturing Capacity: The maximum fault current that the fuse can safely isolate in a circuit

2.2 Type of Fuses

There are general three types of fuses:

(1) Semi-enclosed (rewirable) fuses to BS 3036

(2) Cartridge fuses to IEC 60269-3 (Previously BS 1361 and BS 1362)

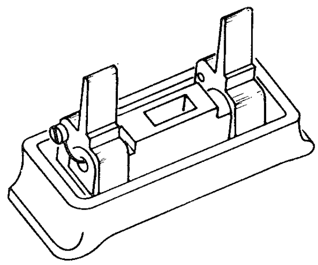
(3) High Breaking or Rupturing Capacity fuses to IEC 60269-2 (Previously BS 88)

2.2.1 Semi-enclosed or Rewirable Fuse

This type of fuse consists of a porcelain bridge and base (carrier).

The bridge has two sets of contacts, which fit into other contacts in the base. The fuse element (tinned copper wire) is connected between the terminals of the bridge. An asbestos tube or pad is fitted to reduce the effects of arching when the fuse-element melts.

The fusing factor of the semi-enclosed fuse is 2. This type of fuse in no longer in use in Singapore for new installations



Semi-enclosed Fuse BS 3036

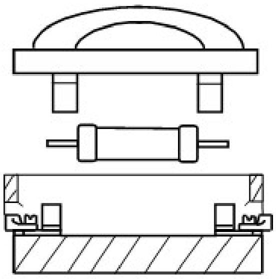
Advantages: relatively cheap and easy to replace the fuse element

Disadvantages

- any size of copper wire can be fitted, thus defeating the purpose of the fuse
- lack of discrimination. It is possible in certain installations for a 15 A fuse-element to melt before a 10 A fuse-element
- deterioration of the fuse-element due to oxidation

2.2.2 Cartridge Fuse IEC 60269-3 (B.S. 1361& 1362)

The cartridge fuse has the construction as shown. The fuse-element is contained in a porcelain tube fitted with two connecting caps. ***The fusing factor of a cartridge fuse is about 1.5.*** This means an overload of 50% will melt the fuse in less than one hour.



Components of a cartridge fuse

These low-voltage fuses cover a large range of fuses incorporating enclosed current-limiting fuse-links with rated breaking capacity of not less than 6 kA. They are used for protection of a.c. circuits of nominal voltages not exceeding 1000 V or d.c. circuits of nominal voltages, not exceeding 1500 V. BS 1361 [Ref. 6] with a breaking capacity of up to 33 kA, use in domestic and office buildings. BS 1362 [Ref.7] with a breaking capacity of 6 kA, use in plugs. (The 13A plugs used for electric kettle.) BS1361 and BS1362 are replaced by IEC 60269-3

Advantages

- the current rating is determined and fixed by the manufacturer
- the current rating is therefore accurately known as indicated on the tube
- the fuse-element are less liable to deteriorate
- the cartridge fuse is so designed that it is not interchangeable except within its own current rating group

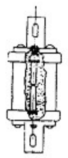
Disadvantages

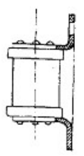
- the fuse element cannot be replaced once the fuse is operated
- it is unsuitable for use where extremely high values of fault current may occur.

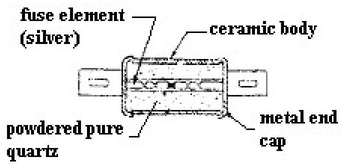
2.2.3 High Breaking Capacity Fuse (High Rupturing Capacity Fuse)(IEC 60269-2 and BS 88 part 2)

HBC fuses are used to protect large industrial loads and main cables. The cartridge barrel or outer cover is usually made of high-grade ceramic material able to withstand the shock conditions when a heavy fault current is interrupted.

HBC Fuse







Front View **Side view** **Cut away view**

Advantages

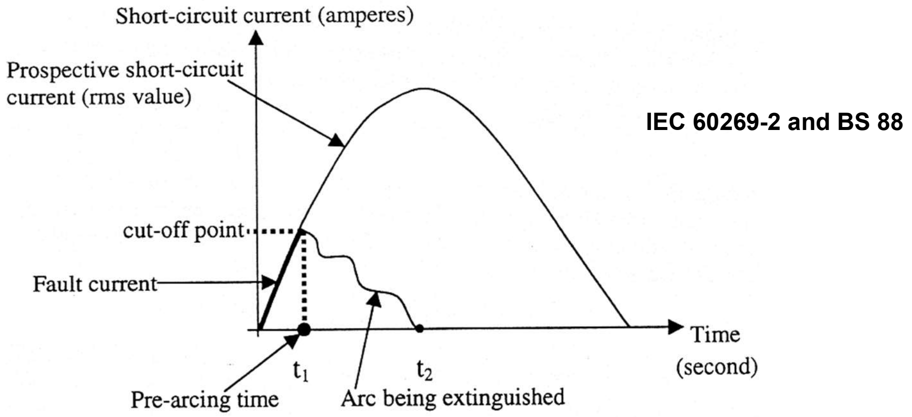
- the fusing characteristic is carefully controlled by the manufacturer
- it can safely interrupt very large fault currents
- it has good discrimination; it can distinguish between high transient current and sustained overload.

Disadvantages

- it is more expensive than the semi-enclosed fuse or the cartridge fuse mentioned above.

Cut-off Characteristic of HBC Fuse

The HBC fuses exhibit an interesting property known as cut-off. The short circuit current is interrupted before it reaches the peak of first prospective current cycle. If the melting of the fuse element prevents the current through the fuse link from reaching the otherwise attainable peak value, the fuse is said to have cut-off. The instantaneous maximum value attained is called cut-off current.

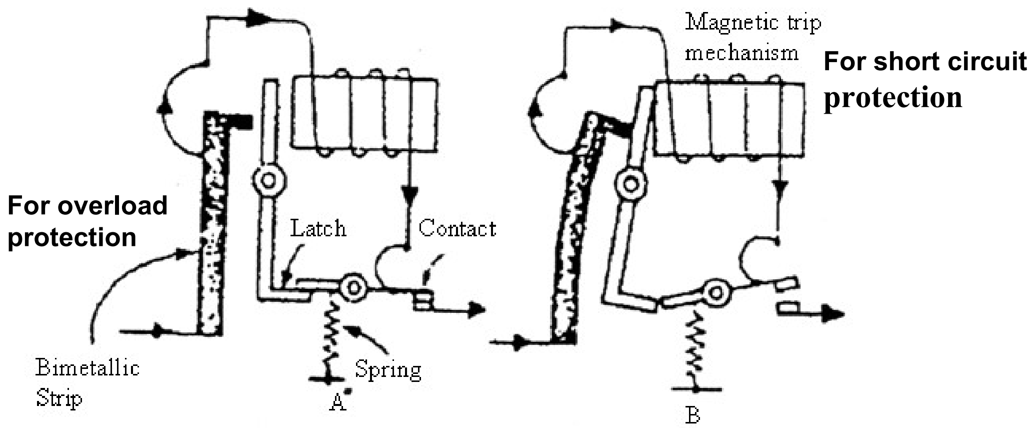


Cut-Off Curve

The figure shows the Cut-off action. On occurrence of short circuit, the current starts increasing. It would have reached a magnitude I_{peak}, if no fuse was there to protect. HBC fuse does not allowed current to reach I_{peak}. Instead when the link has broken and after a brief arching time the current is interrupted. This is because of the high resistance insulator formed by the chemical product of metal vapour and quartz that filled the arc. Cut-off property has a great advantage that the short circuit current does not reach the prospective peak. Hence the system is not subjected to electrodynamic stresses corresponding to peak prospective current.

2.2.4 Circuit Breaker

A circuit breaker is a mechanical device for making and breaking a circuit under every condition. The device breaks the circuit automatically when there is an overload or a short circuit. Air Circuit Breaker, Moulded Case Circuit Breaker and Miniature Circuit Breaker all uses air at atmosphere pressure for contact separation and arc extinction.



Thermal Magnetic Tripping mechanism

Thermal Mechanism
Thermal type air circuit breakers are used primarily for protection against overcurrent. The thermal strip provides a time delay for momentary overloads. A typical thermal circuit breaker schematic as shown operates on the principle of metal expansion when heated. The bimetallic strip heats in proportion to the line current. If the current becomes excessive for a prolonged period, the bimetallic strip bends. When the strip bends sufficiently, it trips the latch and opens the contacts as shown.

Magnetic Mechanism
The magnetic coil provides instantaneous trip on high or short circuit currents. The magnetic trip also protects the bimetallic strip from excessive overheating that can destroy it.

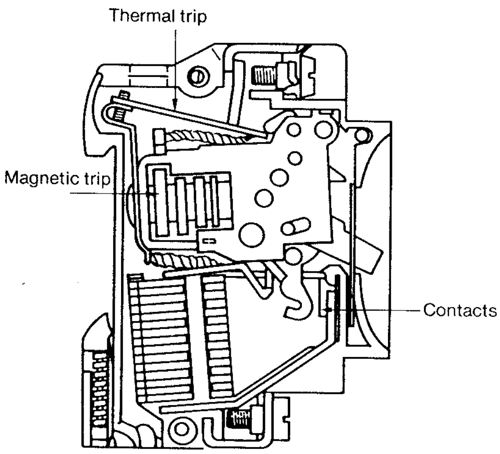
2.2.5 Miniature Circuit Breaker (MCB)

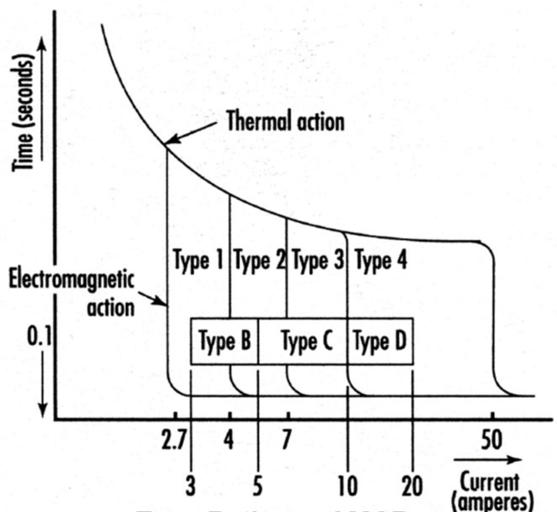
Fuses have served well for overload protection and also for short circuit protection in the case of HBC fuses.

However, the main problem after a fuse has tripped, the circuit is no longer ready for immediate service because the fuse has to be replaced and perhaps there is no spare fuse available. This led to various researches to see whether the technology for MCCBs can be used to produce a miniature version which can take over the function of fuses at low rating.

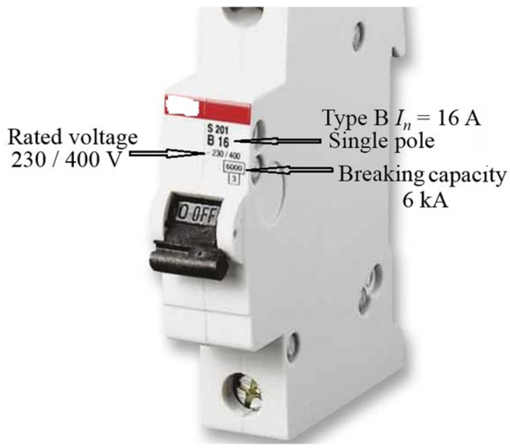
This has produced what is now called the miniature circuit breaker, which is being increasingly, used as an alternative to fuses as a means of protection for domestic, small industrial and commercial loads.

The only disadvantage is that the MCB must be tested regularly to ensure that it will function when required. This is because after a long period of use, it tends to become sluggish in operation and may fail to open when a fault occurs.





Type Ratings of MCBs



When selecting an MCB, there are 3 ratings that have to be considered:

a) Nominal Rating, I_n

b) Type Rating (Type B, Type C, Type D) (Type1, Type2, Type3, and Type4 withdrawn)

c) Short Circuit Rating (kA Rating) or breaking capacity

The ***nominal rating (In)*** is easily identified as the nearest available rating in amperes equal to, or more than, the design current.

The ***breaking capacity***, marked on the device (e.g. as 1 kA, ... , 16 kA) must be not less than the PSCC.

Type1, Type2 and Type3 to BS3871 had been withdrawn and replaced with B, C and D to **BS EN 60898-1 (SS 359 had been replaced with EN60898 however the graphs are still applicable.) MCBs certified to BS EN60898-1 are for residential uses whereas MCBs certified to both BS EN 60898-2 and BS EN 60947-2 are intended for commercial, industrial and infrastructural uses.**

BEAMA (British Electrotechnical and Allied Manufacturers Association) has in June 2015 published a 35 pages Guide to Low Voltage Circuit-Breakers Standards which can be downloaded from the internet.

The common current ratings of MCBs are:

- 5A, 6A, 10A,15A, 16A, 20A, 25A, 30A, 32A, 40A, 45A, 50A, 60A Operating time 1 hour

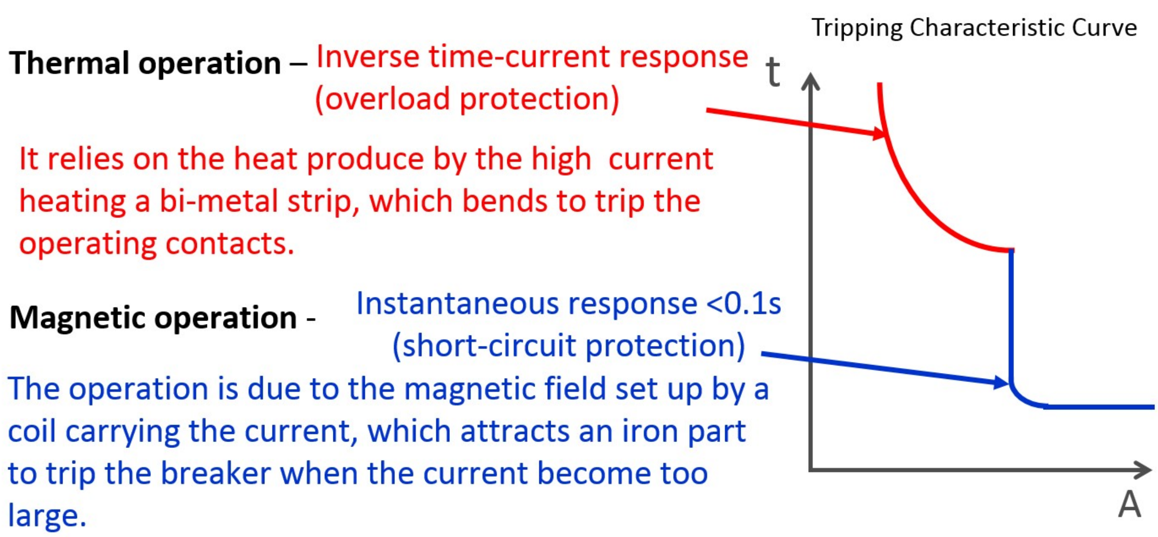
I_2 is current causing effective tripping of MCB rated I_n

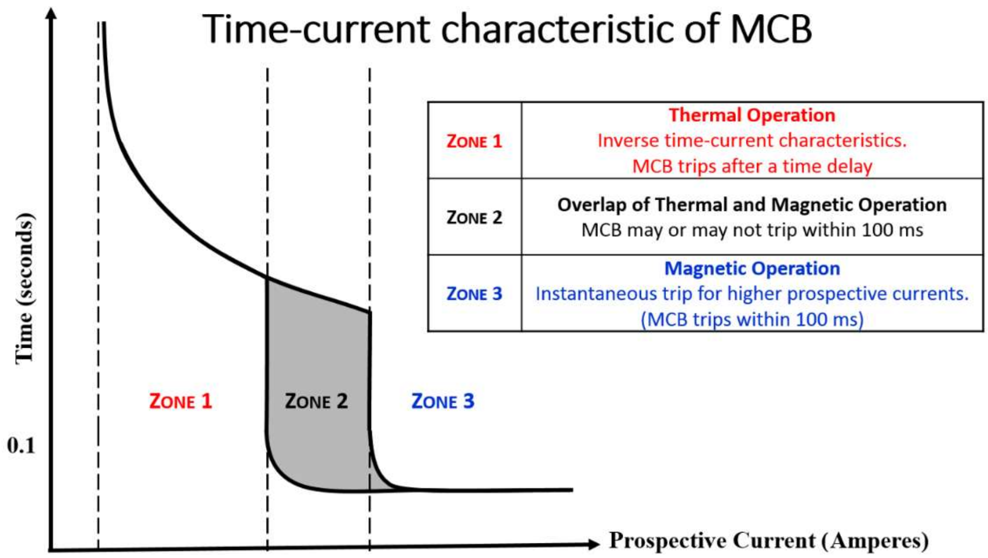
I_2 = Tripping factor x I_n for thermal tripping (bimetallic heating) of MCB

The short circuit ratings are commonly stated in 4 to 5 digits number e.g. 6000 denotes short circuit rating of 6000A. Example, in the PSL meter board, the provision at the supply point of the consumer installation is of a Type C, 6000 MCB, i.e. the MCB is of:

- Instantaneous tripping current > 5.0 I_N but < 10.0 I_n
- Short circuit rating = 6 kA (***ability to handle short circuit current of up to 6kA***)

Combined thermal magnetic action in MCB





Type B MCB

THERMAL TRIPPING:

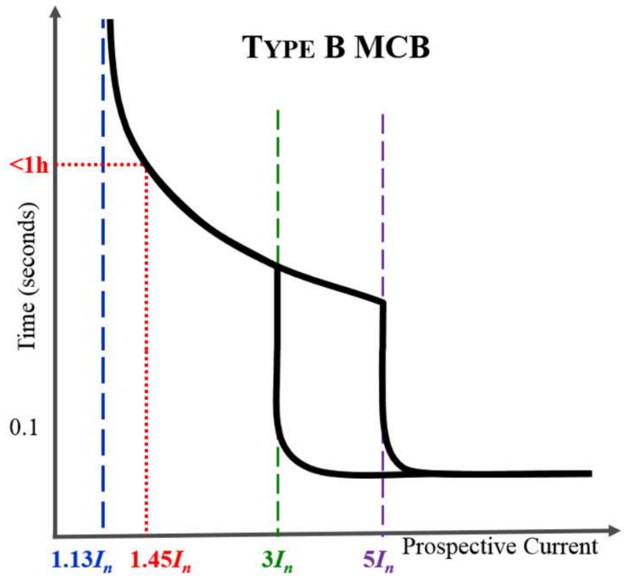
$1.13 \times I_n$: non trip >1h

$1.45 \times I_n$: Trip < 1h

MAGNETIC TRIPPING:

$I > 3 \times I_n$: Trip > 0.1s

$I > 5 \times I_n$: Trip < 0.1s



Type C MCB

THERMAL TRIPPING:

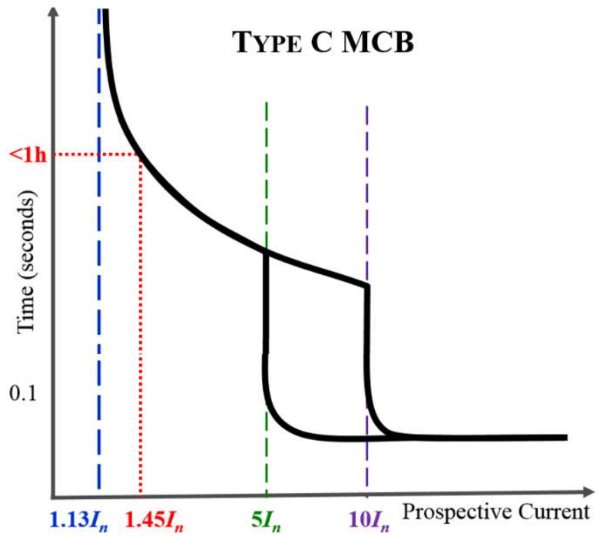
$1.13 \times I_n$: non trip >1h

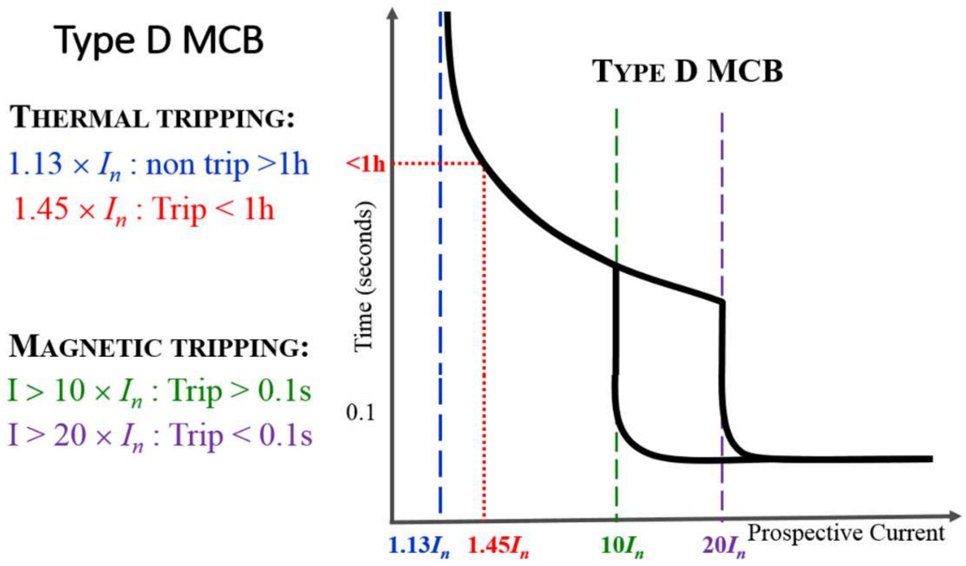
$1.45 \times I_n$: Trip < 1h

MAGNETIC TRIPPING:

$I > 5 \times I_n$: Trip > 0.1s

$I > 10 \times I_n$: Trip < 0.1s





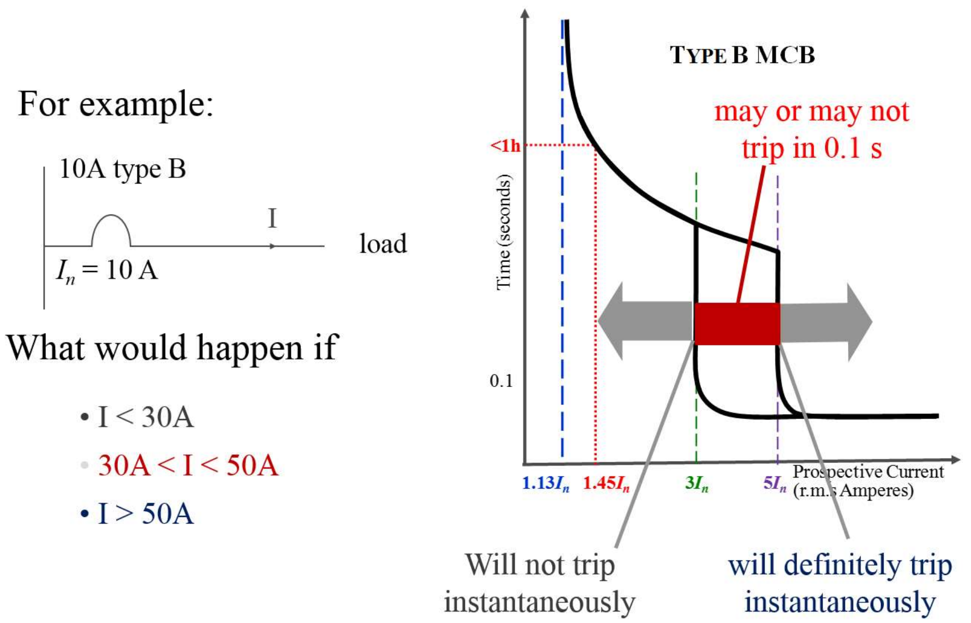


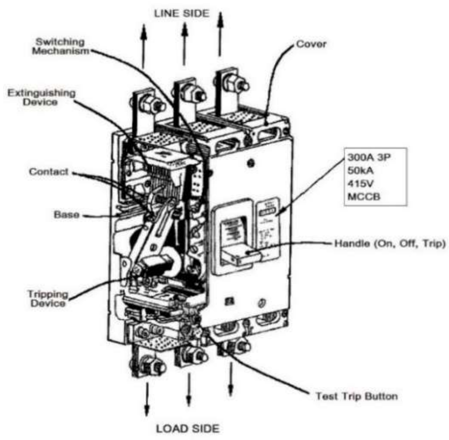
Table 9(4)

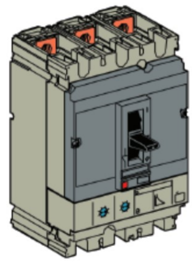
Classification of MCB to IEC 60898 according to the instantaneous tripping current

Type	Instantaneously Tripping Current
B	$3I_n \le I \le 5I_n$
C	$5I_n \le I \le 10I_n$
D	$10I_n \le I \le 20I_n$

2.2.6 Moulded Case Circuit Breaker (MCCB) and Air Circuit Breaker (ACB)

Switchgears located nearer to the source would require higher current rating and breaking capacity than those located further away from the source because of the circuit impedance. At low voltage, it is common to use the air circuit breaker (ACB) and the moulded case circuit breaker (MCCB) for power distribution.





MCCB

The MCCB is available in several frame sizes and interrupting capacities. Triple pole (three phase) breakers have a common trip bar to prevent single phasing and trip free mechanism to isolate automatically when closing on to a fault. Breakers are available with thermal and magnetic trips for protection against overloading and short circuits.
Air Circuit Breaker is a heavy-duty breaker meant for incoming of 1,600 amperes and above and also for very high rupturing capacity (36 kA).

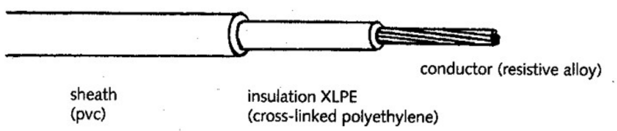
These type of circuit breakers will be covered in more details in ET0919 in the third year.

2.3 Cables

Cables are how electrical energy is distributed from its source to its point of use. Cable requirements are such that they can conduct electricity efficiency, cheaply and safely.

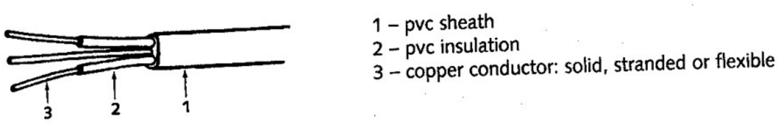
A cable can be defined as a length of insulated single conductor or of two or more such conductors each provided with its own insulation, which are laid up together. The insulated conductor or conductors may or may not be provided with overall covering for mechanical protection.

A single-core cable refers to a cable that has only one insulated conductor with its own cable sheath, and a **multi-core cable** refers to a cable that has multiple cores of insulated conductors within one common sheath.



(a) Single Core Cables

Non-armoured pvc-insulated cables



(b) Multi Core Cables

All types of electric cable consist essentially of a low resistance conductor to carry the current and insulation to isolate the conductors from each other and the surrounding. Cables also form an essential part of communications, security and control systems. Cables for these systems must be chosen to avoid interference from the power cable.

2.3.1 Cable Construction

The conductor of a cable refers to one conductor or several conductors which provides electrical paths. They are fabricated from metals having low resistivity. A conductor may be formed from solid material or made up from a number of strands of smaller wire. Conductors are made in several standard metric cross-sectional areas in the range from 1.5mm^2 to 1000 mm^2.

The two common types of conductor material are copper and aluminium. The specific resistance of copper and aluminium at 70^{0}C is 0.017 and 0.0283 respectively, both expressed in Ω per mm^2 per metre. In recent years, aluminium has become a major alternative to copper as a conductor material because of its attractive price. However, aluminium has a higher specific resistance than copper and is therefore, not a good conductor compared to the same size of the copper conductor. For the same current rating, a 300 mm^2 aluminium cable is approximately equivalent to a 185 mm^2 copper cable under the same conditions of installation.

Besides copper and aluminium, silver conductor is used in special application only such as in mainframe computer cables because of its low loss and good conductivity.

2.3.2 Properties of Copper conductor

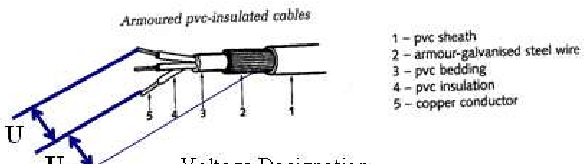
a) Resistant to corrosion in clean environment but ammonia and sulphur fumes have a drastic effect on metal.
b) Easily soldered or mechanically joined without any special precautions regarding electrolytic action. (i.e. it has lower coefficient of expansion.)
c) tensile strength is higher than aluminum conductor.
d) it is heavier than aluminum conductor and cost higher than aluminum.
e) International Electrotechnical Commission established an International Annealed Copper Standard (IACS) with copper of resistivity of 1.724 μohm cm at 20^{o}C assigned as 100%. Generally, for copper conductors the purity is of the order of 99.99%

2.3.3 Properties of Aluminium conductor

a) It is softer than copper and bends easily; it has therefore no restriction on wire size.
b) Conductivity of Aluminum is approximately 60% that of Copper.
c) Aluminum is 1/3 lighter than copper.
d) High coefficient of expansion compared to copper conductor.
e) When exposed to air, aluminum oxide is formed on the surface and is very difficult to remove, has proven difficulty to join. Special joints and termination are required for installation of aluminum cables.

2.3.4 Voltage Designation

The design voltages for cables are expressed in the form U_o/U. U_o is the power frequency voltage between conductor and earth and U is the power frequency voltage between conductors for which the cable is designed, U_o and U both being r.m.s values.



Voltage Designation

Although the local distribution voltage is 230/400 V, the cables are designed for 600/1000 V largely because during manufacture and installation, this grade of cable requires an insulation designed on mechanical rather than electrical parameters.

2.3.5 Stranding

To ensure flexibility and ease of handing, conductors are stranded: a number of small wires twisted together spirally forming a core equivalent to a single wire of the required size. The numbers of strands used are 1, 7, 19, 37, 61 and 127. The sizes of conductors range from 1.0mm^2 (1/1.13 mm) to 630 mm^2 (127/2.52 mm). The latter conductor, for example, consists of 127 strands of circular conductor, each strand of 2.52 mm diameter, with a total cross-sectional area of 630 mm^2.

2.4 Cable Insulation

The basic function of cable insulation is to withstand the electrical pressure or voltage, and thus confine the current to the conductor without any leakage. The insulation surrounds each conductor to prevent direct contact between individual conductors and earth. The type of insulation will depend on the voltage of the system, the operating temperature of the conductors, and the mechanical and environmental conditions affecting the cable during both installation and operation.
A conductor and its immediate insulation is commonly known as a core. A cable may comprise a single core with or without further mechanical protection or a number of cores laid up together and held in position by a sheath or tape binding.

Cable cores are generally identified by colour code: brown, black, grey for phase conductors, blue for neutral and green/yellow for circuit protective conductors.

2.4.1 Cable insulation material

There are 5 basic insulating materials namely

1) Paper
2) Thermosetting (XLPE) or Elastomer compounds
3) Thermoplastic compounds
4) Vanished cloth, laminated tapes
5) Mineral insulation

(1) Paper Insulation e.g. PILC

Used since the very early days but is losing its popularity to other types of cable insulation. The paper used is normally impregnated with oil because paper is hygroscopic if dry. It is also very vulnerable to water penetration through punctured jackets because of its hygroscopic nature.

(2) Elastomer compounds

This is usually a rubber like compound e.g. EPR-ethylene propylene rubber. An elastomer is a material which returns rapidly to approximately its initial shape after substantial deformation at room temperature by weak stress and release of that stress.

Thermosetting compounds are plastic material, which will not soften significantly on heating to temperatures below its decomposition temperature. Example is the XLPE. The trend now is towards the XLPE as it is non-hygroscopic even for high-tension cables. EPR and XLPE are suitable for **operating temperature as high as 90°C** and **short circuit temperature about 250°C.**

(3) Thermoplastic compounds

Thermoplastic compound are plastic material that unlike thermosetting material will soften by heating and hardened by cooling. Many thermoplastic materials can be converted into thermoset by cross-linking of the polymers, e.g. is the cross linking of polyethylene into the

XLPE. Although thermoplastic was invented in 1930s it was not until the 1950s that polyvinyl chloride (PVC) and polyethylene (PE) came into wide spread use for cables.

The disadvantage of PVC is that at temperature above its rated maximum, it melts easily and at too low a temperature it tends to crack. The normal grades of PVC are designed to **operate** from **0^0C to 70^0C**. The **short circuit temperature** is about **160^0C**. It can be used for insulation up to 3.3kV.

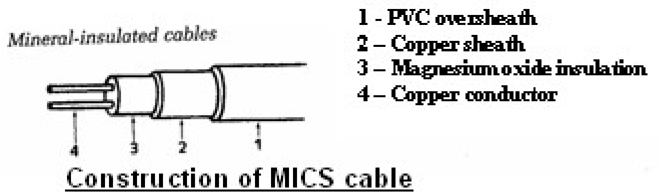
(4) Varnished cloth

This is a cotton or linen cloth impregnated and coated with a special varnish which produces a very smooth finish surface. The cloth is lapped onto the conductors in the form of a tape in the same way as paper insulated cables. These cables may also be sheathed with lead or aluminium.

(5) Mineral Insulation

This is a type of wiring system where copper conductors are embedded in highly compacted mineral insulation and the whole encased in a seamless metal sheath. Typically both the conductors and the sheath are made of copper and the insulation magnesium oxide and the cable is called **MICS** (Mineral Insulated Copper Sheath) cable. Because of the non-organic insulating material the MI cable has characteristic different from those of the other cables. The most notable is the non-aging properties and its performance at high temperatures. Copper MI cables can operate continuously at up to 250°C and for short periods of time at temperature up to **1083°C**. MI cables can also withstand severe mechanical abuse such as bending, twisting and impact without appreciable deterioration of its electrical properties.

This type of cable is not often used for domestic wiring because of its cost, but its many good properties can often be used to advantage in industrial installations, for example, in boiler houses and other hot situations where the heat- resisting properties are of particular value. MICS cables are suitable for use in situations where flammable or explosive dust, vapour or gas is likely to be present; a further advantage in garages is that the cable is resistant to the effects of oil and petrol. As the cables are small in diameter and can be readily bent to follow most contours, they can provide a very neat and unobtrusive installation, extra mechanical protection being needed only where exceptional risk of damage exists.



Construction of MICS cable

2.5 Cable Sheathing

Cable insulation losses its insulating property when it becomes damp, to prevent the ingress of moisture the insulator is invariably enclosed in a metallic sheath. Most common metals used for sheathing are lead or aluminum.

2.5.1 Lead Sheathed cables

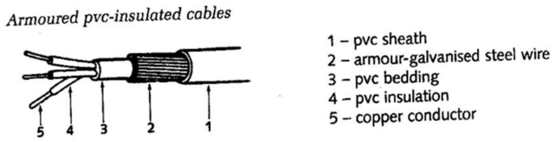
Lead or lead alloy is mostly used due to its flexibility and ease in extruding to fit over the cable cores. However because of its failure due to cracking and fatigue, its used has diminished significantly.

2.5.2 Aluminum Sheathed Cables

This material was very popular after the Second World War because of a shortage of lead. Unfortunately it was not appreciated that the apparently good corrosion resistance of aluminium in free air did not applied to buried conditions, the cable was discontinued until the 1970's where the established PVC is used as an over sheath to overcome the corrosion problem.
Aluminium being harder than lead, armouring was not considered necessary but the cable was less flexible than its lead sheath counterpart. To improve on flexibility, corrugated sheaths are developed and they are in fact replacing smooth sheaths. Cost wise aluminium sheath cables are significantly cheaper compared to the lead sheathed and armoured equivalents.

2.6 Mechanical Protection

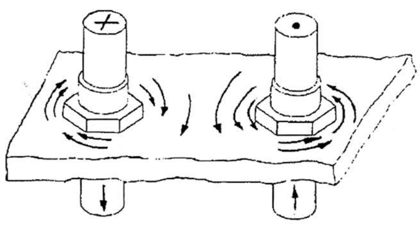
Armouring - the primary purpose of armouring the cable is to provide mechanical protection both during installation and in service. Two types of armouring used, steel tape and steel wire armoured. With steel tape armouring, bitumen coating is required to give corrosion protection, whereas in steel wire armouring the steel wire is galvanised for corrosion resistance.



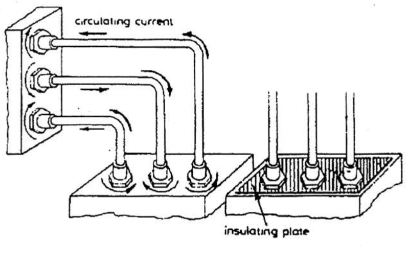
Armoured Cable

2.7 Cables of AC circuits - electromagnetic effects

An alternating current in a conductor sets up an alternating magnetic field, which is much stronger if the conductor is surrounded by ferrous metal such as steel wire armour or steel conduit. The currents in a twin cable carrying phase and neutral conductors will be equal and will provide equal and opposite ampere-turns, so that the magnetic flux in a cable sheath will be negligible. Similarly a three or four core cable carrying a three-phase circuit will have virtually zero magnetic flux in its iron sheath. However a single core armoured cable will set up a strong alternating magnetic field in its steel armouring which will give rise to iron losses (eddy currents and hysteresis) resulting in the heating of the armour.



Iron losses due to single core cables entering a steel enclosure through separate holes



Circulating currents prevented by an insulating plate at one end

For these reasons, it is important that all conductors of each a.c. circuit are enclosed in the same steel conduit or trunking. Again single core cables must not enter steel enclosures through separate holes.

In some cases, it may be necessary to run a high current supply using single-core cables; for example, multicore MI cables are only made with conductors of up to 25mm^2. Above this size, single core cables must be used. If the cable sheaths are solidly bonded at both ends, circulating currents will travel through the sheaths and will reduce the natural cooling of the cables. In addition, cables bonded by means of steel plates will be subject to iron losses hence the bonding plates must not be of ferrous material.

2.8 Types of Wiring System

Before any electrical installation is begun, some careful thought must be given to the factors or conditions which decide the type of wiring system, its associated accessories, the wiring accessories and the electrical equipment and fittings to be installed. The following are some of the most important points to be considered:

a) Type of Building

Permanent or temporary

New installation or alteration/addition

b) Flexibility

Is the system subject to frequent changes? Whether the premises will be changed from office to shop use or showroom, etc.

c) Installation conditions

Indoor? outdoor? underground?

Any likelihood of moisture, water or mechanical damage. Is the premise an explosive or flammable one?

d) Appearance

Need to match installation appearance to building premises and decor. Surface wiring or concealed wiring?

e) Durability

Whether installation is to last for the lifetime of the building or not.

f) Cost (& time)

What is the budget on costs and is there any time constraint for the installation?

g) Safety

Besides the installation conditions, the type of supply and the earthing arrangement have to be considered.

2.8.1 Wiring Systems (Installation Methods)

Taking all the above into consideration, the designer may have to use a combination of the wiring methods to achieve a satisfactory design.

The various methods to install cables are:

a) Plastic trunking system
b) Ducting system
c) Conduit system
d) Trunking system
e) Cable tray/cable ladder system

(a) Plastic Trunking

Easy to install

Cheaper than steel trunking

Suitable for corrosive atmosphere

Not suitable at extreme temperature

(Cracked at low temperature and melt at high temperature)

(b) Ducting (Masonry duct)

Formed in the casting process
Space factor is reduced to 35% to prevent overheating
Long radius four times diameter needed for bends
PVC non sheath cables cannot be drawn into the ducts as the insulation will be damaged in the pulling of cables
MICS cables also must have a sheathing of PVC

(c) Conduit system

A conduit is a tube designed to carry electric cables. There are two classes of steel conduit; Class A and Class B.

Class A is light gauge and the connections are made by slipping the end of the conduit into a socket; very rare in Singapore. Class B is heavy gauge and the joints, fittings; connections are made by screwing together. This is because the heavy gauge allowed grooves to be cut to produce the screw thread needed.

Within Class B conduits, there are two types Class 3 and Class 4.

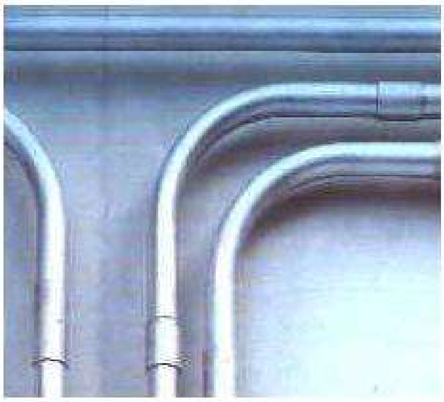
- Class 3 is electrogalvanised on the outside.
- Class 4 is hot dipped galvanised on both sides

The capacities of conduits are governed by relevant code of practice; however the rule of thumb is to ensure that a **space factor of 40% is not exceeded**. The maximum size of conductors installed in conduit is 16mm^2. The purpose of conduit is to afford mechanical protection to the cables, which is normally PVC non-sheath.

Conduits are secured to wall or ceiling by means of saddles (half or full saddle) or pipe hooks. Conduit accessories such as round draw boxes, T-boxes, Y-boxes, elbows are used to facilitate drawing in of cables or for change of direction.

Conduits can be installed on surface (called surface conduit) or they can be installed concealed.

Electrical Conduits installed on ceiling



Conduits on wall

The surface installation, the routes have to be planned to ensure that there is no crossing at change of direction otherwise the crossings will be very unsightly.

For concealed installation, it may take the following forms: cast in situ, chased into brick walls and then plastered over concealed in gypsum partition or above false ceiling

(d) Steel Trunking System

A steel trunking is a rectangular metal enclosure with a removable lid for running of electric cables. (The US called trunking as raceways.)

Depending on the size of the trunking, the thickness will vary. The main problem with installing a trunking system is when the direction changes, cables especially the larger size require substantially bending radius (min 3 times external diameter for the smaller sizes and six times external diameter for csa > 25mm^2), therefore the bends will have to be specially made to accommodate the bends.

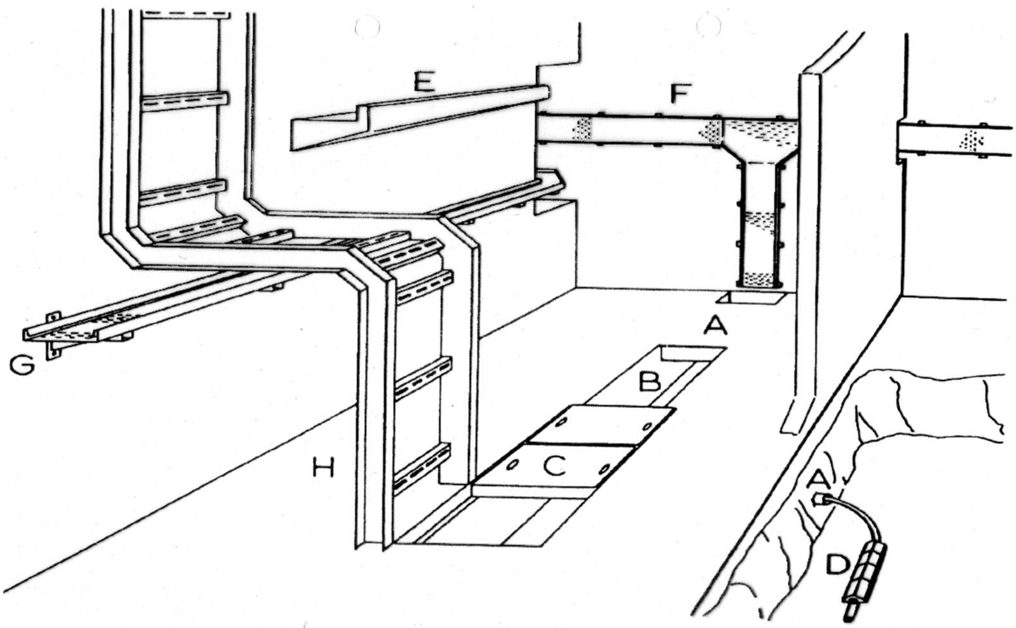
Trunkings are usually used for installation of PVC non-armoured cables to give the required mechanical protection especially in accessible locations.

In modern commercial buildings, very often the underfloor flush duct and skirting systems are installed to facilitate the installation of power and lighting, telecommunication and computer wiring (in separate compartments of the systems).

Similar to conduit there is a limit on the cable capacity for trunking, the ***space factor for trunking is not to exceed 45%.***

(e) Cable Tray/Cable Ladder System

Cable tray and cable ladders is generally used to support installation of fairly large cables and they are usually used in areas which are not accessible to human touch, the minimum sheathing of cables installed on cable tray shall be PVC sheathed.



Cable Tray and Cable Ladder

Chapter 3

Maximum Demand/Diversity Factor, Conduit/Trunking Sizing, Overcurrent Protection and Cable sizing

Objectives

On successful completion of this chapter, you will be able to:

- Use Table 4B of 16th Edition of IEE Regulation Guide Books to determine the connected loads, maximum current demands and suitable incoming circuit breaker size for an electrical distribution board.
- Determine suitable sizes of conduit and trunking to accommodate cables, using Table 12A to 12F as provided in the 16th Edition of IEE Regulation Guide Books.
- Learn the SS638 requirements on protection against overcurrent and the co-ordination between protective device and conductor.
- Learn the factors that affect the current-carrying capacity of cable.
- Determine suitable sizes of cables for use in circuits under various conditions, taking into considerations compliance with the voltage drop and short-circuit current requirements.
- Understand the term “discrimination” as applies to electrical circuit design.

Overview

Correct sizing of electrical loads forms a very important part in electrical installation design. Students of electrical installation will need to understand the use of **diversity factor** in sizing of the maximum demand.
The main objectives are to reduce:

(i) the cross-section areas of the mains and sub-mains cables
(ii) the size of the associated protective devices.

In situation where no information is available, Tables 4A and 4B of the 16th Edition of IEE Regulation Guide Books can be used to assess the maximum current demand. Hence, these tables are used as a guide and they require special knowledge and experience on the part of the designer.

Final circuits of an electrical installation are usually run in conduit, trunking and cable tray. PVC insulated cables are usually drawn into the installed conduits or trunkings to complete the installation. Having decided upon the type, size and number of cables required for a final circuit, it is then necessary to select the appropriate size of conduits or trunkings to accommodate these cables. Tables 12A to 12F of the 16^{th} Edition of IEE Regulation Guide Books are used to determine a suitable size of conduit/trunking required to enclose the cables.

Each circuit conductor shall have adequate protection against overloading, persistent high earth leakage currents and damaging earth fault and short circuit currents. Chapter 43 of SS638 detailed the requirements on protection against overcurrent.

Cable protection against overcurrent is normally in the form of fuses or circuit breakers. The simplest protective device is the fuse. Thermal devices, such as thermal overload relay, can be used to protect cables against overload but often they are used in conjunction with either fuses or circuit breakers. Both fuses and circuit breakers can offer full overcurrent protection against the effects of overload, short-circuit and earth fault. They come in standard available current ratings and possess high breaking capacity to clear high current fault without being damaged.

On cable sizing, the Regulations require that the method used to choose the correct size of the cable be based on the rating of the protective device. All factors which affect the rating of the cable in its installed condition are applied as divisors to the rating of the protective device.

The co-ordination between conductors and protective devices must satisfy these two equations as stated in Section 433.2 requirement. They are:

(i) $I_b \le I_n \le I_z$

(ii) $I_2 \le 1.45I_z$

The selected cable size is then required to be checked for

- voltage drop and
- short-circuit current requirements.

Discrimination is the co-ordination of protective devices such that the protective device nearest the fault operates to clear the fault first, leaving upstream protective devices unaffected. This is done by checking the tripping times of the affected protective devices from the Time-Current Characteristic curves.

Resources and References

To supplement the learning of this chapter, the following resources/references can be harnessed:

- Tutorial 3
- Laboratory Hands-on
- PC-based Software Programme “Miptein” on Cable Sizing and D.B. Design
- Singapore Standard, SS638:2018
- Electrical Installation, 3rd Edition, by E L Donnelly
- Electric Wiring (Domestic) by A J Coker
- Electrical Installation & Regulations by Michael Neidle
- Principles and Design of Low Voltage Systems. 2nd Edition, Teo Cheng Yu (Byte Power Publication, Singapore)
- Commentary on IEE Wiring Regulations, 16th Ed BS7671:2001 by Paul Cook, 2002

Chapter 3

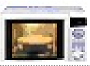
Maximum Demand/Diversity Factor, Conduit/Trunking Sizing, Overcurrent Protection and Cable sizing

3.1 Current demand and Cost of Electricity

In order to have a good understanding of current demand of an electrical installation, it is always a good idea for current demand to be linked to cost of electricity in everyday life.

A huge electric kettle rated 3kW which takes an hour to boil will consumed 3kW x 1 hour = 3kWh. At 20 cents per kWh, this will cost 60 cents. The current demand for 3kW at 230V is approximately 13A. Multiply that by 30 days in a month this will be $18.00. If an electrical installation has a current demand of 13A, this means that it will require 13A for all its operating hours. Assuming 10 hours of operation, the electricity bill will be 10 x $18 = $180.

Let us also have a look at the average electricity bill of a 4-room HDB flat shown below. The electricity tariff is based on 20.49cents per kWh.

Appliances	Rating (W)	No. of hrs used in 1 day	No of appliances	kWh	Cost ($)
 **Refrigerator** (400 litres)	200	24	1	144.00	29.51
 **Instantaneous Water Heater**	2000	1	1	60.00	12.29
 **Single-Spilt Air-Conditioner**	750	8	1	180.00	36.88
 **Fluorescent Lighting**	40	6	6	43.20	8.85
 **Electric fan** (stand type)	75	6	2	27.00	5.53
 **Incandescent bulb**	40	6	3	21.60	4.43
 **Colour TV** 29"	200	3.5	1	21.00	4.30
 **Rice cooker** (4-7 person)	800	20 mins	1	7.99	1.64
 **Microwave oven**	1350	10 mins	1	6.75	1.38
 **Colour TV** 14"	100	2	1	6.00	1.23
 **Electric kettle** (3.5 litres)	2000	5 mins	1	4.98	1.02
 **Desktop Computer**	300	30 mins	1	4.50	0.92
 **Washing Machine** (without heater)	300	30 mins	1	4.50	0.92
 **Electric Iron** (conventional)	1000	20 mins	1	9.99	2.05
 **VCD Player**	20	1	1	0.60	0.12
 **Inkjet Printer**	60	5 mins	1	0.15	0.03
			Grand Total	**542.26**	**111.1**

The incoming circuit breaker for **4-room and 5-room HDB flat is only 40A single phase**. A **200m² private apartment or condominium** has an incoming supply of only **60A three phase**.

3.2 Maximum Demand and Diversity Factor

The number of circuits in an installation can be numerous and it is unlikely that every circuit is turned on and absorbing maximum current at the same instance.

In this case, the aggregate of the connected load is greater than the predicted maximum current the installation would need. This predicted maximum current is known as **Maximum Demand**. The end result is a ***saving on size of the main breaker and incoming feeder cable***. The ratio of the maximum demand to the connected load for a particular distribution is called **Diversity Factor**.

The allowance for diversity is normally based on a set of assumptions. An example, which we shall be using for all our work examples, is shown in Table 4B below.

Table 4B
Allowance for diversity

Purpose of final circuit fed from conductors or switchgear to which diversity applies	**Type of premises**		
	Individual household installations, including individual dwellings of a block	**Small shops, stores, offices and business premises**	**Small hotels, boarding houses, guest houses, etc.**
1. Lighting	66% of total current demand	90% of total current demand	75% of total current demand
2. Heating and power (but see 3 to 8 below)	100% f.l. of total demand up to 10A + 50% of any current demand in excess of 10A	100% f.l. of largest appliance + 75% f.l. of remaining appliances	100% f.l. of largest appliance + 80% f.l. of 2nd largest appliance + 60% f.l. of remaining appliances
3. Cooking appliances	10A + 30% f.l. of connected cooking appliances in excess of 10A + 5A if socket outlet incorporated in unit	100% f.l. of largest appliances + 80% f.l. of 2nd largest appliance + 60% f.l. of remaining appliances	100% f.l. of largest appliances + 80% f.l. of 2nd largest appliance + 60% f.l. of remaining appliances
Motors (other than lift motors which are subject to special consideration)		100% f.l. of largest motor + 80% f.l. of 2nd largest motor + 60% f.l. of remaining motor	100% f.l. of largest motor + 50% f.l. of remaining motor
5. Water heater (instantaneous type)	100% f.l. of largest appliance + 100% f.l. of 2nd largest appliance + 25% f.l. of remaining appliances	100% f.l. of largest appliance + 100% f.l. of 2nd largest appliance + 25% f.l. of remaining appliances	100% f.l. of largest appliance + 100% f.l. of 2nd largest appliance + 25% f.l. of remaining appliances
6. Water heater (thermostatically controlled)	No diversity allowable (100% or 1.0)		
7. Floor warming installations	(Reserved for future use)		
8. Thermal storage space heating installations	(Reserved for future use)		
9. Standard arrangement of final circuits (13A SSOs)	100% of current demand of largest circuit + 40% of current demand of every other circuit	100% of current demand of largest circuit + 50% of current demand of every other circuit	
10. Socket outlets other than include in 9 above and stationary equipment other than those listed above (15A, 20A SSOs)	100% of current demand of largest point of utilisation + 40% of current demand of every other point of utilisation	100% of current demand of largest point of utilisation + 75% of current demand of every other point of utilisation	100% of current demand of largest point of utilisation + 75% of current demand of every point in main rooms (dining rooms, etc) + 40% of current demand of every other point of utilisation

Final circuits are connected to the power supply in one of the following ways:-

a) fixed or portable equipment supplied from switched socket outlets e.g. a vacuum cleaner is portable, a washing machine or a refrigerator is fixed but wired through a flexible cord. For a room air-conditioner, 15A round pin S.S.O. (switched socket outlet) is used.

b) an indoor lighting point uses fixed wiring and is controlled by a switch, a pull cord switch, a dimmer or mounted on a lighting track (except for exit light) which is directly connected to the power source).

c) an electric cooker is controlled by a cooker switch

d) an electric motor exceeding 0.37 kW is connected through a starter or through an isolating switch if the starter is remote from the motor

The current demand of a circuit supplying a number of final circuits can be obtained by adding the current demands of all the equipment supplied by each final circuit and applying the allowances for diversity given in Table 4B.

Current Demand for final circuits supplying the following equipment is to be noted as follows:

(1) Cooking Appliance - 10 Amps plus 30 % full load (f.l.) of connected cooking appliances in excess of 10 amps Plus 5A if a socket outlet is incorporated in the control unit. Refer ***Item 3 of Table 4B***.

(2) Discharge Lightings - calculate from the total wattage of the lamps multiplied by 1.8 if information on full load current and power factor is not given and apply diversity factor given in ***Item 1 of Table 4B.***

(3) Lamp Holders - assumed load of each lamp holder to be 100W if not stated

(4) **Air Conditioning Unit** - Since the one final circuit can only supply to one unit (point of utilisation), the current demand has to be 100 % of the full load current. If there is more than one air-conditioning units in an installation, then the current demand for the other units shall be determined according to ***Item 10 of Table 4B***.

If the incoming circuit breaker exceed 63 A, this would require the use of three-phase supply. Tables 4B is given as a guide and that the amount of diversity should be determined on individual basis after having considered the nature of the load and the purpose of utilisation. In the above example, the socket outlets are used for small appliances most commonly not exceeding 1000W. In practice, the electrical engineer would evaluate the usage of each connected load to determine the diversity to be applied.

Example 3.1

A single-phase supply is connected to a residential apartment with final circuits as follows:

Circuit No	Protective Device Rating	Connected Load
1.	6A	6 lamp-holders (100W per lampholder)
2.	6A	4 nos. of 40W fluorescent luminaire
3.	20A	5 nos. of 13A switched socket outlets (Estimated demand 3kW for the circuit)
4.	30A	5 nos. of switched socket outlets for kitchen (Estimated demand 3kW for the circuit)
5.	30A	7 kW cooker connected to cooker control unit with switched socket outlet

Calculate the followings:-

a) total connected load

b) maximum demand

c) size of main circuit breaker, assuming 25% spare capacity for future expansion.
(standard sizes of main circuit breaker are: 20A, 32A, 40A, 50A, 63A, 75A, 100A)

Solution (to Example 3.1): (Use P=VIcosØ)

Description	**Connected Load**	**D.F.**	**Current demand**
Lamp-holder	(6x100w)/230V = 2.61A	66%	1.73A
Fluorescent	(4x40wx1.8)/230V = 1.25A	66%	0.83A
Socket outlets Largest circuit Remainder circuit	 3000w/230V = 13.04A 3000w/230V = 13.04A	 100% 40%	 13A 5.2A
Cooker with S.S.O.	7000w / 230V = 30.43A excess = 20.43A S.S.O. 5A	1st 10A 30%	10A 6.13A 5A

a) total connected load = 2.61 + 1.25 + 13 + 13 + 30.43 + 5
= 65.29A

b) maximum demand = 1.73 + 0.83 + 13 + 5.2 + 10 + 6.13 + 5
= 41.89A

c) Size of main breaker shall be greater than the maximum demand.

Size of main breaker = 125 % of maximum demand
= 1.25 x 41.89A
= 52.36A

Hence, choose is 63A SPN

Example 3.2

A domestic installation is taking supply from 400/230 V source. The installation is designed to have the following loads:

(i) 18 fluorescent lights, each rated 40 W

(ii) 18 filament lamps, each rated 100 W

(iii) **6 ring circuits** connected to 30 nos 13A socket outlets (Estimated demand **3kW per circuit**. The MCB protecting each ring circuit is a 30A MCB)

(iv) 3 nos. of 3 kW instantaneous water heaters

(v) 2 nos. air-conditioners considered as motors each rated 4.5 kW, *three-phase*, p.f. of 0.8 lagging and an efficiency of 90%, ***running at the same time all the time***.

Find a suitable size for the incoming circuit breaker, assuming 20% spare capacity for future expansion.
(standard sizes of main circuit breaker are: 20A, 32A, 40A, 50A, 63A, 75A, 100A)

Solution (to Example 3.2)

As the single-phase loads are connected to a three-phase supply, it is necessary to balance all the connected loads across the three-phases.

Single Phase Loads (P = V I cos Φ)

Description	**Connected Load**	**D.F.**	**Current Demand**
18 nos. fluorescent lamps	= (18 x 40w x 1.8)/230V = 5.63A	66%	3.72
18 nos. filament lamps	= (18 x 100w)/230V = 7.83 A	66%	5.17
13A socket outlets Largest cct	= 3000w/230V = 13A	100%	13
13A socket outlets Remainder ccts (5 ccts)	= 5 x 3000w/230V = 65A	40%	26
1st Instant water heater	= (1 x 3000w)/230V = 13A	100%	13
2nd Instant water heater	= (1 x 3000w)/230V = 13A	100%	13
3rd Instant water heater	= (1 x 3000w)/230V = 13A	**25%**	3.25
			77.14 (1Φ)

Three phase loads ($P = \sqrt{3}\, V_L\, I_L \cos\Phi$)

Description	**Connected Load**	**D.F.**	**Current Demand**
4.5kW 3-phase aircond no 1	$= \dfrac{4500}{(\sqrt{3})\times400\times0.8\times0.9} = 9.0A$	100%	9.0
4.5kW 3-phase aircond no 2	$= \dfrac{4500}{(\sqrt{3})\times400\times0.8\times0.9} = 9.0A$	100%	9.0

Note: no diversity is allowed for Air-con since they are running at the same time.

The maximum demand will be maximum demand of single phase load divide by 3 plus the three phase demand loads

Maximum demand = 77.14/3 + 18 = 43.71A (3-phase)

Size of main breaker = 120 % of max. demand (allowance 20% spare capacity)

= 1.2 x 43.71A

= 52.46A

Hence, **choose 63A TPN circuit breaker**.

3.3 Conduit and Trunking Sizing

3.3.1 Space Factor Method

Essentially there are two methods being employed in the sizing of conduit and trunking. The first method is sometimes known as the Space Factor method. The Space Factor (SF) is defined as the ratio (expressed as a percentage) of the sum of the overall cross-sectional areas of cables (including insulation and any sheath) to the internal cross-sectional area of the conduit or other cable enclosure in which they are installed. The effective overall cross-sectional area of a non-circular cable is taken as that of a circle of diameter equal to the major axis of the cable. The number of cables which can be drawn in or laid in any enclosure of a wiring system must be such that no damage can occur to the cables or the enclosure during installation. To use this method, the diameter of the cables must be determined to find the cross-sectional area of the cables.

Please note that the following definition when sizing conduits/trunkings:

Type of Circuits	No. of Cables
• Single Phase Circuits	3 (L, N, E)
• Three Phase Circuits	5 (B, B, G, N, E)
• 3-wire Three Phase Circuits	4 (B, B, G, E)
• 4-wire Three Phase Circuits	5 (B, B, G, N, E)

Types of enclosure	Maximum acceptable Space Factor
Duct	35%
Conduit	40%
Trunking	45%

Examples 3.3 (using the Space Factor method)

You are required to select an enclosure either a conduit or trunking for an electrical wiring installation, which consists of the following cables:

- 3 nos. single-phase circuits of 1.5 mm^2 3C/PVC cables, overall diameter = 8 mm
- 4 nos. single-phase circuits of 2.5 mm^2 3C/PVC cables, overall diameter = 10 mm
- 2 nos. single-phase circuits of 4.0 mm^2 3C/PVC cables, overall diameter = 12 mm

Please note that if the size of conduit required exceeds 32 mm diameter, then you have to choose a trunking instead, in either case, you are required to show the workings of the appropriate size of the conduit or trunking required.

Solution (Example 3.3):

Assuming that we can use a conduit to house the cables indicated.

Based on the definition:

$$\text{Space Factor} = \frac{\text{Sum of overall csa of cables}}{\text{Internal csa of the conduit or trunking}}$$

Using space factor for conduit = 40%

$$\frac{(3\times\frac{\pi(8)^2}{4})+(4\times\frac{\pi(10)^2}{4})+(2\times\frac{\pi(12)^2}{4})}{\frac{\pi d^2}{4}} \le 0.4$$

$$\frac{192+400+288}{d^2} \le 0.4$$

$$\therefore d^2 \ge 2{,}200$$

$$\therefore d \ge 46.9mm$$

This gives a diameter of 46.9 mm and this exceeded the standard maximum size of 32 mm for conduit. Hence, we have to find a suitable trunking instead.

Using space factor for trunking = 45%

$$\frac{(3\times\frac{\pi(8)^2}{4})+(4\times\frac{\pi(10)^2}{4})+(2\times\frac{\pi(12)^2}{4})}{A} \le 0.45$$

$$\frac{151+314+226}{A} \le 0.45$$

$$\therefore A \ge 1{,}536mm^2$$

From Table 12F, we therefore choose 5**0 x 37.5 mm^2 or 75 x 25 mm^2 trunking**.

3.3.2 Cable Factor (unit system) Method

Conceptually, the second method is based on the first method, except this is simplified with the use of Tables 12A to 12F. In order to comply with the above requirement, the method employs a unit system whereby each cable is allocated a factor. The cables used are single-core PVC cables, no multi-core cables are indicated in tables 12A to 12F

The sum of the factors for the cables which are to be run in the same enclosure is then compared with a factor given in the tables for different sizes of conduit or trunking, in order to determine the size of conduit or trunking necessary.

Wiring System

- Table 12A (for cables) and Table 12B (for conduit) are meant for sizing of straight conduit not exceeding 3m
- Tables 12C (for cables) and Table 12D (for conduit) are meant for sizing of conduit exceeding 3m
- Tables 12E (for cables) and Table 2F (for trunking) are meant for sizing of trunkings

Definition of bends

- 1 bend is equivalent to a 90^0 bend
- ½ bend is equivalent to a 45^0 bend (or offset)
- 1 set (i.e. 2 no. of ½ bends) of offset is equivalent to 1 bend

Sizing of Conduit (Using the tables 12A – 12D)

- For straight runs less than 3m use Tables 12A and 12B.
- Single-core pvc-insulated cables in conduit run exceeding 3 m in length must incorporate any bends or sets present
- Add all the cable factors so obtained and compare with the conduit factors given in the corresponding tables, taking into account the length of run it is intended to use and the number of bends and sets in that run.
- The conduit size which will satisfactorily accommodate the cables is that size having a factor equal to or exceeding the sum of the cable factors.

Example 3.4

Select a conduit which can house the following circuits:

- 2 nos. single-phase circuit using 2.5 mm^2 single-core PVC-insulated cables
- 1 nos. three-phase circuit using 4.0 mm^2 single-core PVC-insulated cables

Given that the length of the conduit run is 4 m and there are two bends. You may assume that the circuit protective conductor used is of the same sizes as the phase cables. All conductors are of the stranded type.

Solution (Example 3.4)

No. & Types of Circuits	No. of cables	Cable Factor	Total cable factor
2 x single phase (2.5mm^2)	2 x 3	30	180
1 x three phase (4.0mm^2)	1 x 5	43	215
			395

From **Table 12D**, given 2 bends and 4 metre long conduit,
therefore, choose **32 mm diameter** conduit with a factor of 692 $\geq$ 395

Cable Factors and Conduit Factors for Short Runns (< 3m)

Table 12A

Cable factors for short straight runs

(Single core PVC cables)

Type of Conductor	Conductor cross-sectional area (mm^2)	Factor
Solid	1	22
	1.5	27
	2.5	39
Stranded	1.5	31
	2.5	43
	4	58
	6	88
	10	146

Table 12B

Conduit factors for short straight runs

Conduit diameter (mm)	Factor
16	290
20	460
25	800
32	1400

Cable Factors and Conduit Factors for Long Runs (> 3m)

Table 12C

Cable factors for long straight runs or runs incorporating bends

(For Single core PVC cables only)

Type of Conductor	Conductor cross-sectional area (mm2)	Factor
Solid or stranded	1	16
	1.5	22
	2.5	30
	4	43
	6	58
	10	105

Table 12D

Conduit factors for runs incorporating bends

Length of run (m)	Conduit diameter (mm)																			
	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32	16	20	25	32
	Straight				One bend				Two bends				Three bends				Four bends			
1	Covered by Table 12A and 12B				188	303	543	947	177	286	514	900	158	256	463	818	130	213	388	692
1.5					182	294	528	923	167	270	487	857	143	233	422	750	111	182	333	600
2					177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529
2.5					171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474
3					167	270	487	857	143	233	422	750	111	182	333	600				
3.5	179	290	521	911	162	263	475	837	136	222	404	720	103	169	311	563				
4	177	286	514	900	158	256	463	818	130	213	388	692	97	159	292	529				
4.5	174	282	507	889	154	250	452	800	125	204	373	667	91	149	275	500				
5	171	278	500	878	150	244	442	783	120	196	358	643	86	141	260	474				
6	167	270	487	857	143	233	422	750	111	182	333	600								
7	162	263	475	837	136	222	404	720	103	169	311	563								
8	158	256	463	818	130	213	388	692	97	159	292	529								
9	154	250	452	800	125	204	373	667	91	149	275	500								
10	150	244	442	783	120	196	358	643	86	141	260	474								

3.3.3 Sizing of Trunking

- For each cable it is intended to use, obtain the appropriate factor from Table 12E
- Add all the cable factors so obtained and compare with the factors for trunking given in Table 12F.
- The size of trunking which will satisfactorily accommodate the cables is that size having a factor equal to or exceeding the sum of the cable factors.
- For sizes and types of cable and sizes of trunking other than given in Tables 12E and 12F below, the number of cables installed should be such that the resulting space factor does not exceed 45%

Table 12E
Cable factors for trunking

Type of Conductor	Conductor cross-sectional area (mm^2)	Factor
Solid	1.5	7.1
	2.5	10.2
Stranded	1.5	8.1
	2.5	11.4
	4	15.2
	6	22.9
	10	36.3

Table 12F
Factors for trunking

Dimension of trunking (mm x mm)	Factor
50 x 37.5	767
50 x 50	1037
75 x 25	738
75 x 37.5	1146
75 x 50	1555
75 x 75	2371
100 x 25	993
100 x 37.5	1542
100 x 50	2091
100 x 75	3189
100 x 100	4252

Example 3.5

You are given the following circuits and you are required to sizing an appropriate trunking to enclose all the cables.

- 2 No. of single phase circuit consisting of 2.5 mm^2 single core pvc insulated cables
- 3 No. of three phase circuit consisting of 2.5 mm^2 single core pvc insulated cables
- 4 No. of 3-wire three phase circuit consisting of 4.0 mm^2 single core pvc insulated cables
- 2 No. of 4-wire three phase circuit consisting of 6.0 mm^2 single core pvc insulated cables

All conductors are of stranded type.

Solution (to Examples 3.5)

No. & Types of Circuits	No. of cables	Cable Factor	Total cable factor
2 x single phase 2.5 mm^2	2 x 3	11.4	68.4
3 x three phase 2.5 mm^2	3 x 5	11.4	171
4 x 3-wire three phase 4.0 mm^2	4 x 4	15.2	243.2
2 x 4-wire three phase 6.0 mm^2	2 x 5	22.9	229
			711.6

From Table 12F, therefore **choose 75 x 25 mm^2 trunking** (trunking factor = 738 > 711.6)

3.4 Protection Against Overcurrent

Chapter 43 SS638 concerns itself with the regulations governing protection of circuits and apparatus against the effect of overcurrent. The term 'overcurrent' can be subdivided into two categories: **overload currents** and **short circuit currents**.

3.4.1 Overload Currents

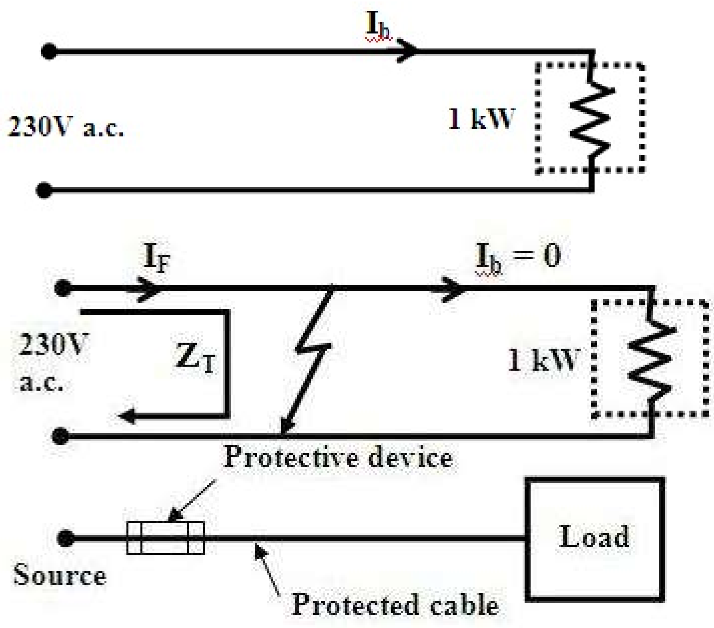
Overload currents occur in circuits which are electrically sound but are carrying more current than the design value because of overloaded machines or equipment, a failure in the estimated diversity, and so on. The danger to the system in such cases is that temperature of the cable conductors and of their insulation will rise to the level where the effectiveness of the insulation, and its expected life, will be reduced. The devices used to detect such overloads, and to break the circuit for protection against them, are fuses and circuit breakers.

3.4.2 Short Circuit Currents

Overload currents are due, as the name implies, to overloading, and are likely to result in currents no more than a few times normal. **Short circuits, on the other hand, are due to fault conditions** where the currents may be several hundred times than normal. In such an event, the circuit protection must break the fault current before danger is caused by over heating or by electro-mechanical stresses. Short circuit protection must not only be capable of breaking such currents, but must also break them rapidly, before damage occurs.

3.4.3 Prospective Short Circuit Current

The current likely to flow in a system under short circuit conditions is called *Prospective Short Circuit Current*. The prospective short circuit current at a particular point in the installation is calculated to include all impedances upstream from that point and the short circuit is of negligible impedance. **Protective devices are selected on the basis of their short circuit capacity** which is the maximum prospective current it can interrupt without damage.



I_b = 1000W/230V = 4.4A

Z_T = Total impedance of fault
= 0.01ohms

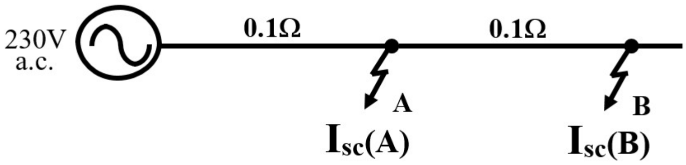
$I_F = 230V/Z_T$

$I_F = 230V/0.01\Omega = 23kA$

I_b = design current

I_F = fault current

The total impedance at the point of fault will depend on the size and length of the conductor from the source. The value of the prospective short-circuit current will fall as the point of fault is further away from the source. On the other hand, the value will be greater if the point of fault is closer to the protective device or source and the supply of the source is larger.



I_{sc} (at point B) $= \dfrac{V}{Z_T} = \dfrac{230v}{(0.1+0.1)ohms} = 1150A$

I_{sc} (at point A) $= \dfrac{V}{Z_T} = \dfrac{230v}{(0.1)ohms} = 2300A$

The protective device used at point A has to have a larger short circuit rating than B.

High fault current endangers personnel, equipment and is a fire hazard.

Protective devices are necessary to limit the magnitude and duration of the fault. For safe operation, protective devices must have adequate breaking capacity to handle the worst fault, i.e. a 3-phase fault.

Breaking Capacity is defined as the ability of a protective device to carry the r.m.s. fault current for a specific time.

3.4.4 Protection Against Overload Current (Regulation 433)

The device used must be capable of breaking the circuit before any overload current could cause a rise in temperature which might damage insulation, terminations, joints or surroundings of conductors. There are however circumstances where **overload protection is not required where continuity of supply is critical compared with the implications of not providing overload protection** e.g. supply to lifting electromagnet, motor circuits of fire pumps.

It is sensible to design an installation in the most economic manner. Savings can be made if attention is given to the requirements of the regulations covering conductors and protective devices.

I_n = nominal current or current setting of device

I_b = design current of the circuit

I_z = effective current carrying capacity of any of the circuit conductors

I_2 = the current which ensures effective operation of the device

The co-ordination requirements (433.1.1) in this case are:

$I_b \le I_n$ i.e. design current must not exceed current setting of device
$I_n \le I_z$ i.e. current setting of device must not exceed the lowest conductor rating

$$I_b \le I_n \le I_z \qquad \textbf{(a)}$$
$$I_2 \le 1.45 \times I_z \qquad \textbf{(b)}$$

The following devices satisfied the expression (a) and (b) stated above:

1. HBC fuse to IEC60269-2 Previously (BS 88)
2. Cartridge fuse to IEC60269-3.
3. Circuit breaker to (BS EN 60898)
4. Circuit breaker to BS EN 60947-2

However, when the device is a rewireable fuse to BS 3036, in order to satisfy expression **(b)** above $I_n \le 0.725\ I_z$. The reason for this is due to the possibility of such a fuse having a fusing factor as high as 2, then

Since fusing current = fusing factor x fuse rating
= 2 x fuse rating
then $I_2 = 2\ I_n$
and to satisfy **(b)** $2\ I_n \le 1.45 \times I_z$
$I_n \le 1.45/2 \times I_z$
$\boxed{I_n \le 0.725 \times I_z}$

In practice then if a BS 3036 fuse is used as the protective device then it means that a larger cable than that determined from normal load conditions must be selected form the cable rating tables.

3.5 Selection Of Cable Size (523 to 525 & Appendix 4L of SS 638:2018)

The selection of cable size is principally based on three considerations:

1. Current carrying capacities
2. Voltage drop
3. Short circuit requirement

Each of these should be checked before arriving at the required size.

It helps to bear in mind the following principles:
• An insulated cable size is only limited by its type of insulation.
• For a given insulation, the rating depends upon both load current and the rate of heat dissipated by the cable to its immediate environment.

3.5.1 Current Carrying Capacities (523 & Appendix 4L)

The most convenient way to establish a rating for a particular cable design is to calculate an amperage which can be carried continuously (often called a sustained rating) under prescribed standard conditions. Appropriate factors may then be applied to cater for the actual installation conditions.

3.5.2 Factors affecting Current Carrying Capacities

During service operation, cables suffer electrical losses which appear as heat in the conductor, insulation and metallic components. The current rating is dependent on the way this heat is transmitted to the cable surface and then dissipated to the surroundings.
The factors affecting current rating of a cable are:

(a) Ambient temperature
(b) Grouping
(c) Thermal Insulation
(d) Other frequencies

(a) Ambient Temperature

The current carrying capacity of a cable depends upon the actual ambient temperature of the location in which the cable is installed. **Table 4C1 and 4C2** provide the correction factor for different ambient temperature.

TABLE 4C1

Correction factors for ambient temperature where protection is not a semi-enclosed fuse to BS3036

		Ambient temperature (°C)														
Type of insulation	Operating temperature	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Rubber (flexible cables only)	60°C	1.04	1.0	0.91	0.82	0.71	0.58	0.41	-	-	-	-	-	-	-	-
General purpose pvc	70°C	1.03	1.0	0.94	0.87	0.79	0.71	0.61	0.50	0.35	-	-	-	-	-	-
Paper	80°C	1.02	1.0	0.95	0.89	0.84	0.77	0.71	0.63	0.55	0.45	0.32		-	-	-
Rubber	85°C	1.02	1.0	0.95	0.90	0.85	0.80	0.74	0.67	0.60	0.52	0.43	0.30	-	-	-
Heat resisting pvc *	90°C	1.03	1.0	0.97	0.94	0.91	0.87	0.84	0.80	0.76	0.71	0.61	0.50	0.35	-	-
Thermosetting	90°C	1.02	1.0	0.96	0.91	0.87	0.82	0.76	0.71	0.65	0.58	0.50	0.41	0.29	-	-
Mineral	70°C sheath	1.03	1.0	0.93	0.85	0.77	0.67	0.57	0.45	0.31	-	-	-	-	-	-
	105°C sheath	1.02	1.0	0.96	0.92	0.88	0.84	0.80	0.75	0.70	0.65	0.60	0.54	0.47	0.40	0.32

NOTES:
1. Correction factors for flexible cords and for 85oC or 150oC rubber-insulated flexible cables are given in the relevant table of current-carrying capacity
2. This table also applies when determining the current-carrying capacity of a cable
3. * These factors are applicable only to ratings in columns 2 to 5 of Table 4D1

TABLE 4C2

Correction factors for ambient temperature where the overload protective device is a semi-enclosed fuse to BS3036

		Ambient temperature (°C)														
Type of insulation	Operating temperature	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Rubber (flexible cables only)	60°C	1.04	1.0	0.96	0.91	0.87	0.79	0.56	-	-	-	-	-	-	-	-
General purpose pvc	70°C	1.03	1.0	0.97	0.94	0.91	0.87	0.84	0.69	0.48	-	-	-	-	-	-
Paper	80°C	1.02	1.0	0.97	0.95	0.92	0.90	0.87	0.84	0.76	0.62	0.43	-	-	-	-
Rubber	85°C	1.02	1.0	0.97	0.95	0.93	0.91	0.88	0.86	0.83	0.71	0.58	0.41	-	-	-
Heat resisting pvc*	90°C	1.03	1.0	0.97	0.94	0.91	0.87	0.84	0.80	0.76	0.72	0.68	0.63	0.49	-	-
Thermosetting	90°C	1.02	1.0	0.98	0.95	0.93	0.91	0.89	0.87	0.85	0.79	0.69	0.56	0.39	-	-
Mineral: bare and exposed to touch or pvc covered	70°C sheath	1.03	1.0	0.96	0.93	0.89	0.86	0.79	0.62	0.42	-	-	-	-	-	-
Bare and not exposed to touch	105°C sheath	1.02	1.0	0.98	0.96	0.93	0.91	0.89	0.86	0.84	0.82	0.79	0.77	0.64	0.55	0.43

(b) Grouping

The current carrying capacities also depend on whether the cables are of single circuit or group together. **Table 4B** provides the correction factors.

TABLE 4B1

Correction factors for groups of more than one circuit of single-core cables, or more than one multicore cable (to be applied to the corresponding current-carrying capacity for a single circuit in Tables 4D1 to 4D4, 4E1 to 4E4, 4F1 and 4F2, 4J1, 4K1 to 4K4, 4L1 to 4L4)**

		Correction factors (Cg)											
Reference method of installation		Number of circuits or multicore cables											
(see Table 4A)		2	3	4	5	6	7	8	9	10	12	14	16
Enclosed (Method 3 or 4) or bunched and clipped direct to a non-metallic surface (Method 1)		0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.48	0.45	0.43	0.41
Single layer clipped to a non-metallic surface (Method 1)	Touching	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70	-	-	-	-
	Spaced*	0.94	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Single layer *multicore* on a perforated metal cable tray, vertical or horizontal (Method 11)	Touching	0.86	0.81	0.77	0.75	0.74	0.73	0.73	0.72	0.71	0.70	-	-
	Spaced*	0.91	0.89	0.88	0.87	0.87	-	-	-	-	-	-	-
Single layer *single-core* on a perforated metal cable tray, touching (Method 11)	Horizontal	0.90	0.85	-	-	-	-	-	-	-	-	-	-
	Vertical	0.85	-	-	-	-	-	-	-	-	-	-	-
Single layer multicore touching on ladder supports (Method 13)		0.86	0.82	0.80	0.79	0.78	0.78	0.78	0.77	-	-	-	-

An overriding point to note before the grouping factor tables are given is the note 523.5 in IEEE 17th Edition BS 7671, which states that where a cable is known to carry 30% or less of its grouped rating, it can be ignored for the purposes of grouping. This is invaluable and should be utilized for cable sizing calculations.

(c) Thermal Insulation (Reg.523-4 & Table 52A page 99)

In appropriately tables of current carrying capacities i.e. **Table 4D1A to 4L4A of SS638:2018** provision is made for installation of cables in a thermally insulated wall or ceiling but in contact with a thermally conductive surface on one side only.

However, for a cable likely to be totally surrounded by thermally insulating material (totally enclosed), the current carrying capacity may be taken as **0.5 times the current–carrying capacity for that cable clipped direct to a surface and open (Reference Method 1).**

Either Ci = 1 or Ci = 0.5

(d) Other Frequencies

The current carrying capacities of cables carrying balanced 400Hz a.c. compared to 50Hz a.c. may be reduced by as much as 50% in cases such as large multi-core cables.
For smaller cables, difference in the 50 Hz and the 400Hz current carrying capacities may be negligible.

3.5.3 Sizing Cables

In order to determine the minimum cross-sectional area (csa) of a conductor, first, the designer will have to establish the design current of the circuit.

e.g. A 50 hp motor operating at full load has a power factor of 0.88 and efficiency of 0.95, at 400 volts three-phase, the operating current will be 64.4 A three-phase.

After determine the design current, $\mathbf{I_b}$, in this case, it is given as 64.4 A,

Then proceed using the equations just derived when overload protection is to be provided by the protective device, when we choose circuit breakers (BS3871 or BS4752), or fuses to BS1361 or BS88

$$I_b \le I_n \le I_z \qquad \textbf{(a)}$$

Select I_n greater than or equal to I_b using standard values of MCBs or fuses.
Next select I_z greater than or equal to I_n. How? Table 4D1A or tables of cables state only I_t.

But $I_z = I_t \times C_a \times C_g \times C_i$ i.e. tabulated values of ccc (I_t) after correct for ambient temperature, grouping and thermal insulation if any will be the actual ccc (I_z) of the cable.

From (a) $I_z \ge I_n$ therefore $I_t \times C_a \times C_g \times C_i \ge I_n$

i.e.

$$I_t \ge \frac{I_n}{C_a C_i C_g}$$

However in the past where rewirable fuses (BS 3036) were used for overload protection

$$I_b \le I_n \le 0.725\text{x } I_z$$

Since $I_z = I_t\, C_a\, C_g\, C_i$

$$0.725 \times I_t\, C_a\, C_g\, C_i \ge I_n$$

Therefore $I_t \ge I_n/(0.725 \times I_t\, C_a\, C_g\, C_i\,)$

(we do not use rewirable fuses in new installations)

However **if protective device is not required to offer overload protection**, eg in a motor control circuit where there is a thermal overload relay, the design current $\mathbf{I_b}$ will be used in placed of $\mathbf{I_n}$ probably resulting in a smaller $\mathbf{I_t}$. i.e. the size of the cable required will be such that its tabulated current carrying capacity.

i.e. $I_t \ge I_b/(C_aC_gC_i)$

Example 3.6

In a single phase circuit, given a design current which has been calculated to be 22 A, to be wired in single-core PVC insulated cables and these are to be installed in trunking with cables of four other single phase circuits. The ambient temperature is 50°C. Choose a suitable size of cable under this condition; assume overload protection is required to IEC 60269-2 (BS 88 fuse: Part 2).

Solution (to Example 3.6)

The next larger size of fuse to BS 88 is 25A. Therefore choose $\mathbf{I_n}$ = 25A.

Cables installed with 4 other circuits, therefore from **Table 4B1** under the column with ***5 circuits*** and row with cables enclosed in trunking (Method 3 or 4) grouping factor $\mathbf{C_g}$ = 0.6

Ambient temperature correction factor $\mathbf{C_a}$ = 0.71. This is read from **Table 4C1** under the column for 50^0 C and the row for general purpose PVC.

$$\begin{aligned} I_t &\geq \frac{I_n}{C_a C_g} \\ &\geq \frac{25}{0.71 \times 0.6} \\ &\geq 58.7 \end{aligned}$$

From **Table 4D1A** (page 217) Column 4 (under Reference Method 3), choose the next larger size of cable with tabulated value 76, hence cable size as read from row is $\mathbf{16mm^2}$**.**

TABLE 4D1A

Single-core pvc-insulated cables, non-armoured, with or without sheath

(COPPER CONDUCTORS) BS6004, BS6231, BS6346

Ambient temperature: 30°C

CURRENT-CARRYING CAPACITY (amperes) Conductor operating temperature: 70°C

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	Vertical flat spaced	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	20	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

TABLE 4D1B

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

Conductor cross-sectionl 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 Methods 1 & 11 (flat and touching)			Reference Method 12 (flat spaced*)		
1	2	3			4			5			6			7			8			9		
(mm²)	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	0.41	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	0.30	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

3.5.4 Voltage Drop (Regulation 525 & Appendix 4)

The second consideration in selecting the conductor size is that of voltage drop. Here only static voltage drop (exclude starting voltage drop, e.g. feeders for motors) calculations will be illustrated.

In **Table 4D1B to 4L4B** of SS638, values of voltage drops in ***millivolts per ampere per metre*** run of cables have been included for each size of conductor as well as for different types of cables under different cable installation method. This is to facilitate the selection of conductor size.

The conductor size of a cable selected for a particular application must be such that excessive voltage drop does not occur when the conductor is carrying maximum current that it has to carry or the current that it is assumed it will be required to carry as determined by max demand current calculations.

The voltage drop on a cable conductor within the installation shall not exceed a value appropriate to the safe functioning of the associated equipment in normal service.

E.g. The above requirements are deemed to be satisfied for a supply if the voltage drop between the origin of the installation (usually the supply terminals) and a socket-outlet or the terminals of the fixed current-using equipment does not exceed **4%** of the **nominal voltage of the supply.**

a) For single-phase of 230 V
   $\mathbf{V_p}$ (permissible voltage drop) = 230 x 0.04 = 9.2 V

b) For three-phase, 400 V
   $\mathbf{V_p}$ = 400 x 0.04 = 16 V

In practice, voltage drop calculation is not necessary for final circuit of a domestic installation if route length is not greater than 25 m, but for mains and sub-mains, the calculation is a must.

The following simple equation can be used in the calculations:

$$V_d = \frac{V_C \times I_b \times L}{1000}$$

where V_d = actual voltage drop in Volts

V_c = volt drop in mV/A/m (as given in tables)

L = route length in metres

I_b = maximum load current or maximum demand current

Note: i) To convert single phase voltage drop mV/A/m values to three phase values, multiply the single phase values by 0.866

ii) To convert 3-phase to single phase values multiply the 3-phase values by 1.155

iii) For our purpose, we shall be using impedance values $(mV/A/m)_Z$ for our calculations for conductors greater than 16 mm^2

For cables having conductors of **16mm^2** or less cross-sectional area their inductances can be ignored and $(mV/A/m)_r$ values only are tabulated.

Therefore Voltage drop = (V_{cc} x I_b x length) /1000

For cables having conductors greater than **16mm^2** cross-sectional area the impedance values are given as $(mV/A/m)_Z$ together with the resistive component $(mV/A/m)_r$ and the reactive component $(mV/A/m)_X$.

Therefore when power factor(θ) is unknown

Voltage drop =(V_{ccz} x I_b x length)/1000 .

Where power factor(θ) is known,

Voltage drop = {($V_{ccr}\cos\theta$ + $V_{ccx}\sin\theta$) x I_b x length}/1000

This will result in a smaller voltage drop and therefore a smaller cross-sectional area which can be significant for large cables.

An example of the voltage drop table (for PVC insulated single core conductor) is shown in Table 4D1B. (Table 4D1A and Table 4D1B are the current currying capacities and voltage drop tables for Single-core PVC insulated copper cables. In fact all such tables are in pairs.)

Example 3.7

A circuit feeding a three-phase heater of 10kW is to be wired in three-core PVC insulated copper cable. The distance of the load is 100 metres away from the circuit breaker protecting it. The ambient temperature is 35^{O}C and the circuit is to be installed in metallic conduit for the entire run of the circuit on wall. There is to be no other circuit sharing with the cable in the conduit. Determine:

(i) the design current of the load
(ii) the current rating, In of the circuit breaker
(iii) the cross-sectional area of the cable to be used taking into account the voltage drop requirement

Solution (to Example 3.7)

(i) First find the designed current:

$$I_b = \frac{P}{\sqrt{3}.V_l.\cos\theta} = \frac{10000}{\sqrt{3}(400)(1)} = 14.43A$$

(ii) Choose I_N = 15A or 16A (assume **we choose 16A**)

(iii) State the correction factors, Ca = 0.94, Cg = 1, Ci = 1.

$$I_t \geq \frac{I_N}{C_a \times C_g \times C_i} = \frac{16}{0.94 \times 1 \times 1} = 17.02A$$

From Table 4D2A, Ref. Method 3 column 5,
choose **2.5 mm^2 size cable**.

Check voltage drop: V_C = 15 mV/A/m from Table 4D2B

$$V_d = \frac{V_c \times I_b \times L}{1000} = \frac{15(14.4)(100)}{1000} = 21.6V$$

This is not acceptable as it is greater than the max allowable V.D. of 16V (= 4% of 400V)

Reselect one size higher, i.e. **4 mm^2**

$$V_d = \frac{V_c \times I_b \times L}{1000} = \frac{9.5(14.4)(100)}{1000} = 13.7V$$

This is acceptable as it is less than the maximum allowable voltage drop of 16V (= 4% of 400V)

TABLE 4D2A

Multicore pvc insulated cables, non armoured (COPPER CONDUCTORS)

CURRENT-CARRYING CAPACITY (amperes)

Ambient temperature 30° C
Conduuctor operating temperature 70 ° C

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 single phase a.c. or d.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
(mm²)	(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

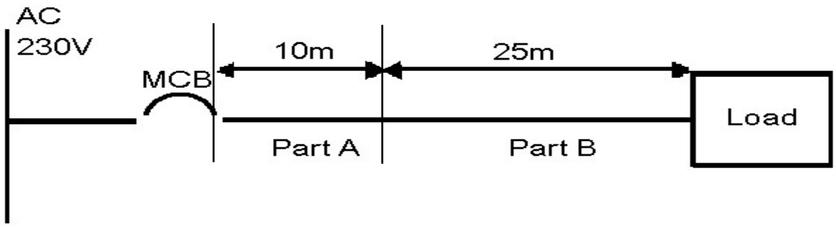
VOLTAGE DROP (per ampere per metre)

TABLE 4D2B

Conductor operating temperature:

Conductor cross-sectional area	Two core cable, d.c.	Two core cable, single phase a.c.			Three or four core cable, three phase a.c.		
1	2	3			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

Example 3.8



In the Fig. above, a single-phase circuit is used to supply electricity to a heater load, rated at 5 kW, 230V located 35 m away from the Type C MCB (BS EN60898). The circuit runs through two parts, i.e. Part A and Part B, of the building which are being subjected to different conditions as follows:

Part A : the circuit is run in surface trunking together with one other circuit, ambient temperature at 30^0 C

Part B : the circuit branches out and is run (alone) in concealed conduit in a wall to the heater load in the kitchen. The ambient temperature at this part can reach a high of 40^0 C

(i) Determine the designed current of the load and the nominal rating of the protective device.

(ii) Determine the minimum cable size required where two-core XLPE-insulated (thermosetting) copper cable is used.

(iii) Calculate its voltage drop and state whether it meets the SS638:2018 voltage drop requirement.

Choose Type C MCB ratings with reference to standard sizes as in Topic 5.

Solution to Example 3.8

(i) First find the designed current:

$$I_b = \frac{P}{.V\cos\theta} = \frac{5000}{230(1)} = 21.74A$$

Therefore, choose I_N = 25 A { Type C MCB }

(ii) **Part A:**

C_a = 1 ; C_g = 0.8 ; C_i = 1

Reference Method 3

$$I_t \geq \frac{I_N}{C_a \times C_g \times C_i} \geq \frac{25}{1 \times 0.8 \times 1} \geq 31.25A$$

Hence, <u>choose 4 mm² XLPE cable</u> (Table 4E2A)

TABLE 4E2A

Multicore cable having thermosetting insulation, non armoured
(COPPER CONDUCTORS)

CURRENT CARRYING CAPACITY (amperes) BS 5467 BS 7211 Ambient temperature 30 °C Conductor operating temperature 90 °C

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 etc.)		Reference Method 1 (clipped direct)		Reference Method 11 (on a perforated cable tray) or Reference Method 13 (free air)	
	2core cable* single phase a.c or d.c	3 or 4 core cable* three phase a.c.	2 core cable* single phase a.c or d.c	3 or 4 core cable* three phase a.c.	2 core cable* single phase a.c. or d.c.	3 or 4 core cable* three phase a.c.	2 core cable* single phase a.c. or d.c.	3 or 4 core cable* three phase a.c.
1	2	3	4	5	6	7	8	9
(mm²)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1	14.5	13	17	15	19	17	21	18
1.5	18.5	16.5	22	19.5	24	22	26	23
2.5	25	22	30	26	33	30	36	32
4	33	30	40	35	45	40	49	42
6	42	38	51	44	58	52	63	54
10	57	51	69	60	80	71	86	75
16	76	68	91	80	107	96	115	100
25	99	89	119	105	138	119	149	127
35	121	109	146	128	171	147	185	158
50	145	130	175	154	209	179	225	192
70	183	164	221	194	269	229	289	246
95	220	197	265	233	328	278	352	298
120	253	227	305	268	382	322	410	346
150	290	259	334	300	441	371	473	399
185	329	295	384	340	506	424	542	456
240	386	346	459	398	599	500	641	538
300	442	396	532	455	693	576	741	621
400	-	-	625	536	803	677	865	741

Part B:

$C_a = 0.91$; $C_g = 1$; $C_i = 1$

Reference Method 3

$$I_t \geq \frac{I_N}{C_a \times C_g \times C_i}$$

$$\geq \frac{25}{0.91 \times 1 \times 1}$$

$$\geq 27.47A$$

hence choose 2.5 mm² XLPE cable (Table 4E2A)

Therefore, select 4 mm² XLPE cable for the circuit (based on the largest of the two sections which happens to be the same size)

TABLE 4E2B

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

Conductor Cross-Sectional area 1	2 core cable d.c 2	2 core cable single-phase a.c. 3			3 or 4 core cable three phase a.c. 4		
(mm²)	(mV/A/m)	(mV/A/m)			(mV/A/m)		
1	46	46			40		
1.5	31	31			27		
2.5	19	19			16		
4	12	12			10		
6	7.9	7.9			6.8		
10	4.7	4.7			4.0		
16	2.9	2.9			2.5		
		r	x	z	r	x	z
25	1.85	1.85	0.160	1.90	1.60	0.140	1.60
35	1.35	1.35	0.155	1.35	1.15	0.135	1.15
50	0.98	0.99	0.155	1.00	0.86	0.135	0.87
70	0.67	0.67	0.150	0.69	0.59	0.130	0.60
95	0.49	0.50	0.150	0.52	0.43	0.130	0.45
120	0.39	0.40	0.145	0.42	0.34	0.130	0.37
150	0.31	0.32	0.145	0.35	0.28	0.125	0.30
185	0.25	0.26	0.145	0.29	0.22	0.125	0.26
240	0.195	0.20	0.140	0.24	0.175	0.125	0.21
300	0.155	0.160	0.140	0.21	0.140	0.120	0.185
400	0.120	0.130	0.140	0.190	0.115	0.120	0.165

(iii) The voltage drop for the circuit is calculated as follows:

$$V_d = \frac{V_c \times I_b \times L}{1000} = \frac{12(21.74)(35)}{1000} = 9.13V$$

where V_C = 12 mV/A/m (Table 4E2B)

Hence, it complies with the regulation since it is less than 4% of 230 V (i.e. 9.2 V)

Example 3.9

A 3-phase motor with a full load current of 100A and a power factor of 0.8 is to be fed by three single-core, PVC insulated and PVC sheath, copper conductor mounted on a horizontal cable tray 80m away from the MCCB. Determine the size of the conductor if the permissible voltage drop from the MCCB to the motor is 2%. Ambient temperature is 30°C.

Solution to Example 3.9

The designed current: I_b = 100A, pf = cosØ = 0.8, therefore sinØ = 0.6

C_a = 1; C_g = 1; C_i = 1

Therefore $I_t \geq$ 100A, from Table 4D1A, column 9, a 25mm^2 cable with a rating of 112A is initially selected. The voltage drop is calculated as

Voltage drop = *{(V_{ccr}cosØ + V_{ccx}sinØ) x I_b x length}/1000*
= {(1.5x0.8 + 0.175x0.6} x 100 x 80}/1000
= 1.305 x 100 x 80/1000 = 10.44V or 2.61% of 400V

(cosØ = 0.8,
Ø = cos^{-1} (0.8) = 36.86°
sinθ = sin 36.86° = 0.6)

The calculated voltage drop of 2.61% exceeds the 2% requirement, thus the next higher cable size of 35mm^2 is selected and the voltage drop is recalculated,

Voltage drop = {(1.1x0.8 + 0.17x0.6} x 100 x 80}/1000
= 0.982 x 100 x 80/1000 = 7.856V or 1.96% of 400V

Which is acceptable, therefore 35mm^2 cables is selected.

3.6 Protection Against Short Circuit Current (Fault Protection) [434]

For protection against short circuit, the overcurrent device must be able to:
a) Withstand the short circuit current (device breaking capacity); and
b) Disconnect sufficiently quickly to prevent damage to the cables.

Determination of Prospective Short-Circuit Current I_F

The regulations require that the prospective short circuit current I_F at every relevant point of the complete installation must be determined. This is done either by measurement or calculation. Measurement has limited application because it is concerned with existing supplies. The calculation requires knowledge of the system impedance. The value of I_F obtained is usually at the load terminals of the protective device at the distribution board.

From Ohms' Law,

$$I_F = \frac{V_{ph}}{Z_s}$$

Z_S is the total earth fault loop impedance of the short circuit which includes the impedance of the supply transformer secondary winding and impedance of the cables up to the point of fault. The impedance of the cables from the transformer to the fault will depend on their size and on their length.

It is therefore only possible to give a value for prospective short circuit current (prospective fault current) for a specific point in the installation but not on the whole installation. However it is obvious that the prospective short circuit current is greatest at the source and fall away from the source which has been explained and illustrated in the previous note.

The basic requirement for protection against short circuit is that all currents caused by a short circuit at any point in the circuit shall be interrupted in a time not exceeding that which will bring the cable conductors to the admissible limiting temperature.

The maximum time, t, for which the protective device should allow the short circuit to persist, is derived from the adiabatic equation:

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

where I = the effective short circuit current (r.m.s.) in amperes
S = the cross-sectional area of cpc in mm²
k = factor for a particular type of cable (Table 54.3 page 120 or Table 43.1 of SS638 : 2018 gives values for common materials)
t = duration of short circuit in seconds

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

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

[a] This value shall be used for bare cables exposed to touch.

Fault current through a conductor raises the temperature of the conductor and the amount of heating is proportional to the value of current. The insulation and cable will not suffer any permanent damage if the

Thermal capacity of the conductor (**k^2S^2**) ≥ Let through energy of the protective device (**I^2 t**).

Example 3.10

Given that the short circuit current = 10 kA, K = 115, S = 10 mm^2 PVC insulated cable, circuit breaker operation time, t = 0.1 sec. Can the circuit breaker protect the conductor from short circuit current?

Solution (to Example 3.10)

The min. conductor size required is:

$$S = \frac{\sqrt{I^2 t}}{K} = 27.5mm^2$$ this shows the conductor size is not adequate.

From Table 4D1A of SS638:2018 in this notes, standard single-core pvc-insulated, non-armoured cable of size 35mm^2 is suitable for use.

Example 3.11

You are required to design the cabling to a riser circuit where the highest loading is expected to be 20kW, 400V, pf 0.85. Single-core PVC sheathed copper conductors are being used and the circuit is run in metal trunking. The temperature inside the riser is expected to be about 35^0 C.

(i) Find the design current of the circuit and select the appropriate Type B miniature circuit breaker.

(ii) Select the minimum cable size, taking into account the correction factors applicable to the circuit.

(iii) If a short-circuit current of 1000A flows through the circuit, will the circuit breaker be able to protect the cable? Given that K = 115.

Choose Type B MCB ratings with reference to standard sizes as per T/I characteristics.

Solution to Example 3.11

(i)

$$\begin{aligned} I_b &= \frac{P}{.\sqrt{3}.V_l \cos\theta} \\ &= \frac{20000}{\sqrt{3}(400)(0.85)} \\ &= 34A \end{aligned}$$

Therefore, choose I_N = 40 A (standard MCB ratings from T/I curves)

(ii)

$$\begin{aligned} I_t &\geq \frac{I_N}{C_a \times C_g \times C_i} \\ &\geq \frac{40}{0.94 \times 1 \times 1} \\ &\geq 42.6A \end{aligned}$$

From Table 4D1A, **choose 10 mm^2** cable

(iii) Let through energy = $(I_F)^2$ t = $(1000)^2$ $(0.01)^2$ = 10,000 J

Heat capacity of cable = K^2 S^2 = $(115)^2$ $(10)^2$ =1,322,500 J

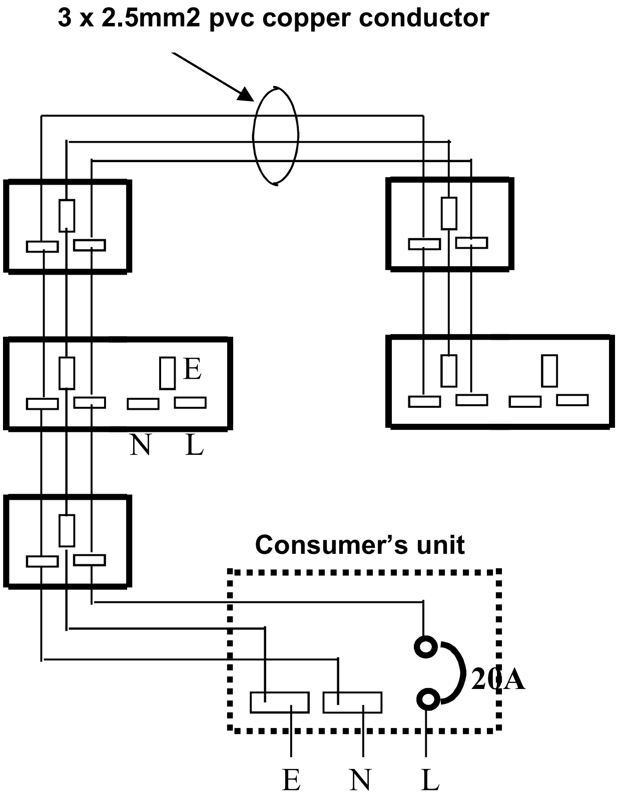
Since = K^2 S^2 ≥ $(I_F)^2$ t , <u>therefore, cable is protected</u>

3.7 Sizing of Final Socket Outlet Circuits

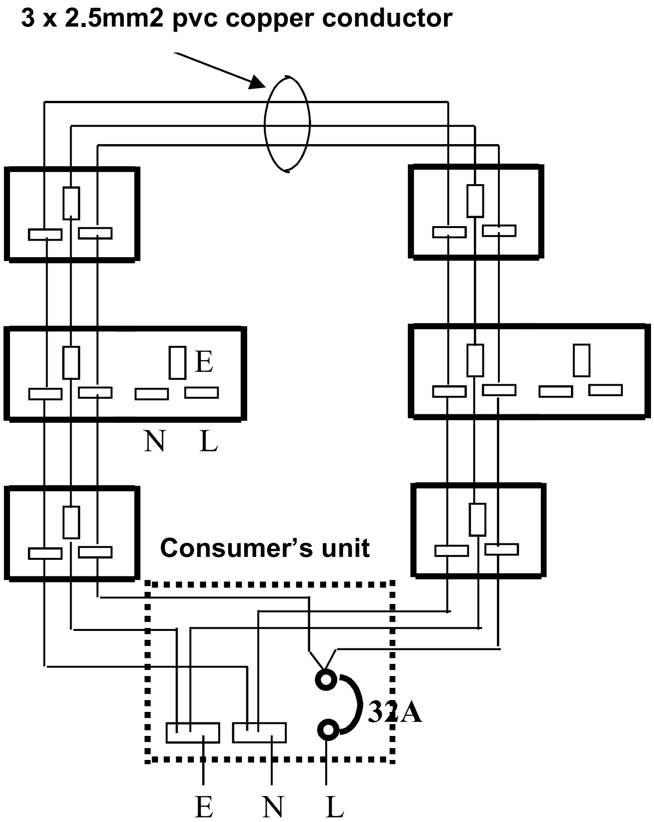
Final socket outlet circuit (schematic diagram shown below) can be divided into two main types:

(i) Radial socket outlet circuits

(ii) Ring socket outlet circuits



Radial circuit with BS 1363 socket outlets



Ring circuit with BS 1363 socket outlets

There will be **no limit** to the number of socket outlets to be connected to either the ring or radial socket outlet circuits. The total number of fused spurs is also unlimited but the number of non-fused spurs should not exceed the total number of socket outlets and items of stationary equipment connected directly in the circuit.

A non-fused spur feeds only one single or one twin socket outlet or one permanently connected equipment, such as at joint boxes or at origin of the circuit in the distribution board.

A fused spur is connected to the circuit through a fused connection unit, the rating of the fuse in the unit should not exceed that of the cable forming the spur, and not exceeding 13A.

The total floor area served by a typical radial or ring final socket outlet circuit should comply with the requirements shown below in Table 5A.

Table 5A
Final circuits using BS 1363 socket outlets

Type of circuit	Overcurrent protective device		Minimum conductor size			
	Rating	Type	Copper conductor, rubber or pvc insulated cables	Copper-clad aluminium conductor pvc insulated cables	Copper conductor mineral insulated cables	Maximum floor areas served
1	2	3	4	5	6	7
A1 Ring	A	A	mm^2	NA	mm^2	m^2
	30 or 32	Any	2.5	NA	1.5	100
A2 Radial	30 or 32	Cartridge fuse or circuit breaker	4	NA	2.5	75
A3 Radial	20	Any	2.5	NA	1.5	50

Note: The number of socket outlets that can be connected to each circuit is unlimited

Example 3.12

An electrical installation in domestic premise having a floor area of 120 m^2 for the living and dining areas requires 14 number of 13 A switched socket outlets to be installed. Determine the numbers of ring circuit required to meet Table 5A regulation.

Solution (to Example 3.12)

From Table 5A, the maximum area that can be served by a ring circuit (Type A1) is 100m^2.

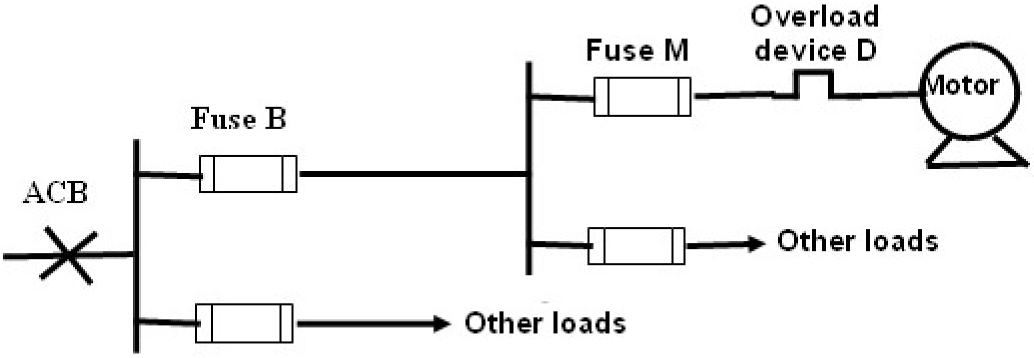
Therefore, minimum no. of circuits required ≥ 120/100
≥ 1.2
= **2 circuits**

(**round up** as 1 circuit cannot serve 120m^2)

3.8 Discrimination

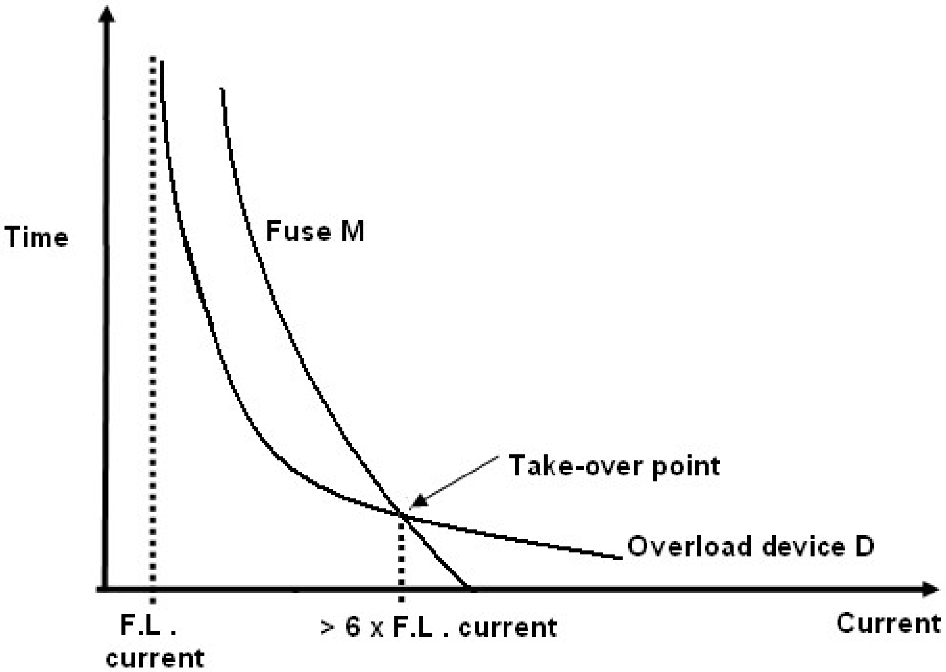
Discrimination or selective tripping is the co-ordination of protective devices such that the protective device nearest the fault operates to clear the fault first leaving upstream protective devices unaffected.

The example below will demonstrate the co-ordination of protective devices to achieve discrimination.



3.8.1 Co-ordination between Fuse and Overload Device

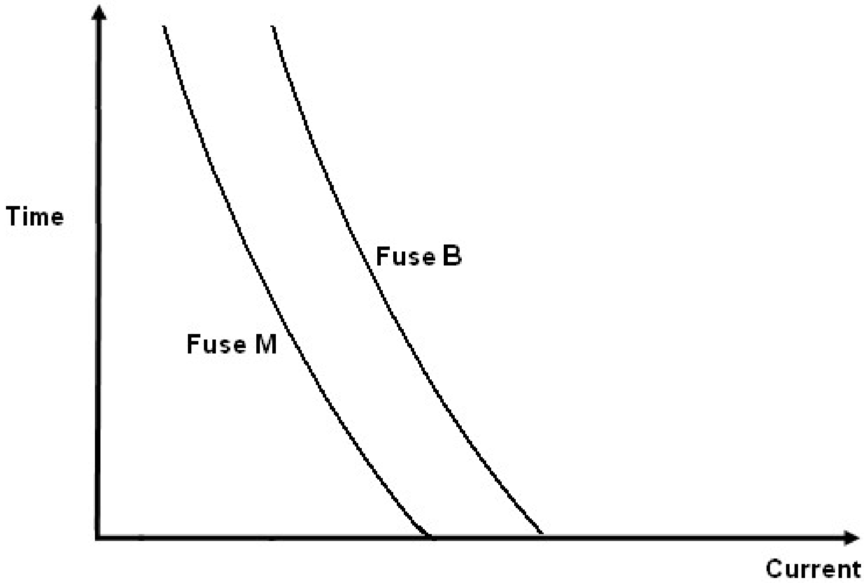
The first stage of protection co-ordination is between the overload thermal relay D and the final circuit fuse M.



The rating of the fuse is so selected that its time-current characteristics intersect the overload relay characteristics at not less than 6 times the full load current of the motor as shown.

The intersection of the two characteristics curves is referred to as the ***take-over point***. Before the take-over point, the overload thermal relay will operate first with the final circuit fuse M operating as back-up protection but after the take-over point under short circuit condition the fuse M will operate first to break the short circuit current.

3.8.2 Co-ordination between Fuse M and Fuse B



Thus in the event of a short circuit in the final circuit, Fuse M will operate first with Fuse B acting as the back-up fuse. Discrimination under these conditions can be relied on provided the arcing time of the fuse is small compared to the pre-arcing time.

However, at higher values of short-circuit current, since the pre-arcing time is short and since the time-current characteristics are based on pre-arcing time, discrimination from time-current characteristics cannot be predicted when the arcing time assume a higher proportion of the total operating time. Discrimination can only be ensured by calculating the I^2t summation during pre-arcing and arcing times.

As accurate selection of protective devices can only be made by reference to the individual I^2t (amperes^2 /second) characteristics described in manufacturer's literature.

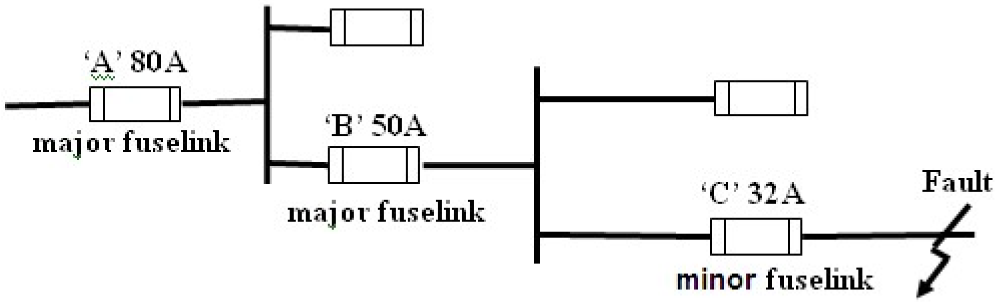
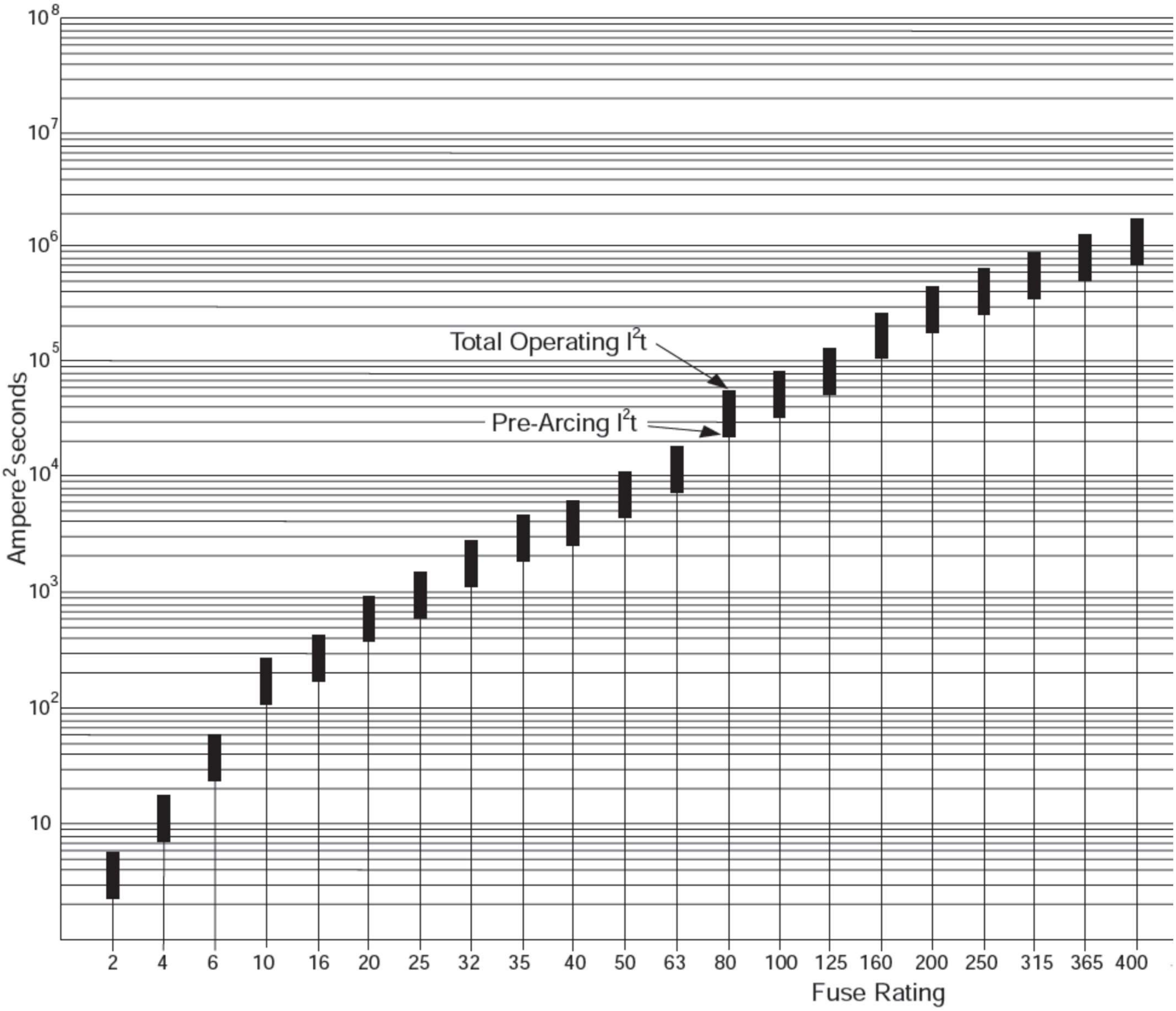


Figure illustrating the principle of discrimination between Fuses

An example will demonstrate the principle. In the single-line diagram below, 'A' is a BS88 fuselink rated at 80A, 415V (breaking capacity 80 kA), which will discriminate with 'B' a 50A, 415V fuselink (breaking capacity 80 kA) at a fault level of 300A. Reference to time/current characteristics of each device 'A', 'B' and 'C' will show that the operating time for the 32A fuse is 0.15 second and the 50A fuselink operating time is one second.
Reference to the Figure below will show that let-through current (total I^2t) of the minor protective device (2.9 kA^2s) does not exceed the pre-arcing current of the 50A major device (4.4 kA^2s) and the pre-arcing current of the 80 kA major device (22 kA^2s). Thus discrimination is achieved.

I^2 t Characteristics with a prospective current up to 80kA, 0.15 p.f. at 415 Volts Type T

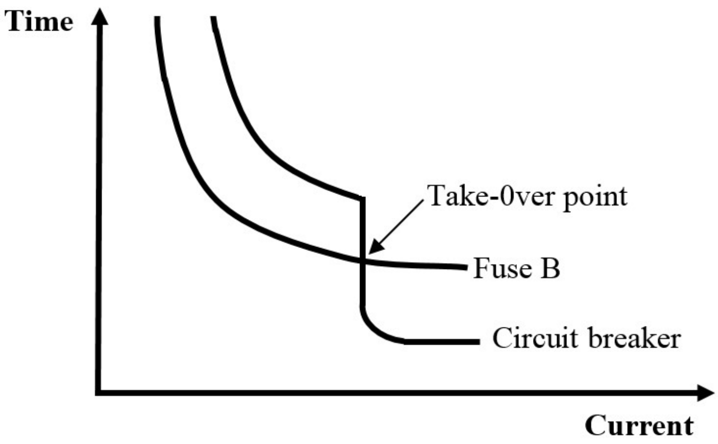


Discrimination between fuse-links is achieved when the total I^2t of the minor fuse-link does not exceed the pre-arcing I^2t of the major fuse-link

Co-ordination between Fuse B and Circuit Breaker

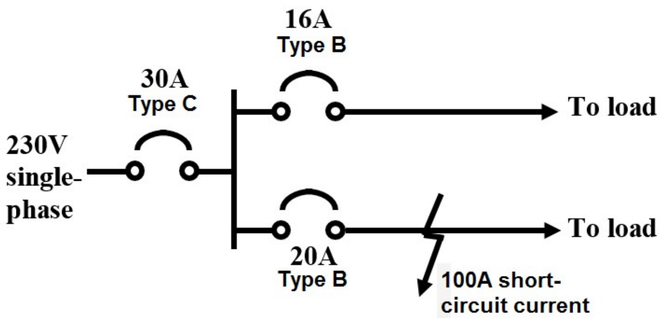
For this circuit, the third stage of protection co-ordination is between the sub-circuit Fuse B and the main circuit breaker A.

In this case, the time-current characteristics of the circuit breaker must be everywhere above that of the Fuse B except after the take-over point corresponding to a severe short circuit, when the circuit breaker can be designed to operate instantaneously.

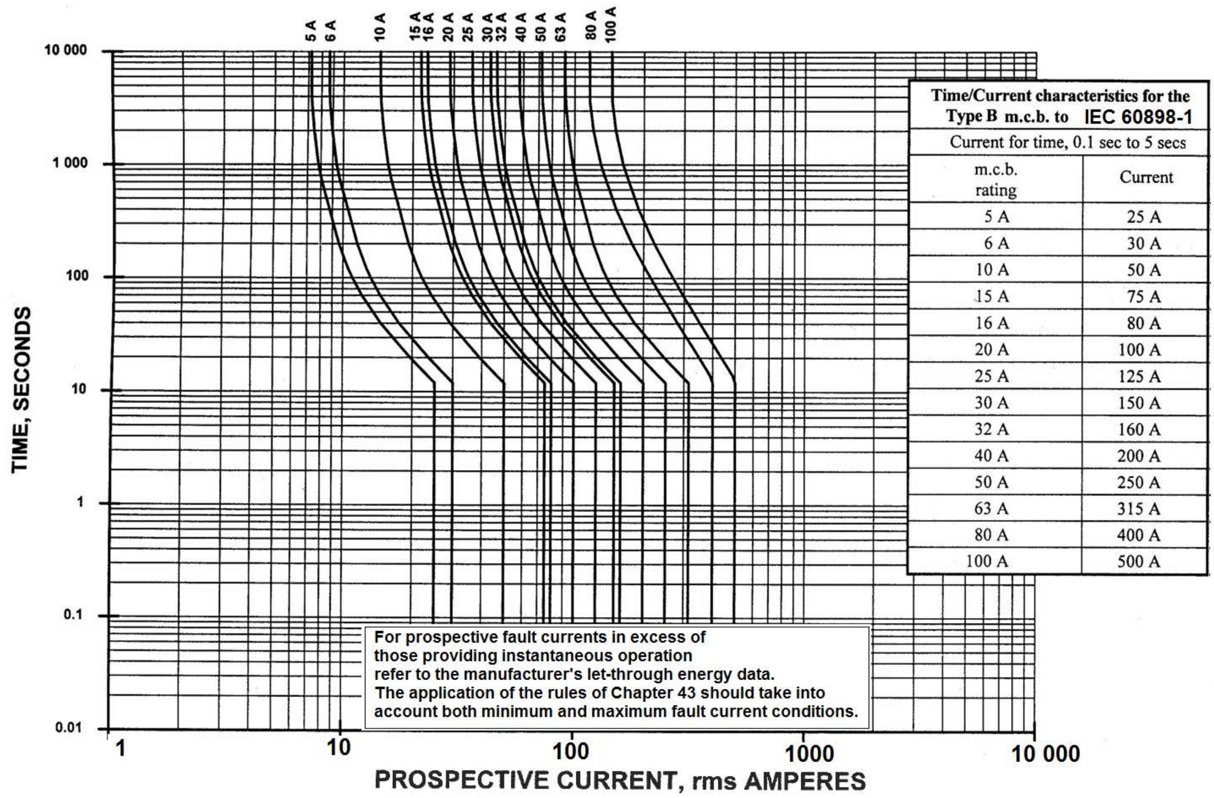


Example 3.13

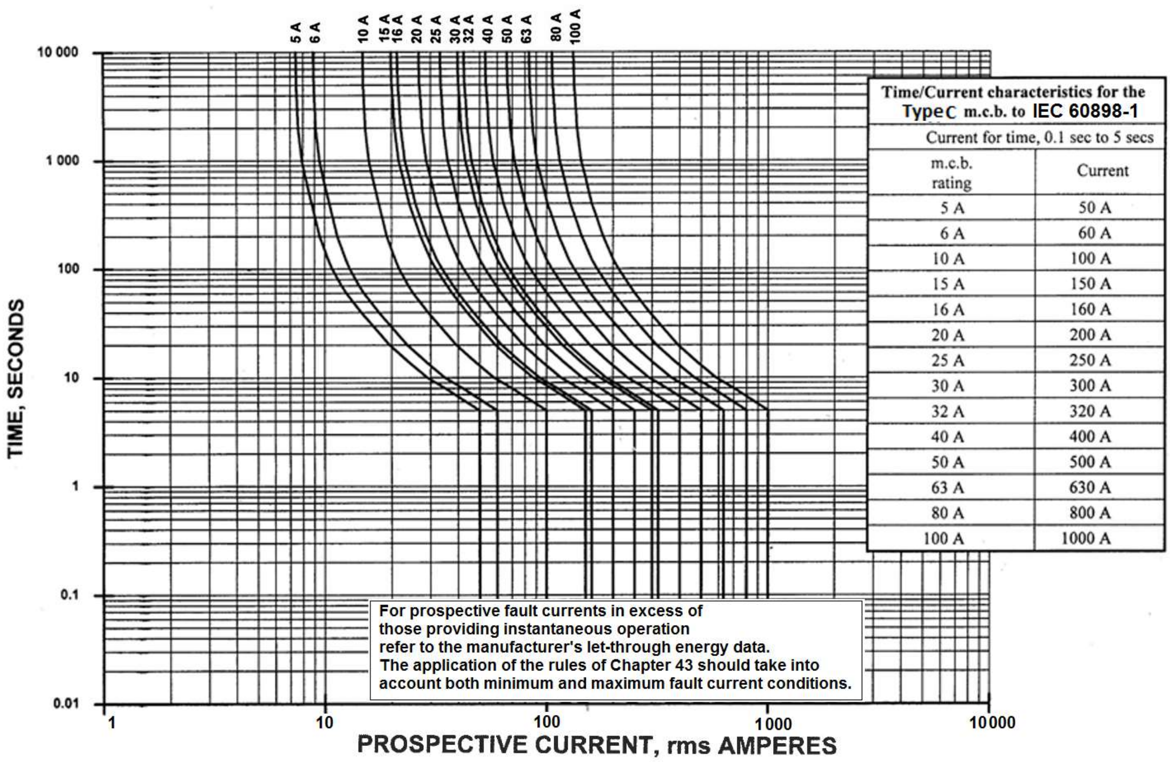
A short circuit current of 100A occurred downstream in a circuit protected by a 20A Type B miniature circuit breaker as shown in Figure A10. From the time/current characteristic curves, determine the corresponding disconnection time for the 20A Type B MCB and 30A Type C MCB. State clearly whether discrimination is achieved in this case.



Solution (to Example 3.13)
From T/I curve for 20A Type B MCB, tripping time = 0.1 s
From T/I curve for 30A Type C MCB, tripping time is 35 to 38 s
As the 20A Type B MCB nearest the fault has a tripping time that is shorter than 30A Type C MCB upstream, hence discrimination is achieved.



Time/Current characteristics for the Type B m.c.b. to IEC 60898-1	
Current for time, 0.1 sec to 5 secs	
m.c.b. rating	Current
5 A	25 A
6 A	30 A
10 A	50 A
15 A	75 A
16 A	80 A
20 A	100 A
25 A	125 A
30 A	150 A
32 A	160 A
40 A	200 A
50 A	250 A
63 A	315 A
80 A	400 A
100 A	500 A



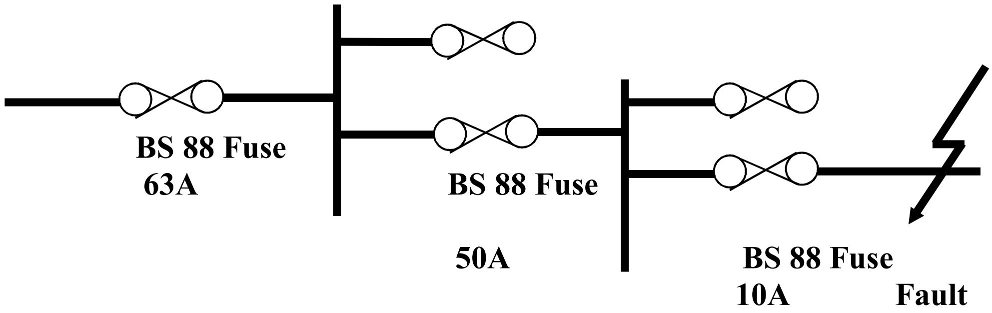
Time/Current characteristics for the Type C m.c.b. to IEC 60898-1	
Current for time, 0.1 sec to 5 secs	
m.c.b. rating	Current
5 A	50 A
6 A	60 A
10 A	100 A
15 A	150 A
16 A	160 A
20 A	200 A
25 A	250 A
30 A	300 A
32 A	320 A
40 A	400 A
50 A	500 A
63 A	630 A
80 A	800 A
100 A	1000 A

Example 3.14

In the single-line diagram below, 415V BS 88 HBC fuses are used in the design. From their I^2 t characteristics, given a high current fault as shown, determine:

(i) the energy let-through (i.e. I^2 t) of the devices

(ii) whether discrimination are being achieved? Please give reason.



Solution (to Example 3.14)

The total I^2 t of the downstream BS 88 fuse must be less than the pre-arcing I^2 t of the upstream device.

(i) From BS 88 I^2 t curve,

For the 63A fuse
Pre-arcing I^2 t = 7.2 kA^2 s
Total I^2 t = 18 kA^2 s

For the 50A fuse
Pre-arcing I^2 t = 4.4 kA^2 s
Total I^2 t = 11 kA^2 s

For the 10A fuse
Pre-arcing I^2 t = 110 A^2 s
Total I^2 t = 280 A^2 s

(ii) Based on above criterion, discrimination is achieved between 50A and 10A fuse; since 4.4 kA^2 s (50A) > 280 A^2 s (10A).

However, no discrimination is achieved between 63A and 50A fuse since the pre-arcing I^2 t of the 63A fuse (= 7.2 kA^2) is not greater than the total I^2 t of the 50A fuse (= 11 kA^2).

Chapter 4

Control Circuits

Objectives

On successful completion of this chapter, you will be able to :

- Use symbols to draw ladder diagrams for the control and power circuits.
- Recognise a two-wire and a three-wire control.
- Understand the working of the on-delay timer, relay, contactor and the various components.
- Design the latching, flickering circuits and other similar control circuits.
- Explain the operation of direct-on-line starter used in the control of the motor to perform the various assigned tasks.

Overview

Motors controls and control circuits cover numerous types of control device/component like pushbutton switch, relay, contactor, timer, etc. Typical industrial control circuits such as direct-on-line (DOL) starter is explained to help the student understand, to read and interpret schematic diagrams. This is supplemented by the relevant hands-on in the laboratory.

A simple motor control uses manual pushbutton to start, stop and change operation of a motor or electrical load. This simple control circuit can be developed into a complex control circuit using Programmable Logic Controller to sense movement, level, pressure, etc for motor's position control. The learning of DOL starter provides a basis for the control and operation of single-phase or three-phase motors. The control and power circuits of the DOL starter enable further understanding of star-delta starter, reversing starter, auto-transformer starter, sequencing control, etc. These starters are widely used in the control of motors in industries.

The two types of control circuits are studied, viz. the two-wire and the three-wire control circuits. These are developed into starter circuits, remote and local controlled circuits, jogging circuit, etc.

Resources and References

To supplement the learning of this chapter, the following resources/references can be harnessed :

- Tutorial 4
- Laboratory Hands-on
- Singapore Standard, Code of Practice CP5:1998
- Singapore Standard SS638:2018
- Electrical Motor Control by Gary Rockis/Glen Mazur
- Modern Industrial/Electrical Motor Controls by Thomas E. Kissel

Chapter 4

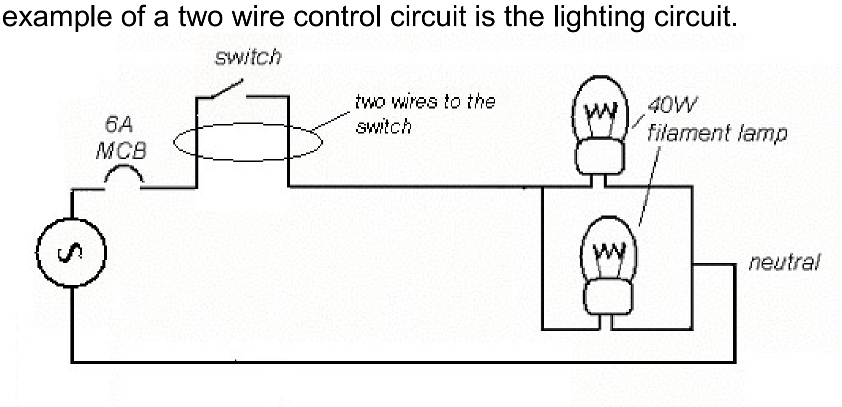
Control Circuits

4.1 Types of Control Circuit

There are two basic types of control circuits: **three-wire** circuits and **two-wire** circuits.

4.1.1 Two-wire Control Circuit

The simplest example of a two wire control circuit is the lighting circuit.



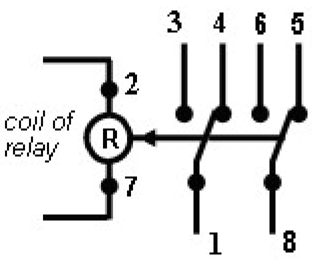
If there is a power interruption, the switch will not open. Upon restoration of power, the lamps will light up again without human intervention. Two-wire control circuits are used in application where this self-restarting characteristic is desirable. This enables equipment such as blower fans and pumps to restart after a power failure without an electrician having to walk around the plant to restart each equipment.

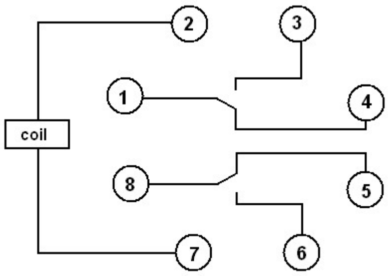
Since two-wire control does permit automatic restarting of equipment, it could become a safety hazard to people working around the equipment. For this reason, two-wire controls should be used only when there is little or no danger of a person being injured if the equipment should suddenly restart after a power failure.

4.1.2 Three-wire Control Circuits

The two-wire control can be modified to a three-wire control by replacing the switch with a momentary contact stop and start push button and a relay.

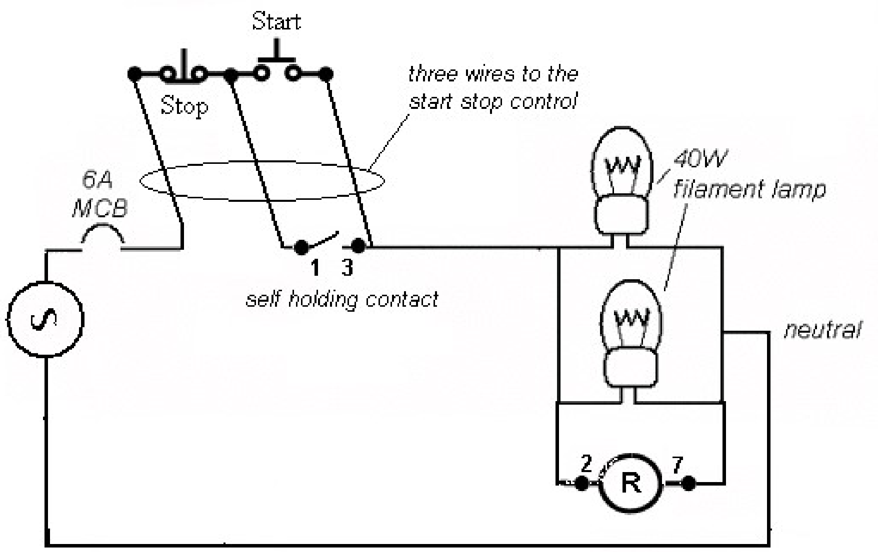
A relay consists of a coil (solenoid) and normally two pairs of normally open and closed contacts.





The numbers in the diagram indicates the pin number for connecting to the relay. i.e. the coil of the relay is located between pin 2 and pin 7. A normally open contact is available between pin 1 and pin 3.

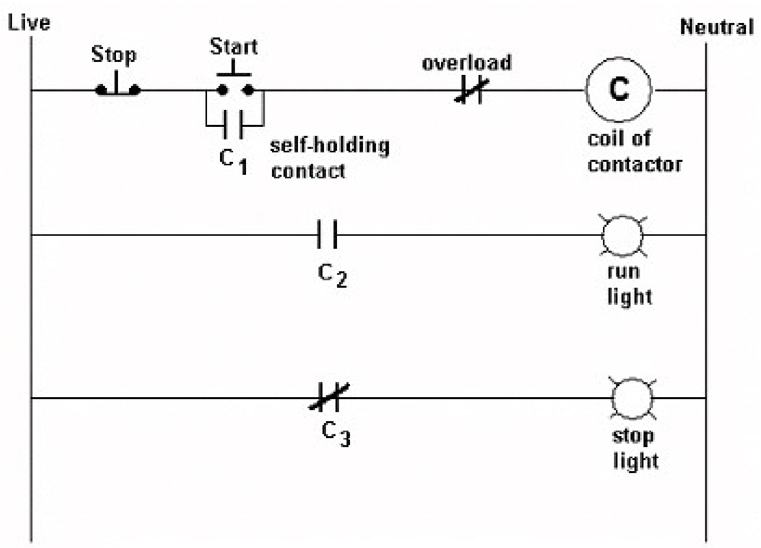
When there is no supply at the coil, the normally open contact between pin 1 and pin 3 is open. When the coil is energised (supply on) the normally open contact is now closed, i.e. pin 1 is shorted to pin 3. When supply is turned off, the contact between pin 1 and pin 3 reopens.



In the three-wire control circuit when there is a power interruption, the circuit will ceased to function and will not restart when power is restored to the system. This is especially important in automated process where the process must be restarted in a particular sequence in the event of a power failure. Using three-wire control, various other control functions can be introduced, such as remote start-stop, sequencing and other safety controls.

4.1.3 Simple rules in setting up control circuits

(i) The control circuit is also called ladder diagram. Each rung of the ladder, i.e. each line between the live and neutral must have one and only one load. Either a coil or a lamp. No load means _________________. Two loads in series means the circuit will not work, why?



(ii) To stop the circuit, connect the element of control (either a stop button or normally closed contact) in series with the stop button.

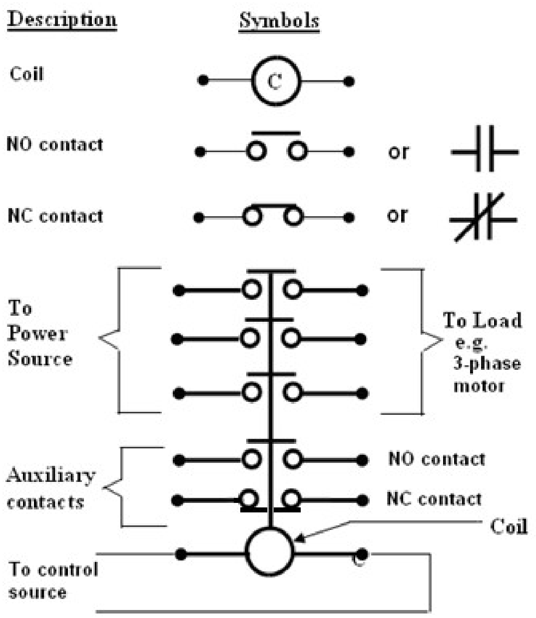
(iii) To start the circuit, connect the control element in parallel with the start button. (Remote start/stop can be implemented.)

4.2 Components of Control Circuits

4.2.1 Contactors

This is a mechanical switching device controlled by an electromagnet. When the coil of the electromagnet is energised, the contacts on the moving parts of the electromagnet close on the fixed contacts, thus completing the circuit between the main supply and the load. As soon as the coil of the contactor is de-energised, the contacts open under the effect of the return spring.

The contactor has a coil and a plunger that moves through an opening in the coil. A contactor may have multiple pairs of contacts and these contacts are connected to the moving plunger. When the coil is energised, the plunger moves down due to the forces produced by the magnetic field. The moving plunger will cause the closed contacts to open; open contacts to close. These contacts are referred to as normally-closed (NC) contacts; or normally-open (NO) contacts; i.e. when the coil is in the de-energised state.



Contactor & Symbols

4.2.2 Auxiliary Contacts

These are additional contacts operating simultaneously with the main contacts to provide self-holding and interlocking as well as signalling in control operation.

4.2.3 Control Relays

Control relays are similar to contactors in operation. They are designed to switch low currents and perform control functions such as interlocking, signalling, sequencing, etc. As the contact ratings are smaller than the contactors, the relays are more compact in size.

The principal differences between the contactor and the relay are in their ***physical size and contact ratings***. Generally, the contactors are bigger sizes and their contact ratings are much higher than that of the relays.

4.2.4 Timers

Time relays are available in two forms:

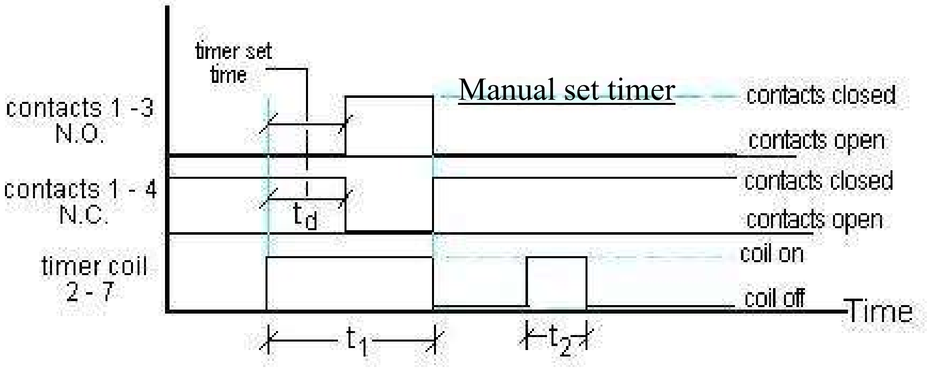
(i) On-delay timer

The contacts are delayed in operation upon energising.

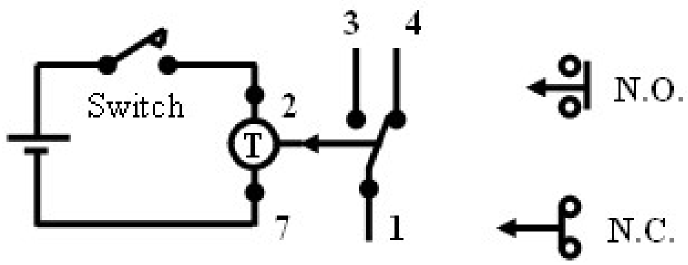
(ii) Off-delay timer

The contacts are activated instantly upon energising but delay in reverting back to original state on de-energising.

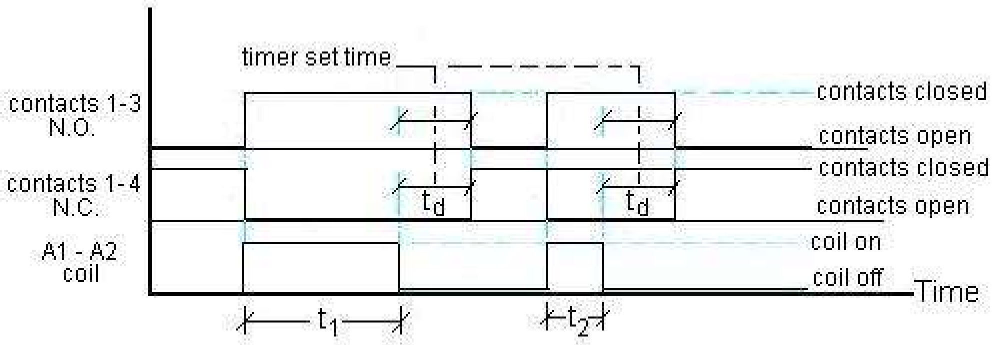
On-delay Timer – Timing Chart



Timing diagram for on-delay timer



Off-delay Timer – Timing Chart



Timing diagram for off-delay timer

4.2.5 Pushbutton Switches

There are of two types:

(i) Non-maintained contact

The contacts remain closed or opened as long as the button is depressed. Once the button is released, a spring will return the contacts to their original states.

(ii) Latching type

When the button is depressed, it remains latched in position and the contacts will remain in their operated condition. To reset, press the button another time, the contacts will return to their original states.

Pushbuttons are available in the N.O. of N.C. types. Many types of operators are available to suit most applications: (1) standard flush head (2) extended head (3) mushroom head

Flush Button Operator

Extended Button Operator

Mushroom Head Operator

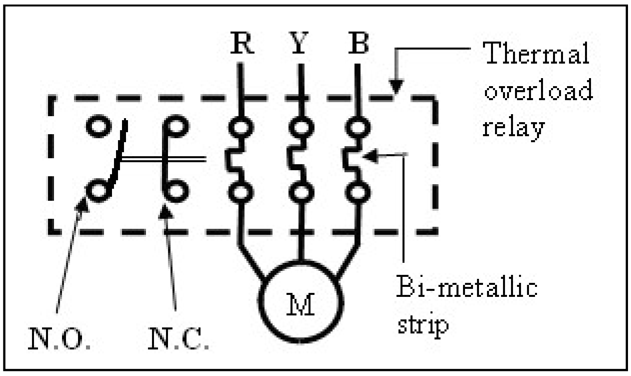
4.2.6 Overload Relays

These relays are provided to give protection against sustained overloading of the motor that might lead to deterioration of the insulation and shortening the lifespan of the motor.

The overload device contains 3 bimetallic elements. Each element is connected in series with each phase of the motor. The elements are mechanical linked by a trip bar to activate the contacts mounted within the unit. Usually, an adjustable knob is provided for setting of the full load current load current of the motor to be protected.

The tripping current is between 1.05 - 1.2 times the current setting.

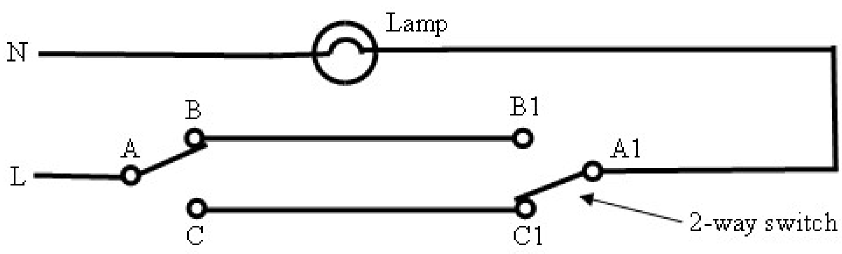
When activated, the overload relay will operate the auxiliary contact (N.C.) which will interrupt the control supply to the contact, thus stopping the motor. The contacts can be reset manually by a reset lever.



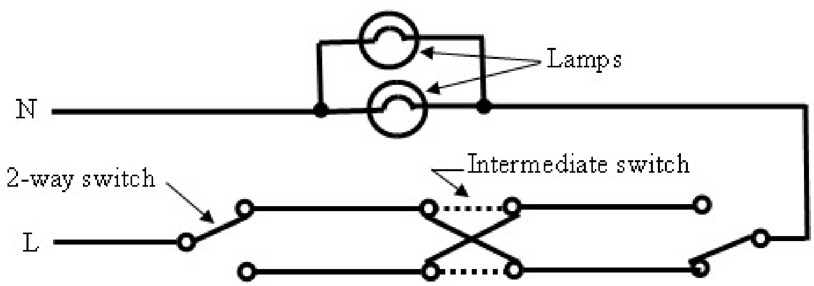
4.3 Lighting Circuits

When it is necessary to control a lighting outlet from two positions, then a 2-way switching circuit may be utilized. When three or more control positions are necessary, then a 2-way intermediate circuit will be required.

Figures below are (i) two-way switching and, (ii) two-way with intermediate switching. The wiring diagrams show one or more lighting outlets can be controlled by two 2-way switches (or by intermediate switches) in any room having more than one entrance door, in a hall or corridor, as well as on a staircase. Note that the 2-way switch has three terminals, one being common, to which the phase conductor is connected.



2-way switching



Use of 2-way and intermediate switching

4.4 Direct-on Line (DOL) Starters

This is a full voltage starter as full line voltage is applied to the motor for starting purpose. As it does not reduce starting current, it is only suitable for use with motors of 2.2 kW and below. One of its basic functions is to provide manual start/stop of the motor. If the motor has stopped because of power failure, the DOL starter would prevent an automatic restarting when power supply is restored.

Fig. 4.4 is the power and control circuits for DOL Starter

Note:

1. The top of the diagram is called the ***power circuit*** as it controls the electrical supply to the load (e.g. a motor). The lower part of the diagram shows the control circuit consisting of control devices to operate the motor.
2. The thermal elements of the overload relay are connected in series with the motor.
3. A normally closed (N.C.) contact of the overload relay is used to trip the motor circuit.
4. Three N.O. main contacts, M1-1, M1-2 and M1-3 of contactor, M1, are connected to the motor in series arrangement. When stopping the motor, these 3 contacts will operate simultaneously to prevent imbalance fault.

The ***control circuit*** operates as follows:

1. When the *START* pushbutton is pressed, contactor M1 energised; M1-4, M1-5, M1-6 and the 3-pole M1-1, M1-2, M1-3 contacts toggle.
2. Motor runs up; *RED* indication light goes off and *GREEN* indication light comes on.
3. Contact M1-4 serves as **self-holding** contact. It will continue to provide a path for current to flow to energise the contactor when the *START* is released.
4. To stop motor from running, press *STOP* button and the contactor, M1 , de-energised. All the M1-contacts de-activate and reset to original state.

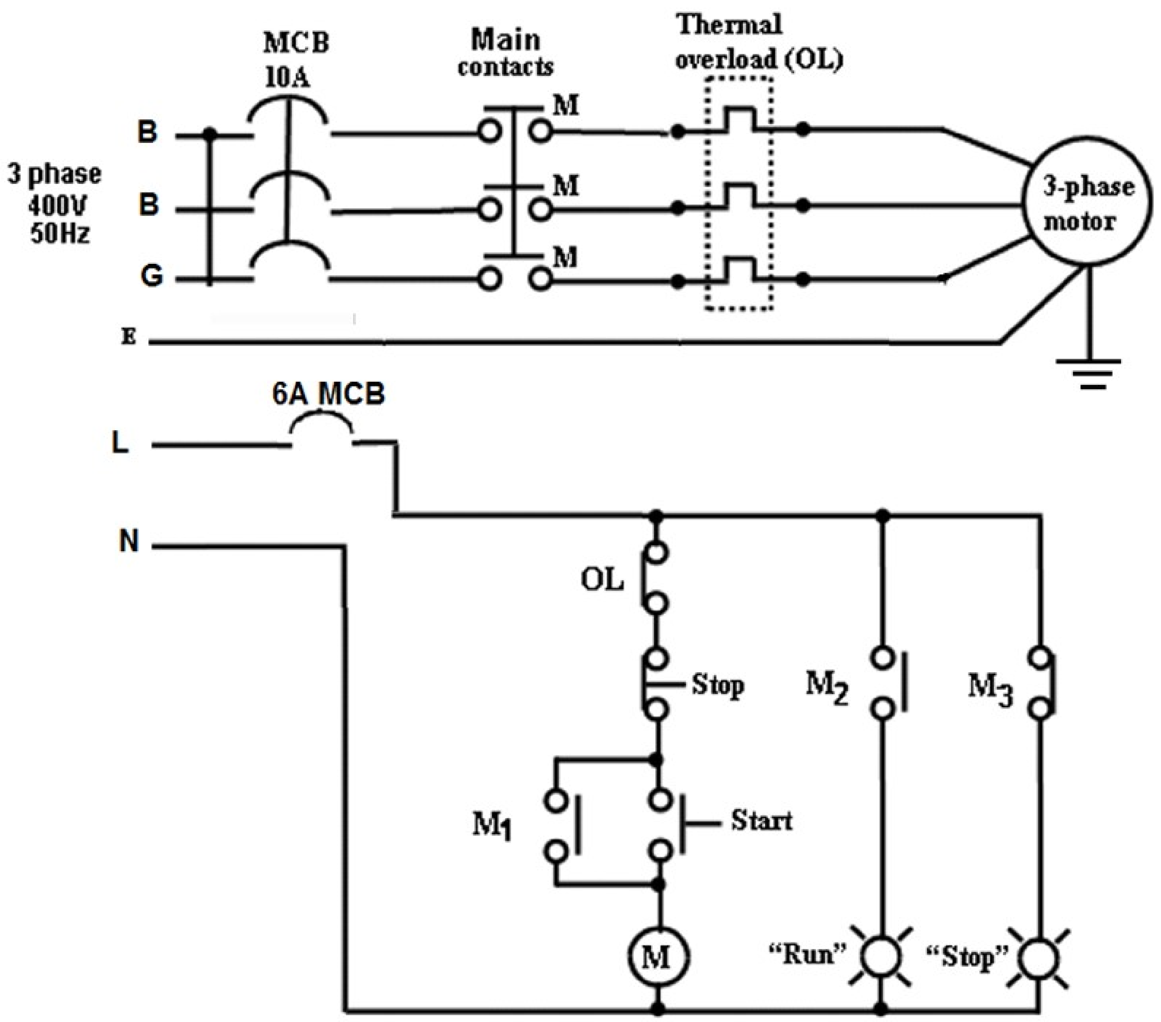


Figure 4.4 Schematic Diagram of DOL Starter

Chapter 5

Protection against Electric Shock & the Importance of Earthing

Objectives

On successful completion of this chapter, you will be able to:

- Learn more about earthing and the reasons for earthing.
- Know the two types of earthing systems, i.e. TT and TNS systems in used in Singapore.
- Know the measures in protection against electric shock.
- Interpret the Index of Protection code.
- Understand the principle of operation of a Residue Current Circuit Breaker
- Know the various types of earth electrode.
- Use the earth fault loop impedance, Z_s, to determine the earth fault current.
- Learn the use of Table 41.2, 41.3L and 41.4 of SS638:2018 on Z_s requirement
- Use Tables 17A and 17B of 16th Edition of IEE Regulation Guide Books to determine maximum length of phase and protective conductors.
- Use Table 54G to derive suitable sizes of circuit protective conductor or use the formula as stated in Section 543.1.

Overview

The earth may be considered as a vast conductor which is at zero potential. The process of earthing is: (i) to connect all exposed and extraneous conductive parts to earth (ii) to provide a path for the fault current to flow so that the protective device will operate, thus maintaining earth potential in an electrical installation.

They are two types of earthing system accepted in Singapore. These are: (i) TT System (ii) TNS System.

A person can receive an electric shock in two ways, firstly by coming into contact with live parts (Direct Contact) and secondly by touching metallic parts that have become live due to a fault (Indirect Contact). Protection against electric shock is covered by three sections in Chapter 41 of the SS. Protection against direct contact will be called Basic Protection, protection against indirect contact will now be called Fault Protection.

As a measure (Fault Protection) to protect against indirect contact by earthed equipotential bonding and automatic disconnection of supply, the earth loop impedance at every socket outlet is such that the disconnection time occurs within 0.4 s and that for the fixed equipment, it is 5 s. Tables 41.2, 41.3L and 41.4 of SS638:2018 give maximum values of earth fault loop impedance, Z_S, for the types and current ratings of the protective devices used. In cases where there is a need to determine the maximum length of the circuit, Tables 17A and 17B of IEE Regulation Guide Books will be needed.

Protective conductors refer to: (i) earthing conductor (ii) circuit protective conductor (iii) main equipotential bonding conductor and (iv) supplementary equipotential bonding conductor.

The sizing of protective conductors is important since safety from shock depends on the protective conductor being of adequate cross-section area. Table 54.7 of SS638 543.1 can be used to derive suitable sizes of circuit protective conductor. However, an alternative method, which results in cost saving, can be used to calculate the minimum size of protective conductor, using the formula as given in Section 543.1.3 which is developed from the adiabatic equation.

Resources and References

To supplement the learning of this chapter, the following resources/references can be harnessed:

- Tutorial 5
- Laboratory Hands-on
- PC-based Multimedia on Earthing
- Singapore Standard, SS638:2018
- Modern Wiring Practice by W E Steward
- The Electrician Guide to IEE Wiring Regulation by John Whitfield
- Principles and Design of Low Voltage Systems. 2nd Edition, Teo Cheng Yu (Byte Power Publication, Singapore)

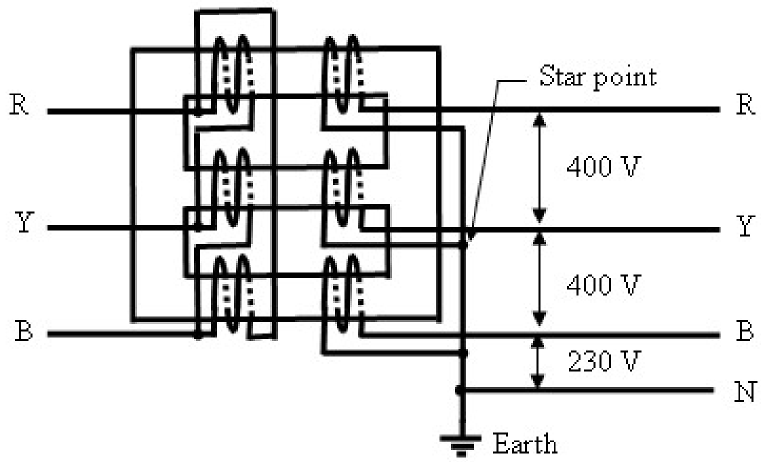
Protection against Electric Shock and the Importance of Earthing

5.1 Earthing

What Is Earthing?

The earth can be considered to be a vast conductor which is at reference (zero) potential. The purpose of earthing is to provide a low impedance path for fault current, so that in the event of a fault, the dangerous potential differences that may exist will be removed by operation of the protective device before a dangerous shock can occur.

The system is connected to earth at the secondary winding of the supply transformer, where one conductor, which is usually the neutral, is connected to an earth electrode, buried in the mass of earth. This is called **system earthing**.



Three-phase 4-wire delta-star transformer supply system

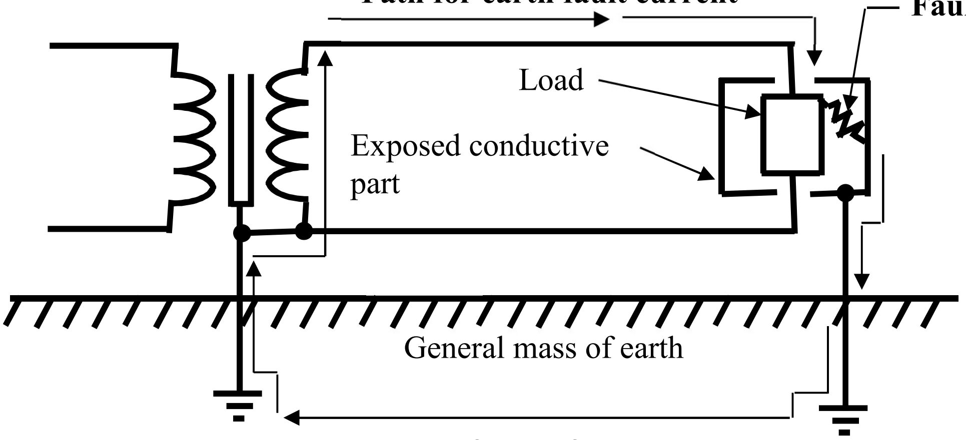
5.1.1 Reasons for Earthing

The three main functions of earthing are:

(i) To maintain the potential of any part of a system at a definite value with respect to earth. (System Earthing)

(ii) To allow current to flow to earth in the event of a fault, so that the protective gear will operate to isolate the faulty circuit. (Equipment Earthing)

(iii) To make sure that, in the event of a fault, apparatus normally 'dead' cannot reach dangerous potential with respect to earth (earth is taken as 0 V). (Equipment Earthing)



Path of earth fault current

5.2 Arrangement of Live Conductors and Type of Earthing

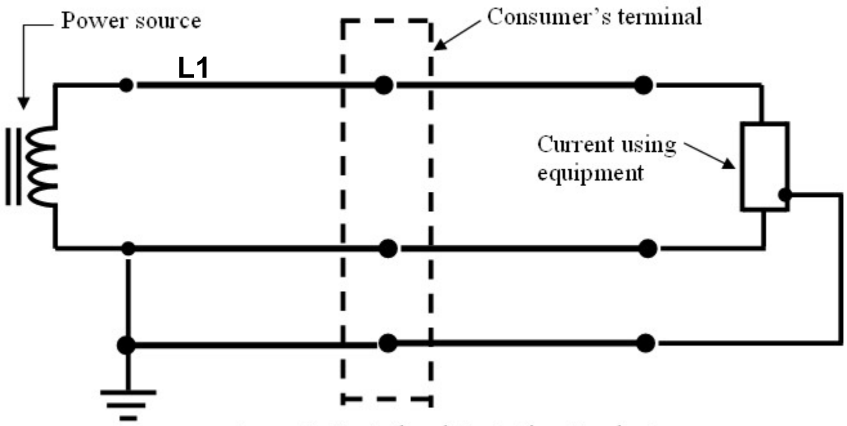
Refer to clause 312 page 46 and page 47 of SS638:2018 for the general requirements for the arrangement of live conductors and types of earthing system.

SP Services may supply electricity in single-phase or 3-phase. The number of live conductors will vary depending on the circuits to be used within an installation (e.g. single-phase two-wire a.c., three-phase four-wire a.c. etc.). And as for earthing, there are only two types of earthing arrangements which are allowed in the Republic of Singapore for buildings.

Symbol to understand:

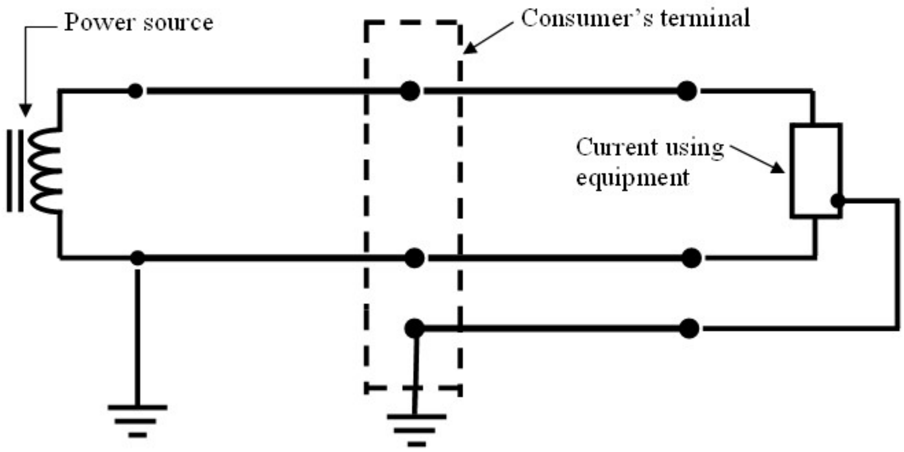
- **T - Terra**, as in good old Mother Earth i.e. real ground! (Terra is a French word)
- **I - Isolated**, as in no connection to *terra firma*
- **N - Neutral**, the supply leg 'neutralized' with the surroundings i.e. Earth
- **S - Separate**, also refers to Neutral and Protective Earth.

(1) TN-S System (single-phase)

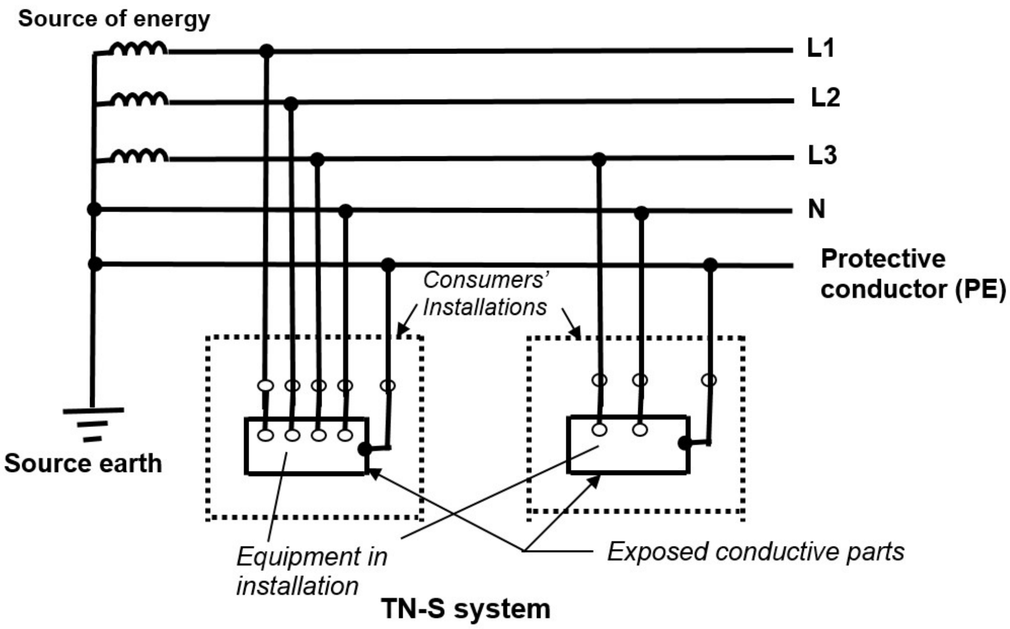


Separate Neutral and Protective Conductors

(2) TT System (single-phase)



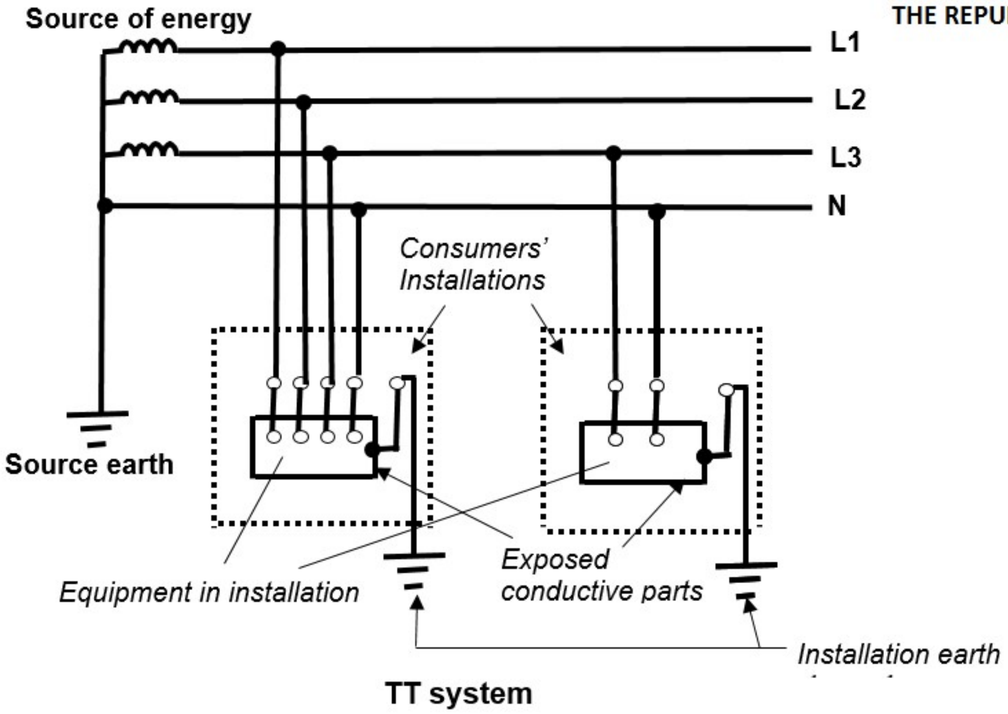
For diagrams illustrating both single-phase and three-phase current-using equipment adopting the TN-S or TT earthing systems, refer to Types of System Earthing in SS 638 : 2018 - Code of practice for Electrical Installations (formerly CP 5).



Separate neutral and protective conductors throughout the system

TNS system is used when the source of energy belongs to the consumer.

Note: ALL OTHER SYSTEM SHALL NOT BE ALLOWED IN THE REPUBLIC OF SINGAPORE



TT system is used when the source of energy does not belong to the consumer.

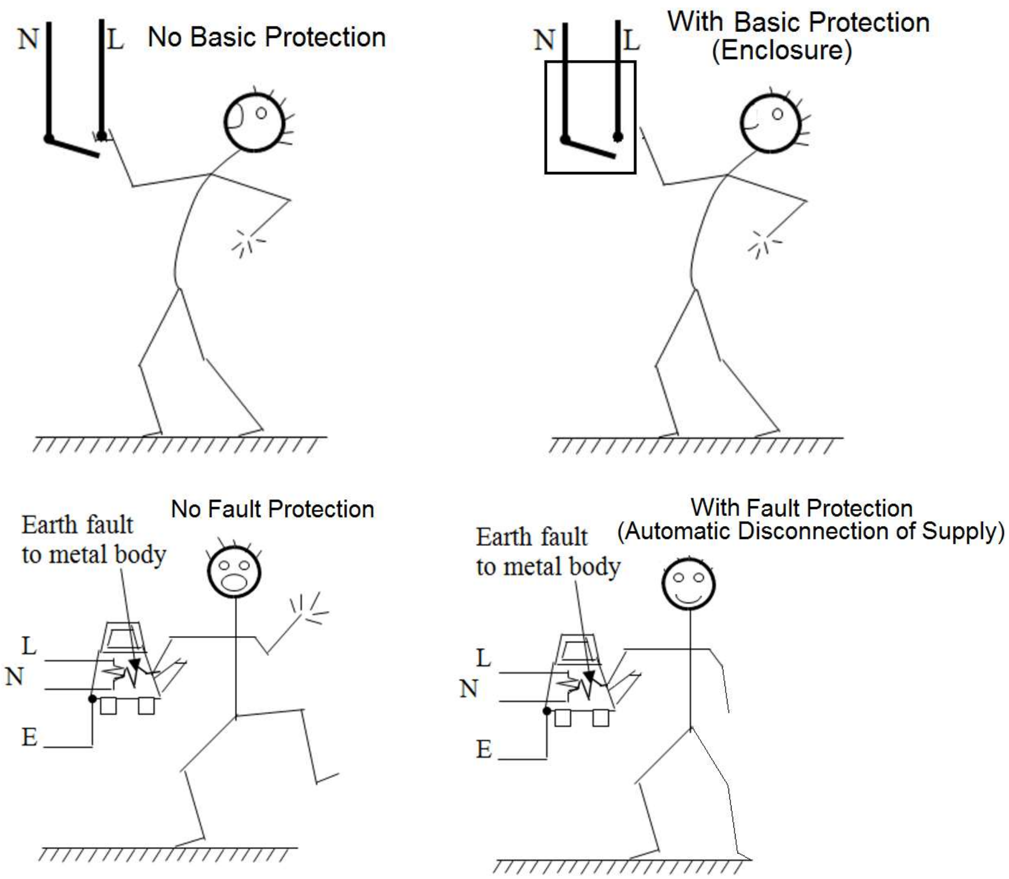
The letters **T, N** and **S** have the following meanings:

First letter – Relationship of the power system to Earth:
T = direct connection of one point to Earth;
Second letter – Relationship of the exposed-conductive-parts of the installation to Earth:
T = direct electrical connection of exposed-conductive-parts to Earth, independently of the earthing of any point of the power system;
N = direct electrical connection of the exposed-conductive-parts to the earthed point of the power system (in a.c. systems, the earthed point of the power system is normally the neutral point or, if a neutral point is not available, a line conductor).

Subsequent letter(s) (if any) – Arrangement of neutral and protective conductors:
S = protective function provided by a conductor separate from the neutral conductor or from the earthed line (or, in a.c. systems, earthed phase) conductor.

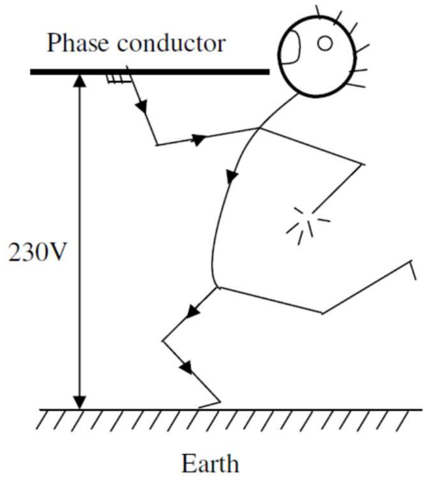
5.3 Protection against Electric Shock

A person can receive an electric shock in two ways, firstly by coming into contact with live parts and secondly by touching metallic parts that have become live due to a fault. A protective measure shall consist of an appropriate combination of a provision for basic protection and an independent provision for fault protection or an enhanced protective provision which provides both basic protection and fault protection.

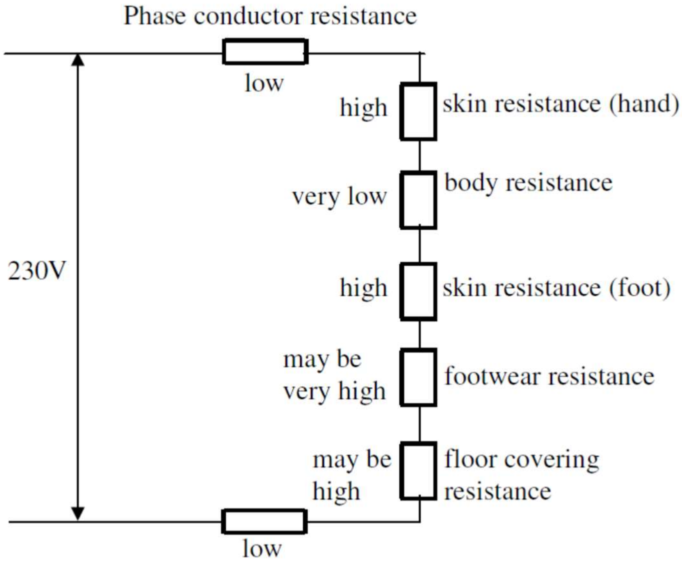


Exposed Conductive parts – metallic parts of electrical equipment or electrical installation which are normally dead but can become live due to fault (shorted to live part). E.g. body of stainless steel electric kettle, steel trunking housing electrical cables.

Extraneous Conductive parts – metallic parts which are not part of electrical installation or electrical equipment which are normally dead but can become live due to fault (shorted to live part). E.g. copper water pipes, air conditioning ducts, and metal gas pipes.

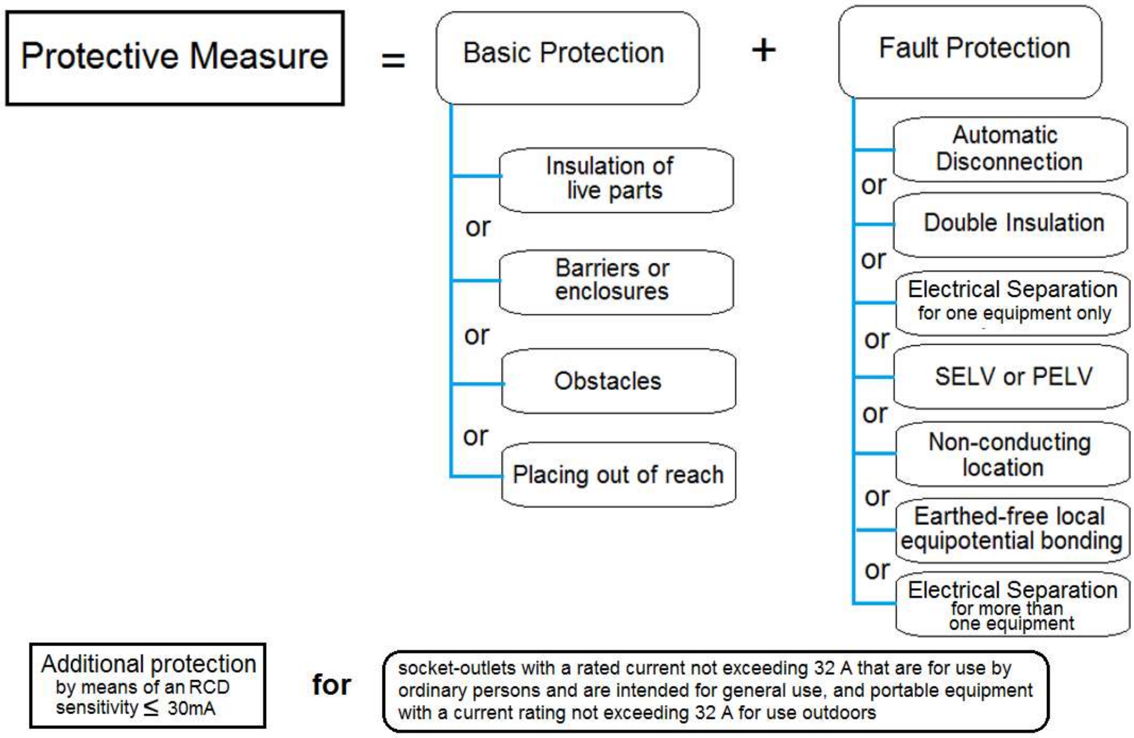


Path of electric shock



Earth path resistance

Protection against electric shock can be describe by the diagram below.



5.3.1 Protection using Extra-low voltage provided by SELV or PELV

Although this is now classified as fault protection, it will be covered first as it involves extra-low voltages. The following three methods of protection may be used:

(1) protection by separated extra low voltage (**SELV**)

(2) protection by PELV or FELV

(3) protection by limitation of discharge energy.

(1) **SELV**

- safety electrical sources are from one of the following: battery, ELV generator, isolating transformer. (Refer to Fig. 5.3.1(a) & Fig. 5.3.1(b))
- exposed conductive parts must not be connected to earth or to the protective conductors or extraneous conductive parts of another system
- SELV circuits conductors should not run along-side higher voltage conductors to avoid induced voltage
- SELV circuits to be electrically separated from other circuits; e.g. by installing in separate metal conduits or compartmental metal trunking
- using SELV to protect against direct contact, nominal voltage shall not exceed 25 V a.c. or 60 V d.c.
- using SELV to protect against indirect contact only, nominal voltage shall be within ELV limits i.e. 50 V a.c. or 120 V d.c.

Application examples:

(i) underwater swimming pool lights, voltage does not exceed 12 V d.c.

(ii) halogen lamps used for shop front product display < 12 V d.c.

Fig. 5.3.1(a) Safety source of SELV circuits
Primary supply at a voltage greater than extra low voltage

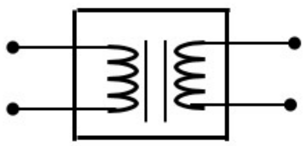
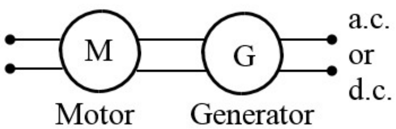
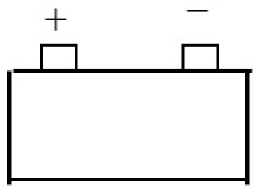
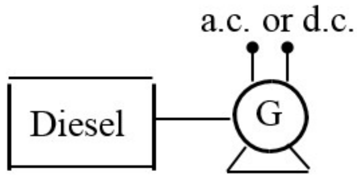
Equipment	Installation	Requirement
Safety isolating transformer to IEC 61558-2-6 3535		Secondary winding to be earth-free and voltage less than or equal to 25V rms a.c. (60V a.c.) for protection against direct contact unless live parts in IP2X enclosure or insulated for 500V test
Motor generator set or other source		Giving isolation between output and input equal to IEC 61558-2-6 3535 safety isolating transformer

Fig. 5.3.1(b) safety source for SELV circuits

Supply from source of energy independent of any higher voltage circuit

Equipment	Installation	Requirement
Electrochemical source		For example, a battery or a solar cell, etc.
Source driven by prime mover		For example, a diesel generator or air motor generator 25V rms a.c. (60V d.c.) or less

(2) **PELV or FELV**

If for functional reasons, it is not possible to meet all the requirements of SELV system e.g. if the secondary winding of extra voltage transformer to IEC 742 is earthed or live parts or exposed conductive parts of the SELV circuit are connected to the protective conductors of other system the system becomes FELV system, protection against direct contact to be by:

(a) enclosures having protection at least IP 2X or

(b) insulation capable of resisting a test voltage of 500 V r.m.s. for one minute

(3) **Protection by Limitation of Discharge of Energy**

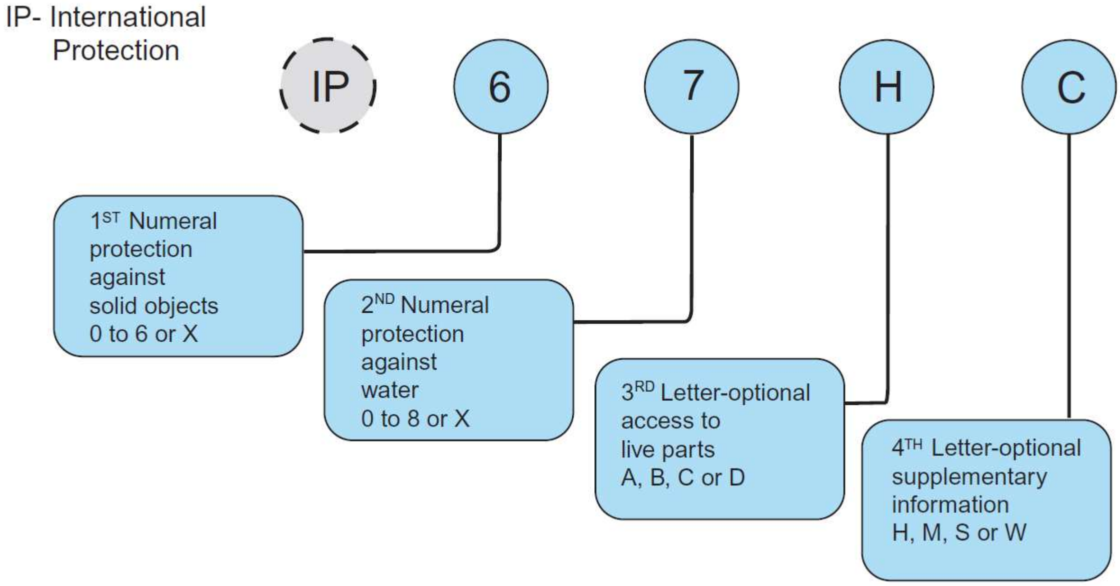
Protection against electric shock can be achieved by using equipment which incorporates a mean of limiting the current which can pass through a person or livestock to a value lower than the shock current. Circuits relying on this measure shall be electrically separated from other circuits in a manner similar to the separation required for SELV circuits.

IP Code (International Protection Marking)

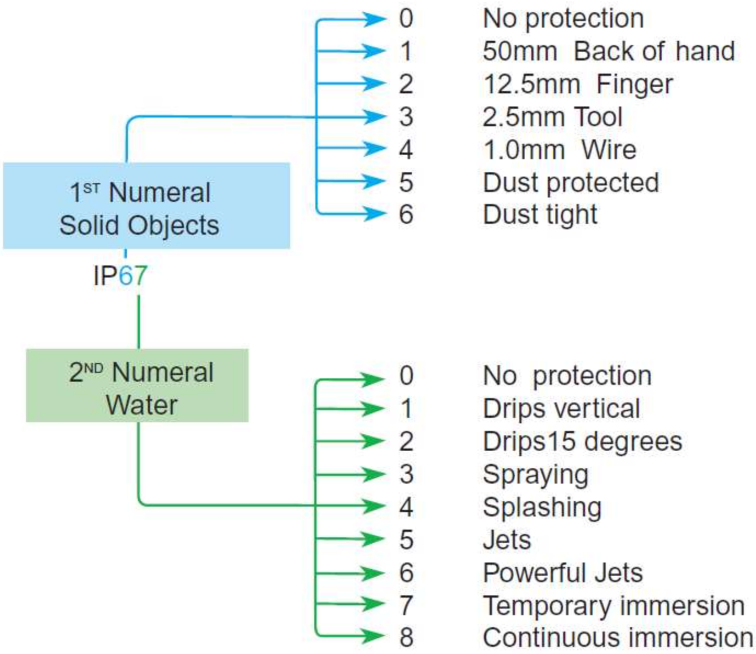
The European Standard BS EN 60529: *Degrees of protection provided by enclosures (IP Code)* is a ‘ Standard for Standards ’ document and provides information about the degrees of protection that can be expected of equipment, when allocated with a particular IP Code.

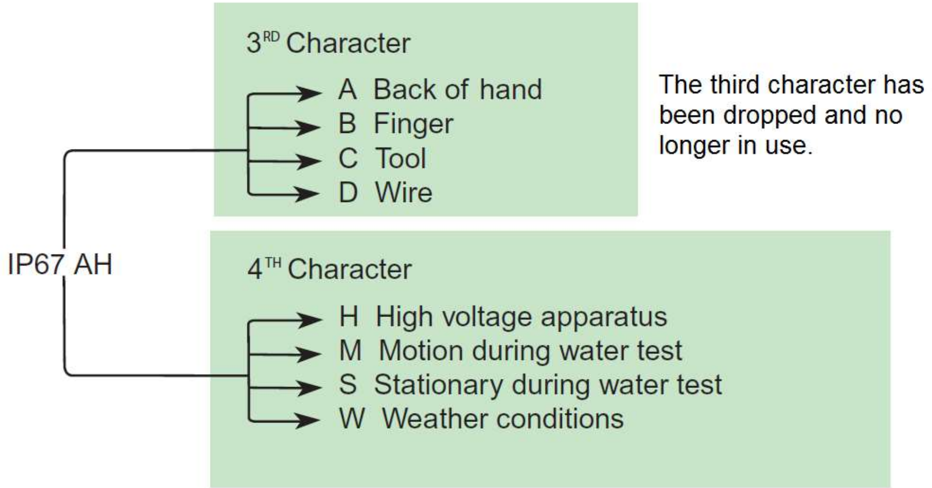
The IP code provides an indication of the protection the equipment will afford in terms of access to hazardous parts such as live or moving parts, ingress of foreign objects (such as tools), dirt, and liquids such as water. Exact confirmation on particular performance should always be sought from the manufacturer.

The arrangement of the IP code is made up of four characters, some of which are optional. The arrangement of the code is as follows:



The protection levels can be understood and these are often only specified using the first two characters, as follows:





5.3.2 Basic Protection (Previously Protection against Direct Contact)

One or more of the following shall be used:

(1) Insulation of live parts (2) barriers or enclosures

(3) Obstacles (4) placing out or reach

(1) Insulation of Live Parts

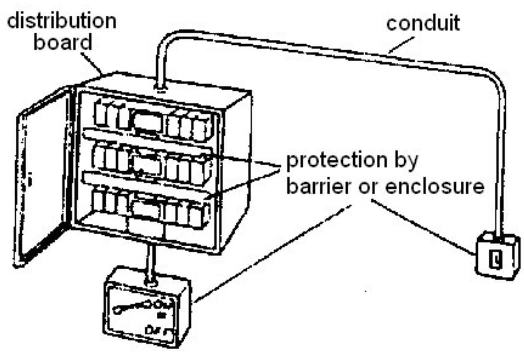
Live parts of an installation must be protected by durable and irremovable insulation which is able to withstand any stress (mechanical, electrical, thermal or chemical) e.g. electric cable

Paints, varnishes and lacquers are ***not*** in themselves, considered to provide the degree of protection.

(2) By Barriers or Enclosures

Live parts shall be inside enclosures or behind barriers of at least the degree of protection IP2X (Refer IP table for degree of protection) which is for the standard finger 80 mm long and 12 mm in diameter.

Examples of enclosures: enclosures for consumer unit, switchboard, socket outlet boxes, light fittings for lamps.

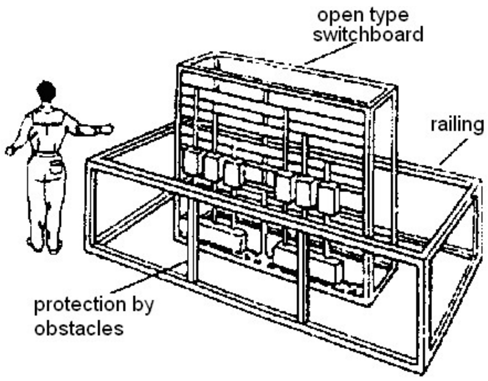


(3) By Obstacles

Obstacles shall be used to prevent:

- Unintentional bodily approach to live parts

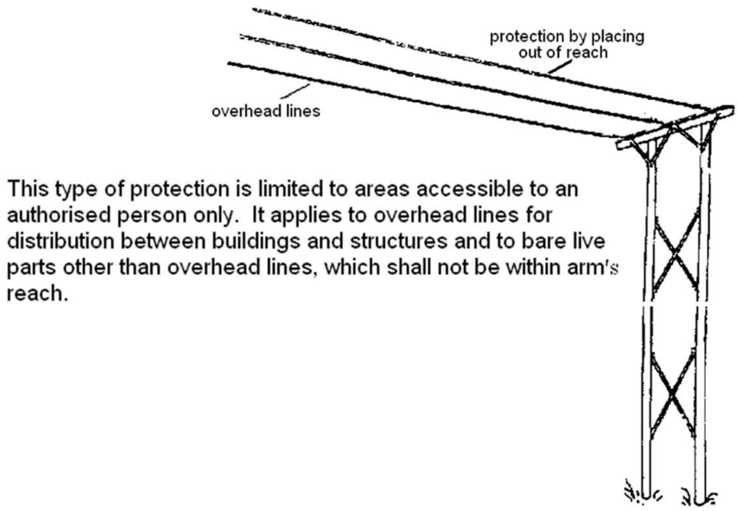
Obstacles should only be used in areas accessible by competent persons for protection against direct contact



Example:

Handrail around an open switchboard. These are firmly fixed to prevent accidental or unintentionally bodily contact with live parts.

(4) By Placing out of Reach



5.3.3 Fault Protection (Previously Protection against Indirect Contact)

One or more of the following protective measures for fault protection shall be used:

(1) Earthed equipotential bonding and automatic disconnection of supply
(2) Double Insulation (Use of Class II equipment or equivalent insulation)
(3) Electrical separation for the supply to one item of current-using equipment
(4) SELV or PELV
(4) Non-conducting location
(5) Earth-free local equipotential bonding
(6) Electrical separation for the supply to more than one item of current-using equipment

The last three items shall be applied only where the installation is under the supervision of skilled or instructed persons so that unauthorised changes cannot be made.

(1) **Earthed Equipotential Bonding and Automatic Disconnection of Supply**
The basic rule is given in the Code of Practice requires the characteristics of the protective devices, the earthing arrangements for the installation and the impedances of the circuits to be co-ordinated so that during an earth fault the voltages appearing between simultaneously exposed and extraneous conductive parts occurring anywhere in the installation shall be of such magnitude and duration as not to cause danger. This basic rule co-ordinates two subjects, equipotential bonding and automatic disconnection and they are more easily understood if considered separately.

Earthed Equipotential Bonding

To minimise the magnitude of voltages that can appear between exposed and extraneous conductive parts, the regulations require that main equipotential bonding conductors are installed between the extraneous conductive parts and the main earthing terminal of the installation.

The items to be bonded include: *main water pipes, gas pipes, metal conduits/trunkings, metallic ventilation ducts*, and exposed metallic parts of the building structure. (Refer Fig. 5.3.3) For isolated sections of metalwork which are not connected to the main equipotential bonding conductors, whether they require supplementary bonding conductors can be determined by reference to code.

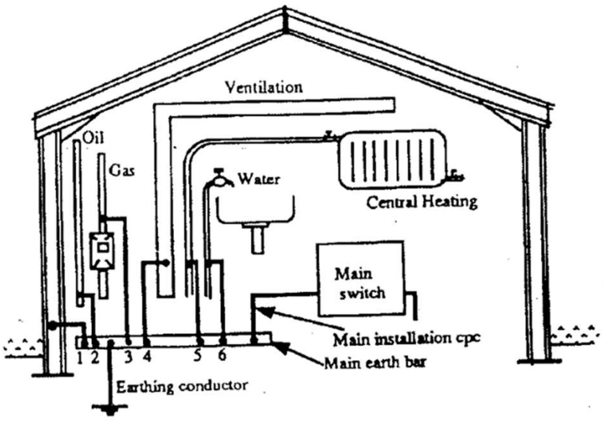


Fig. 5.3.3 Earth Equipotential Bonding

Automatic Disconnection in case of a Fault

Since a voltage will exist between exposed and extraneous conductive parts when a fault occurs, it is essential to remove this voltage as quickly as possible, this is the objective of code.

The maximum disconnection time stated in Table 41.1 shall be applied to final circuits not exceeding 32 A where disconnection is by an overcurrent protective device.

Table 41.1 – Maximum disconnection times

	$50\ V < U_0 \leq 120\ V$		$120\ V < U_0 \leq 230\ V$		$230\ V < U_0 \leq 400\ V$		$U_0 > 400\ V$	
System	seconds		seconds		seconds		seconds	
	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.
TN-S	0.8	See NOTE below	0.4	5	0.2	0.4	0.1	0.1
TT	0.3	See NOTE below	0.2	0.4	0.07	0.2	0.04	0.1

NOTE – Disconnection is not required for protection against electric shock but may be required for other reasons, such as protection against thermal effects.

Where, in a TT system, disconnection is achieved by an overcurrent protective device and protective equipotential bonding is connected to all the extraneous-conductive-parts within the installation, the maximum disconnection times applicable to a TN-S system may be used.

This requirement is satisfied for final circuits if the earth fault loop impedance is such that: Supply to final circuits not exceeding 32A is disconnected within **0.4** second.

(In simple language, any circuit connected to a 230V a.c. mains protected by an overcurrent device not exceeding 32A shall be disconnected within 0.4s. In Singapore all extraneous conductive parts must be bonded to the protective equipotential system, therefore both TNS and TT may use the 0.4s)

In a **TN-S system**, a disconnection time not exceeding **5 s** is permitted for a distribution circuit and for a circuit not covered by above. (Refers to circuits protected by overcurrent protective devices rated above 32A.)
In a **TT system**, a disconnection time not exceeding **1 s** is permitted for a distribution circuit and for a circuit not covered by above. (Refers to circuits protected by overcurrent protective devices rated above 32A.)
(In simple language, the 5s and 1s disconnection times refers to overcurrent protective devices other than MCBs.)

Additional protection

In a.c. systems, additional protection by means of an RCD in accordance with rated residual operating current not exceeding 30 mA shall be provided for:

(i) socket-outlets with a rated current not exceeding 32 A that are for use by ordinary persons and are intended for general use, and
(ii) Portable equipment with a current rating not exceeding 32 A for use outdoors.

In addition, for domestic installations, all socket outlet and lighting circuits shall be protected by one or more RCD with rated residual operating current not exceeding 30 mA

Protection by Over Current Protective Device

The speed at which a protective device will disconnect a circuit is dependent upon the magnitude of the fault current, which in turn is dependent upon the value of earth fault loop impedance, Z_S.

Earth fault loop impedance, Z_S shall be not more than values stated in Tables 41.2, 41.3L and 41.4. For other types of over current protective device, refer to necessary time/current characteristics from equipment manufacturer for the required disconnection times.

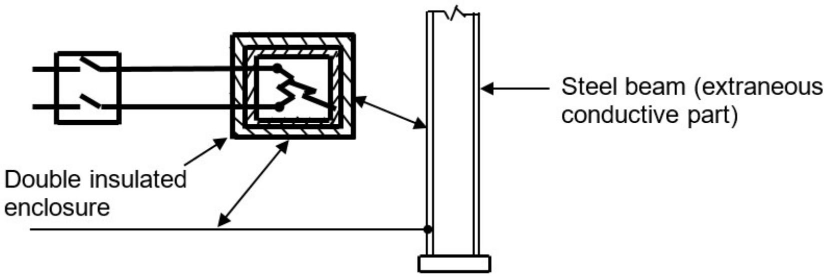
e.g. (a) Fuses to IEC 60269-2

Rating (A)	6	10	16	20
Z_S (ohm)	8.21	4.89	2.56	1.77

Protection by Residual Current Device (RCD) in an Installation which is part of a TT or TNS System

- The product of rated residual operating current in amperes and the earth fault loop impedance in ohms shall not be more than 50v
- In a ***household***, all socket outlet and lighting circuits shall be protected by residual current device with ***residual operating current ≤ 30 mA***
- Automatic disconnection using fault-voltage operated protective devices shall be prohibited.

(2) **By Use of Class II Equipment or by Equivalent Insulation**



- **Class II equipment is double insulated and is not provided with an earth terminal as this is considered unnecessary and may also bring into fault voltages from other circuits having earth fault connected to the same earth terminal.**
  This does not mean that there should be no exposed conductive parts and that the casing of equipment should be of an insulating material; it simply indicates that live parts are so well insulated that faults from live to conductive parts cannot occur.

5.4 The Operation Of The Residual Current Circuit Breaker (RCCB)

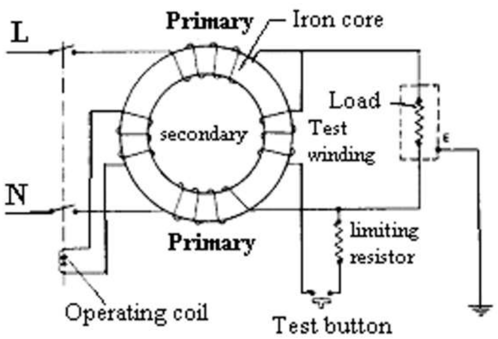


Fig. 5.4. Circuit diagram of a residual current circuit breaker

The basic principle of operation depends upon more current flowing into the live side of the primary winding than the return by the neutral or other return (earth) conductor. The essential part of the residual current circuit breaker (RCCB) is a transformer with opposed windings carrying the incoming and outgoing current. In a healthy circuit, where the values of current in the windings are equal, the magnetic effects cancel each other out.

However, a fault will cause an out-of-balance condition and create a magnetic effect in the transformer core which links with the turns of a small secondary winding. An emf (electromotive force measured in volts) is induced in this winding. The secondary winding is permanently connected to the trip coil of the circuit breaker. The induced emf will cause a current to flow in the trip coil will become energise to trip the breaker contacts. A test switch is provided for testing the function of trip circuit.

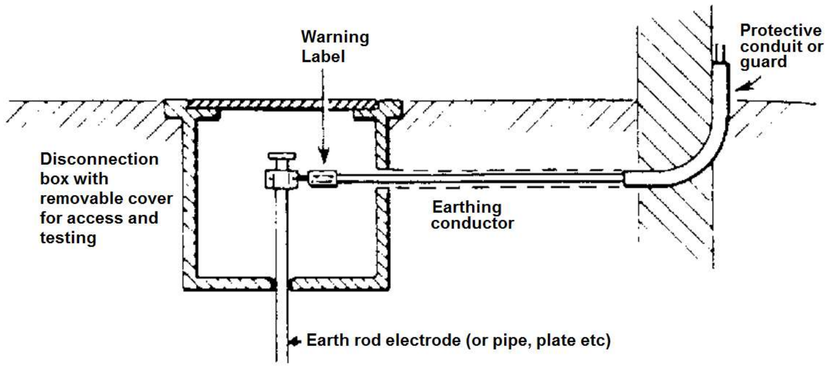
5.5 Earth Electrodes

The following types of earth electrode are recognised by SS 638:2018 (542.2.3L)

(i) Earth rods (ii) Earth tapes

(iii) Earth plates (iv) Earth electrodes embedded in foundations,

(v) any other methods stated in SS 551.



Typical earth electrode installation

Minimum cross-sectional area of a buried earthing conductor

	Protected against mechanical damage	Not protected against mechanical damage
Protected against corrosion by a sheath	2.5 mm² copper 10 mm² steel	16 mm² copper 16 mm² coated steel
Not protected against corrosion	25 mm² copper 50 mm² steel	

5.6 Protective Conductors

Earthing Conductors

The earthing conductor connects a consumer's main earth terminal to the earth electrode. It is the most important part of the safety system, so that great pains must be taken to ensure that it will not become broken or disconnected. The connection to the earth electrode must be clearly and permanently labelled “Safety **Electrical Connection - Do Not Remove** "

Aluminium cables must not be used as earthing conductors because of electrolytic corrosion.

If buried and protected against both corrosion and mechanical damage, cross-sectional area must be the same as that for circuit protective conductors.

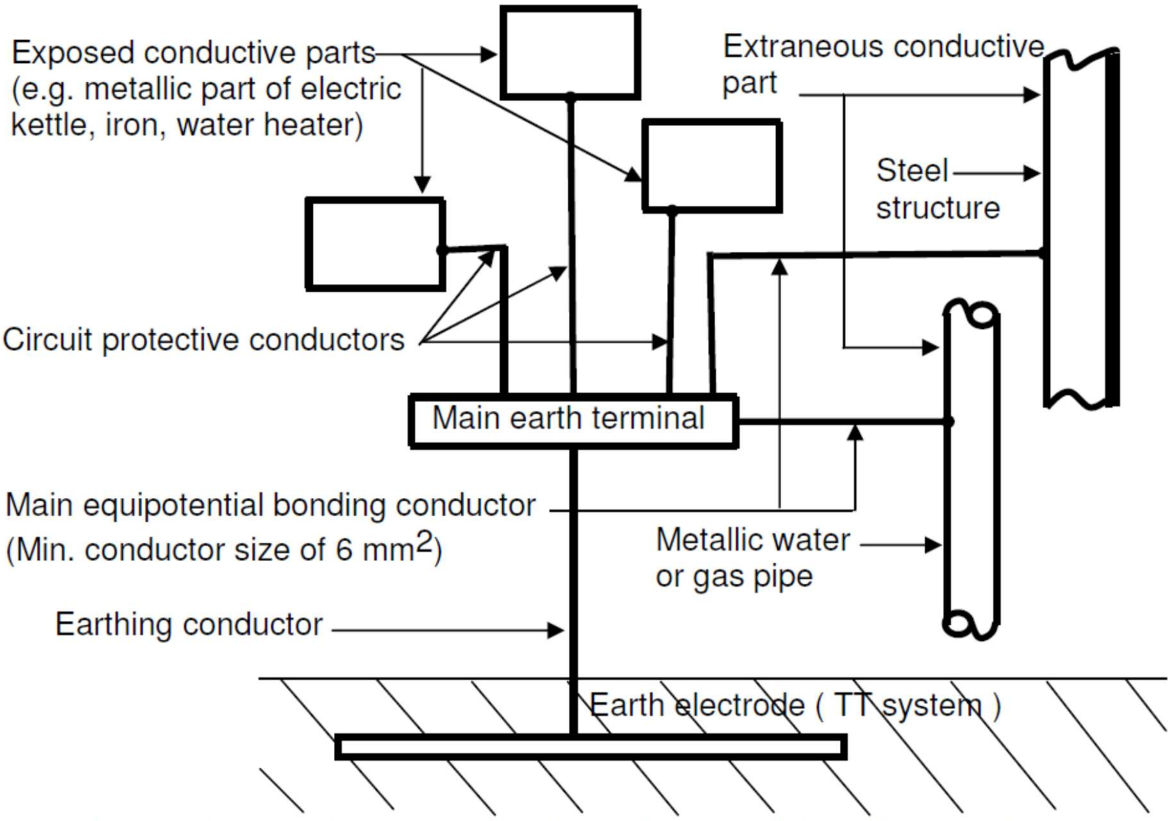
5.6.1 Types of Circuit Protective Conductor (c.p.c)

The circuit protective conductor was formerly known as the earth continuity conductor and connects together all exposed conductive parts and the main earthing terminal. In general, **Bonding** means electrical connection, not normally for the purpose of carrying current, but so as to ensure a common potential.

The circuit protective conductor may take many forms, which include:

1. A separate conductor with green/yellow insulation
2. A conductor included in a sheathed cable with other conductors.
3. The metal sheath and/or armouring of a cable.

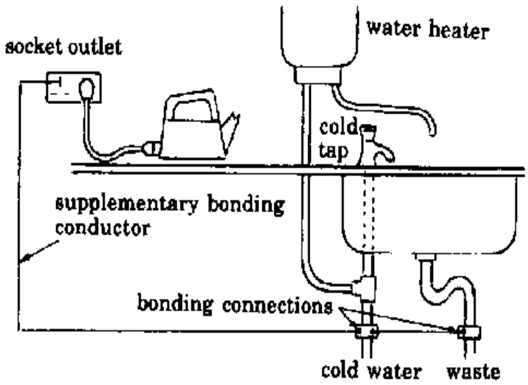
A circuit protective conductor shall be run to and terminated at each point in wiring and at each accessory except a lampholder having no exposed-conductive-parts and suspended from such a point.



Protective conductors and main equipotential bonding conductors

Protective conductors must be protected by insulation when they do not exceed 6 **mm²** in cross-section. Protective conductors which are not larger than 10 **mm²** in cross-sectional area must be of copper. Extraneous conductive parts shall not be used as protective conductors.

In some situations, ***supplementary bonding conductors*** may be necessary. For example, in a kitchen where it is likely that a person filling an electric kettle will be in contact with the metal body of the kettle (and hence with the earthed electrical system) at the same time as with hot or cold taps, or with a metal sink, it is unwise to rely on the electrical continuity of the water services. The conductor must be no smaller than that of the smallest protective conductor connected to exposed conductive parts, subject to a **minimum of 2.5 mm² if mechanically protected, or otherwise 4 mm².**



In SS 638 **Supplementary equipotential bonding may be omitted** when all the following conditions are met:

All final circuits of the location comply with the requirements for automatic disconnection in the event of a fault.

All final circuits of the location have additional protection by means of RCD of sensitivity not more than 30mA.

All extraneous-conductive parts of the location are effectively connected to the protective equipotential bonding at the main earthing terminal.

5.7 Calculation of Protective Conductor Size (For automatic disconnection of supply, and Table 17A/B in module note)

The sizing of protective conductors is extremely important since safety from shock depends on the protective conductor being of adequate cross-sectional area. This safety can always be assured if the designer installs very large protective conductors; however, such an approach would make for a very expensive installation.

Table 54.7 of SS 638:2018, part of Regulation 543.1.4, can be used to select the circuit protective conductors (cpc) if desired.

Table 54.7

Minimum cross-sectional area of protective conductor in relation to the cross-section area of associated phase conductor

Cross-sectional area of phase conductor S mm^2	Minimum cross-sectional area of the corresponding protective conductor	
	If the protective conductor is of the same material as the phase conductor mm^2	If the protective conductor is not the same material as the phase conductor mm^2
S $\leq$ 16	**S**	$(k_1/k_2) \times S$
16 < **S** $\leq$ 35	16	$(k_1/k_2) \times S$
S > 35	S/2	$(k_1/k_2) \times S$

where :

K_1 is the value of k for the phase conductor, selected from Table 43.1 in Chapter 43 according to the materials of both conductor and insulation.

K_2 is the value of k for the protective conductor, selected from Table 54.2 to 6, as applicable.

Table 54.3 – Values of k for protective conductor incorporated in a cable or bunched with cables, where the assumed initial temperature is 70 °C or greater

Material of conductor	Insulation material		
	70 °C thermoplastic	90 °C thermoplastic	90 °C thermosetting
Copper	115/103*	108/86*	143
Aluminium	76/68*	66/57*	94
Assumed initial temperature	70 °C	90 °C	90 °C
Final temperature	160 °C/140 °C*	160 °C/140 °C*	250 °C

* Above 300 mm^2

An alternative to this use of very large protective conductors is to calculate the minimum size of protective conductor using data given in Section 543.1.3. This is based on the same adiabatic equation used in Section 434.5.2L and is given as :

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

where
- S is the nominal cross-sectional area of the conductor in **mm^2**
- I is the fault current in A, assuming a fault of zero impedance
- t is the operating time of the protective device in second corresponding to the fault current
- k is a factor depending on the conductor material, the insulation, the assumed initial and the final temperature that the cable insulation can tolerate.

To determine csa of cable, S, from the above formula, proceed with the steps as follows:

(1) To find I

Since $$I = \frac{V_S}{Z_S}$$ where V_S = nominal supply voltage
Z_S = earth-fault loop impedance

Given: $\mathbf{Z_S = Z_E + (R_1 + R_2)}\Omega$, where of Z_E can be obtained from Supply Authorities.

The values of (R_1 + R_2)mΩ/m can be determined from **Table 17A**.

Next, obtain a multiplier from **Table 17B** to allow for the temperature rise under fault conditions.

Hence, $$\mathbf{(R_1 + R_2)\ \Omega = 1.38 \times (R_1 + R_2) \times 10^{-3}\ \Omega/m \times Length}$$

(2) To find t

As fault current, I, is determined in step (1), we need to use it to obtain the protective device's operating time, t, from the T/I characteristics in **Appendix 3 SS 638:2018** in pages 98 to 100 in this printed notes.

For example, consider the protective device is a 20A Type B MCB to IEC 60898-1 and that the calculated fault current is 1000A. From T/I characteristic in page 97 the time, t, is 0.1 sec.

(3) To find k

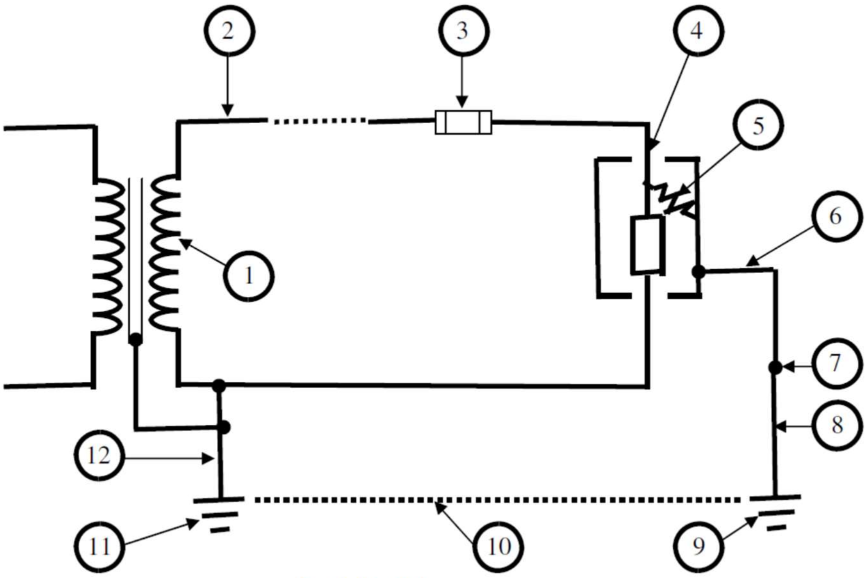
Values of k can be found in **Tables 54.2 to 54.6** (page 153/4) of **SS 638:2018**

(In MST and examination, Tables 54.2 to 54.6 will be provided or values of k will be given.)

5.8 Earth Fault Loop Impedance (Z_S)

If a fault of negligible impedance occurs from a phase conductor to earthed metal casing, the supply voltage will provide a fault current, in addition to the normal load current, through the earth fault loop is made up of the :

(1) secondary winding of the supply transformer
(2) phase conductor from the transformer to the installation
(3) protective device(s) in the installation
(4) installation phase conductors from the intake position to the fault
(5) fault itself (usually assumed to have zero impedance)
(6) protective conductor system
(7) main earthing terminal
(8) earthing conductor
(9) installation earth electrode
(10) general mass of earth
(11) Supply Authority's earth electrode
(12) Supply Authority's earthing conductor



Earth fault loop

This list applies directly to **TT System**. For a **TN-S System**, item 9 to 11 are replaced by the PE conductor which is usually the sheath and armouring of the supply cable.

5.8.1 Significant of Earth Fault Loop Impedance

To calculate the earth-fault current, the phase-to-earth voltage and the loop impedance must be known.

$$I_F = \frac{V_{ph}}{Z_s}$$

where
I_F = fault current (A)
V_P = phase voltage (V)
Z_S = earth-fault loop impedance (Ω)

Example:

A 230V circuit protected by a 16A IEC 60269-3 fuse has an earth loop impedance of 2.3 ohms. The earth fault current is 230/2.3= ***100 A***. The earth-fault current of 100 A will cause the fuse to operate quickly enough to prevent danger.

From **IEC 60269-3 Time/Current characteristics (page 98),** the time will be less than 0.4 s. Any load current in the circuit will be additional to the earth-fault current, and will operate the protective device marginally more quickly. However, such load current cannot be taken into account because it is possible that the load may not be connected when the fault occurs.

(IEC 60269-3 fuses are for use by unskilled persons – usual applications household.)

It is important to note that the line/earth voltage of a three-phase supply is the same as that for a single-phase supply derived from it. In other words, there are no three-phase earth faults**,** (although three single-phase faults may occur simultaneously on a three-phase system). Thus the **Tables in SS 638:2018** for maximum values of earth-fault loop impedances (**Table 41.2, 41.3L, 41.4**) apply equally to single-phase and three-phase systems.

5.8.2 Values of Fault Loop Impedance (Regulation 413-2, Appendix 3 SS638:2018)

Table 41.2, 41.3L and 41.4 of regulation 411 gives a series of maximum values for earth fault loop impedance for circuits feeding socket outlets. Such circuits must be disconnected within **0.4 sec** in the event of an earth fault of negligible impedance, so the loop impedance must be low enough to enable the supply voltage to pass a current high enough to operate the protective device within that time. It follows that a larger-rated device will need more current to operate than a low-rated device, **Table 41.2** gives a max fault loop impedance of :

(i) 10.45Ω for a 5A IEC60269-3 fuse (fault current is 230/10.45 = 22A)

(ii) 0.96Ω for a 32A IEC60269-3 fuse (fault current is 230/1.15 = 200A).

A circuit breaker is more reliable, so figures for Type B MCB. **Table 41.3L** are :

(i) 7.67 Ω for a 6A MCB (fault current of 230/7.67 = 30A at 230 V) and

(ii) 1.44 Ω for a 32A MCB (fault current 160A at 230 V).

Distribution circuits and circuits feeding fixed equipment exceeding 32A are required to be disconnected within **5 sec for TNS earthing system**. (1 sec disconnection time for TT earthing system.)
This longer disconnection time is justified because it is considered that the shock risk from such circuits is considerably less likely than that from portable appliances, some types of which are firmly gripped in normal use.

5.9 Maximum Length of Circuit

(Tables 41.2, 41.3L, 41.4 and Table 17A/17B)

Tables 17A and 17B provided in this module notes, allow us to calculate the resistance of various combinations of phase and protective conductors.

Example:

Consider the single-phase final circuit to a 8kW heater (fixed equipment) protected by a 40A cartridge fuse to IEC 60269-2. External loop impedance, (Z_E), is given as 0.8 Ω. Select cross sectional are for circuit conductor size used, protective conductor used and also determine the maximum length the circuit can be run using the selected conductor sizes. To use twin core PVC for circuit conductor.

Given that $\mathbf{Z_s = Z_E + \{R_1 + R_2\}\Omega}$ **-------- Equation (1)**
where $\{R_1 + R_2\}\Omega$ = *1.38 x (R_1 + R_2)mΩ/m x Length*

For 40A IEC 60269-2 cartridge fuse From **Table 41.4**, maximum earth-fault loop impedance, $Z_{s(max)}$ = 1.35 Ω

Table 41.4 – Maximum earth fault loop impedance (Z_s) for fuses, for 5 s disconnection time with U_0 of 230 V (see 411.4.8)

(a) General purpose (gG) and motor circuit application (gM) fuses to IEC 60269-2 – fuse systems E (bolted) and G (clip in)								
Rating (amperes)	6	10	16	20	25	32	40	50
Z_s (ohms)	12.8	7.19	4.18	2.95	2.30	1.84	1.35	1.04
Rating (amperes)	63	80	100	125	160	200		

Next, select 10 **mm^2** (based on I_b = 8000w/230v = 34.8A and I_N = 40A) twin core pvc. sheathed cable.

From **Table 17 A**, the combined resistance per metre for 10 **mm^2** phase and 4 **mm^2** protective conductors is 6.44 mΩ/m {this is ***(R_1 + R_2) in mΩ/m*** } at 20**^{o}C**.

Table 17A
Values of resistance/metre for copper and aluminium conductors and of (R1 + R2)/metre at 20°C in milliohms/metre

Cross-sectional area (mm^2)		Resistance/metre or (R_1 + R_2)/metre	
Phase conductor	Protective conductor	Plain copper (mΩ/m)	Aluminium
10	4	6.44	
10	6	4.91	
10	10	3.66	

To allow for the increased resistance of the cable when it gets hot under fault conditions, we must apply the 1.38 multiplier from **Table 17B**.

To determine the maximum length, L, from equation (1), we have

$$\mathbf{Z_s = Z_E + \{R_1 + R_2\}\Omega \text{ where } \{R_1 + R_2\}\Omega = \mathit{1.38 \times (R_1 + R_2)m\Omega/m \times Length}}$$

$$\mathbf{Z_s = Z_E + 1.38 \times (R_1 + R_2)m\Omega/m \times Length}$$

$$\mathbf{1.35 = 0.8 + 1.38 \times 6.44\ m\Omega/m \times L}$$

$$\mathbf{L = (1.35-0.8)/(1.38 \times 6.44 \times 10^{-3}) = 61.8m}$$

If this circuit length is insufficient, we reduce the resistance of the cables feeding the heater by selecting a larger protective conductor size.

For example, the heater could be fed with 10 **mm^2** phase conductor with a 6 **mm^2** protective conductor, the cables being pvc -insulated enclosed in a pvc trunking.

Example 1

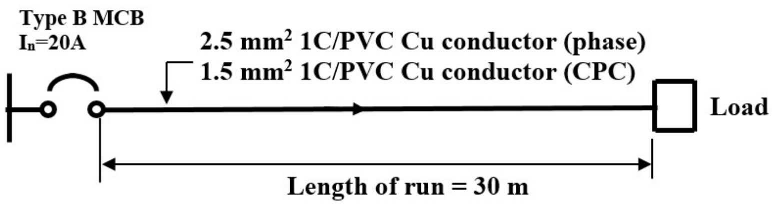
In an electrical installation, all the socket outlet circuits were designed using 2.5 mm^2 single-core copper conductor PVC insulated sheath cable for the phase conductors and 1.5 mm^2 for the circuit protective conductors. The circuits were all protected by 20A Type B MCBs. The circuit length for the furthest circuit is estimated to be 30m and Z_E is 0.7 Ω.

(i) Find the earth fault loop impedance for the furthest circuit

(ii) Check whether it is protected against indirect contact

(iii) Check whether the circuit protective conductor of this circuit can withstand the earth fault current (given K = 115 for pvc-insulated cables)

Solution:



(i) $Z_s = Z_E + \{R_1 + R_2\}\Omega$

$Z_s = Z_E + 1.38 \times \{R_1 + R_2\}m\Omega/m \times L$

where $\{R_1 + R_2\}m\Omega/m = 19.51m\Omega/m$ --- From Table 17A (page 101)

$Z_{s(actual.)} = 0.7\ \Omega + 1.38 \times 19.51 \times 10^{-3}\ \Omega/m \times 30\ m$

$= 0.7 + 0.808$

$= 1.508\ \Omega$

(ii) From Table 41.3L, maximum $Z_{s(max)} = 2.30\ \Omega$

Since actual $Z_{s(actual.)} < Z_{s(max)}$, the circuit is protected against indirect contact.

(iii) $I_F = 230/Zs(actual.) = 230/1.508 = 152$ A

From graph (Fig. 9, page 106), t = 0.1 sec. (approx.)

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

$$S = (I_F/K)\sqrt{t} = 152/115 * \sqrt{(0.1)} = 0.42\ mm^2$$

Since actual S used is 1.5mm^2 which is greater than 0.42mm^2 the circuit can withstand the earth fault current.

Example 2

A fixed resistive load of 6 kW, located 3 meters away, is protected by a 30 A Type C MCB. The phase and circuit protective conductors suggested are 4.0 mm^2 and 1.5 mm^2 single-core PVC insulated cables respectively. If the external impedance, Z_E is 0.6 Ω, determine:

(i) the actual earth fault loop impedance, Z_S
(ii) the fault current of the circuit and the corresponding tripping time of the MCB to comply with 0.4 s disconnection time
(iii) the maximum allowable earth fault loop impedance and hence, the longest length for the circuit that can be run
(iv) check whether the circuit protective conductor used is able to meet the thermal constraints (given K = 115 for pvc-insulated cables)

Solution:

(i) From Table 17A/B,

$$Z_{S(cal)} = Z_E + R_1 + R_2$$

$$Z_{S(cal)} = 0.6 + \frac{1.38*16.71*3}{1000} = 0.669\Omega$$

(ii) $$I_F = \frac{V_s}{Z_{S(cal)}} = \frac{230v}{0.669\Omega} = 344A$$

From Fig. 8 (page 105), the tripping time is 0.1 s (approx.)

(iii) $Z_{S(max)}$ = 23/30 = 0.767Ω (from Table 41.3L)
Given Ze = 0.6 Ω

From Table 17A/B,

$$Z_S = Z_E + R_1 + R_2$$

$$0.767 = 0.6 + \frac{1.38*16.71*l}{1000}$$

$$\therefore l = 7.24m$$

(iv) Using the adiabatic equation $K^2S^2 \geq I^2t$

$$\min \quad S \geq \frac{I}{K}\sqrt{t}$$

$$\geq \frac{300}{115}\sqrt{0.1} \geq 0.825\, mm^2$$

As the cable size used 1.5mm^2 is greater than the minimum required of 0.825mm^2, cpc meet the thermal requirement.

Table 17A
Values of resistance/metre for copper and aluminium conductors and of (R1 + R2)/metre at 20ºC in milliohms/metre

Cross-sectional area (mm^2)		Resistance/metre or (R_1 + R_2)/metre	
Phase conductor	Protective conductor	Plain copper (mΩ/m)	Aluminium
1	-	18.10	
1	1	36.20	
1.5	-	12.10	
1.5	1	30.20	
1.5	1.5	24.20	
2.5	-	7.41	
2.5	1	25.51	
2.5	1.5	19.51	
2.5	2.5	14.82	
4	-	4.61	
4	1.5	16.71	
4	2.5	12.02	
4	4	9.22	
6	-	3.08	
6	2.5	10.49	
6	4	7.69	
6	6	6.16	
10	-	1.83	
10	4	6.44	
10	6	4.91	
10	10	3.66	
16	-	1.15	1.91
16	6	4.23	-
16	10	2.98	-
16	16	2.30	3.82
25	-	0.727	1.2
25	10	2.557	-
25	16	1.877	-
25	25	1.454	2.4
35	-	0.524	0.868
35	16	1.674	2.778
35	25	1.251	2.068
35	35	1.048	1.736

Table 17B - Multipliers to be applied to Table 17A

Insulation Material	p.v.c.	85^0 C Rubber	90^0 C Thermosetting
Multiplier	1.38 (1.30)	1.53 (1.42)	1.60 (1.48)
Note : The values in brackets are applicable to the resistance of circuit protective Conductors where Table 54B applies.			

The multipliers given in Table 17B are based on the simplified formula given in BS 6360 for both copper and aluminium conductors namely that the resistance temperature coefficient is 0.004 per °C at 20°C.

Table 41.2 – Maximum earth fault loop impedance (Z_s) for fuses, for 0.4 s disconnection time with U_0 of 230 V (see 411.4.6)

(a) General purpose (gG) and motor circuit application (gM) fuses to IEC 60269-2 – fuse systems E (bolted) and G (clip in)

Rating(amps)	6	10	16	20	25	32
Z_s (ohms)	8.21	4.89	2.56	1.77	1.35	1.04

(b) Fuses to IEC 60269-3 fuse system C

Rating(amps)	5	16	20	32
Z_s (ohms)	10.45	2.42	2.04	0.96

(c) Fuses to BS 3036

Rating(amps)	5	15	20	30
Z_s (ohms)	9.58	2.55	1.77	1.09

(d) Fuses to SS 167

Rating(amps)	3	13
Z_s (ohms)	16.4	2.42

NOTE – The circuit loop impedances given in the table should not be exceeded when the conductors are at their normal operating temperature. If the conductors are at a different temperature when tested, the reading should be adjusted accordingly. See Appendix 14(L).

Table 41.3L – Maximum earth fault loop impedance (Z_s) for circuit-breakers with U_0 of 230 V, for instantaneous operation giving compliance with the 0.4 s disconnection time of 411.3.2.2L and 5 s disconnection time

(a) Type B circuit-breakers to IEC 60898-1

Rating(amps)	3	6	10	16	20	25	32	40	50	63	80	100	125	I_n
Z_s (ohms)	15.33	7.67	4.60	2.87	2.30	1.84	1.44	1.15	0.92	0.73	0.57	0.46	0.37	$46/I_n$

(b) Type C circuit-breakers to IEC 60898-1

Rating(amps)	6	10	16	20	25	32	40	50	63	80	100	125	I_n
Z_s (ohms)	3.83	2.30	1.44	1.15	0.92	0.72	0.57	0.46	0.36	0.29	0.23	0.18	$23/I_n$

(c) Type D circuit-breakers to IEC 60898-1

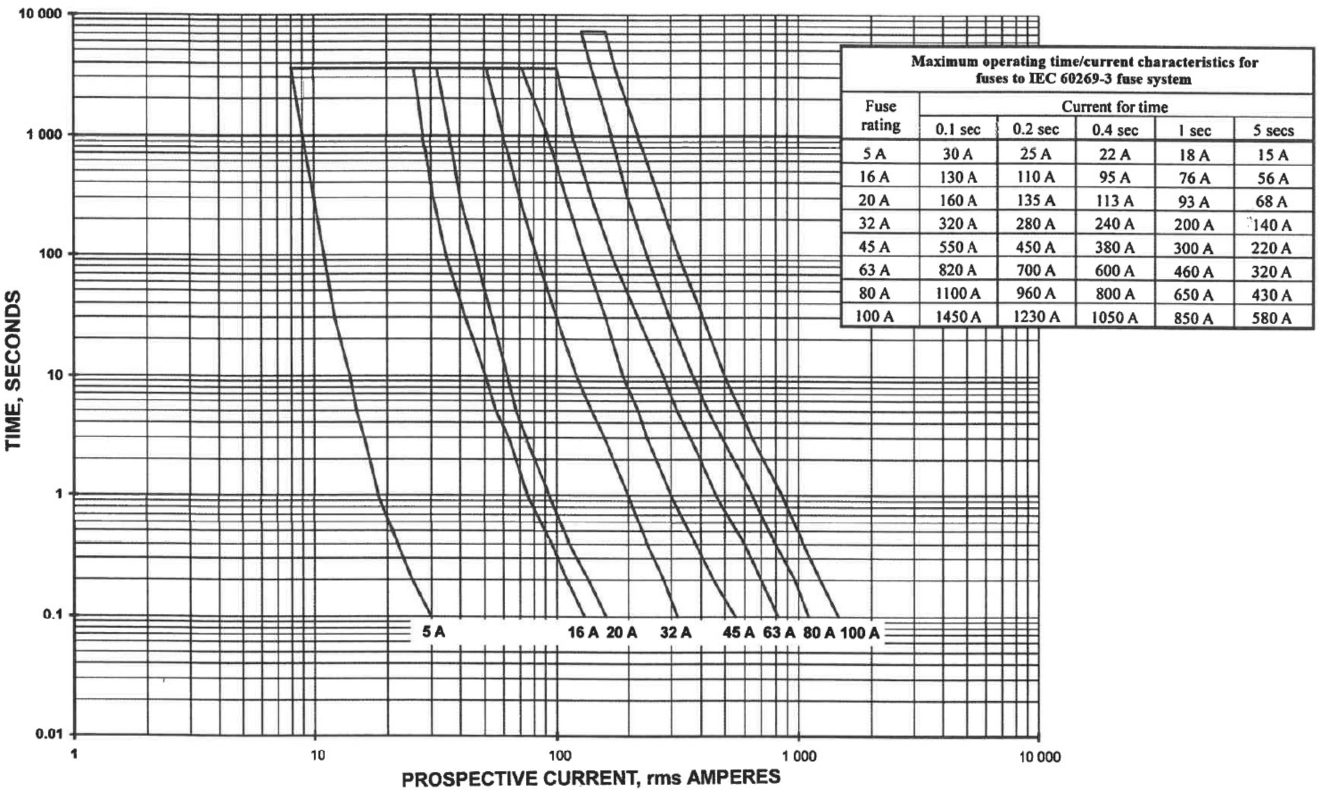
Rating(amps)	6	10	16	20	25	32	40	50	63	80	100	125	I_n
Z_s (ohms)	1.92	1.15	0.72	0.57	0.46	0.36	0.29	0.23	0.18	0.14	0.11	0.09	$11.5/I_n$

NOTE – The circuit loop impedances given in the table should not be exceeded when the conductors are at their normal operating temperature. If the conductors are at a different temperature when tested, the reading should be adjusted accordingly. See Appendix 14(L).

Table 41.4 – Maximum earth fault loop impedance (Z_s) for fuses, for 5 s disconnection time with U_0 of 230 V (see 411.4.8)

(a) General purpose (gG) and motor circuit application (gM) fuses to IEC 60269-2 – fuse systems E (bolted) and G (clip in)								
Rating(amps)	6	10	16	20	25	32	40	50
Z_s (ohms)	12.8	7.19	4.18	2.95	2.30	1.84	1.35	1.04
Rating(amps)	63	80	100	125	160	200		
Z_s (ohms)	0.82	0.57	0.46	0.34	0.28	0.19		
(b) Fuses to IEC 60269-3 fuse system C								
Rating(amps)	5	16	20	32	45	63	80	100
Zs (ohms)	15.33	4.11	3.38	1.64	1.04	0.72	0.53	0.40
(c) Fuses to BS 3036								
Rating(amps)	5	15	20	30	45	60	100	
Z_s (ohms)	17.7	5.35	3.83	2.64	1.59	1.12	0.53	
(d) Fuses to SS 167								
Rating(amps)	3	13						
Z_s (ohms)	23.2	3.83						

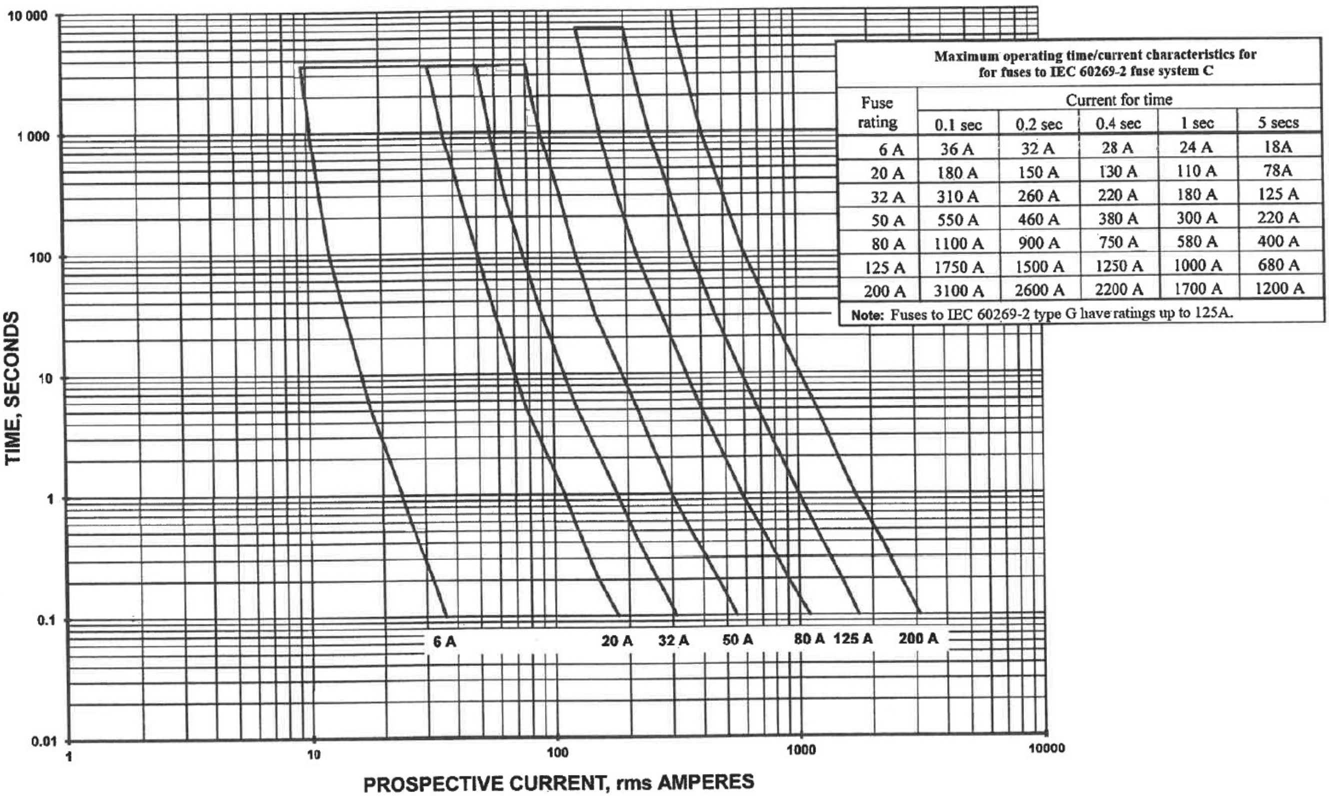
NOTE – The circuit loop impedances given in the table should not be exceeded when the conductors are at their normal operating temperature. If the conductors are at a different temperature when tested, the reading should be adjusted accordingly. See Appendix 14(L).



Maximum operating time/current characteristics for fuses to IEC 60269-3 fuse system

Fuse rating	Current for time				
	0.1 sec	0.2 sec	0.4 sec	1 sec	5 secs
5 A	30 A	25 A	22 A	18 A	15 A
16 A	130 A	110 A	95 A	76 A	56 A
20 A	160 A	135 A	113 A	93 A	68 A
32 A	320 A	280 A	240 A	200 A	140 A
45 A	550 A	450 A	380 A	300 A	220 A
63 A	820 A	700 A	600 A	460 A	320 A
80 A	1100 A	960 A	800 A	650 A	430 A
100 A	1450 A	1230 A	1050 A	850 A	580 A

Figure 4

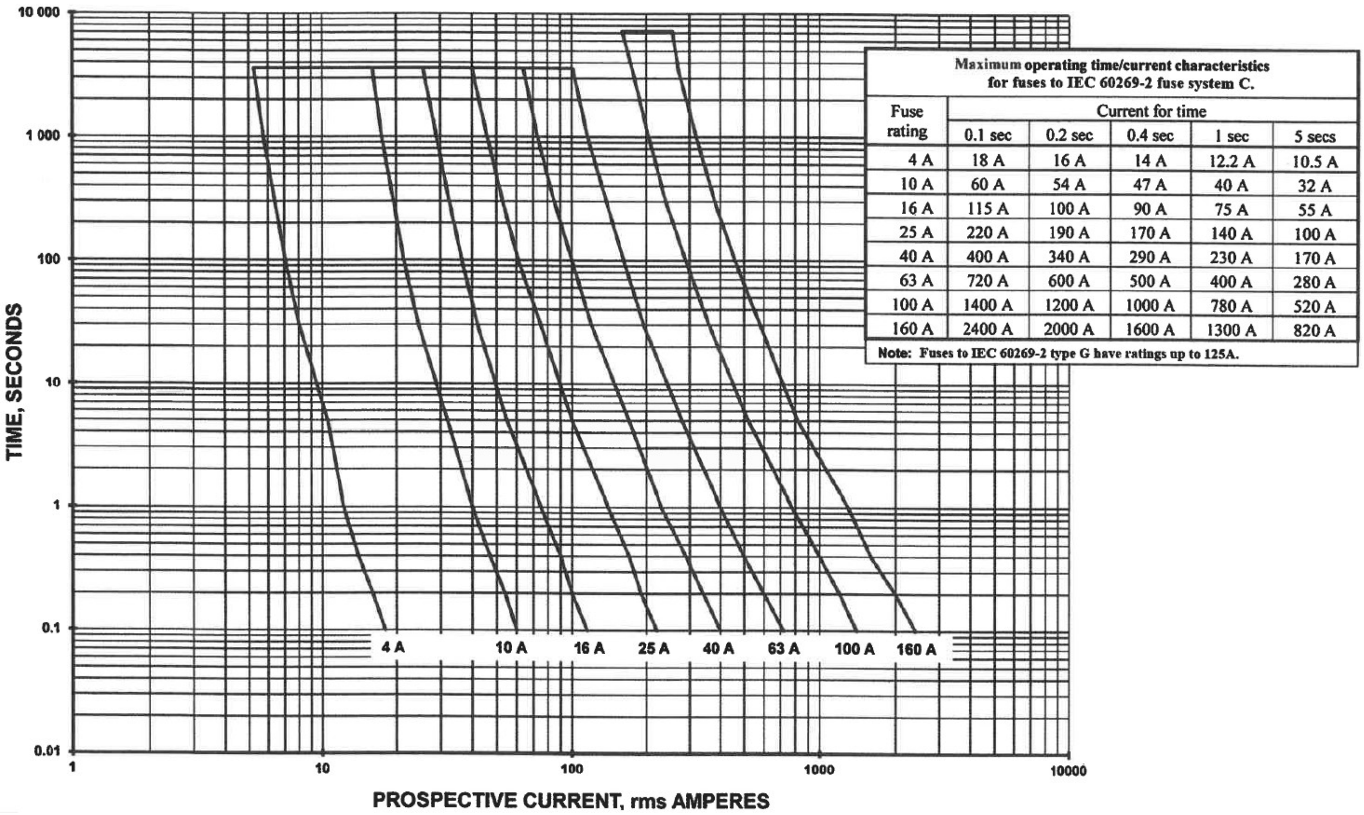


Maximum operating time/current characteristics for for fuses to IEC 60269-2 fuse system C

Fuse rating	Current for time				
	0.1 sec	0.2 sec	0.4 sec	1 sec	5 secs
6 A	36 A	32 A	28 A	24 A	18A
20 A	180 A	150 A	130 A	110 A	78A
32 A	310 A	260 A	220 A	180 A	125 A
50 A	550 A	460 A	380 A	300 A	220 A
80 A	1100 A	900 A	750 A	580 A	400 A
125 A	1750 A	1500 A	1250 A	1000 A	680 A
200 A	3100 A	2600 A	2200 A	1700 A	1200 A

Note: Fuses to IEC 60269-2 type G have ratings up to 125A.

Figure 5



Maximum operating time/current characteristics for fuses to IEC 60269-2 fuse system C.

Fuse rating	Current for time				
	0.1 sec	0.2 sec	0.4 sec	1 sec	5 secs
4 A	18 A	16 A	14 A	12.2 A	10.5 A
10 A	60 A	54 A	47 A	40 A	32 A
16 A	115 A	100 A	90 A	75 A	55 A
25 A	220 A	190 A	170 A	140 A	100 A
40 A	400 A	340 A	290 A	230 A	170 A
63 A	720 A	600 A	500 A	400 A	280 A
100 A	1400 A	1200 A	1000 A	780 A	520 A
160 A	2400 A	2000 A	1600 A	1300 A	820 A

Note: Fuses to IEC 60269-2 type G have ratings up to 125A.

Figure 6

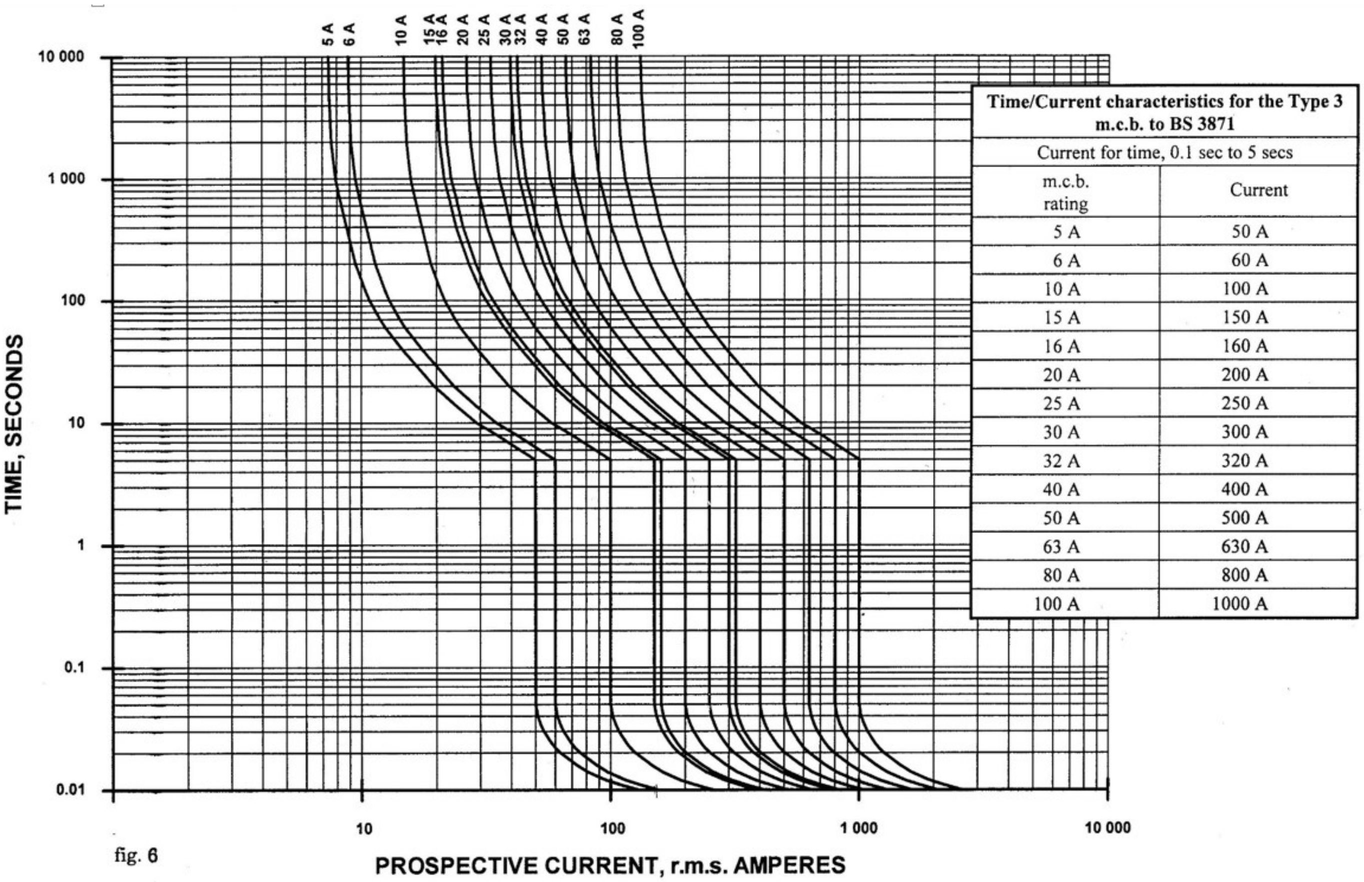


Figure 7

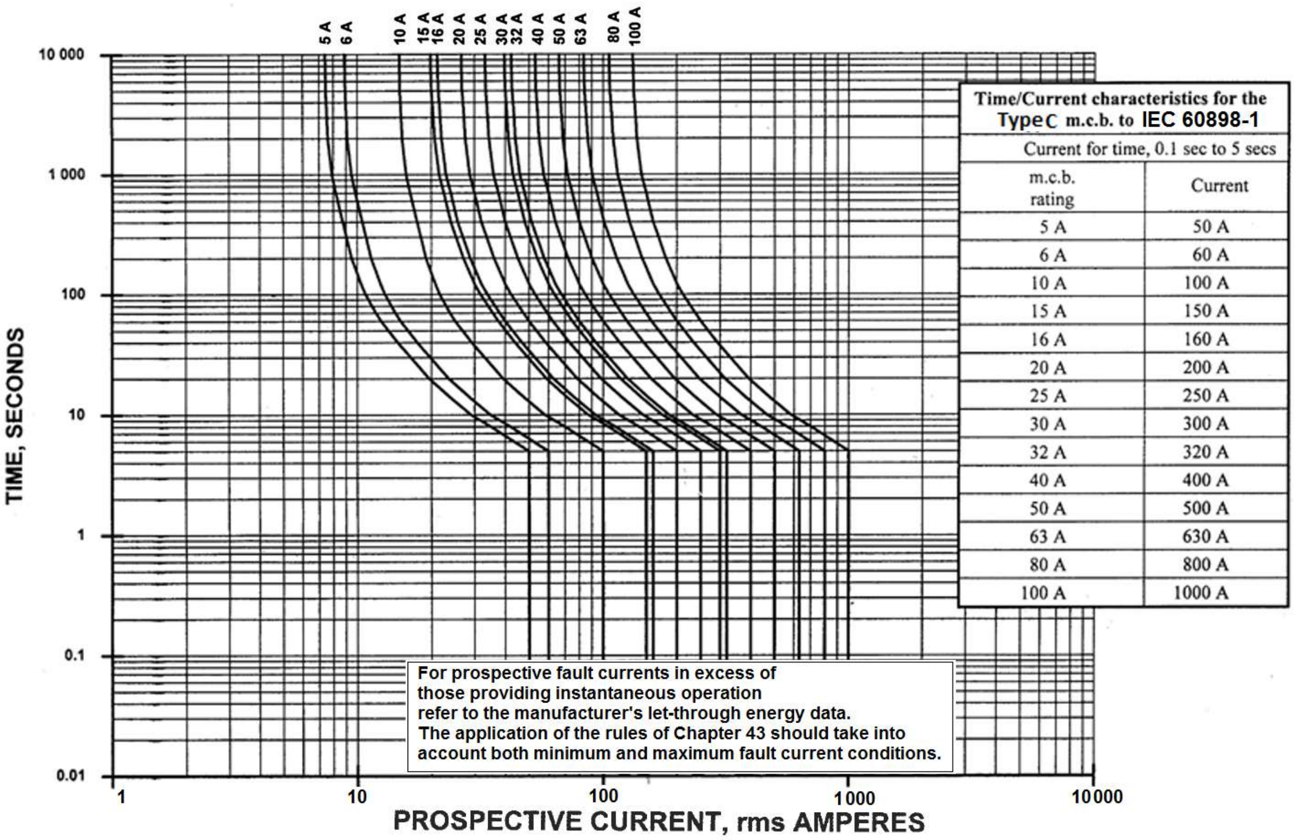
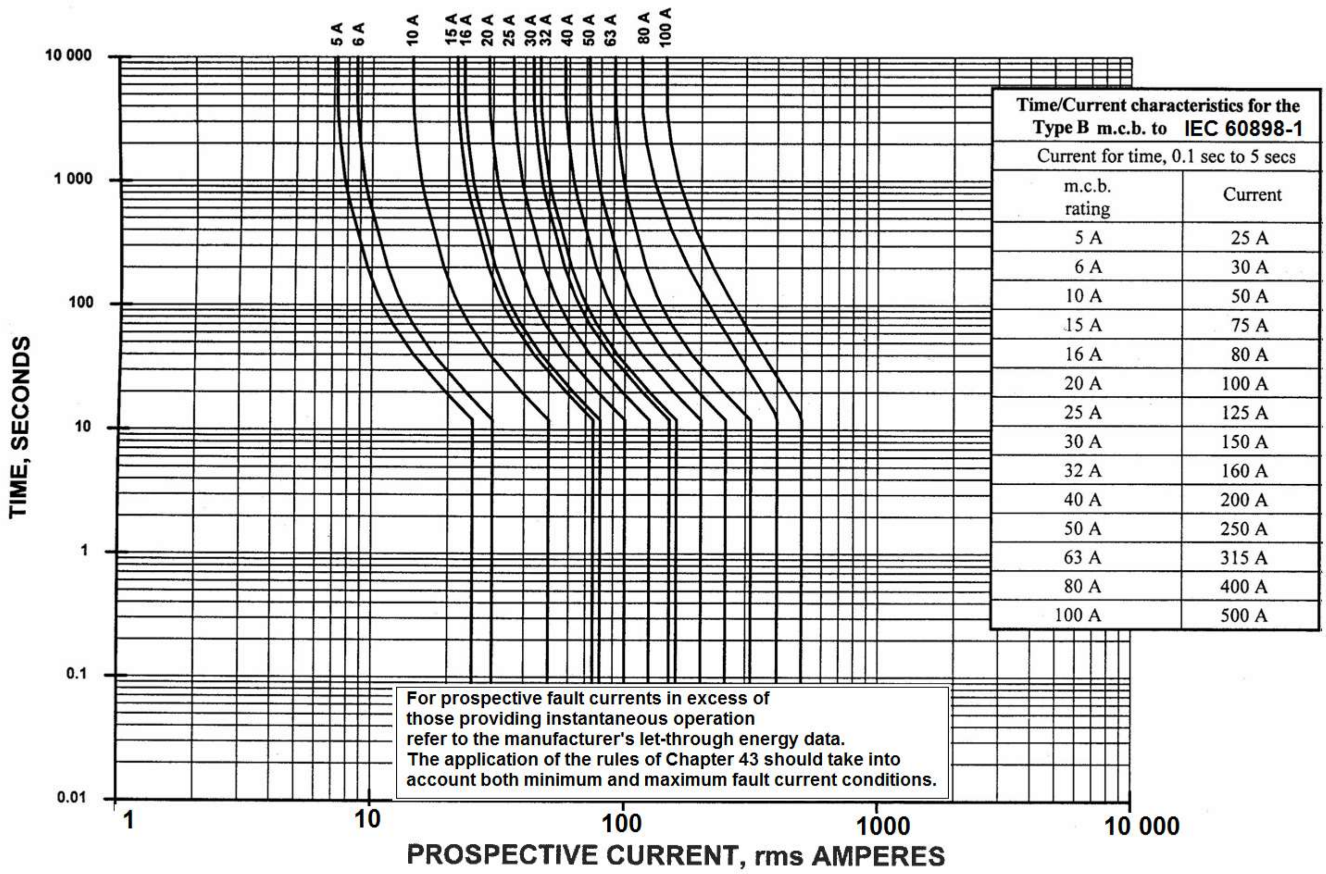


Figure 8



Time/Current characteristics for the Type B m.c.b. to IEC 60898-1

Current for time, 0.1 sec to 5 secs

m.c.b. rating	Current
5 A	25 A
6 A	30 A
10 A	50 A
15 A	75 A
16 A	80 A
20 A	100 A
25 A	125 A
30 A	150 A
32 A	160 A
40 A	200 A
50 A	250 A
63 A	315 A
80 A	400 A
100 A	500 A

Figure 9

Chapter 6

Inspection and Testing

Objectives

On successful completion of this chapter, you will be able to :

- Perform visual inspection of newly completed electrical installation.
- Perform various tests such as continuity of ring final circuit conductors, earth electrode resistance, insulation resistance, polarity, earth fault loop impedance.
- Use Section 611 of the Code as checklist for visual inspection of installations.
- Use Section 611 of the Code with regard to standard methods of testing.
- Describe some basic testing procedures and record results obtained.
- Know the basic requirements and relevant regulations pertaining to inspection and testing of electrical installations.
- Learn the use of various measuring instruments used in the tests.

Overview

After completion of any new wiring installation or major alteration to an existing installation, the work shall be inspected and tested to ascertain that there are no defects and that all necessary items have been included. These procedures will ensure that the completed electrical installations will be safe to use and that they will function efficiently both under normal and abnormal conditions.

Chapter 61 (Section 611.3) gives a checklist for initial inspection of installations by visual mean. The visual inspection must also include checks to make sure that there is no danger to person using the installation from coming into direct contact with the live terminals/parts. Relevant information such as diagrams, charts, tables and details of circuits, including their design data shall be made available for the purpose of visual inspection.

Following this initial inspection, tests shall be carried out in accordance with the standard methods of testing as detailed in Chapter 61 (612). It is important that these tests are carried out in the order shown so as to avoid danger from the test voltage shall faults be present during the tests. A full test of the completed installation shall be carried out, the results carefully recorded and any defects/faults, if found, shall be rectified.

Resources and References

To supplement the learning of this chapter, the following resources/references shall be harnessed:

- Tutorial 6
- Laboratory Hands-on
- Video Show on Inspection and Testing
- Electric Wiring by A J Cooker
- Singapore Standard, SS638:2018
- Electric Wiring (Domestic) by A J Coker
- Electrical Installation, 3rd Edition, by E L Donnelly
- Electrical Installation & Regulations by Michael Neidle

Chapter 6

Inspection and Testing (PART 6 of the Code)

It is mandatory that any electrical installation shall be inspected and tested before supply can be made available and the system energised. The electrical worker who is responsible for the installation is to submit to Singapore Power Supply Limited (SPSL) a completed form (Form C) certifying the fitness of the installation.

For non-domestic premises with approved load above 45 kVA, the consumer must apply for a licence from Energy Market Authority (EMA) to use or to operate the electrical installation. For premises involved in dangerous trades, licensing is required even if the load is less than 45 kVA.

6.1 General Requirements (Chapter 610)

Every completed installation must be inspected and tested before being connected to the supply and energised as mentioned. This should be done in such a manner that no danger to persons or damage to property or equipment can occur, even if the circuit tested is defective.

The following information should be made available to the persons carrying out the inspection and testing of an installation. (514.9.1L).

-- Diagrams, charts or tables indicating:
  - (a) the type of circuits
  - (b) the number of points installed
  - (c) the number and size of conductor
  - (d) the type of wiring system

-- The location and types of devices used for:
  - (a) protection
  - (b) isolation and switching

-- Details of the characteristics of the protection devices for automatic disconnection, the earthing arrangements for the installation, the impedances of the circuits and a description of the method used for compliance (410.3.2L)

410.3.2L A protective measure shall consist of:
(i) an appropriate combination of a provision for basic protection and an independent provision for fault protection, or
(ii) an enhanced protective provision which provides both basic protection and fault protection. NOTE 2 - An example of an enhanced protective measure is reinforced insulation

6.2 Inspection and testing (Part 6 of the Code)

An inspection should be made of an installation to verify that installed electrical equipment is:

-- in compliance with the requirements of Section 511 (Chapter 51). This may be ascertained by mark or by certification furnished by the installer or the manufacturer, and

-- correctly selected and erected in accordance with this Section, taking into account manufacturers' instructions, and

-- not visibly damaged or defective so as to impair safety

611.3 provides a checklist for inspection as follows:

- -- connection of conductors
- -- identification of conductors
- -- selection of conductors for current-carrying capacity and voltage drop
- -- connection of single-pole devices for protection or switching in phase conductors only
- -- correct connection of accessories and equipment
- -- presence of fire barriers and protection against thermal effects
- -- methods of protection against electric shock
- -- prevention of mutual detrimental influence
- -- presence of appropriate devices for isolation and switching
- -- presence of under voltage protective devices
- -- choice and setting of protective and monitoring devices
- -- labelling of protective devices, switches, and terminals
- -- selection of equipment and protective measures appropriate to external influences
- -- adequacy of access to switchgear and equipment
- -- presence of danger notices and other warning notices
- -- presence of diagrams, instructions and similar information
- -- erection methods

6.3 Testing (Section 612)

The following items, (where relevant to the installation being tested), must be tested in the following sequence:

- -- Continuity of protective conductors including main and supplementary bonding
- -- Continuity of ring final circuit conductors
- -- Insulation resistance
- -- Protection by separation of circuits (electrical separation)
- -- Protection against direct contact (basic protection) by a barrier or enclosure provided during erection (IP2X or IP4X)
- -- Insulation of non-conducting floors and walls
- -- Polarity
- -- Earth electrode resistance (For TT system)
- -- Earth fault loop impedance
- -- Additional protection (RCD)
- -- **Prospective fault current**
- -- Phase sequence testing
- -- Functional testing
- -- Verification of voltage drop (not normally required during initial verification)

6.3.1 Continuity of Protective Conductors (612.2.1)

The initial test applied to protective conductors are intended to verify that the conductors are both correctly connected and electrically sound, and the resistance is such that the overall earth fault loop impedance of the circuits is of a suitable value to allow the circuit to be disconnected from the supply in the event of an earth fault. (Within the disconnection times selected to meet the requirements of this Section).

A d.c. ohmmeter can be used for the test. The protective conductor should be inspected throughout its length to verify that no inductor has been incorporated in the circuit.

6.3.1.1 Testing Continuity of Protective Conductors

Method 1 (see Fig. 6.3.1.1 (a))

Step 1: Connect one terminal of the continuity tester to a long test lead and connect this to the consumer's earth terminal.

Step 2: Connect the other terminal of the continuity tester to a short lead and use this to make contact with the protective conductor at various points on the installation, testing such items as switch boxes and socket outlets.

The resistance reading obtained by the above method actually includes the resistance of the test leads. Therefore the resistance values of the test leads should be measured and this value deducted from any resistance reading obtained for the installation under test.

Method 2 (see Fig. 6.3.1.1 (b))

If the distance between the distribution board and the circuit under test involves the use of very long test leads, an alternative (Method 2) using the phase conductor as a test lead may be used:

Strap the phase conductor to the protective conductor at a distant socket outlet, to include all the circuit and test between phase and earth terminals at the distribution board as illustrated in the diagram shown on next page.

The resistance measured by the above method includes the resistance of the phase conductor from the main switch to the point under test.

The approximate resistance of this conductor can be obtained by joining together the phase and neutral conductors at the socket outlet (at the point under test) and measuring the resistance as shown. The value of conductor resistance being half the value obtained by this test.

The value of earth continuity conductor resistance is calculated as the initial reading, minus phase conductor resistance.

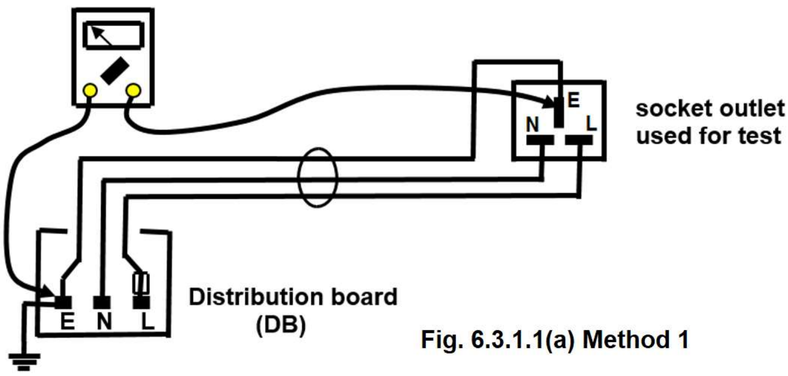


Fig. 6.3.1.1(a) Method 1

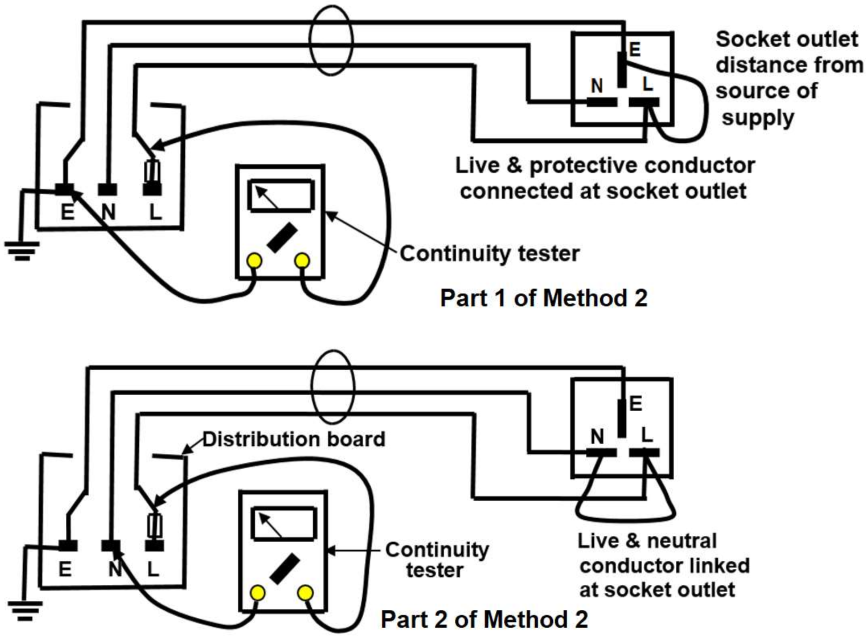


Fig. 6.3.1.1(b) Method 2

6.3.2 Continuity of Ring Final Circuit Conductors (612.2.2)

612.2.2 calls for a test to verify the continuity of each conductor including the protector conductor, of every ring final circuit. Two methods of testing are recommended, and, in each case, the test is made to verify the continuity of the phase, neutral and cpc of a ring final circuit.

Method 1 :

The resistance between the opened ends of each of the three rings (phase, neutral and earth) is measured and recorded. Then measure the resistance of the long test lead and note result.

The two ends of each of the three rings are then twisted together, and readings taken from the twisted end to an outlet near the middle of the ring (mid-point), using the above long test lead. The actual results of the second test should deduct away the resistance of the long test lead. Compare the results of the first and second test, the result of the second test should be about one quarter of the result of the first test. The test sequence is illustrated in Fig. 6.3.2(a).

Step A: Measure resistance between ends of phase conductor (A).

Step B : Measure resistance of test lead (B).

Step C: Measure resistance from closed ends of phase conductor to mid-point of ring (C).

Check that results are $A/4 = C - B$

Repeat tests for neutral and protective conductors.

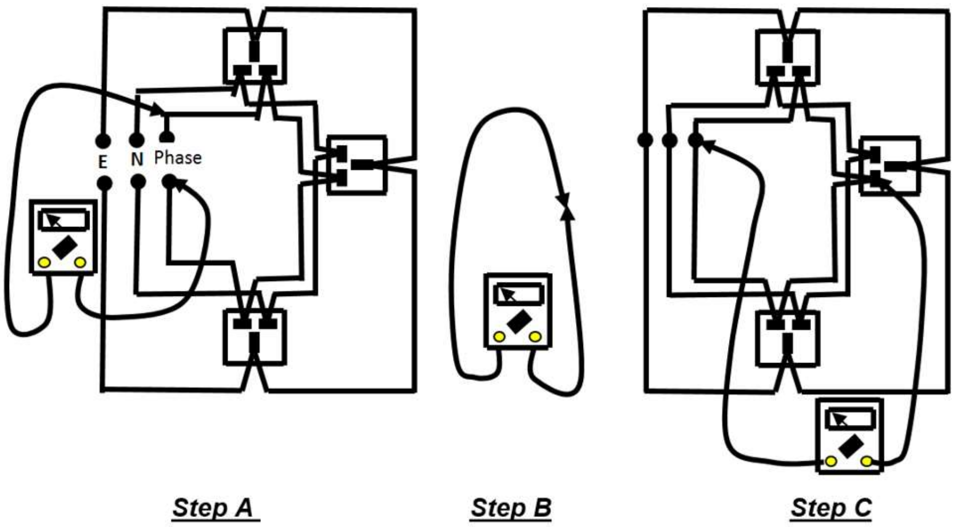


Fig. 6.3.2(a) Continuity test of ring circuit (Method 1)

Method 2 :

This method does not need a long test lead to make contact with the midpoint of the ring, and the test sequence is illustrated in Fig. 6.3.2(b).

Step 1 : With the ring opened at its ends, measure resistance between ends of protective conductor, phase conductor and neutral conductor respectively, say A, B and C ohms.

Step 2 : Connect the ends of the ring, measure between phase and neutral with mid-point conductors short circuited and check that the resistance value is

B/2 = C/2

Step 3 : Measure between phase and protective conductor with mid-point short circuited and check that the resistance value is:

A /4 + B/4

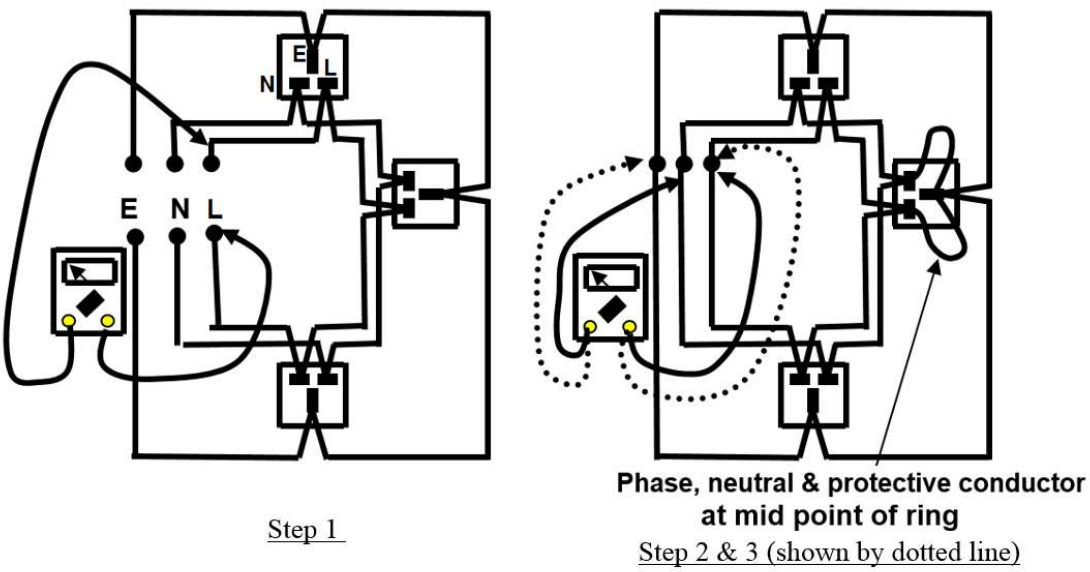


Fig. 6.3.2(b) Continuity test of ring circuit (Method2)

6.3.3 Insulation Resistance (612.3)

These tests are to verify that the insulation of conductors and electrical accessories and equipment is satisfactory, and that electrical conductors or protective conductor are not short circuited, or show a low resistance (which would indicate a deterioration in the insulation of the conductors).

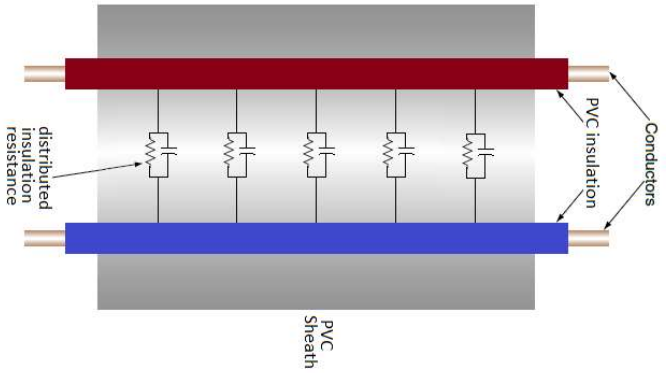
Type of Test Instrument

An insulation resistance tester should be used which is capable of providing a d.c. voltage of not less than twice the nominal voltage of the circuit to be tested (r.m.s. value for an a.c. supply). The test voltage need not exceed

-- 500 V d.c. for installations connected to 500 V

-- 1000 V d.c. for installations connected to supplies in excess of 500 V and up to 1000 V

Insulation resistance



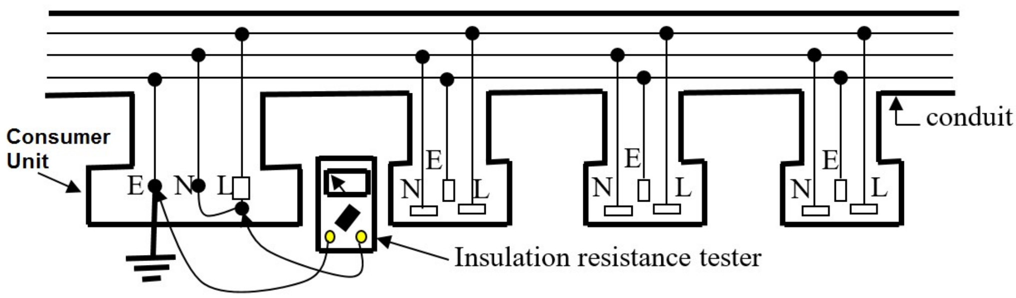
An insulation resistance test is performed to ensure that the insulation of conductors, accessories and equipment is in a healthy condition, and will prevent dangerous leakage currents between conductors and between conductors and earth. It also indicates whether any short circuits exist.

Insulation resistance is the resistance measured between conductors and is made up of countless millions of resistances and capacitance in parallel. The more resistances there are in parallel, the lower the overall resistance, and in consequence, the longer a cable the lower the insulation resistance.

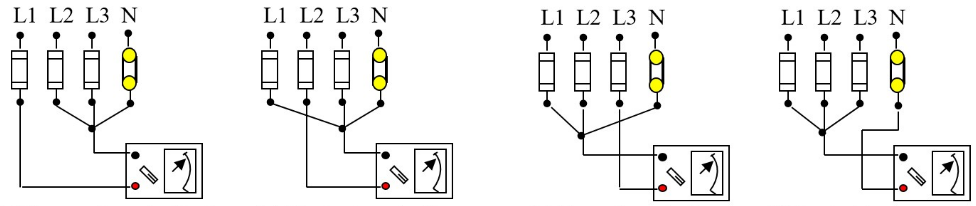
Testing Procedure

Disconnect all items of equipment such as capacitors and indicator lamps as these are likely to give misleading results. Remove any items of equipment likely to be damaged by the test, such as dimmer switches, electronic timers, etc. Remove all lamps and accessories and disconnect fluorescent and discharge fittings. Ensure that the installation is disconnected from the supply, all fuses are in place, and circuit breakers and switches are in the on position. In some instances, it may be impracticable to remove lamps, etc. and in this case the local switch controlling such equipment may be left in the off position.

Join all live conductors of the supply and test between this join and earth. Alternatively, test between each live conductor and earth in turn. Test between line and neutral. For three-phase systems, join all lines and test between this join and neutral. Then test between each of the lines. Alternatively, test between each of the live conductors in turn. Each of the reading obtained should not be less than ***1.0megohm as per SS638:2018.*** ***(~~The old CP5:1998 the value of not less than 0.5Mohm is acceptable.~~)***



Insulation resistance test (L-E, N-E)



(a) Brown phase to Black, Grey & Neutral connected together

(b) Black phase to Brown, Grey & Neutral connected together

(c) Grey phase to Brown, Black & Neutral connected together

(d) Neutral to Brown, Black & Grey connected together

Large Installations

A large installation with many circuits has the insulation resistance of each circuit in parallel. As an example, in a large installation with many outlets, (say 50 circuits), the supply source might have an insulation resistance value to earth of 0.2 megohm. If the 50 circuits were tested individually the insulation resistance of each circuit could be 10 megohm.

Since an insulation resistance test on an installation should not be less than **1.0 megohm,** for some large installations tested at the supply source the test would prove the installation unsuitable for connection to the supply.

Large installations may be divided into two or more sections of not less than 50 outlets for insulation testing purposes.

The term outlet includes every switch, socket outlet and luminaire. Appliances which incorporate a switch in their construction are regarded as one outlet.

Example 1

(a) An electrical installation has four final circuits, the results of an insulation test for each circuit is as follows:

(i)	lighting circuits	---	10 MΩ
(ii)	switched socket outlets	---	15 MΩ
(iii)	air-condition units	---	5 MΩ
(iv)	water heaters	---	2 MΩ

Determine the equivalent insulation resistance value at the supply terminal.

(b) What is the minimum value of insulation resistance as required to comply with SS638:2018? Is the above insulation resistance value acceptable?

Solution:

(a) The equivalent insulation resistance value, R_e , is obtained as follows:

$$\frac{1}{R_e} = \frac{1}{10M\Omega} + \frac{1}{15M\Omega} + \frac{1}{5M\Omega} + \frac{1}{2M\Omega}$$

$$R_e = 1.15M\Omega$$

(b) The minimum value to meet the SS638:2018 requirement is 1.0 MΩ. The above Insulation Resistance value of 1.15 MΩ is acceptable.

6.3.4 Polarity Test (612.6)

This test must be carried out to verify that:

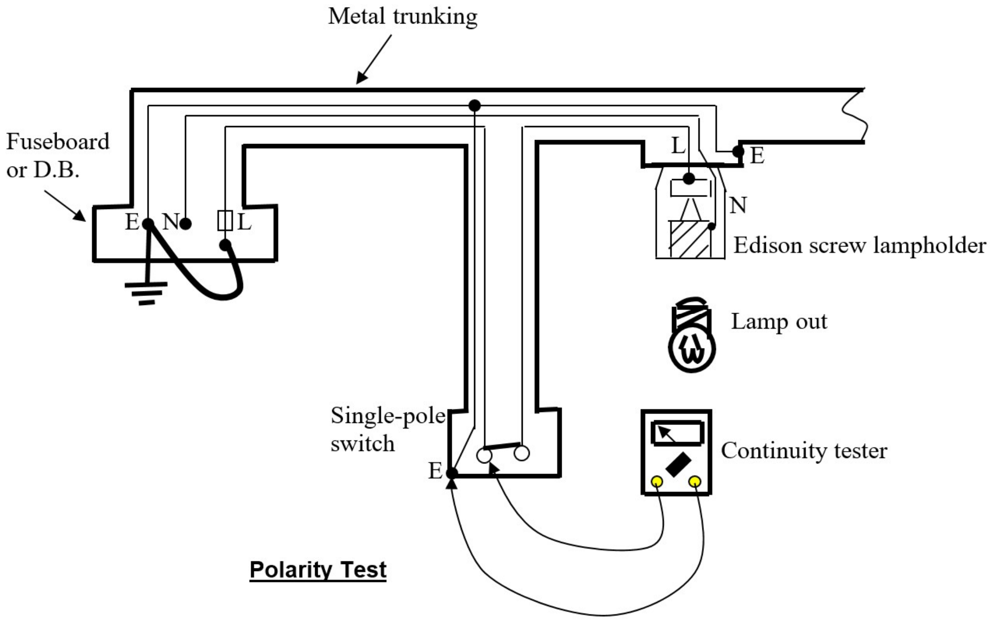
(a) all fuses, circuit breakers and single pole control devices such as switches are connected in the phase conductor only.

(b) the centre contact of an Edison-type screw lamp holder is connected to the phase conductor and the outer metal threaded parts are connected to the neutral or earthed conductor.

(c) any socket outlets have been correctly installed i.e. phase pin 13 A socket outlet on right when viewed from the front.

The installation must be tested with all switches in the 'on' position and all lamps and power consuming equipment removed.

A test of polarity can be carried out using a continuity tester as illustrated.



Polarity Test

Although polarity is towards the end of the recommended test sequence, it would seem sensible and practicable, on lighting circuits for example, to conduct this test at the same time as that for continuity of circuit protective conductors.

6.3.5 Earth Electrode Resistance (612.7)

Where the earthing system incorporates an earth electrode as part of the installation, it is necessary to verify that the resistance of the electrode does not raise the earth fault loop impedance in a TT system to an undesirable level.

There are two common methods of testing earth electrode resistance:

-- alternating current method; employing a mains supply transformer.

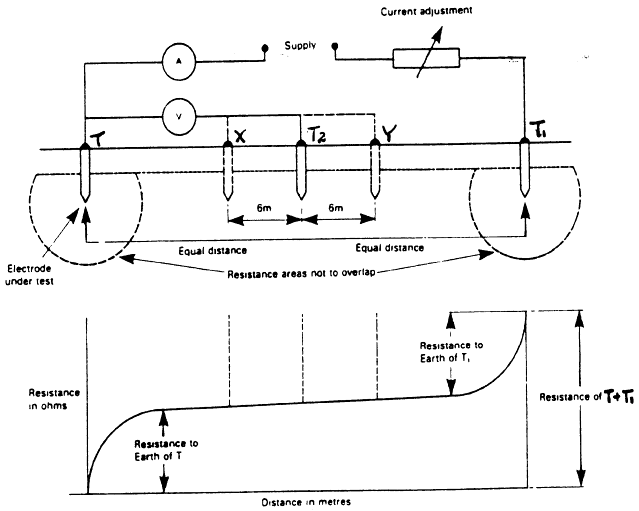
-- proprietary earth testers.

6.3.5.1 Alternating Current Method

An alternating current of a steady value is passed between the earth electrode under test (T) and an auxiliary earth electrode (T_1) placed at such a distance from (T) that the resistance areas of the two electrodes do not overlap. A secondary auxiliary earth electrode (T_2), (which may be a metal spike driven into the ground) is then inserted half-way between (T) and (T_1), and the voltage drop between (T) and (T_2) measured. The resistance of the earth electrodes is then the voltage between (T) and (T_2) divided by the current flowing between (T) and (T_1) provided that there is no overlap of the resistance.

To check that the resistance of the earth electrodes is a true value two further readings are taken with the second auxiliary electrode (T_2) moved 6 m further from and 6 m nearer to (T) respectively. If the three readings are substantially in agreement, the mean of the three readings is taken as the resistance of the earth electrode under test (T). If there is no such agreement the tests are repeated with the distance between (T) and (T_1) increased.

The test is made either with current at power frequency, in which case the resistance of the voltmeter used must be high (of the order of 200 ohms per volt), or with alternating current from an earth tester comprising a hand-driven generator, a rectifier (where necessary), and a direct-reading ohmmeter.



Measurement of Earth Electrode Resistance

T - earth electrode under test disconnected from all other sources of supply

T_1 - auxiliary earth electrode

T_2 - second auxiliary earth electrode

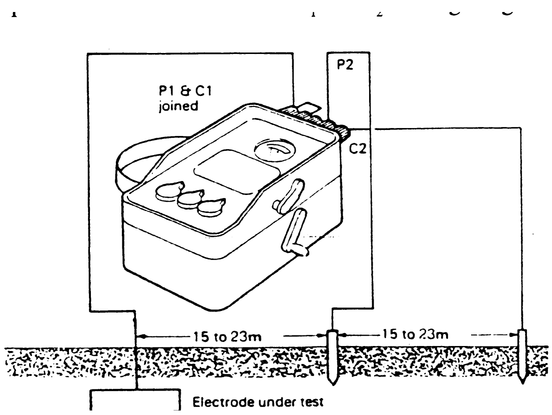
X - alternative position of T_2 for check measurement

Y - further alternative position of T_2 for check measurement.

6.3.5.2 Proprietary Earth Testers

These have a d.c. hand-operated generator fitted with a current reverser to provide an a.c. supply at the output terminal or an a.c. hand-operated generator; or they may be battery operated.

Proprietary earth tester pass a current through the resistance under test from C_1 to C_2, and the resultant potential is measured between P_1 and P_2 causing the galvanometer to deflect.



Proprietary Earth Tester

6.3.5.3 Improvements on Earth Electrode Resistance

Earth Electrode Resistance can be improved by :

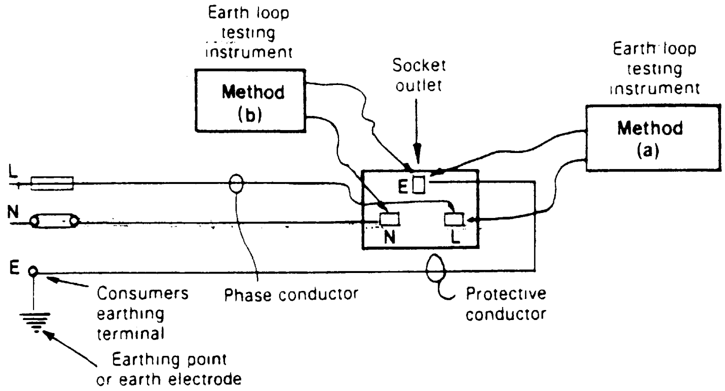
(a) driving the earth electrode deeper so that it can contact with wet soil.
(b) having one of more earth rods connected in parallel with the existing one.
(c) relocating earth rod to marshy ground.
(d) using earth mats.
(e) using earth plate.

6.3.6 Earth Fault Loop Impedance (612.9L)

The earth fault current path, phase to earth loop, starting at the point of fault comprises: circuit protective conductor consumer's earthing terminal and earthing conductors; the metallic return path in TN-S systems, or the earth return path in TT systems; the path through the earthed neutral point of the supply transformer and transformer winding; and the phase conductor from the transformer back to the point of fault.

The symbol for earth loop impedance is $\mathbf{Z_S}$ and for earth loop impedance external to installation is $\mathbf{Z_E}$.

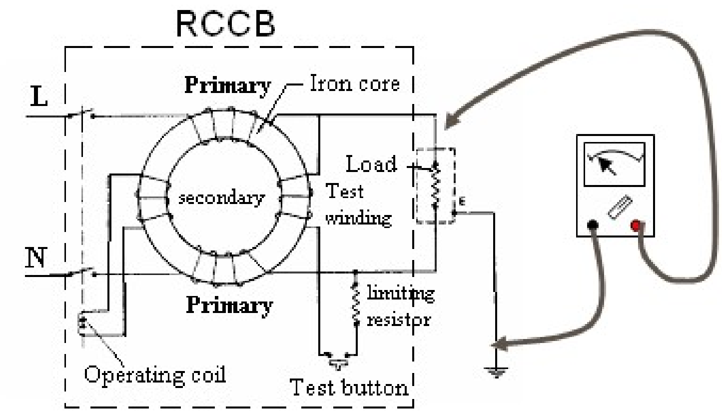
The test is usually carried out by using a proprietary earth fault loop impedance test instrument that is plugged into a socket outlet to test the earth loop impedance. The instrument operates at a current of approximate 20 A applied for 25-50 ms, with indicator lights to show the condition of polarity and continuity. It is necessary to verify the continuity of the protective conductor, this would prevent the loop current from flowing and the whole of the protective conductor would be connected to the phase conductor.



Methods of testing the impedance of the earth loop circuit (a) Line-earth loop test (b) Neutral-earth loop test

6.3.7 Additional Protection (Operation of Residual Current Operated Devices) (612.10)

The test is made on the load side of the circuit breaker between the phase conductor and the circuit protective conductor so that a suitable residual current flow.



Circuit diagram of a Residual Current Circuit Breaker

Trip tests

½ x 30mA	-	No trip
1 x 30mA	-	Trip within 100ms
5 x 30mA	-	Trip within 40ms

6.3.8 Prospective fault current (612.11**)**

Prospective fault current (PFC) shall be determined at the origin of the installation. This is achieved by enquiry, calculation or measurement.

6.3.9 Phase sequence testing (612.12**)**

For multiphase circuits, it shall be verified that the phase sequence is maintained.

6.3.10 Verification of Voltage Drop (612.14)

Where required the voltage drop may be evaluated by measuring the circuit impedance or by using calculations. Verification of voltage drop is not normally required during initial verification.

Chapter 7

SS650 Socket Outlet Assembly and Solar Photovoltaic Power Supply System

7.1 SS650

What is SS650 (CP88)?

CP88: 2001 Temporary Electrical Installations is introduced in May 2001. It is developed as a result of a review carried out by the Technical Committee appointed to update CP44 – Code of Practice (COP) for Temporary Electrical Installations for Construction and Building Sites. One of the key recommendations is the introduction of Socket Outlet Assembly (SOA). SS650:2019 is the revised edition of CP88.

Socket Outlet Assembly (SOA)

SOA is basically a metal or plastic cabinet or box in which the various circuit protective devices are housed, and is typically equipped with up to 6 socket outlets.

Figure 1: Wall mount SOA

The SOA will allow for the connection of portable electrical equipment such as electrical hand tools, lamps, welding sets and water pump. Thus, it is necessary for each and every piece of portable electric equipment to be connected up using only industrial plug. This will enable the equipment to be plugged directly into the industrial socket outlets fitted on the SOA.

The SOA has to be manufactured in accordance to the standards specified in the SS650 2018

Purpose of SOA

The basic purpose is to move the construction industry towards a more systematic approach in setting up of temporary electrical installation. This also applies to festive lighting, trade-fairs, mini-fairs and exhibition sites.

Important Points to note when using SOA

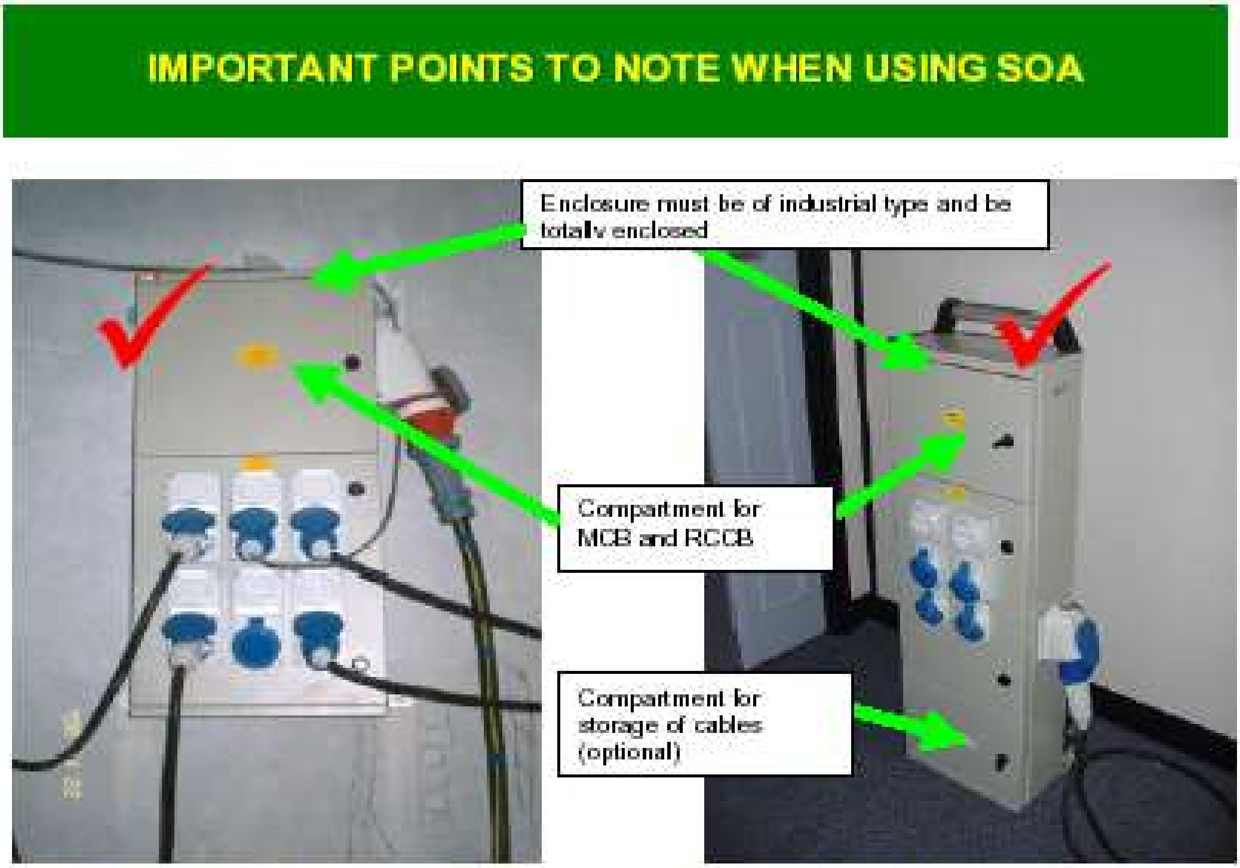


Figure 2: Essential features to take note when using SOA

Enclosure

SOA must be totally enclosed with all the live parts totally protected from direct contact.

Protection

Socket outlets must be equipped with:

- Miniature Circuit Breaker (MCB)
- Residual Current Circuit Breaker (RCCB)
- Fuses prohibited (Not allowed) for final circuits

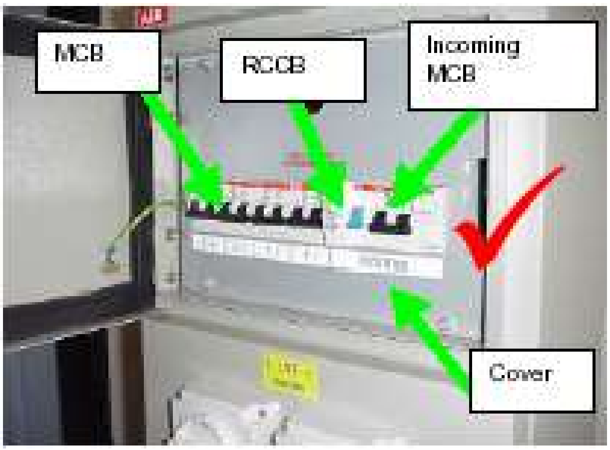


Figure 3: Circuit breakers inside the SOA

Single-phase socket-outlet assembly fed from single-phase source:

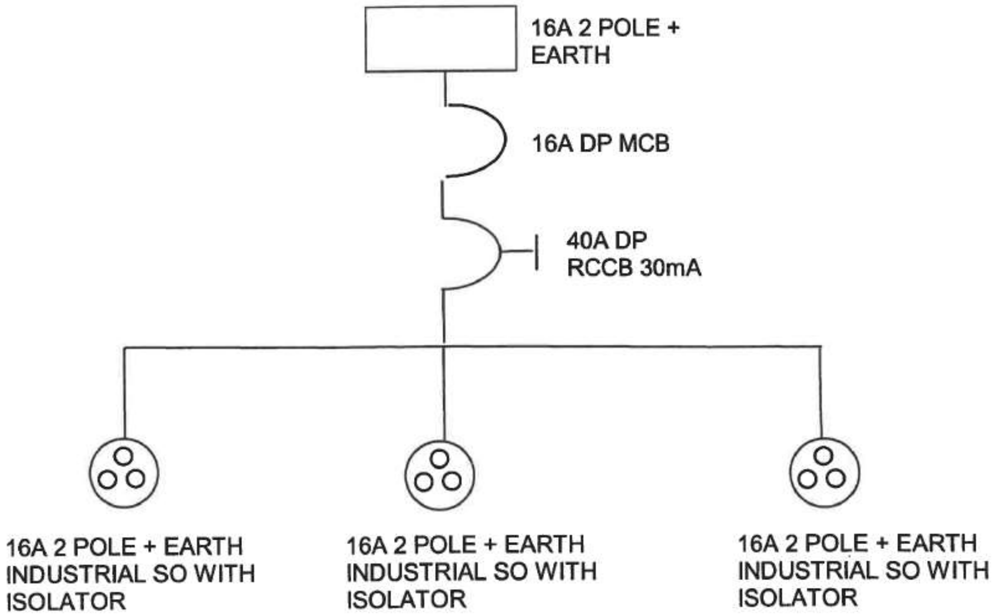
Either a 32A single-phase 230V source
or a 16A single-phase 230V source
connected by a fixed plug of the corresponding rating

- 32A 1Ø 230V source
  - A 32A DP MCB shall be provide to control the incoming supply
  - A maximum of up to six numbers of 16A 2-pole and earth socket-outlets shall be provided
  - Each socket-outlet shall be controlled by a double-pole MCB not exceeding 16A current rating
- 16A 1Ø 230V source
  - A 16A DP MCB shall be provide to control the incoming supply
  - A maximum of up to three numbers of 16A 2-pole and earth socket-outlets shall be provided
  - Each socket-outlet shall be controlled by a double-pole isolator of at least 16A rating or MCB not exceeding 16A current rating

Single-phase socket-outlet assembly fed from three-phase source:
using a 32A three-phase 400V source
Connected by a fixed plug of the corresponding rating and controlled by a 32A 4-pole MCB

- A maximum of up to nine numbers of 16A 2-pole and earth socket-outlets shall be provided
- Each socket-outlet shall be controlled by a double-pole MCB not exceeding 16A current rating

Single Line Diagram of various SOA configuration



SSO Figure 1 – Example of single-phase socket-outlet assembly fed from a 16A single-phase source

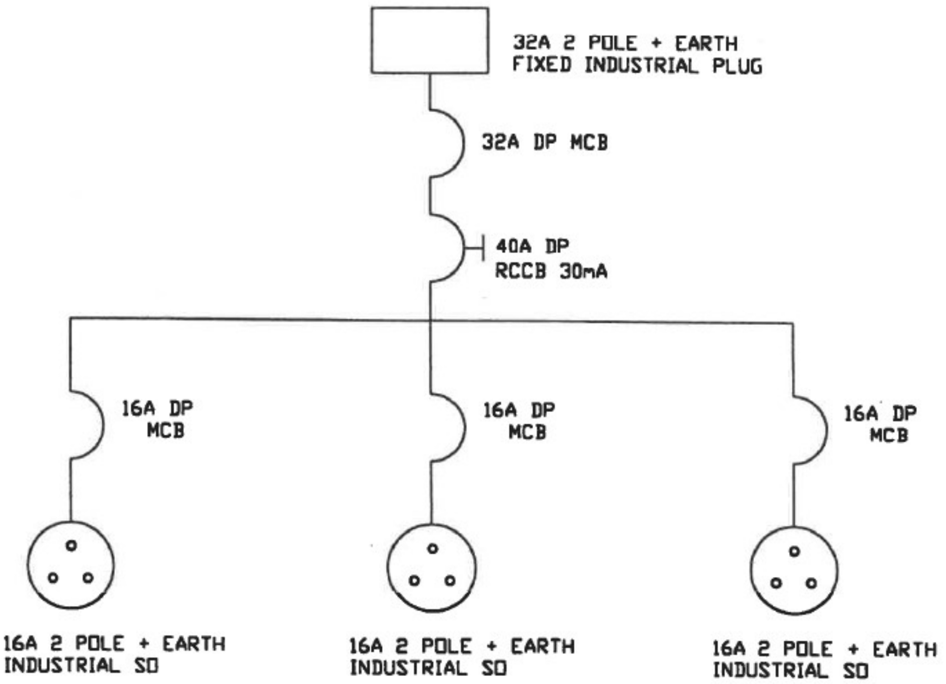


Figure 2 – Example of single-phase socket-outlet assembly fed from 32A single-phase source

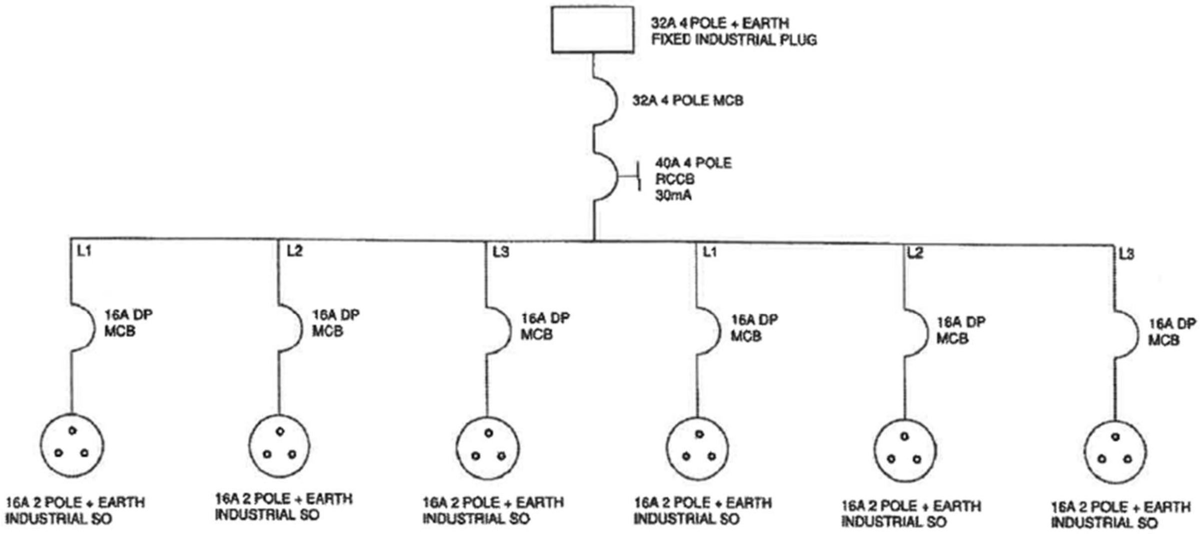


Figure 3 – Example of single-phase socket-outlet assembly fed from three-phase source

Number of single-phase socket-outlets can go up to maximum of nine.

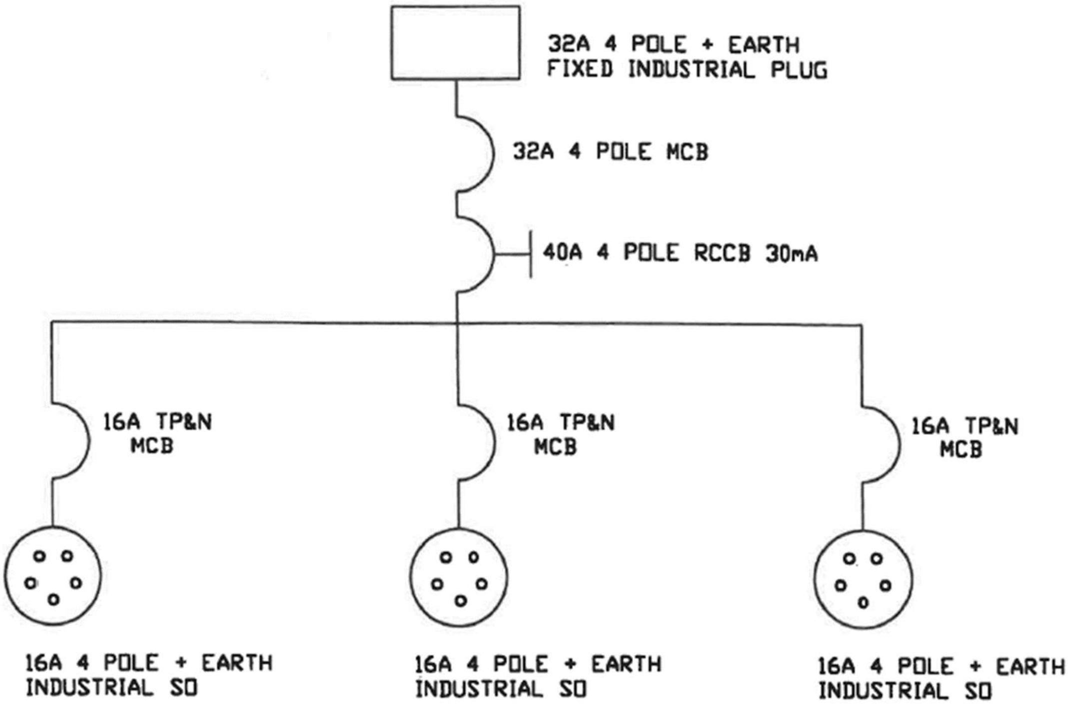


Figure 4 – Example of three-phase socket-outlet assembly

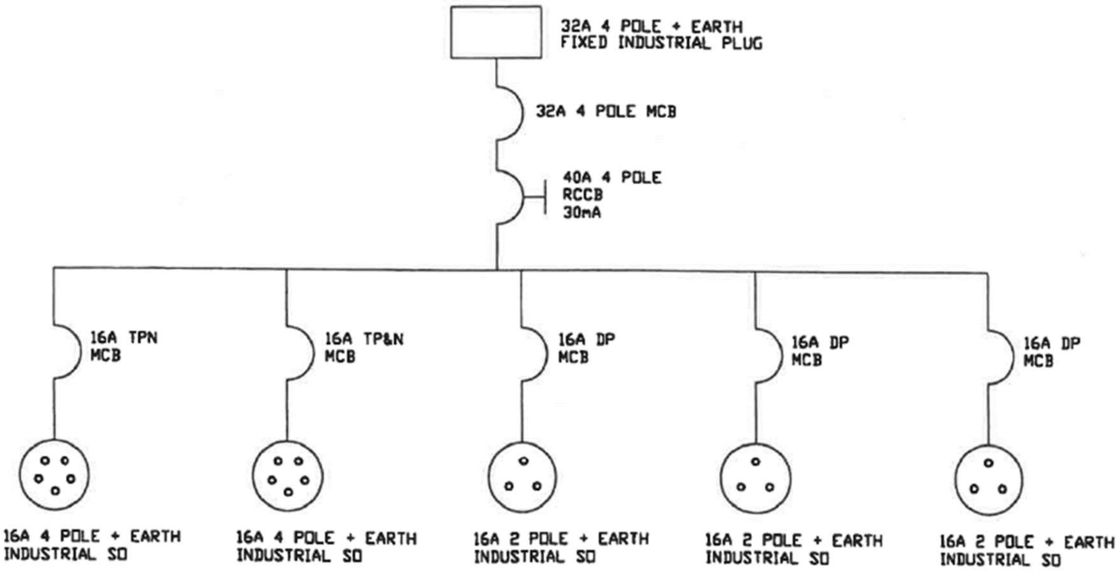


Figure 5 – Example of three-phase and single-phase socket-outlet assembly

Industrial Plugs & Socket Outlets

The respective colour code of the corresponding industrial plugs and socket outlets are exemplified as follows:

Operating Voltage (V)	Colour	examples
55	White	
110	Yellow	
230	Blue	
400	Red	

Figure 4: Colour code of industrial plug and socket outlets

Portable Electrical Equipment

Flexible cables used for portable electrical equipment such as hand-held tools must not exceed 3 metres or such other length as supplied by the manufacturer.

Legislation

The latest (2019) revision of the Code of practice for Temporary Electrical Installations resulted in SS650 Part 1 and Part 2. Part 1 is applicable to the Temporary Electrical Installation of Construction and Building sites. Part 2 is applicable to the Temporary Electrical Installation of Festive Lightings, Trade Fairs, Mini Fairs and Exhibition Sites.

The latest codes of practices takes effect on 15 Nov 2019. The transition period of one year, i.e. existing projects can continue to use CP88 up till 14 Nov 2020.

Inspection Checklist

It is essential to acquire the basic knowledge on the necessary items to be checked for temporary electrical installation from the SS650 relevant standards.

- SS650 Part 1 : Construction and building sites
  - ✓ Temporary electrical installations inspection checklist for construction and building sites.
- SS650: Part 2 : Festive lighting, trade-fairs, mini-fairs and exhibition sites
  - ✓ Temporary electrical installations inspection checklist for festive lighting, trade-fairs, mini-fairs and exhibition sites

Inspection Requirement (EMA's requirement)

The inspection shall be performed by an authorized Licence Electrical Worker (LEW) and the inspection frequency is appended as follows:

Type of installation	Inspection Frequency	Remarks
Construction Worksites	**At least once per month**	**Electrical installations at construction worksites are subjected to more wear and tear and shall be inspected at least once a month to ensure they remain safe to use.**
Trade fairs, mini-fairs, festive lightings etc	**Daily**	**Safety inspections should be carried out daily to ensure all parts accessible to the public remain safe and all protective devices in good working conditions.**

INSTALLATION REQUIREMENT FOR ELECTRIC BIDET USED IN TOILET

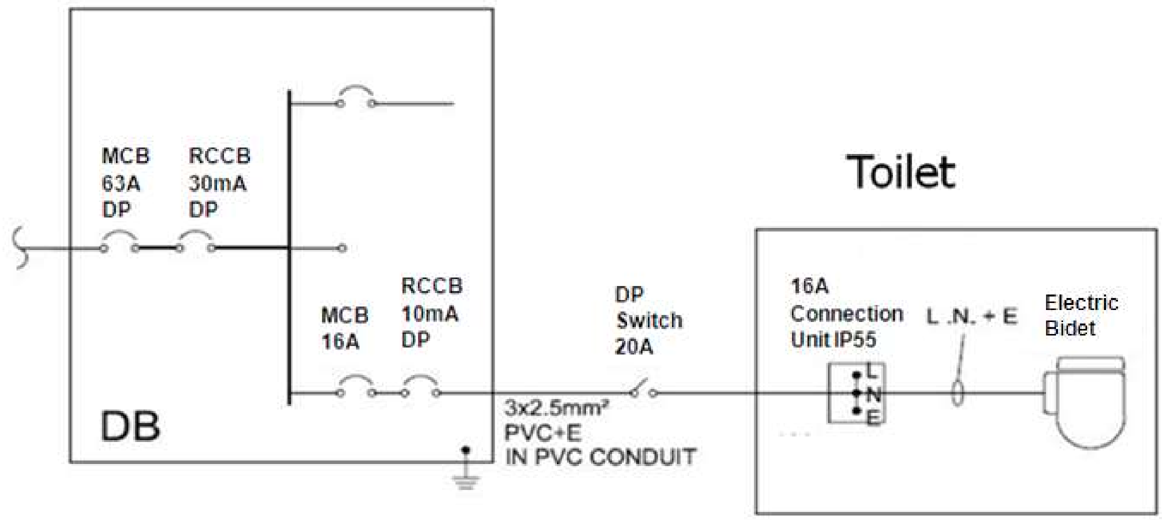
1. The final circuit for the electric bidet shall be protected by a 16A MCB and 16A rated RCCB with 10mA tripping sensitivity at the DB.

2. The electric bidet shall be controlled by a 20A double pole switch outside the toilet. A 16A weatherproof connection unit of IP55 with non-metallic casing shall be installed near to the control box of the electric bidet for connection of supply cable.

3. A Licensed Electrical Worker (LEW) shall be appointed by the supplier to supervise the installation of the equipment and the method of wiring installation shall comply with the requirements of this Code.

4. The electric bidet shall be tested for compliance to IEC 60335-2-84 (Safety of Household and Similar Electrical Appliances, Part 2-84: Particular Requirements for Toilets) or equivalent.

5. A schematic diagram showing the recommended set-up is as follow:



TOPIC 1 – Power Supplies and Distribution

Short Questions

1. A consumer requires electricity supply to his premise which utilises 23 kVA of power. Suggest the likely electricity supply to be provided by SP Services; clearly stating the voltage, frequency and phase of the supply.

2. Classify the supply voltages provided by SP Services into the low and high-tension categories for the electricity consumers.
Transmission of electricity from the power stations to the consumer is always in high voltages. Why?

3. The current taken by a 230V, 50 Hz, single-phase induction motor running at full load is 40A at 0.75 power-factor lagging. Calculate the electrical power in kW drawn form the supply. (Ans : 6.9 kW)

4. What is meant by the terms three-wire and four-wire system as applied to a three-phase supply arrangement?

5.

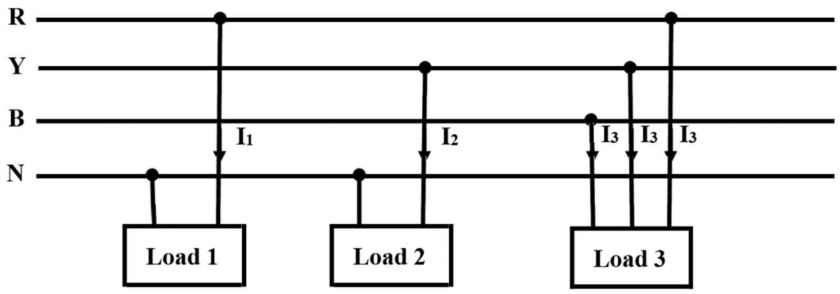


Fig. Q5

The circuit shown in Fig. Q5 consists of two single-phase loads and one three-phase load connected to a three-phase four-wire 400/230V 50Hz supply. The particulars of the connected loads are:

Load 1 : 6.5 kW single-phase 230V at unity power factor

Load 2 : 5 kW single-phase 230V at a lagging power factor of 0.85

Load 3 : 15 kW motor, three-phase 400V at a lagging power factor of 0.75 and has an efficiency of 92 %

Determine the current flowing Load1, Load 2, and Load 3.
(Ans : 28.3A ; 25.6A ; 31.4A)

6. A three-phase motor consumes 20 kW at 0.8 power factor lagging from a 400V three-wire three-phase supply. Calculate the line current consumed by the motor. What is the current in each phase coil of the motor assuming that the coils are delta-connected?
(Ans : I_L = 36.1A ; I_{ph} = 20.8A)

7. A star-connected resistive load is connected to a three-phase supply of 400V, determine the line current and the resistance per phase if it consumes 9 kW. The same resistive load is now arranged in delta connection and connected to the same three-phase supply of 400V, determine the phase current flowing in the resistor and also the line current

(Ans: Star I_L = 12.98 or 13.04A, $R_{per\ phase}$ = 17.77 or 17.64Ω, Δ I_{Phase} = 22.51 or 22.67A, I_L = 38.99 or 39.27A)

8. The full load efficiency of a 25 kW, 400V 3-phase motor is 85 %. The power factor is 0.8 lagging. Calculate the value of the full-load current. (Ans : 53.1A)

9. What is the difference between watts and volt-amperes in an a.c. circuit? When are these two quantities equal?

10. A three-phase, 50 hp, 400V, delta-connected motor with 0.8 power factor lagging and 88 % efficiency is connected to a 400V three-phase supply. Calculate the line current taken from the supply and also the phase current of the motor. (1hp = 746W) (Ans: 76.5A, 44.15A)

11. A single phase motor has an output of 3725W and its efficiency is 84 % when taking a current of 22A from a 240V supply. Calculate:
    (i) the power input in kW to the motor
    (ii) the volt-amperes
    (iii) the power factor (Ans : 4.44 kW ; 5280VA ; 0.84)

12. Explain the difference between a schematic diagram and a single-line diagram.

13. Draw the single-line diagram of an electrical distribution board comprising the followings:
    (i) Incoming MCB 30A TPN
    (ii) RCCB 40A 4P 30 mA,
    (iii) 5 number final circuits consisting of:
    Circuit 1 : 10A MCB SPN connected to 10 nos 2x36W fluorescent lamps
    Circuit 2 : 10A MCB SPN connected to 6 nos 50W filament lamps
    Circuit 3 : 20A MCB SPN connected to 8 nos 13A switched socket outlets
    Circuit 4 : 30A MCB SPN connected to 12 nos 13A switched socket outlets
    Circuit 5 : 30A MCB TPN connected to 5 kW 3-phase motor

Tutorial 2 - Types of Protective Device, Cable, Wiring System and KNX (EIB) Technology

This topic involves learning at your own pace supplemented by one-hour lecture on KNX (EIB) Technology. The materials are available in your module notes, notwithstanding you are free to access websites and books available in the Library.

Once you have learned sufficiently, you are encouraged to attempt as many times as you wish through the Blackboard, the quizzes generated randomly from our question pools for this purpose.

Relating to this topic, every student doing this module is required to sit through a quiz to be conducted through the blackboard, scheduled during the Tutorial 7 (Week 7). The quiz, in the form of 20 MCQ, will be generated from our question pools and has a weightage of 5% as part of the Course Work assessment.

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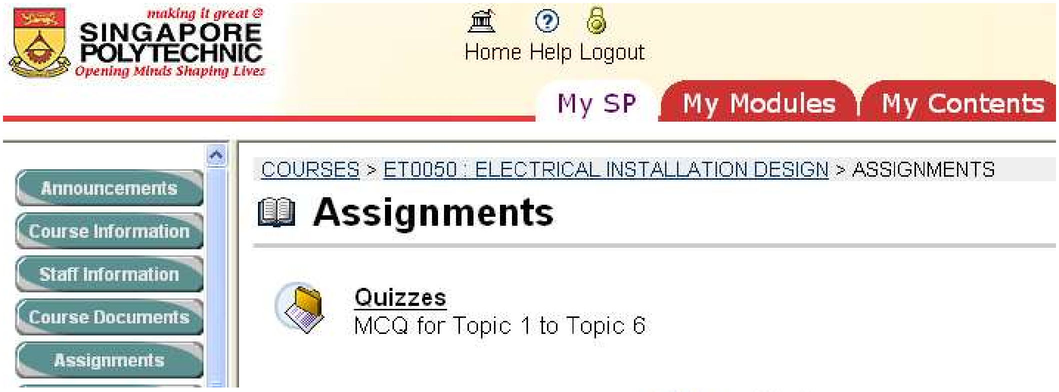

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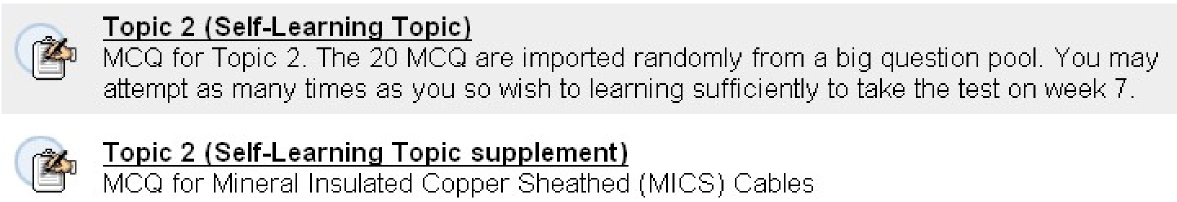
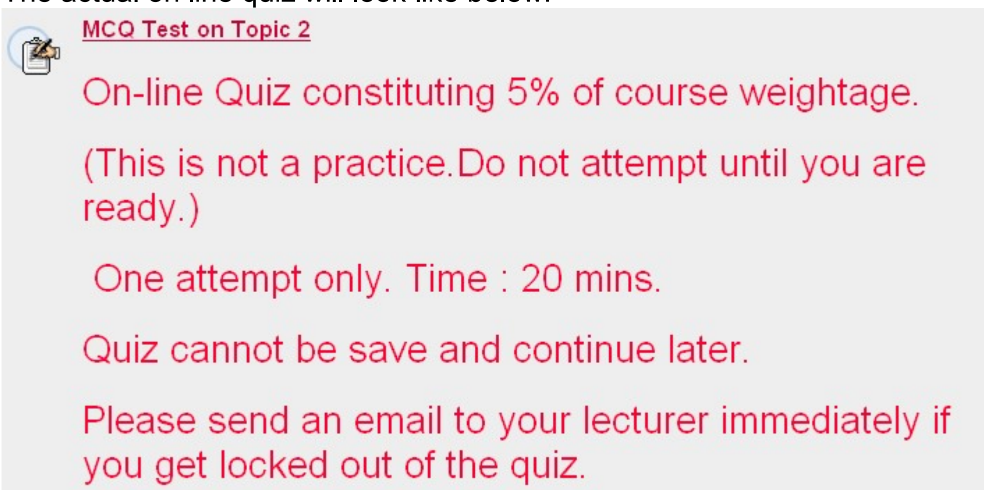


The actual on line quiz will look like below:



TOPIC 3 – **Maximum Demand/Diversity Factor, Conduit/Trunking Sizing, Overcurrent Protection and Cable sizing**

Short Questions

1. (a) What is the assumed current demand of 10 numbers of 230V 40W fluorescent luminaires installed in an office? (Ans: 2.82A)

   (b) A 230V 8kW cooking appliance in a home has a control point incorporating a 13A switch socket outlet. What is the assumed current demand? (Ans: 22.4A)

2. Define 'Space Factor'. What is the maximum space factor for conduit and trunking?

3. A single-phase circuit consisting of 6mm^2 PVC single core cables is to be installed in steel conduit having two 90^o bends between draw-in boxes which are 10m apart. Two 3-phase circuits using 2.5mm^2 PVC single core cables are also enclosed in the same conduit running in the same length as the 6mm^2 PVC cable. The circuit protective conductors used are of similar sizes to phase conductors. Calculate a suitable size of the conduit to be installed. (Ans: 32mm ϕ)

4. Determine the size of a trunking that can be used to contain the following circuits:

   12 Nos single phase circuits using 1.5mm^2 single core PVC insulated cables
   8 Nos single phase circuits using 2.5mm^2 single core PVC insulated cables
   3 Nos single phase circuits using 4mm^2 single core PVC insulated cables
   3 Nos 3 phase 4-wire circuits using 4mm^2 single core PVC insulated cables

   The size of circuit protective conductors will be the same as the corresponding phase conductors. All conductors are of the stranded type.
   (96/97 S1) (Ans: 100x25mm)

5. Calculate the minimum size of metal trunking required to accommodate eighteen numbers of 4 mm^2 and twenty-one numbers of 6 mm^2 3-core PVC/PVC cables.
   Given that:
   Nominal overall diameter of 4mm^2 cable - 7.8mm (Area = 4814.55mm^2)
   Nominal overall diameter of 6mm^2 cable - 8.9mm (Ans: 100x50mm)

6. Contrast between overload current and short circuit current.

7. Name three devices for protection against overcurrent.

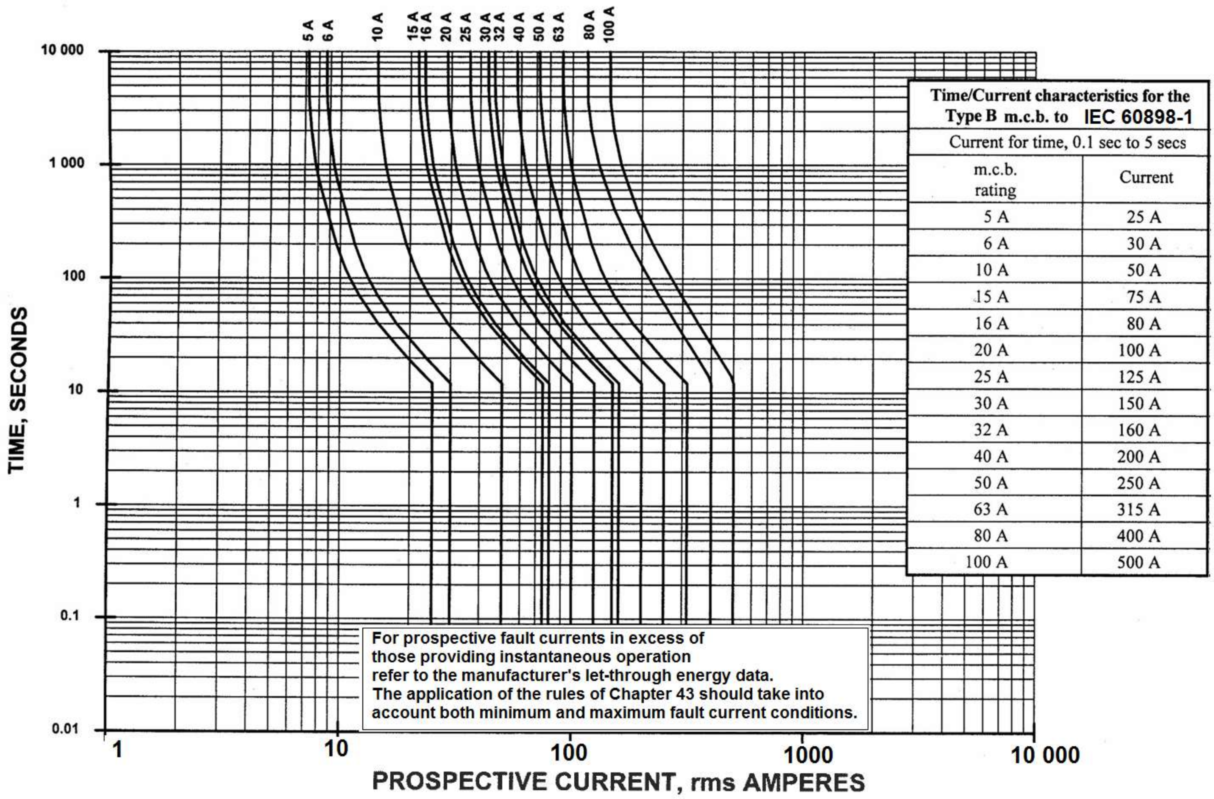
8. State the conditions that must be satisfied so as to provide co-ordination between the conductors and protective devices against overload current.

9. (a) Select a MCB with suitable rating to protect a 230 V 3 kW resistive load.

   (b) Select a HBC fuse with suitable rating to protect a 50 kW 3-phase motor with efficiency 90% and power factor 0.8 lagging. The fuse should have how many poles? {Ans: (a) 15 A; (b) $I_N \geq 2I_b$; Select I_N = 200 A, 3-poles}

10. How do you provide protection against short-circuit current. Give 2 requirements for such protection.

11. Calculate the maximum permitted time for a fault to exist in a circuit with a 16 mm^2 PVC cable subject to a prospective current of 3000 A. (K of cable is 115).
    For these conditions, a 50 A Type B MCB to IEC60898 is selected to provide protection. Comment if this MCB is adequate to disconnect the fault in time. (Refer to T/I curve below). (Ans: t_{max} = 0.1 s ; t = 0.1 s)



12. Determine the operating time of the following protective devices, if:
    (a) Short circuit current of 1000 A is let-through a 50 A Type C MCB.
    (b) Overload current of 150 A is flowing through a 45 A semi-enclosed fuse.
    (c) Prospective current of 80 A is flowing through a 20 A Type B MCB.

{Ans: (a) 0.1 s; (b) 3.0-3.5 s; (c) 20 s}

13. State the formulae for current carrying capacity of a cable if overload protection is provided by:
    (a) MCB
    (b) Semi-enclosed fuse to BS 3036

14. A 45A rewirable fuse is used to protect a 40A load. If the ambient temperature correction factor is 0.91 and the grouping correction factor is 0.7. What is the minimum current carrying capacity of the conductor? (Ans: 97.4A)

15. What is the maximum permissible voltage drop in a domestic final circuit protected by an overcurrent protective device having a nominal current not exceeding 100A?

(Ans: 9.2 V)

16. (a) An office has a floor area of 170m^2. A minimum of 50 numbers of 13A switch socket outlets are required and if radial circuit with protective device rating of 20A is to be used as per Table 5A of CP5:1998 Guide Books, determine the minimum number of circuits required. (Ans: 4 circuits)
    (b) If you intend to reduce the number of final circuits, what can be done? Outline the changes to nominal rating of the protective device and the cable size, if any.

17. A heater rated at 230V 3 kW is to be installed using single core PVC insulated and sheathed cable. The circuit is wired from one of the spare way in a consumer's unit containing cartridge fuses to IEC 60269-3. The circuit is run in conduit where it shares with 2 other similar circuits. The ambient temperature is 35^{o}C.

(a) Determine the appropriate fuse rating required and minimum acceptable cable size required. (Ca =0.94, Cg = 0.7, I_t = 32A) (Ans: 16A, 4.0mm^2)

(b) If the distance of the circuit from the consumer unit to the load is 45m, determine whether the cable size selected still meets the voltage drop requirement. If not, re-size the cable. (Ans: 4 mm^2)

Long Questions

1. A household installation is supplied at 230V with the following final circuits:

Circuit Nos.	MCB rating (A)	Connected Load
1	5	7 lamp-holders
2	5	5 Nos 20W fluorescent luminaires
3	20	6 Nos 13A socket outlets (Estimated 400W per outlet)
4	20	7 Nos 13 A socket outlets (Estimated 300W per outlet)
5	20	3 kW instant water heater
6	30	5 kW cooker with no socket outlet

(a) Calculate the followings:

(i) Total connected load (Ans: 58.17A)

(ii) Maximum current demand (Ans: 43.17A)

(iii) Suitable size of main breaker (assume no provision for future expansion) (Ans: 50A SPN)

(Standard sizes of main breaker are 20A, 30A, 40A, 50A, 60A, 75A, and 100A)

(b) Draw the single-line diagram for the above installation.

2. An office has the following loads:

- 18 Nos of 2 x 36 W fluorescent light fittings
- 6 Nos of 30 A final ring circuits connected to a total of 60 Nos of 13 A switch socket outlets (Estimated demand of 5kW per ring circuit.)
- 2 Nos of air-conditioning units where the electrical loads can be considered to be 2 motors (3-phase) each rated 10 kW with efficiency of 0.8 and power factor of 0.83. (The motors are assumed to be running at full load at all times)

The office is taking supply at 400 V, 3-phase. Assume the loads are distributed evenly over three phases and allowing 20% for future expansion, determine a suitable current rating for the main circuit breaker after applying the appropriate diversity factors.
(Standard circuit breaker ratings are: 30A, 50A, 63A, 80A, 100A, 125A, and 150A)

(94/95 S1) (Ans: Max Demand = 71.9 A, after 20% allowance, select 100A TPN)

3. The following loads are installed in an office:

- 24 nos. fluorescent luminaires each comprising 2 x 36 W fluorescent tubes, 2 nos. ballast with 6 W losses each and a power factor correction capacitor which corrects the power factor to 0.9 lagging.
- 6 radial circuits (protective device rating 30 A each) connected to a total of 45 nos of 13 A switch socket outlets. (Estimated demand of 3kW per radial circuit)
- A 15 kW three phase motor which is used to run an air-conditioning unit. Efficiency of the motor may be taken as 0.9 and power factor of 0.86 (the motor is assumed to be operating at full load of 15 kW).

(a) Determine the following:

(i) The design current of each fluorescent luminaire (in amps) taking into account of the ballast losses and the power factor. (Ans: 0.41 A)

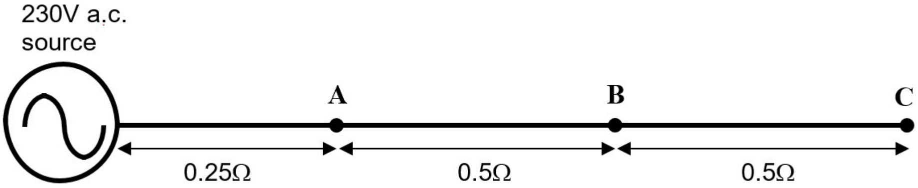
(ii) The design current of the 15 kW motor. (Ans: 28A, 3-phase)

(b) The office is taking supply at 400V 3 phase. Assume that the loads are evenly distributed over the 3 phases and allowing another 25% for future expansion, determine a suitable current rating for the main circuit breaker (3 phase). (Standard breaker nominal ratings are 30, 50, 63, 80, 100,125 and 150A)
(Max Demand = 46.11A 3phase) (Ans: 63A TPN)

(c) Determine a suitable breaker size and a suitable cable size for the 15 kW motor circuit. Single core PVC cables are to be used for this circuit and the cables are to be installed in trunking. There are no other cables installed in the trunking. The ambient temperature is 30ºC. The circuit length is 40 m.

Check whether the cables chosen for the motor circuit could meet the voltage drop requirement and re-select the cable size if necessary.
(Ans: I_b = 28A & $I_N \geq 2I_b$; Select I_N = 63A Type B or 32A Type C; 4mm^2 Voltage drop = 10.64V)

4. An installation has a source rated at 230 V. At the supply points A, B, and C, the impedance are as shown:



Find the prospective short circuit currents at :

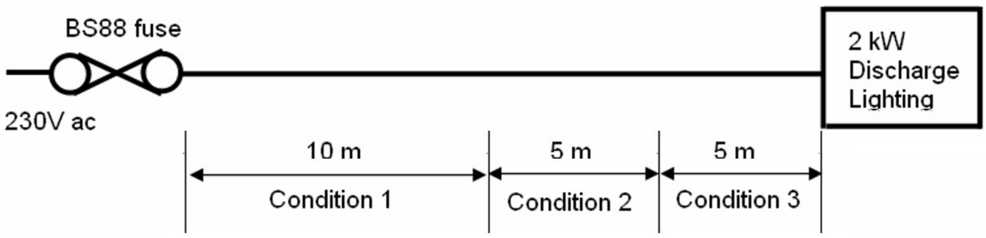
(a) point **A**
(b) point **B**
(c) point **C**

Ignore the source impedance; answer shall be in kilo-amperes.

(Ans: (a) 0.92 kA; (b) 0.31 kA; (c) 0.18 kA)

From the above calculations, what can be concluded in the size of the MCBs from the source to downstream (from A to C), i.e. is the fault current larger at source than at downstream? Give your reason.

5.



Lighting load in the above diagram uses discharge lamps and is supplied by single core PVC cables installed in conduit under various conditions shown. The length of the circuit for each condition is as shown on diagram. The circuit is protected by HBC fuse to BS88. (Now IEC 60269-2) The installation conditions are as follows:

Condition 1 : The lighting circuit shares the same conduit with 2 other similar circuits with ambient temperature being **35°C**.

Condition 2 : The lighting circuit alone (in conduit) passes through a boiler room where the ambient temperature is **45°C.**

Condition 3 : The lighting circuit alone is totally enclosed in thermal insulation. The ambient temperature is **30°C**.

With the above constraints, determine the followings:

(a) A suitable fuse size for the circuit. (Ans: 16 A)

(b) The size of cable required for the lighting circuit. (Ans: 4 mm^2)

(c) Voltage drop from the fuse to the lamp load. (Ans: 3.44 V)

(d) The minimum size of conduit required in Condition1 where the conduit has no bend i.e. a straight run. Assuming that the phase and circuit protective conductors are of the same size for all circuits. (Ans: 25 mm ϕ)

6. A short circuit current of 12 kA flows through a circuit consisting of 10mm^2 PVC cable. The value of K is 115 and the duration of short circuit before the circuit breaker trips is 0.1 second.

(a) Show by calculation whether the 10 mm^2 PVC cable can be protected by the circuit breaker used. (Ans: $I^2 t = 14.4 \times 10^6$; $K^2 S^2 = 1.32 \times 10^6$)

(b) If the 10 mm^2 PVC cable cannot be protected by the circuit breaker, what suitable size of PVC cable is able to withstand the same short circuit current using the same circuit breaker. (Ans: 35 mm^2)
(The available size of cable in the market is 10, 16, 25, 35, 50, 70, 95 mm^2).

7. (a) State 2 advantages of using XLPE insulated cables compared to that of PVC cables.

(b) For a particular installation, the consultant has decided to use multi-core XLPE insulated copper conductors to provide electricity supply to a distribution board (DB). The maximum demand of this DB is expected to be 10 kW, 400V power factor = 0.8. The circuit is run in cable tray (touching) together with one other similar circuit. The highest temperature experienced is 45^0 C.

(i) Calculate the design current of the load, and select the appropriate circuit breaker for the circuit. (Ans : I_b = 18 A; I_N = 20 A)

(ii) Find the correction factors applicable for the circuit and select the minimum cable size required. {Ans : C_a = 0.87 ; C_g = 0.86 ; C_i = 1
$I_t \geq$ 26.7 A, hence choose 2.5 mm^2 cable (Table 4E2A)}

(iii) Find the longest distance the circuit can be run without violating the voltage drop requirement. (Ans : $l_{Max.}$ = 55.6 m)

8. a) What is discrimination? Why is it important to evaluate discrimination between two protective devices installed in electrical distribution system?

b) Fig.Q8 shown a single-line diagram of an electrical supply distribution system. Briefly explain, with tripping times obtained from the time-current characteristic of the protective devices, whether there is discrimination:
(i) when an overload current of 30A flowing in Load 2
(ii) when a fault of 300A occurs at Point A

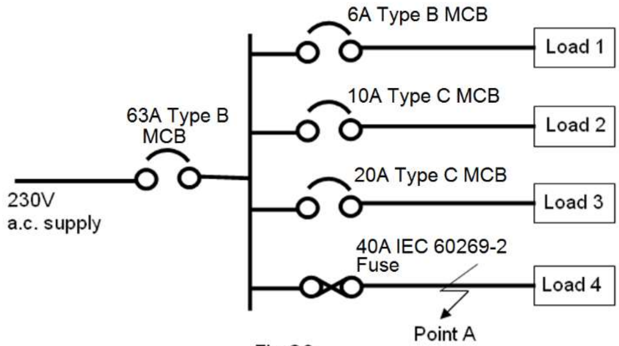


Fig.Q8

Answer:

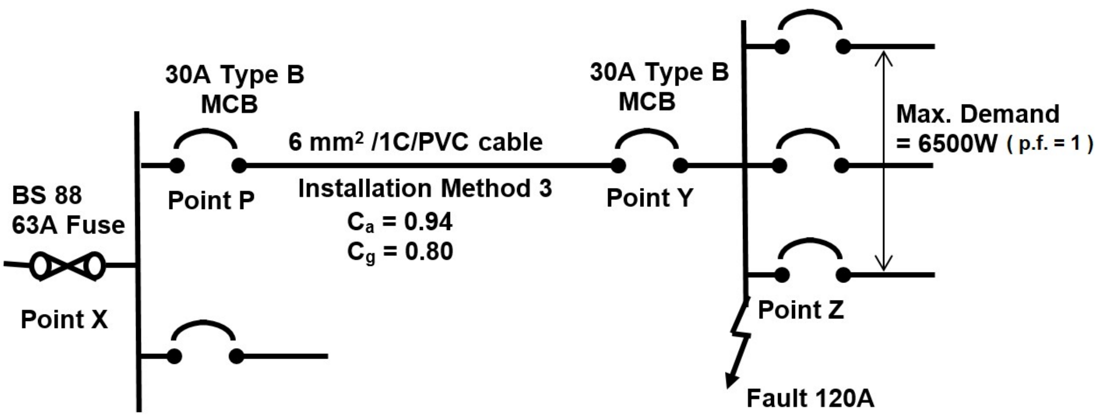
(i) From T/I curve of 10A Type C MCB, tripping time for 30A = 35 to 40s
Tripping time for 63A Type 1 MCB is infinity. As the 10A MCB nearest the overcurrent trips first, hence discrimination is achieved.

(ii) For current of 300A, From T/I curve of 40A BS 88 fuse, fusing time = 0.33s
Tripping time for 63A Type B MCB is 0.1s
As the 40A fuse nearest the fault fusing time is longer than 63A MCB upstream, hence no discrimination is achieved.

9. The single-line diagram of an electrical installation (230 V single-phase) is as shown below:

(a) If an overcurrent of 120 A occurs at point, Z, determine if there is discrimination between the MCB at point Y and the cartridge fuse at point X.
{Ans: 30A MCB trip time = 0.05 s; 63A fuse fused time (approx.) = 1000 s}

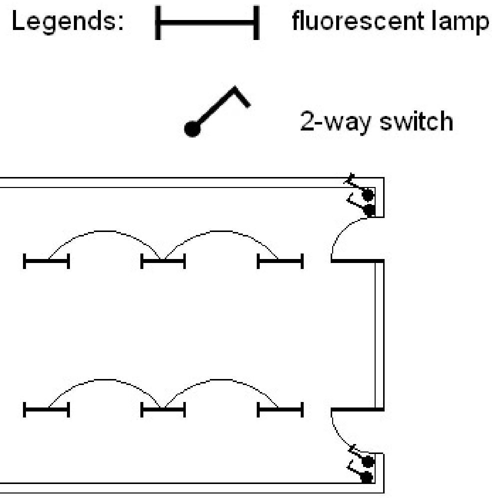
(b) Determine if the 30 A MCB at point P is suitably chosen to protect the 6 mm^2 cable against overload current. Tripping factor of the MCB is 1.45.
(Ans: I_2 = 40.5 A; I_Z = 30.8 A; verify that 1.45 $I_Z \geq I_2$)



TOPIC 4 – CONTROL CIRCUITS

Short Questions

1. Describe the operation of the on-time and off-time delay timers.
2. A direct-on line (DOL) starter is used to control the operation of a three-phase induction motor in a conveyor system. Draw its three-phase power circuit and its single-phase control circuit incorporating thermal overload relay for motor overload protection.
3. Design a lighting circuit with two lighting point that can be controlled from three different locations.
4. A room is fitted with 2 rows of fluorescent lamps. Each row consists of 3 lamps and it may switch from 2 different locations. All these 6 lamps were wired to a single circuit. Design a switching circuit to allow for switching on/off of these rows of lighting separately.



Long Questions

L1. Draw a motor control circuit which has the following functions :
- Motor 1 and Motor 2 may be started independently.
- When Motor 1 is running, Motor 2 could not be started; and vice versa.
- The operation of a STOP push-button will stop the motors from running.
- Separate indicating lamps (green, red and orange) to show if each motor is in RUN, STOP or FAULT (overload) conditions.

L2. Draw a motor control circuit which has the following operations:
- There are three motors to be started in sequence.
- Motor 1 is started by operating a start push-button, 5 minutes after Motor 1 is started, Motor 2 will start up automatically.
  10 minutes after Motor 2 has started, Motor 3 will start up automatically.
  After Motor 3 has started, an indication lamp will light up.
- The operation of a stop push-button will stop the running of the three motors.

L3 The human traffic at certain busy pedestrian crossings is to be signalled by two lights, one on each side of the road {see Fig.Q3}, blinking in synchronism i.e. both lights will be switched on or switched off at the same time. If two number of on-delay Timer, and one each of start push button (N.O), Stop push button (N.C) and Relay are provided in the control panel, design the control circuit to control the pedestrian crossing lights.

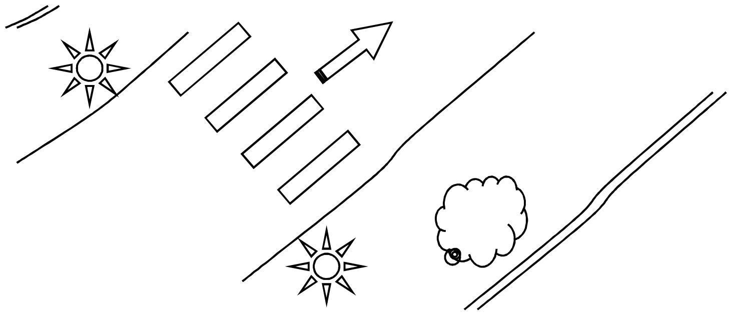


Fig. Q3

L4 Briefly explain the operation of the control circuit shown in Figure L4 when the start pushbutton is depressed.

(5 marks)

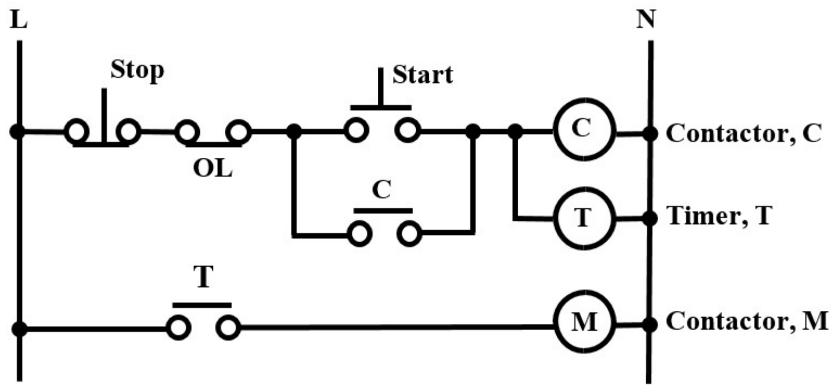


Figure L4

L5 Modify the control circuit shown in Figure L5 to provide for additional remote Stop and Start in another location...

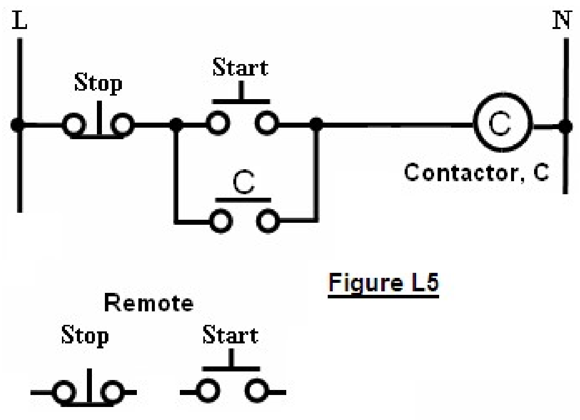


Figure L5

TOPIC 5 – ELECTRIC SHOCK AND EARTHING

Short Questions

1. State 3 reasons why earthing is required.

   Explain (basing on the above 3 reasons) how a person may be protected against electric shock from indirect contact.

2. Draw a diagram to show a single-phase consumer utilising a 'TN-S' and 'TT' earthing systems. Contrast the TN-S and the TT systems.

3. In using SELV to protect against direct contact, what is the maximum nominal voltage for a.c. and d.c.? Name two examples of SELV source.

4. Give 2 measures each for protection against:
   (i) basic protection (previously direct contact)
   (ii) fault protection (previously indirect contact.)

5. Give 2 examples each for the followings in a domestic installation:
   (i) Class II equipment
   (ii) exposed conductive parts
   (iii) extraneous conductive parts

6. Fig. Q6 depicts a final circuit that has an earth leakage current of 28 mA and the resistance of the circuit protective conductor (cpc) is 1.8 kΩ. If a person unknowing touches the exposed conductive part, would he or she be protected against electric shock by indirect contact? Give reason(s) to support your answer.

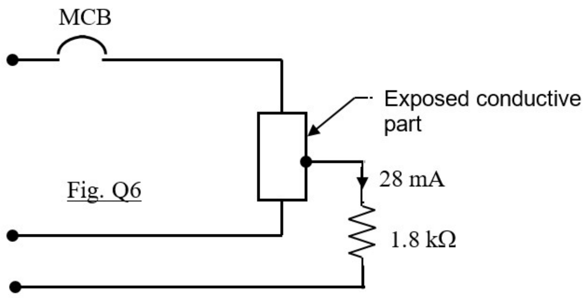


Fig. Q6

7. Draw the circuit diagram of a residual current operated circuit breaker and describe how it works.

8. In a particular single-phase 230V domestic installation, the operation of an electric oven trips the RCCB. Calculate the minimum insulation resistance that would allow the electric oven to be operated without tripping. (Ans : 7.7 kΩ)

9. Name 3 types of earth electrodes that are recognised by SS638:2018.

10. A fault of negligible impedance occurs between a phase conductor and the earthed metal casing of an electrical equipment (230V) in an installation. Draw the earth fault current path if the earthing system is :
    (i) a TT system
    (ii) a TN-S system.

Long Questions

L1. In an installation, one of the radial circuit is protected by a 20 A MCB Type B. The circuit is wired with 2.5 mm^2 single core PVC cables including the cpc enclosed in conduit. Z_E is 0.6 ohm.

If the circuit length is 10 metres to the furthest s/s/o, calculate the earth fault loop impedance for earth fault occurs at this s/s/o and check whether the MCB can provide protection against indirect contact. Hence calculate the earth fault current and check if the size of cpc can withstand the earth fault current using the adiabatic equation. (K = 115).

(Ans : Z_S = 0.805 I_f = 285.7 A)

L2. A fixed equipment takes 40A from a 230 V single-phase supply and is protected by a 40A HBC fuse to BS88. (Now IEC 60269-2) The wiring consists of 6 mm^2 single core PVC-insulated and sheathed cables in a duct, the length of run being 18 m. The value of the earth-fault loop impedance external to the installation is assessed as 0.7 ohm.

Calculate the cross-sectional area of a suitable PVC-insulated and PVC sheathed protective conductor.

(Hint : the size of cpc must satisfy both shock protection and thermal constraint)

(Ans : c.p.c. = 2.5 mm^2)

L3. A 20A **Type C** MCB protective device is used for 12 nos. of 13A socket outlet connected in radial circuit. The circuit using 4 mm^2 PVC-insulated copper conductor for live circuit and 1.5 mm^2 PVC-insulated copper conductor for protective conductor. The length of the cable run is 12 m and if the value of Z_E is given as 0.5 Ω, Determine:

(i) the line-to-earth short circuit current and the corresponding tripping time of the MCB.

(ii) the maximum circuit length to the furthest switched socket outlet

Ans : (i) I_F = 296A ; Tripping time = 0.1 s

(ii) $Z_{s(max)}$ = 1.15Ω (From Table 41B2), L = 28.2m

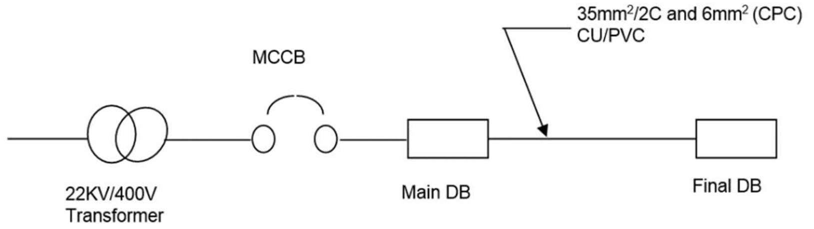
L4. In part of a TN-S system, the supply to a final DB is fed from a 22kV/400V transformer via a main DB as shown in Figure. The sub-circuit from the main DB to the final DB is a twin-core PVC-insulated copper cable of 35 mm^2 with a separate CPC of 6 mm^2 PVC-insulated copper conductor cable. The impedance of the earth fault loop is 0.1 Ω and the operating time of the MCB in the final DB is 0.1 second. Given that K = 143 for a separate CPC as per Table 54.3 of SS638:2018.

(i) Calculate the line–to-earth short circuit current

(ii) Determine the minimum CPC size

(iii) Verify whether the 6mm^2 cpc size chosen is suitable. If not, re-size.

(Standard cable sizes available are: 2.5 mm^2, 4 mm^2, 6mm^2 , 10 mm^2 and 16 mm^2)



Ans : (i) 2300A, (ii) 5.09mm^2 , (iii)Since 6mm^2 > 5.09mm^2 cpc size is suitable.

TOPIC 6 - INSPECTION & TESTING

Short Questions

1. Why do we need to carry out visual inspection on installed electrical equipment before energisation? State the requirements in the SS638 on initial inspection of electrical installations.

2. What is the minimum acceptable value of insulation resistance between conductors to earth and in-between conductors obtained during an insulation resistance test?

3. A final circuit supplying a 2 x 36 watts fluorescent light of an electrical installation shows that the lighting switch is connected to the neutral of the supply circuit. What is the danger?

4. In the polarity test on a domestic final circuit supplying an Edison-type screw lamp holder controlled by a switch,
   (a) name two verifications that needed to be carried out.
   (b) state the test requirement with regards to the position of the switch and the lamp.

5. Describe with the aid of a diagram, the method of measuring earth electrode resistance.

6. Tabulate the stipulated test results of the tripping time of a Residual Current Circuit Breaker of 30mA tripping sensitivity.
   (Ans. : 15mA RCCB shall not operate, 30mA RCCB trips at 100ms and 150mA RCCB trips at 40ms)

7. Explain the main purpose of carrying out an earth fault loop impedance test.

8. (a) Explain why it is not acceptable to use a multimeter to check the insulation resistance of a completed electrical installation.
   (b) Other than the insulation resistance test and earth electrode resistance test, name any two tests to be carried out before energising a completed electrical installation.

9. (a) Suggest two tests that should be carried out to verify the integrity of a new radial socket outlet circuit which is added to an existing installation.
   (b) Suggest two methods which can be used to improve the earth electrode resistance.

10. The overall insulation resistance of the electrical installation in Block 14, Singapore Polytechnic is 0.8 MΩ. The electrical installation has a total of 150 points (lighting and socket outlets). Does the overall insulation resistance value comply with SS638:2018?

11. An electrician is going to conduct an insulation resistance test on the lighting circuit as shown in Fig.Q11. The status of the lighting circuit is : (i) all light bulbs are inserted (ii) both switches s1 and s2 are open, and (iii) mcb is closed. Provide him with proper step-by-step instructions, to carry out the insulation resistance test.

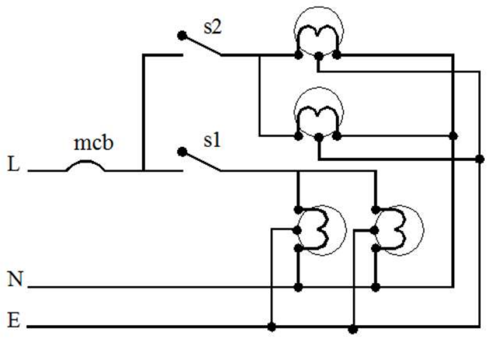


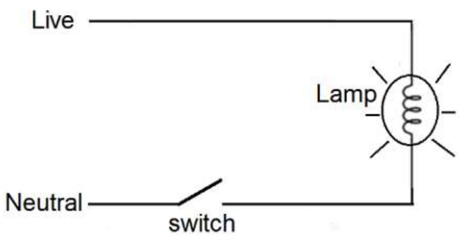
Fig. Q11

12. A large electrical installation with many circuits was divided into four sections to prepare for the Insulation Resistance Test. The values obtained are 25 MΩ, 15 MΩ, 12 MΩ and 5 MΩ. What is the equivalent insulation resistance value for the installation and the minimum I.R. value as required by SS638:2018?

(99/00 S2)

Ans : R_e = 2.56 MΩ ; Min. I.R. value is 1.0 MΩ in SS638:2018

13. During the inspection of an electrical installation, the circuit Figure below was identified. What is the fault in this circuit? (2 marks)



TOPIC 7 – SS650: Socket Outlet Assembly

Short Questions

1 Explain briefly the purpose of Socket Outlet Assembly (SOA) for use in Temporary Electrical Installations. State the requirements relating to the enclosure of the assembly and type of protective devices used for the SOA, also state the colours used for 55 volts, 110 volts, 230 volts and 400 volts industrial plugs and sockets. (10 marks)

2. Temporary Electrical Installations for Construction and building sites requires the use of Socket Outlet Assembly (SOA). State four other areas where SOA is also applicable for temporary electrical installations. State the requirements relating to the enclosure of the assembly and type of protective devices used for the SOA, also state the colours used for 230 volts and 400 volts industrial plugs and sockets. (10 marks)

3. Temporary Electrical Installations is introduced in 2001. One of the key recommendations is the introduction of Socket Outlet Assembly (SOA). Explain briefly the purpose of SOA and the requirements relating to the enclosure and protection. (10 marks)

4. Temporary Electrical Installations for Construction and building sites requires the use of Socket Outlet Assembly (SOA). (10 marks)
   (i) State any three other areas where SOA is also applicable.
   (ii) State the requirements relating to the enclosure of the assembly and type of protective devices used for the SOA.
   (iii) State the colours used for 230 volts and 400 volts industrial plugs.
   (iv) State the Inspection frequency required of Temporary Electrical Installations **at other places besides** Construction Worksite.

5 Socket Outlet Assembly (SOA) are mandated for use in Temporary Electrical Installations. (10 marks)
   (i) State the four areas where SOA is compulsory.
   (ii) State the requirements relating to the enclosure of the assembly and type of protective devices used for the SOA.
   (iii) State the maximum length for flexible cables used for handheld equipment when connecting to SOA.
   (iv) Explain whether it is correct to loop from an existing industrial socket outlet fitted on the SOA to two 13A switched socket outlets.

Singapore Polytechnic
School of Electrical and Electronic Engineering

Laboratory Orientation

Objective : At the end of the Lab Orientation, the students will learn the:

1) Importance of electrical safety when using electricity.
2) Various electrical components used in laboratory exercises.
3) Use of various electrical test instruments.

Electrical Safety

The danger of electricity is well known. It can cause injury, burns or death in prolonged direct contact with live electric circuits when the human body becomes a conductor for current to flow. The danger zone is when the limit of safe current exceeds 30mA.

Current (mA)	Effects on the human body
30 - 40	Serious and very painful contraction of the muscles, breathing stops, but normally resumes if current is interrupted
40 - 60	Interference with the respiratory system, loss of consciousness
60 - 100	Ventricular fibrillation. This is the serious disturbance of normal heart beat. The main pumping chamber (ventricles) beat very fast, irregularly and inefficiently leading to collapse followed by unconsciousness and absent heartbeat
100 - 200	Serious burns and muscle contraction of such a degree that the thoracic muscles constrict the heart thus inhibit it action.

The safe limit of touch voltage under normal body resistance condition is 50Va.c. At 220V, the max. disconnection time should not exceed 0.05 seconds.
One should note that the degree of danger is dependent on the point of contact and the body resistance. Body resistance will be lowered if the body is wet or in contact with wet surfaces.

Live parts are not exposed to touch. Appliances with metallic coverings have their exposed conductive body connected to earth points to prevent becoming live and a source of hazard.

Earth leakage protective devices can be made to disconnect automatically from the supply if current is abnormally conducted to earth. If the human body acts as a bridge for the current to flow, then a lot of harm could be done. The worst scenario is when the person is connected across the supply directly i.e. live and neutral conductor. There is no available protective device to prevent this. Under this situation, the only measure that can be taken is to turn off the power immediately.

Besides shock hazards, electrical faults caused by bad connections or misuse can result in explosions, intense heat or fire. A person in the vicinity of an explosion may be endangered by flying objects.

The following rules must be always observed to prevent accidents:

1. **Students must not carry out wiring and testing work with power connected and turned on (i.e. LIVE) to equipment or circuit.**

2. **Students should be supervised with a lecturer in attendant during testing. This is in conformance with ELECTRICITY ACTS & REGULATION.**

3. **Colour coding of wires shall be strictly adhered to. This will allow quick checking of polarity and possible short circuits before circuit is energised**.

There is a heavy penalty for failure to follow rules. The student may also be required to replace damaged equipment if found negligent.

In certain experiments, a supply voltage of **400V** is used. This voltage is very dangerous as it can electrocute a person. Please do not take risks and always isolate the circuit completely from the supply before working on it.

Always Listen to INSTRUCTIONS given by the LECTURER in charge.

General Housekeeping

Our laboratories are frequently visited by the public and guests from overseas. The laboratory must be kept clean and tidy at all times. It should be treated in a similar manner to any workplace in the industry. Students are requested to maintain and be responsible to clean up their work areas before they leave.

Test Equipment

Proper use of test instruments is necessary to prevent damage. Electrical circuits can be verified with a multimeter set to an appropriate resistance range to check for continuity. Testing with the circuit live is forbidden except by the lecturer.

Insulation testing is a final test conducted on electrical lighting and power wiring before the system is energized. This test will be explained to you in the lab exercise.

Electrical Wiring Accessories

The various electrical components used in the lab exercise is displayed and their usage will be explained by the lecturer in charge.

Singapore Polytechnic
School of Electrical and Electronic Engineering

Experiment : Lighting Controls

Objectives: After carrying out the experiment, the student will be able to:
1) understand simple switching methods for lighting systems.
2) learn the use of contactor in bulk switching of fluorescent light.
3) use two-way and three-way switches for two or more position control of light.

Components :
1-way light switches
2-way light switches
Intermediate light switches
Lam-holders
Single-core PVC wires
Light control panel
Lamp bulbs

Information :

Switching is a basic requirement for the control of any lighting system. The purposes are to:

1) control the operation according to needs.

2) isolate for the purpose of carrying out maintenance.

3) save energy by good energy management.

To serve large areas of lighted space, luminaires can be arranged to operate in groups. Controls can also be operated from remote locations. This can be achieved with electromagnetic contactors. The design can also incorporate energy saving measures using time program as in computerised building automation systems. The control functions can be further enhanced by introducing dimmers, photoelectric sensors and standalone programmable controllers.

The following exercise covers simple switching control. However, it can be easily adapted for more complicated control systems.

Procedures :

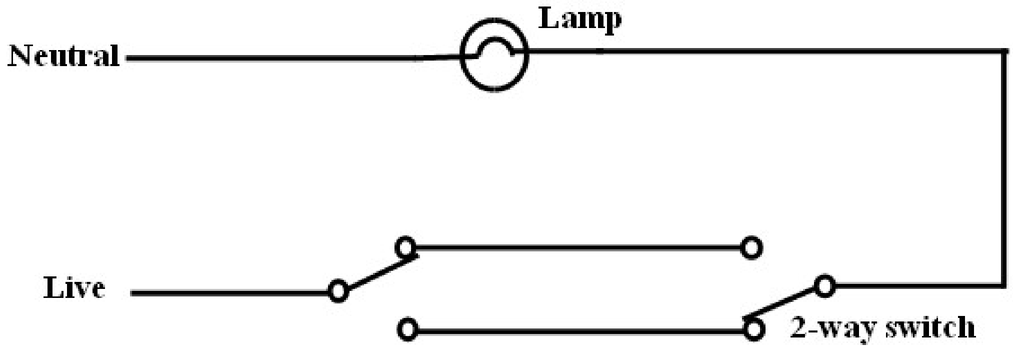
1. Study each schematic drawing and understand its operation.
2. Wire the circuit and verify for continuity.
3. Ensure that there are no loose connections and tidy up the wiring before testing.

Testing :

1. Connect the lamp bulb and using a multi-meter to verify the control functions.
2. If the verification check is successful, request the lecturer to carry out the "Live" functional test.

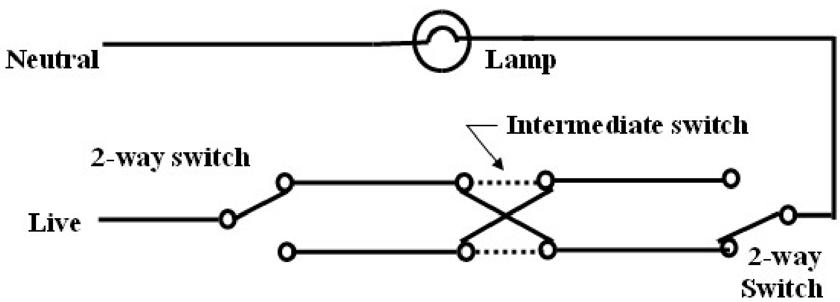
Note: Every lighting point has a terminal for the protective conductor. A light fitting with metal housing which is an exposed conductive part would be required to be connected to earth via the protective conductor.

(1) Two-position Control



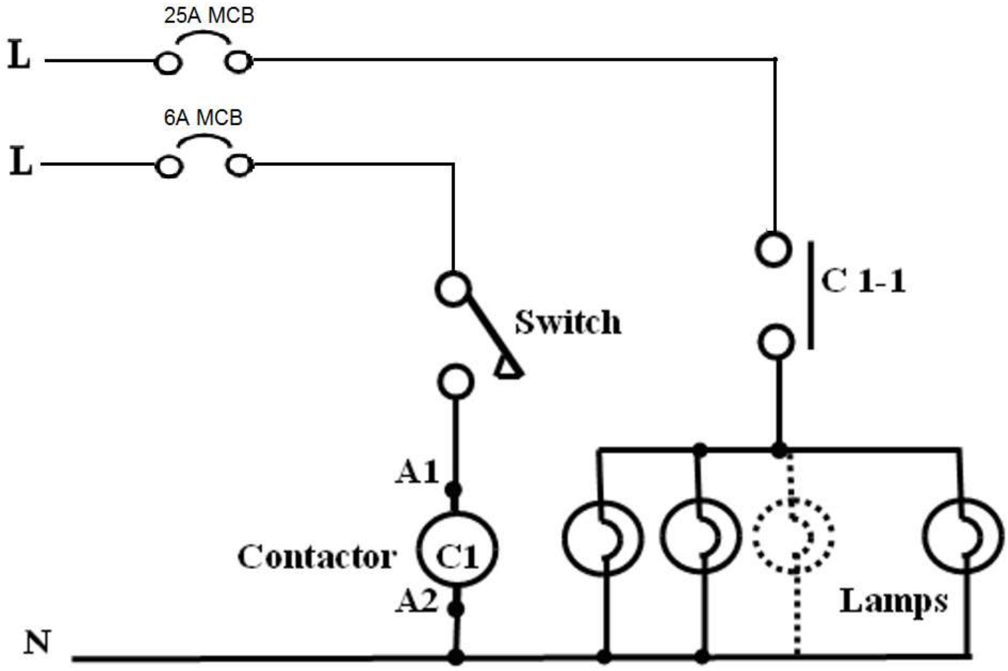
Circuit 1 – Two-way Switching

(2) Three-position Control



Circuit 2 – Two-way & Intermediate Switching

(3) Bulk Switching



Circuit 3 - Lighting Control Circuit

Singapore Polytechnic
School of Electrical and Electronic Engineering

Experiment : Introduction to LEDs, the Fluorescent lamp circuits and Power Factor

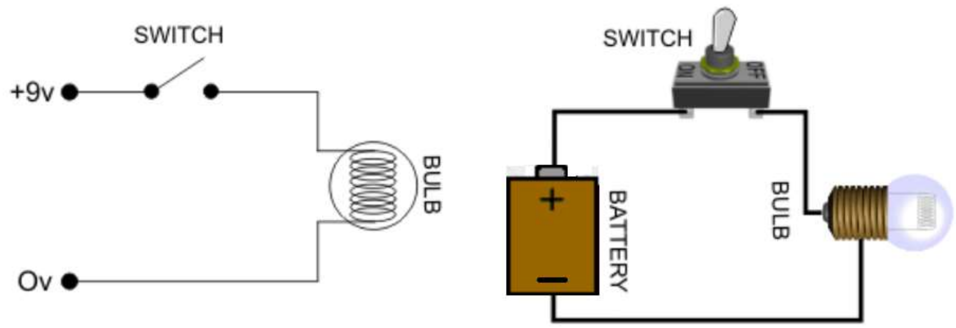
Objectives : After completing the hands-on, the students will be able to:

1) know the technology used in LEDS
2) understand the basic circuits commonly used for starting and control of fluorescent tubes
2) recognise and identify the various components used in these circuits
3) understand the role of capacitor in power factor correction

First the basics:

Filament lamps:

This is the first light invented by Thomas Edison, it runs on both ac and dc depending on the voltage the lamp is rated.



Filament or Incandescent light bulbs give off most of their energy in the form of heat-carrying infrared light photons -- only about 10 percent of the light produced is in the visible spectrum. Quite a lot of energy is wasted. Many countries have banned the sale of filament lamps.

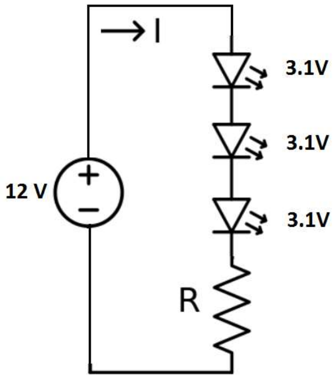
Fluorescent lamps:

The fluorescent tube uses a flow of electrical current through an ionized gas and coated phosphor tube to produce visible light which is about six times more efficient than filament lamps. However there is still losses in the circuit and in the last decade another type of light has been quietly and slowly replacing the various types of incandescent lamps and some fluorescent lamps. Here comes the LEDs

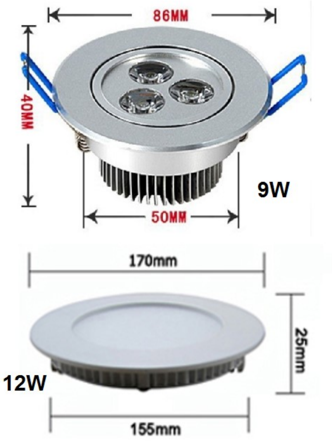
Introduction to LEDs lamps:

An **LED lamp** (or LED **light bulb**) is a solid-state lamp that uses light-emitting diodes (LEDs) as the source of light. LED lamps offer long service life and high energy efficiency, but initial costs are higher than those of fluorescent and incandescent lamps.

Light-emitting diodes use direct current (DC) electrical power. To use them on AC power they are operated with internal or external rectifier circuits (sometimes called drivers by the LED industry) that provide a regulated current output at low voltage. LEDs are degraded or damaged by operating at high temperatures, so LED lamps typically include heat dissipation elements such as heat sinks and cooling fins.



Basic LED circuit



However LED lamps had not reached the "economic price" for mass replacement of fluorescent lamps due to the problem of degradation of light output and the failure of LEDs at high operating temperature. Fluorescent lamps will still be around for a few more years. (Watch the video and demo on LEDs.)

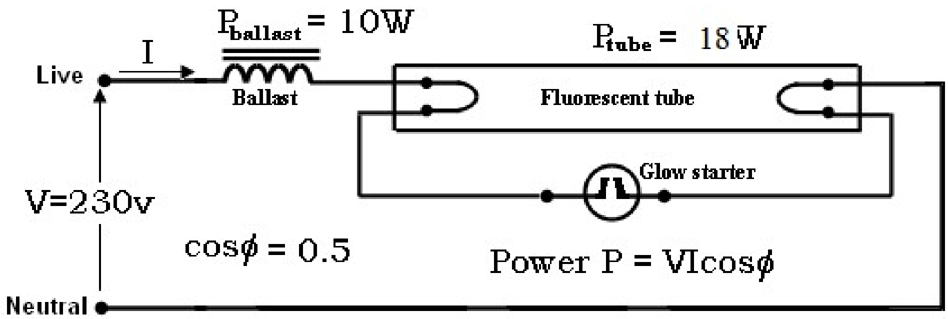
The Fluorescent lamps circuits:

The fluorescent tube requires a means of starting and a device to control the current once the arc has struck. This device is sometime called the ballast or chokes and is provided as a series impedance to limit the lamp current. Without this impedance, the current would increase to a point where the lamp would be destroyed. At each end of the tube is a coiled coil filament with the active element to emit the electrons.

To start the discharge lamp, a voltage higher than the supply voltage would be required to initiate the arc to strike. Two commonly used methods are switch-start and starterless.

Switch-start lamps are started by heating the lamp electrodes before applying a high voltage. The preheating, which may take a few seconds, is initiated by a bimetal starter (glow starter). The starter consists of bimetal strip electrodes enclosed in a glass bulb containing an inert gas.

Discharge lamp $V = -L di/dt$ $P = VI\cos Ø$



Switch start fluorescent circuit

$$I = (P_{ballast} + P_{tube}) / (V\cos\phi) = (10 + 18)/(230 \times 0.5)$$

$$= 0.243 \text{ mA}$$

The 230V across the electrodes ionise the gas and the gaseous conduction provides heat to operate the bimetal which break the circuit causing sudden collapse of the current flowing in the inductor. This will in turn induce a high voltage across the fluorescent tube and initiate the arc to cause the fluorescent tube to conduct.

The power factor of the ballast is generally low i.e. ~0.5, hence power factor (pf) correction capacitor should be provided. The use of pf correction capacitor will result in a reduction in the current drawn from the mains but the power consumption of the fluorescent tube and the ballast will remain unchanged. A demonstration using pf correction will be shown.

All lamps operated from the mains will cause light pulsation at 100 times per sec. It produces a stroboscopic effect on rotating and moving machinery. The light fluctuations synchronise with the speed on the rotating part to give an apparition that the speed is changing or sometimes appear to have stopped. This may be undesirable from the safety point of view, especially in machine shops.

If stroboscopic effects are to be avoided, two switch start lamps can be connected in a lead lag circuit arrangement. A suitable capacitor is connected in series with the choke. The combined effect will result in a near unity power factor load current. Light is a form of electromagnetic radiation. Light waves oscillate in tandem with the load current. The two circuits produce out of phase light waveforms that can cancel the stroboscopic effects. Similar cancellation of the apparent light fluctuations can be achieved by using 3 phase supplies. The lighting fittings within the room can be connected and distributed amongst the 3-phases of the supply.

Conventional ballast consumes about 10 to 12W of electrical energy due to i^2R loss in the coil. Low loss ballast rated at 6W is available at higher cost. There is also super low loss ballast rated at about 3.5W. Besides the rating, how does one tell which ballast has a lower loss?

The latest event of technological advancement in the field of electronics incorporates high efficacy, low power factor, flicker-free and instant start features in electronic ballast design thereby resolving many deficiencies found in the conventional system.

Components

Luminaire housing	Switch start ballast
5.5 microfarad capacitor	Electronic ballast
Capacitor for lead lag circuit	Switch starters
36/40W fluorescent tubes	spring loaded lamp holders

Procedures:

1. Wire up the circuit for the electronic ballast as shown in Circuit 1 below.
2. The completed wiring must be checked before the lecturer is invited to witness the test.
3. Rewire the luminaire for the lead lag circuit and test.

Characteristics of fluorescent lamps as compare with incandescent

<u>**Advantages**</u>	<u>**Disadvantages**</u>
Energy saving	requires control gear
High luminous output	Inductive circuit
	Can cause stroboscopic effects

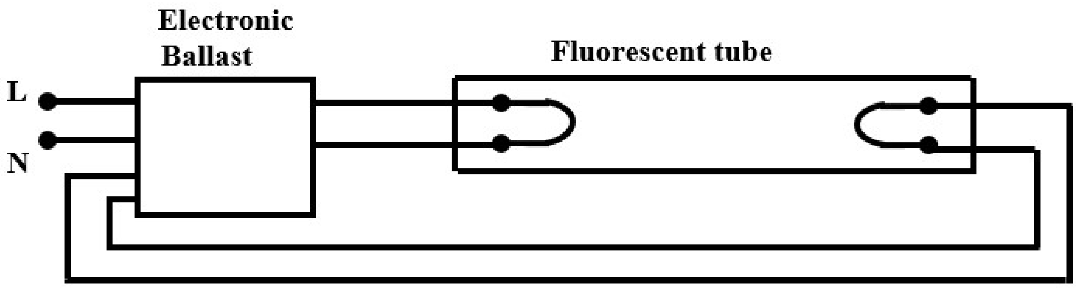

Typical Electronic Ballast


Typical conventional Ballast


Glow Starters S2 and S10

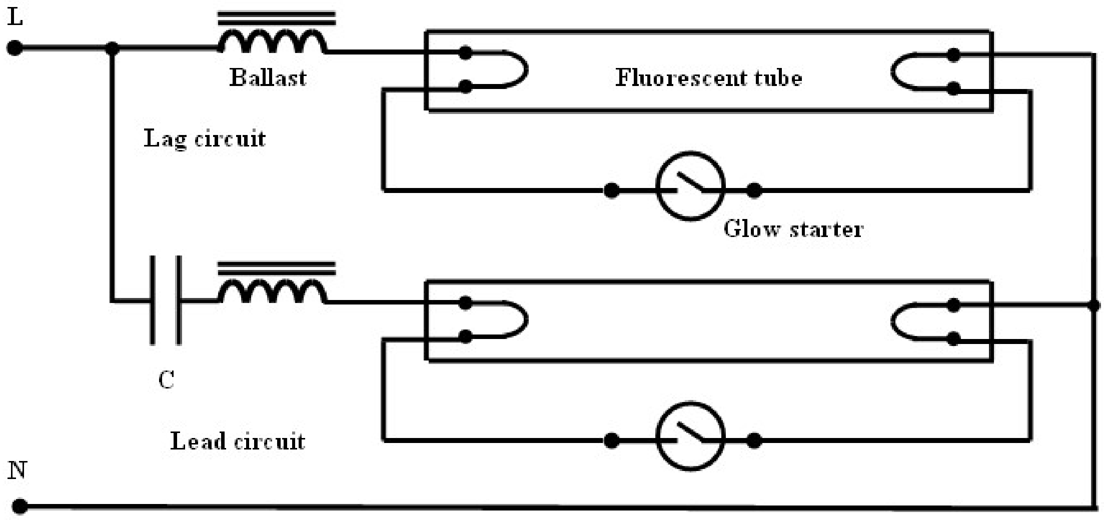

Typical Condenser (Capacitor)


High loss Ballast



Circuit 1 - Electronic Ballast Circuit

2 x 36W tubes $P = VI\cos\emptyset$ $I = (P_{watt}/V) \times 1.8$



Circuit 2 - Lead-Lag Twin Lamps Circuit

Singapore Polytechnic
School of Electrical and Electronic Engineering

Introduction to the KNX (Formerly EIB System Technology)

The KNX system is being regulated worldwide by the KNX Association. KNX is an Alliance of more than 400 manufacturers in 125 countries and are headquartered in Brussels, Belgium. It is founded in 1990, and currently, it groups more than 400 leading companies, which together manufacture more than 80% of all electrical installation equipment sold in Europe.

It has an important task of ensuring worldwide installation standard. Amongst its responsibilities are:

- Licensing the Trademark
- Conducting Quality Survey
- Performing compatibility Tests, and collaborating with accredited testing centres to award the KNX trademark to products produced by companies
- Draws up technical regulations, quality specifications and inspection procedures
- Coordinating the promotion of KNX systems

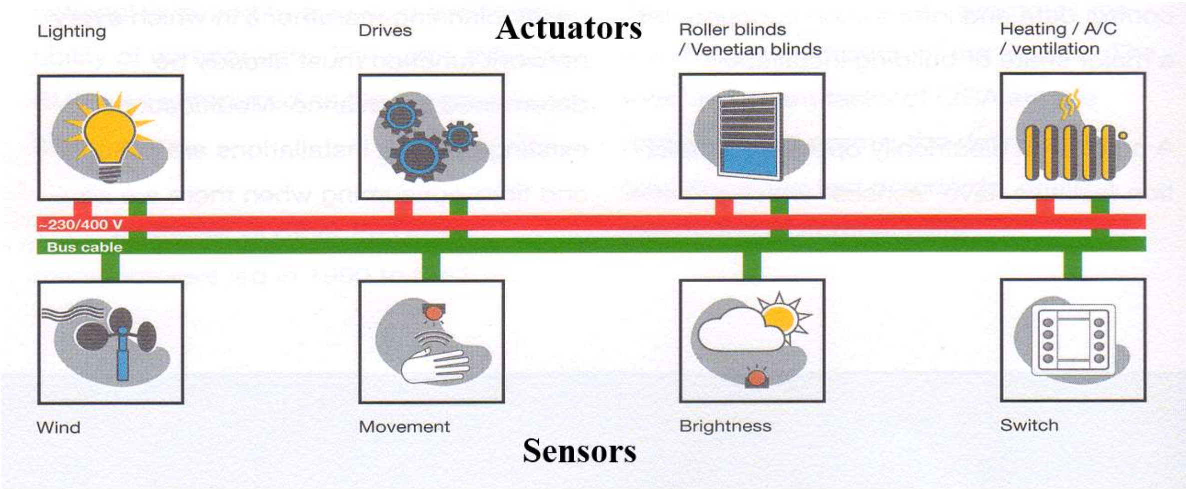
Amongst the List of Members & Licensees as of Sep 2020 are:

- *Siemens*
- *Daikin Industries Ltd*
- *Fujitsu General Limited*
- *ABB*
- *Aztech Technologies Pte Ltd (S)*
- *Johnson Controls International*
- *Schneider Electric*
- *Elero*
- *Hangzhou EaseMore Technology Co*
- *Hager Controls*
- *ChangXing*
- *Cytech technology Pte Ltd (S)*
- *Zumtobel AG*

One of the main objectives of KNX is to ensure "standardisation", NOT "sameness". This means that an installation may comprise products from different companies working together as one installation.

2.9.1 What is KNX?

It is one system for lights, temperature control, blinds, signalling, security, remote control, etc. Intelligent microprocessor based devices are used for control, signalling, display, information and monitoring. There is just one line along which all bus devices may communicate and all components speak the same language. Less wiring is required and cost of installation can be reduced. All bus devices are categorised as sensors, actuators, controllers or systems components.



KNX Actuators and Sensors

KNX is an OSI compliant Fieldbus and is specifically designed for Home and Building Automation. It is distributed, peer to peer networking system, based on a fully OSI compliant serial transmission protocol. They are connected to one another on twisted pair (24V dc) transmission medium.

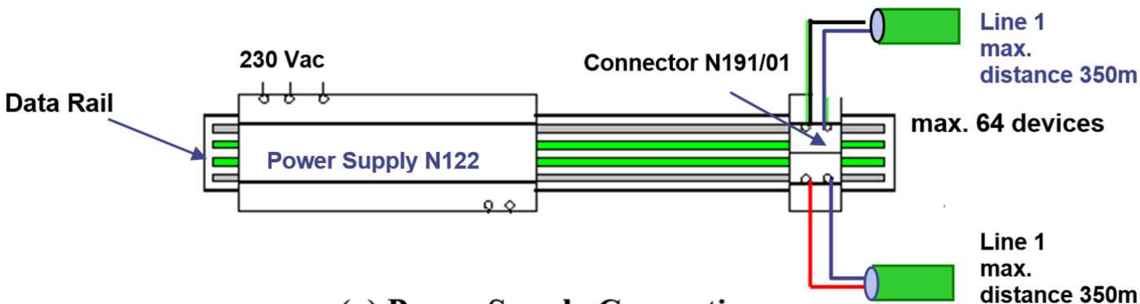
2.9.2 Why KNX system

Amongst the advantages of the KNX systems are as follows:

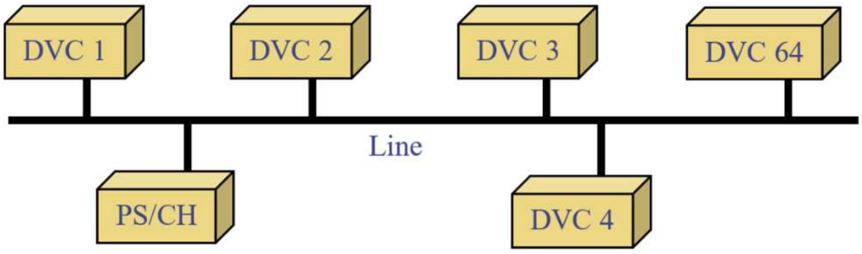
- *It can handle complex configurations by offering flexible solutions*
- *Cost Effectiveness (as opposed to cheapness)*
- *Low Energy Consumption*
- *Fast adaptation to customer needs*
- *Attractive Design*
- *High Reliability*

2.9.3 The Hardware

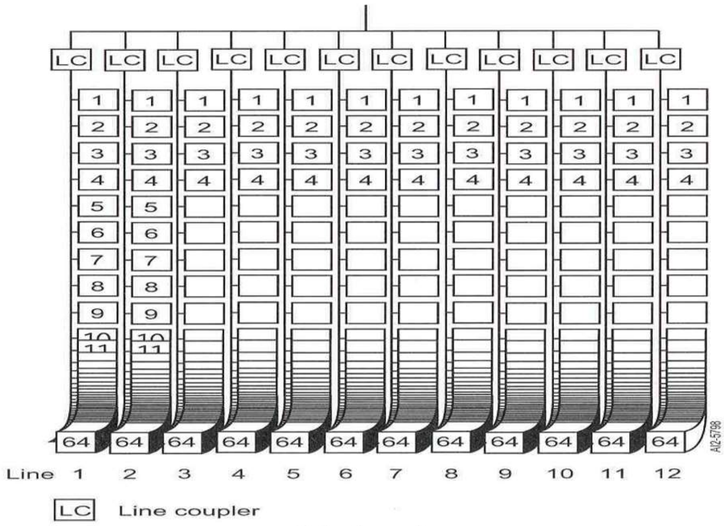
Every line normally starts in the distribution board, comprising of a power supply and the devices connected to the line as shown below.



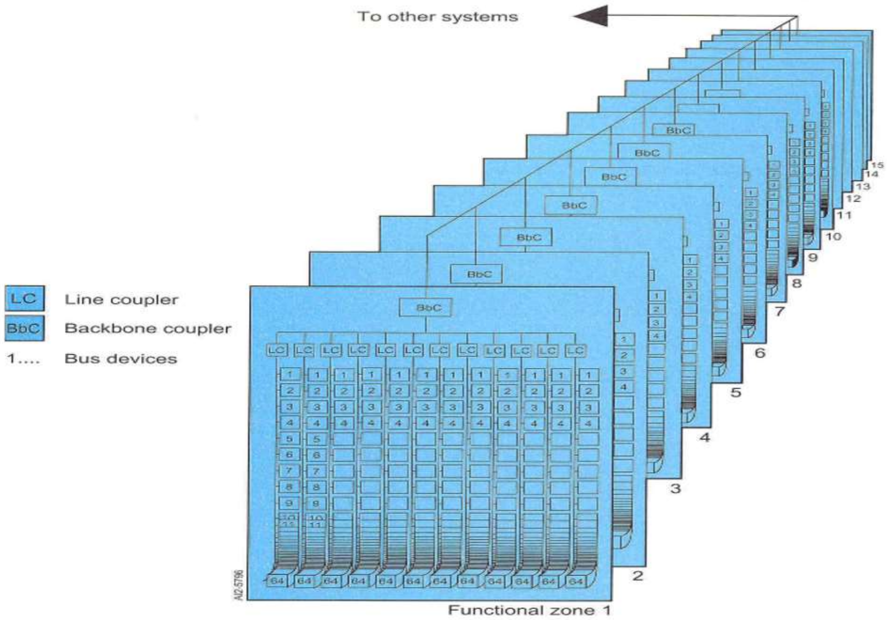
(a) Power Supply Connection



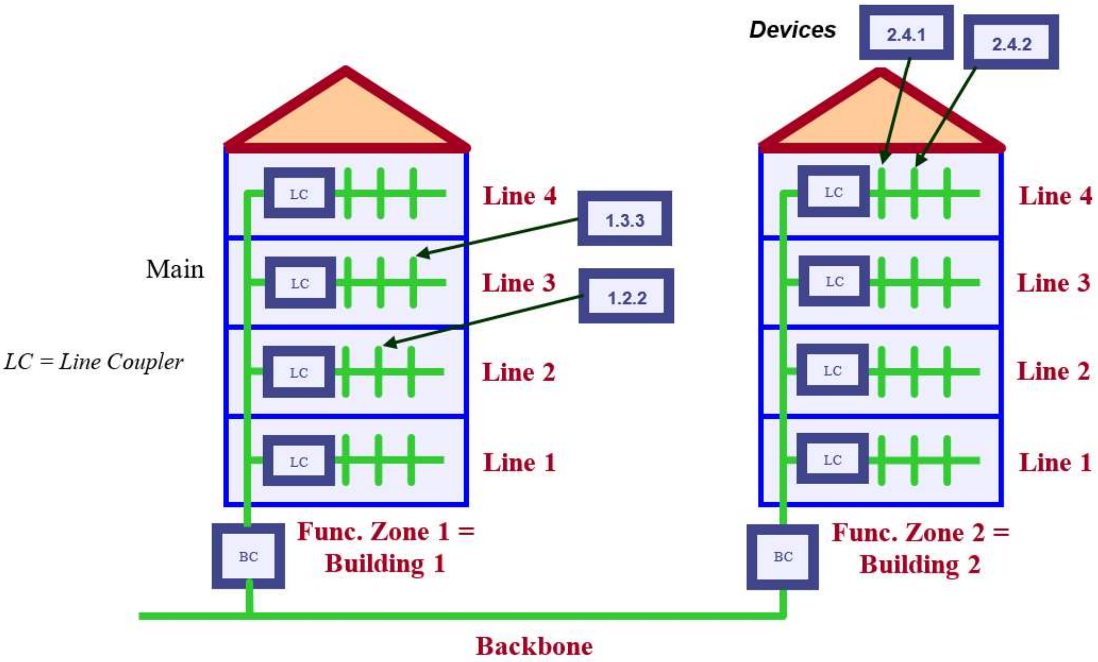
(b) A Line



(c) An Area



(d) A Zone



Practical Structure

2.9.4 Wiring system of KNX compared to Conventional System

- Actuators can installed centrally in the distribution board or decentrally near the load
- No power line necessary for the sensors but conventional system required power supply
- Less cables needed compared to the conventional cabling system
- Wiring is simpler and less complicated

2.9.5 ETS Software

The software that is being used is called ETS (EIB Tools Software). This software is standardised and used universally irrespective of the make of the KNX device, and is used to design, edit and commission all KNX systems.

KNX Technology (Expt 1)

1.0 Objective

At the end of the experiment, students will be able to:

1.1 Appreciate the latest technology used in the modern electrical installation
1.2 Understand the hardware and software used in the design of KNX system
1.3 Use the ETS4 software to design simple circuits:
1.3.1 On-off circuits,
1.3.2 Multiple control circuits,
1.3.3 Editing of circuits
1.4 Use the ETS4 software to commission project.

2.0 Introduction

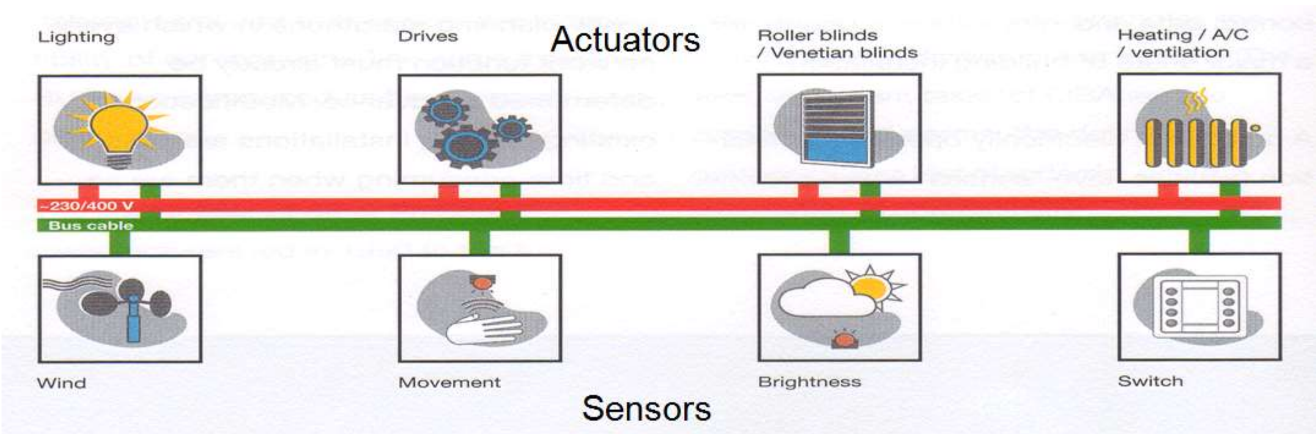
In modern residential and utility buildings, more and more control and monitoring networks are being installed to meet the demands for more safety and reliability and convenience. This means however more wiring, running from the sensors and actuators to the control and monitoring centres. Such a mass of wiring means more planning and installation effort, increased fire risks and soaring costs. A major advantage of a KNX installation: the system can be modified and expanded at any time without noise and dirt. If new or other functions are desired, they can be simply programmed. As long as they are KNX compatible, devices from different makes can be integrated as one system.

To transfer control data in the building installation network, a system is called for, which dispenses with previous insular concepts and allows simpler, more flexible planning together with more efficient installation. This means a building management system with just one route along which all information can be exchanged as desired.

The solution to these problems is to use the KNX (EIB) system.

2.1 The KNX system

In this system, there is just one line along which all bus devices may communicate and all components speak the same language. Less wiring is required and cost of installation can be reduced. All bus devices are categorised as either sensors, actuators, controllers or systems components.

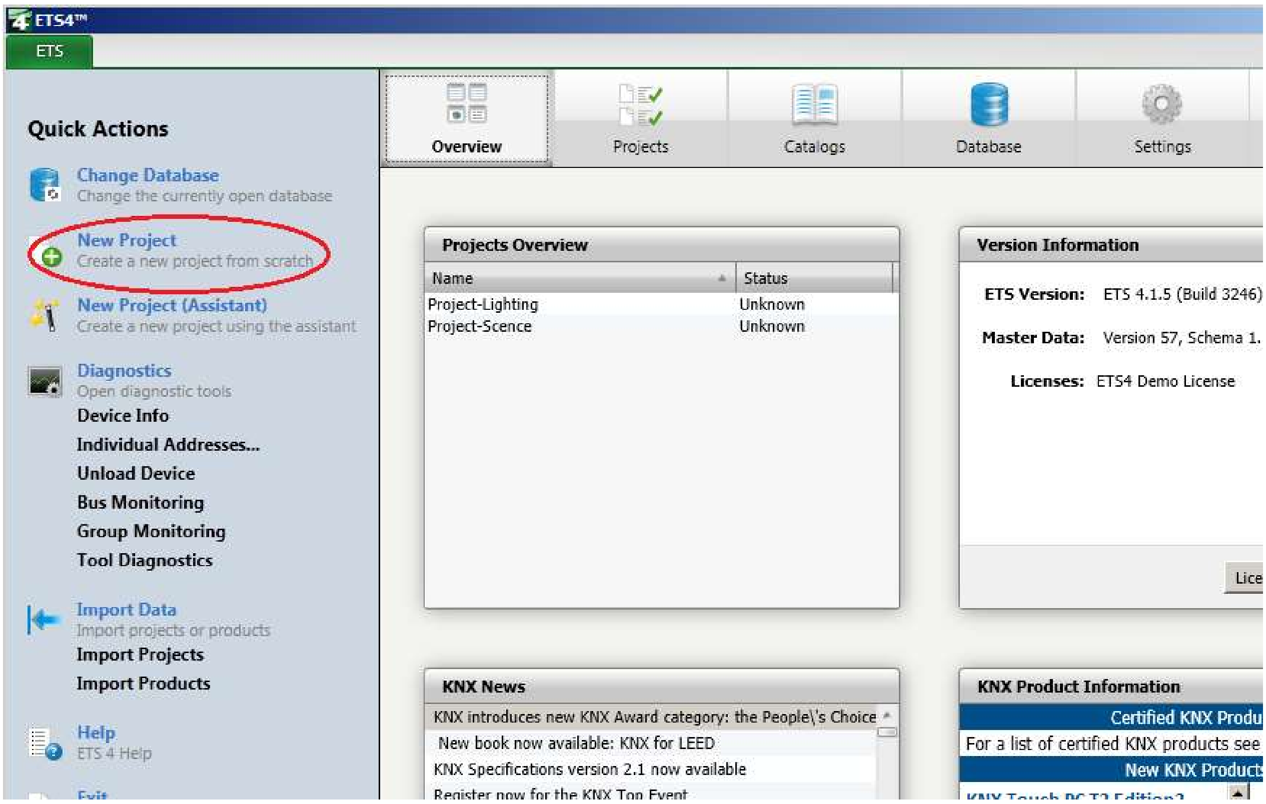


KNX is an intelligent system for electrical installation that with automation and remote control makes living more convenient, safe and flexible. It is distributed, peer to peer networking system, based on a fully OSI compliant serial transmission protocol. They are connected to one another on twisted pair (24V dc) transmission medium.

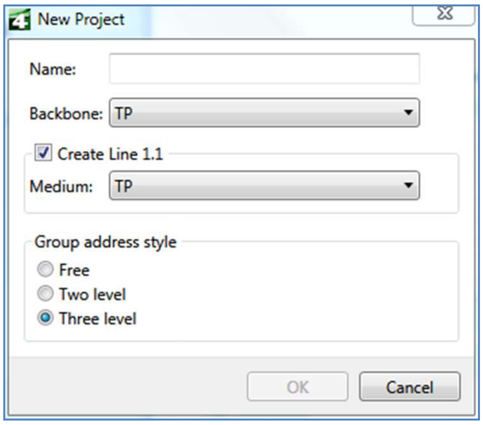
This experiment prepares the student for a new project to perform Lighting control using 4-gang universal push button sensor interface that has 8 push buttons and 4-gang switch actuator

1 Double click on the ETS4® icon to launch ETS4.

[Quick Actions] <New Project>, or [Tabs: Projects] <New>



[Dialog: New Project] {Name:} Enter name of new project, e.g. “MyProject1” (ignore quotes).



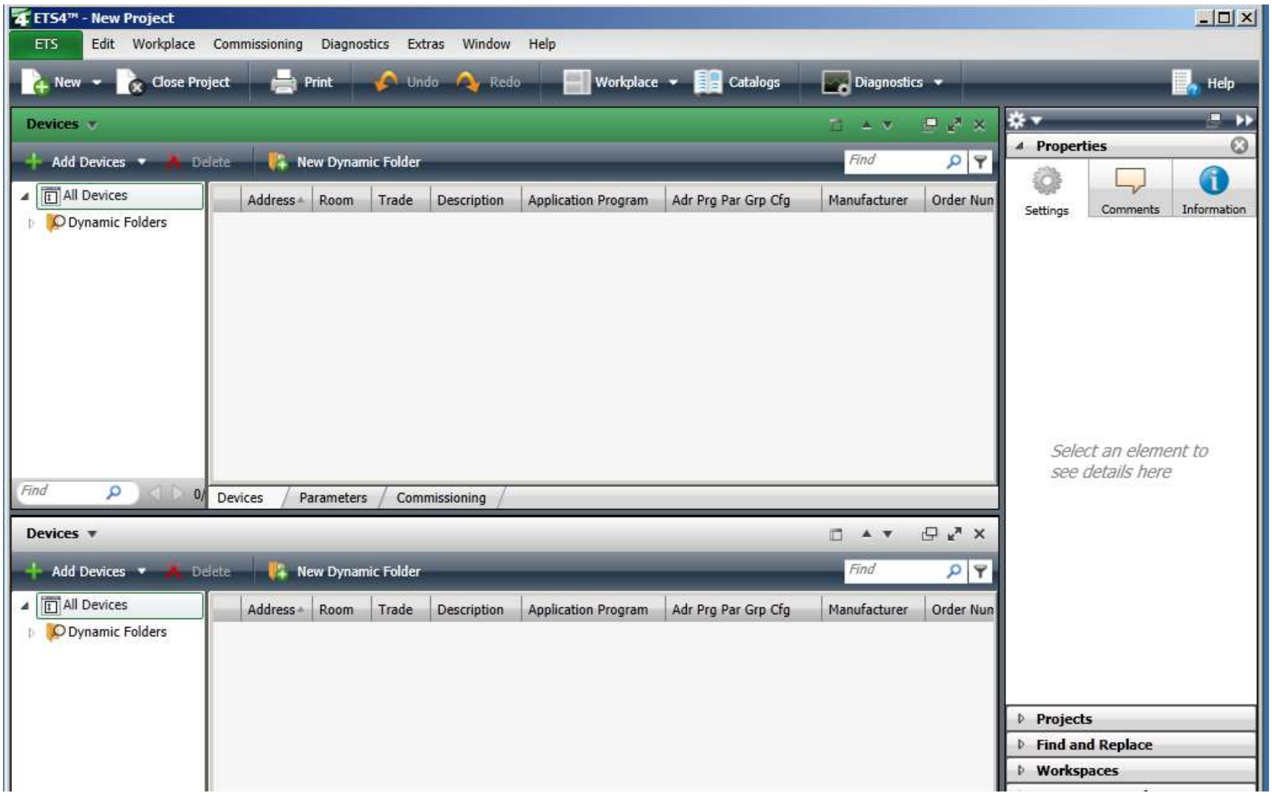
{Backbone:} <TP>

{Medium:} <TP>

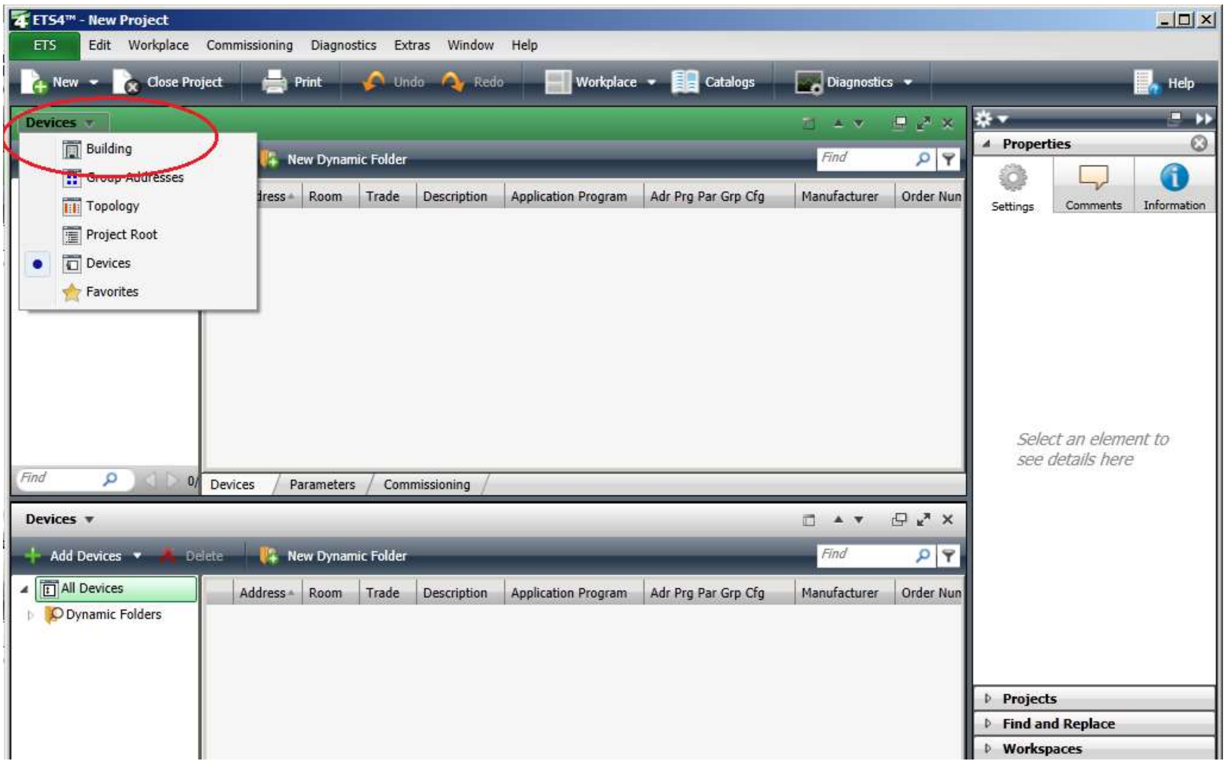
{Group address style} <Three level>

<OK>

The new project will open automatically. If not, open it manually.



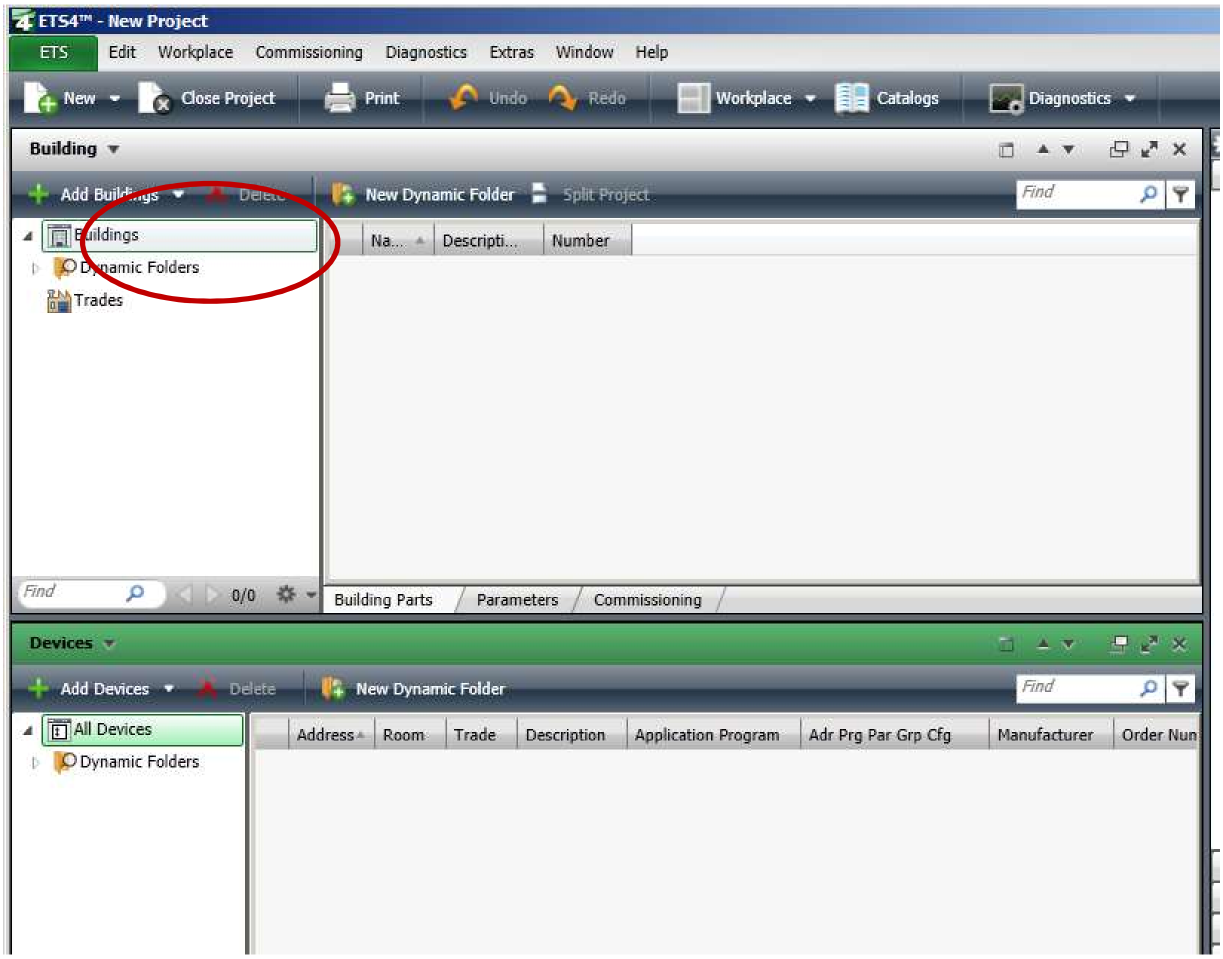
Switch current panel to “Building”.



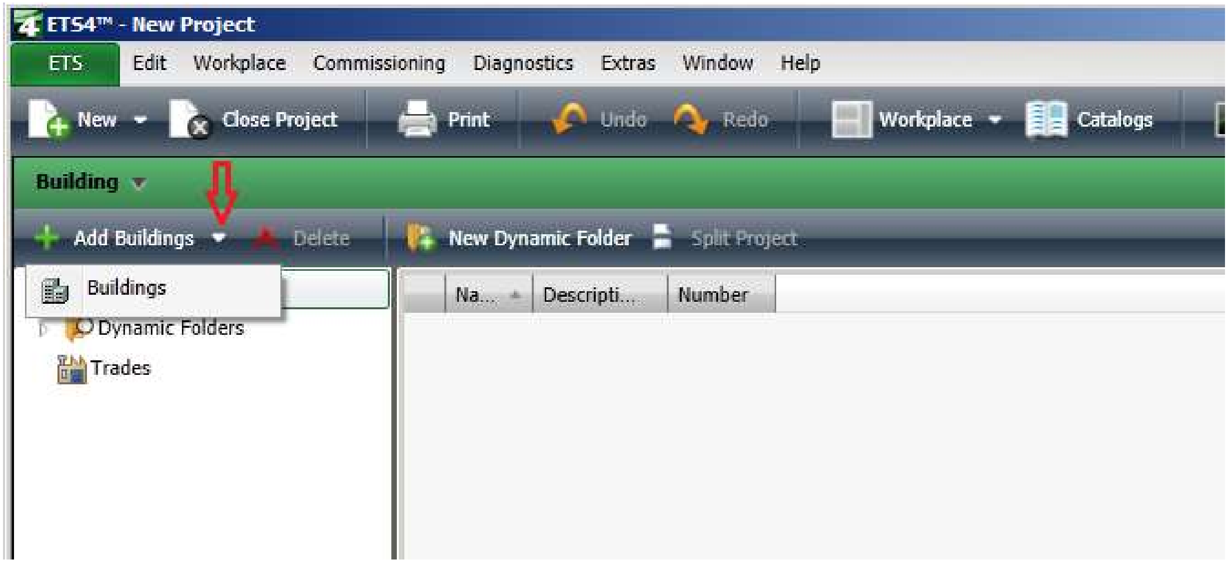
Notes:

- ✓ The "Building" Panel looks at the project from the point of view of physical installation or location.
- ✓ The objective is to define the actual physical installation or location of the KNX project.
- ✓ For example, we can build the installation "SP" → "Block 8" → "Level 1" → "T813".
- ✓ Another example, we can build the location "YY Group" → "Bishan" → "Level B1" → "Science Room".
- ✓ For this experiment, we will build the exercise "Block 8" → "Level 1" → "T813".

[Panel: Building] Select "Buildings" node.



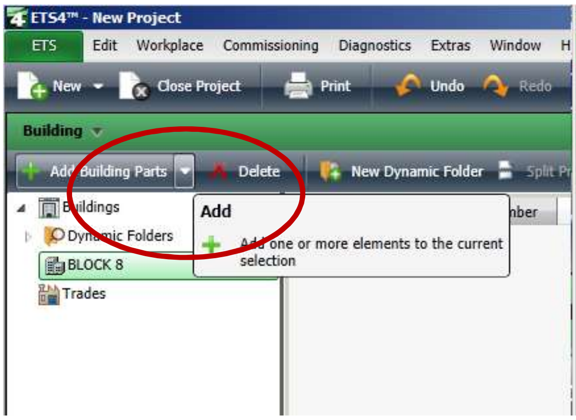
<Add Buildings>

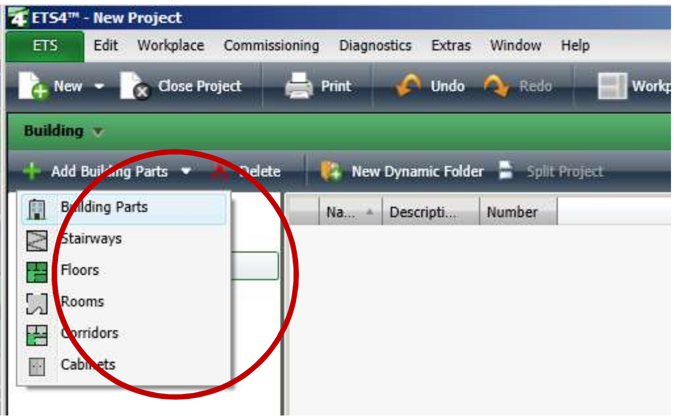


[Dialog: Add Buildings] Enter building name e.g. "BLOCK 8".

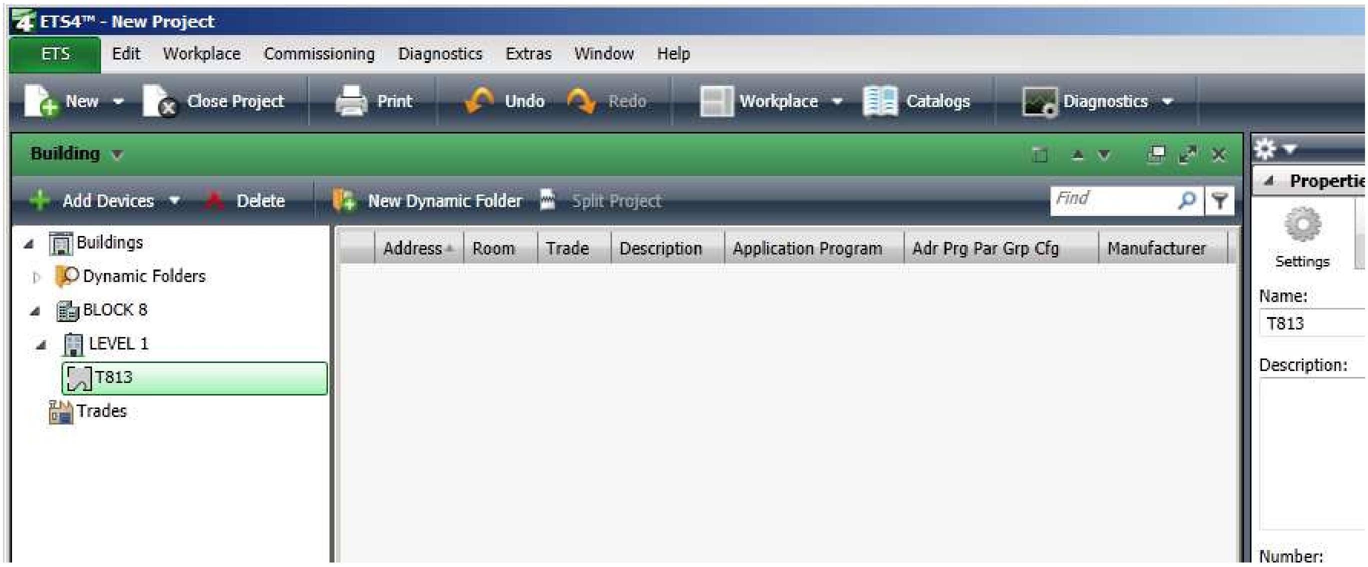
<OK>

Select the node created in the above step (click on BLOCK 8), add a sub node (or a second-level label) <"Building Parts", "Stairways", "Floors", "Rooms", "Corridor" or "Cabinet">, e.g. "Workshop 1".

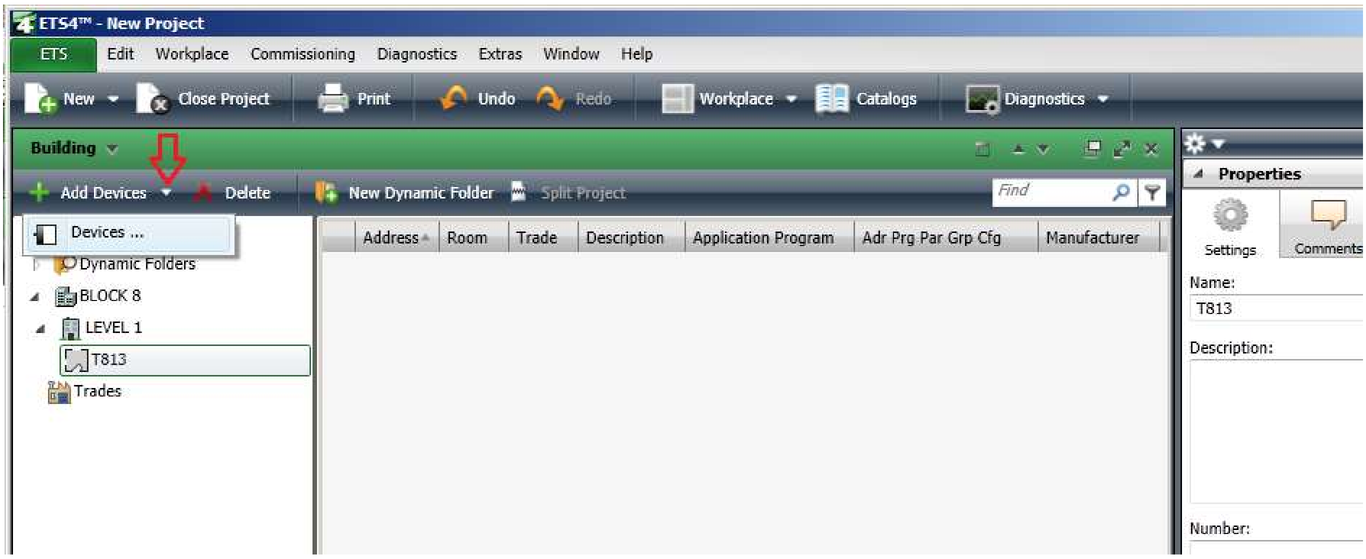




Select the sub node created in the above step, continue to add a final node (or a third-level label) <"Building Parts", "Stairways", "Floors", "Rooms", "Corridor" or "Cabinet">, e.g. "T813".



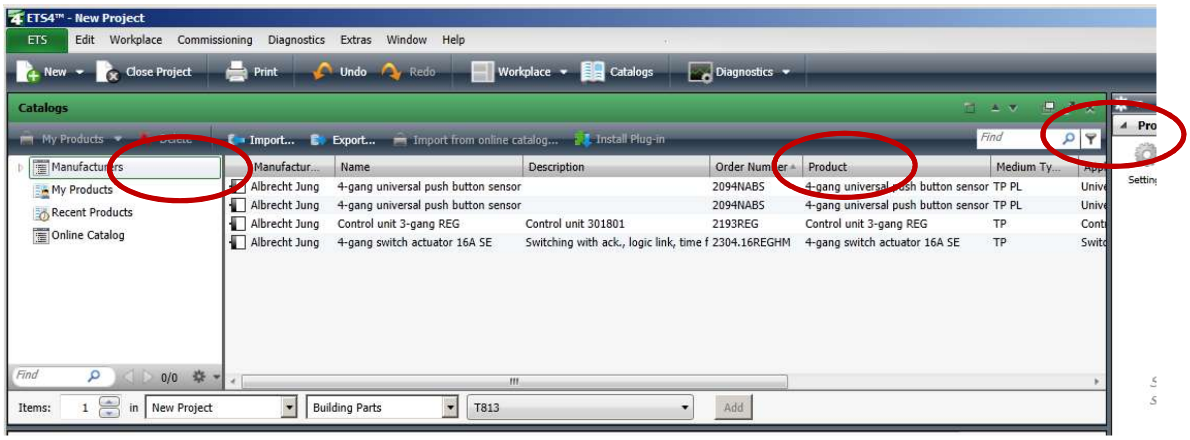
2. <Add Devices>



Notes:

- ✓ The “Add Devices” action will open the “Catalogs” Panel which contains KNX devices and products from different KNX manufacturers.
- ✓ By default, the “Catalogs” Panel is empty. Users have to download the necessary KNX devices and products, in the form of product databases, from the manufacturer’s website and then perform an import into ETS4®.

Using the “Find” input box to search for KNX devices based on “Order Number”, add all the necessary KNX devices which are needed for the experiment.



The item list is as follows.

Manufacturer	Product	Order Number	Application	Qty
Albrecht Jung	4-gang switch actuator 16A SE	2304.16REGHM	Switching with ack., logic link, time func. 209011	1
Albrecht Jung	Universal dimming actuator, 2-gang	3902REGHE	Dimming 302312	1
Albrecht Jung	Control unit 3-gang REG	2193REG	Control unit 301801	1
Albrecht Jung	4-gang universal push button sensor	2094NABS	Universal/switch 104E01	3
ABB	LM/S1.1 Logic Module, MDRC	GH Q631 0080 R0111	Logic threshold scene/1.1a	1

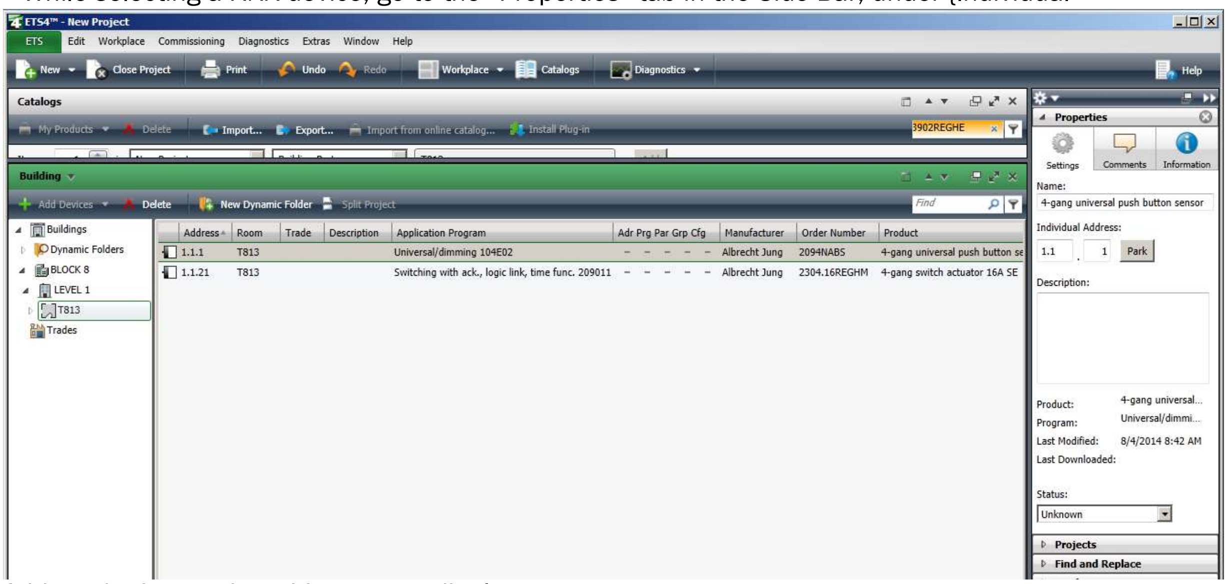
Notes:

✓ Each KNX device has its order number. Please check that **each selected device has the exact and correct order number** before using.

Add only the two items listed in the table below and set the individual physical addresses of the KNX devices as follows.

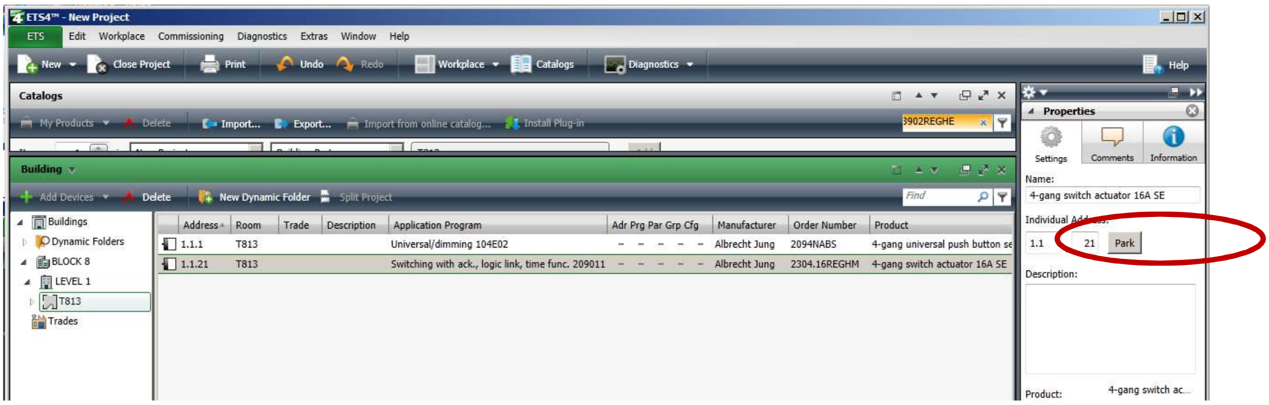
S/N	Product	Order Number	Individual Address
1	4-gang switch actuator 16A SE	2304.16REGHM	1.1.21
2	4-gang universal push button sensor	2094NABS	1.1.1

While selecting a KNX device, go to the “Properties” tab in the Side Bar, under {Individual

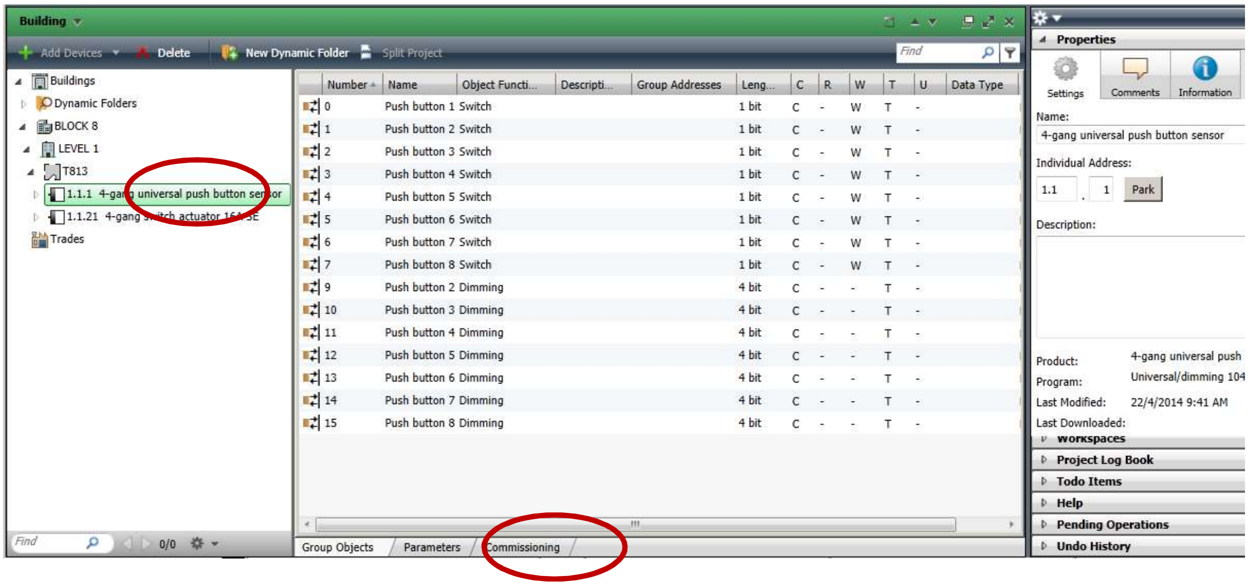


Address:}, change the address accordingly.

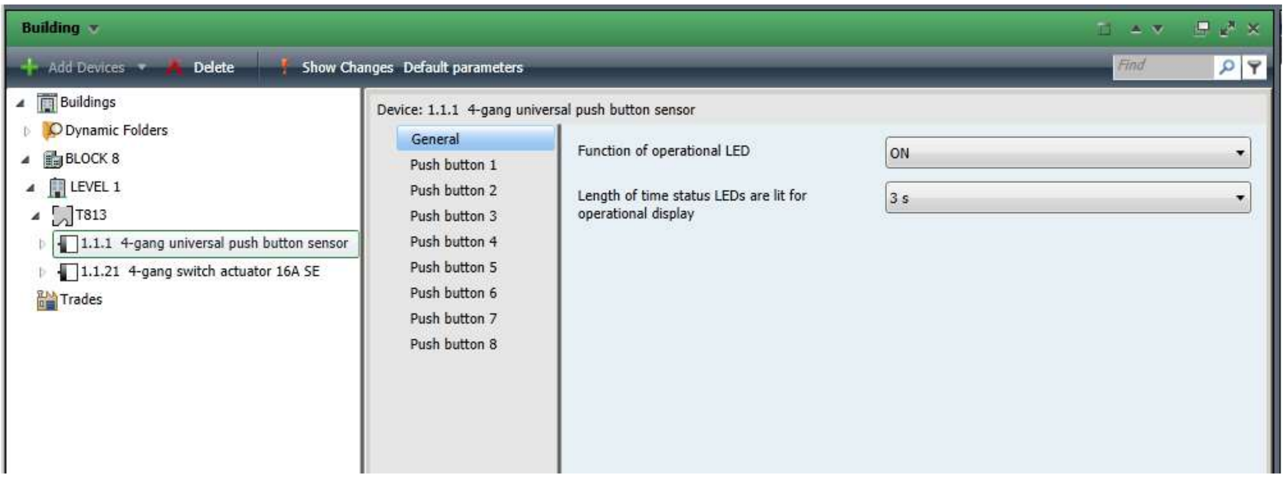
Repeat the individual address change for each KNX device.



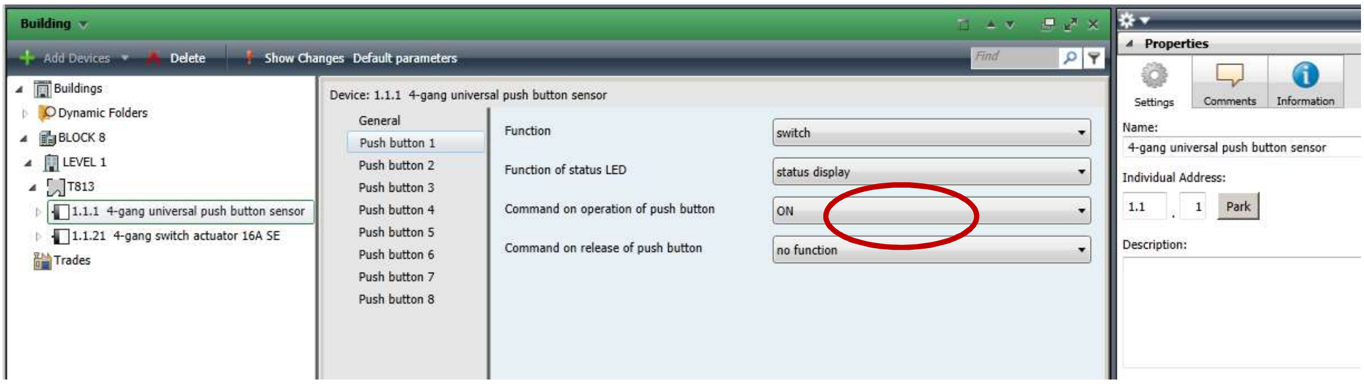
Left Click on the ► on the left of T813 to expand the devices installed, Then clicked on the 1.1.1 4-gang universal push button sensor to see the associated objects.



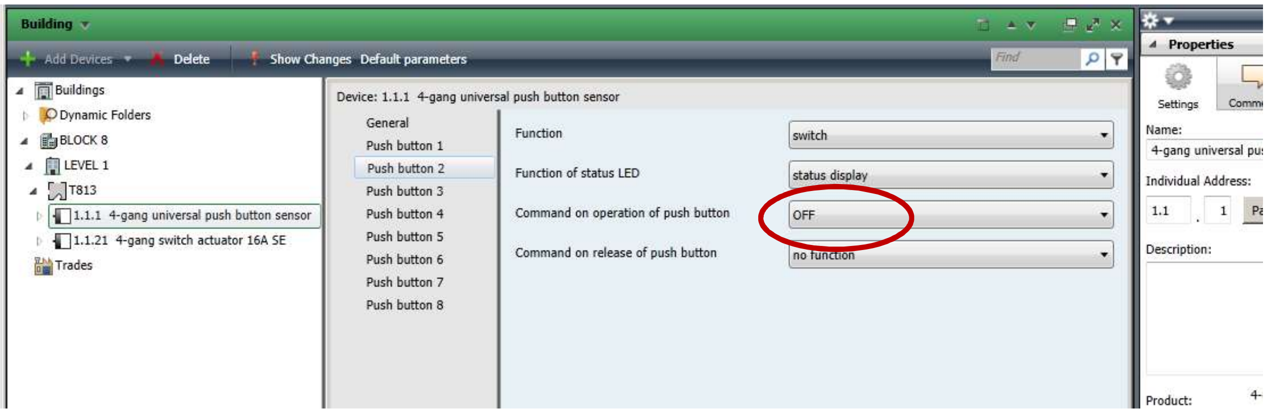
Click on the Parameters Tab at button of window to show the parameters of the object.



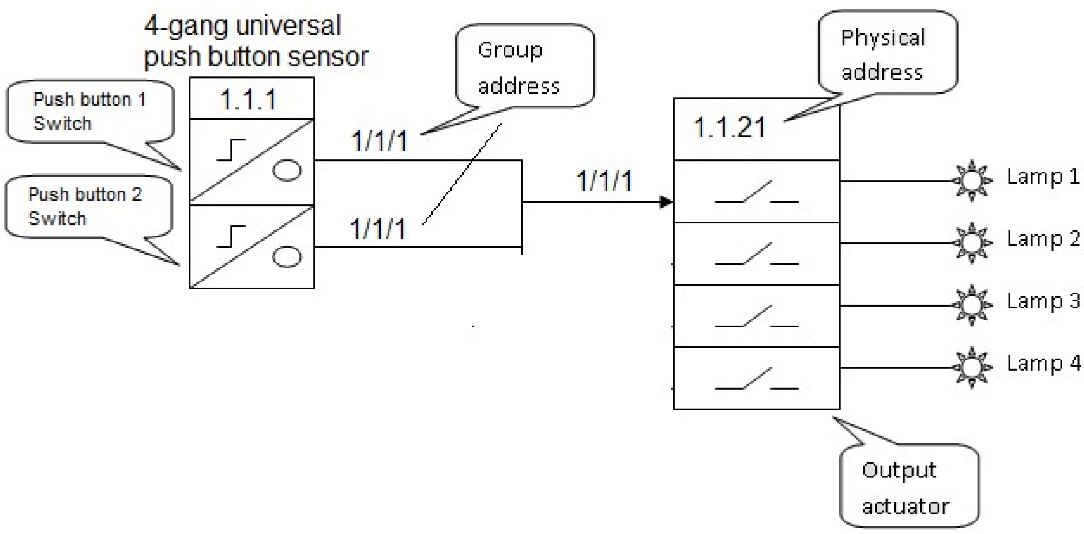
Click on the Push button 1 and change the parameters to :



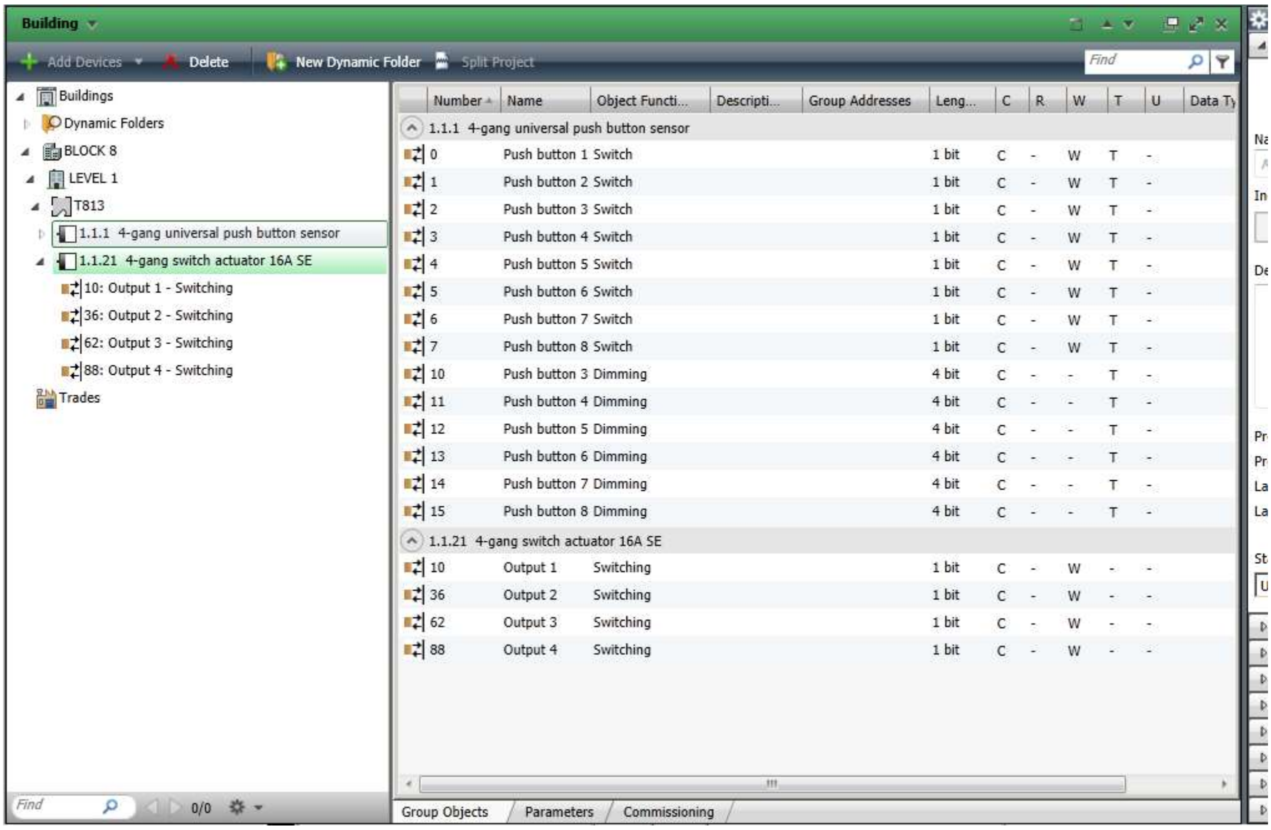
Click on Push button 2 and change the parameters to



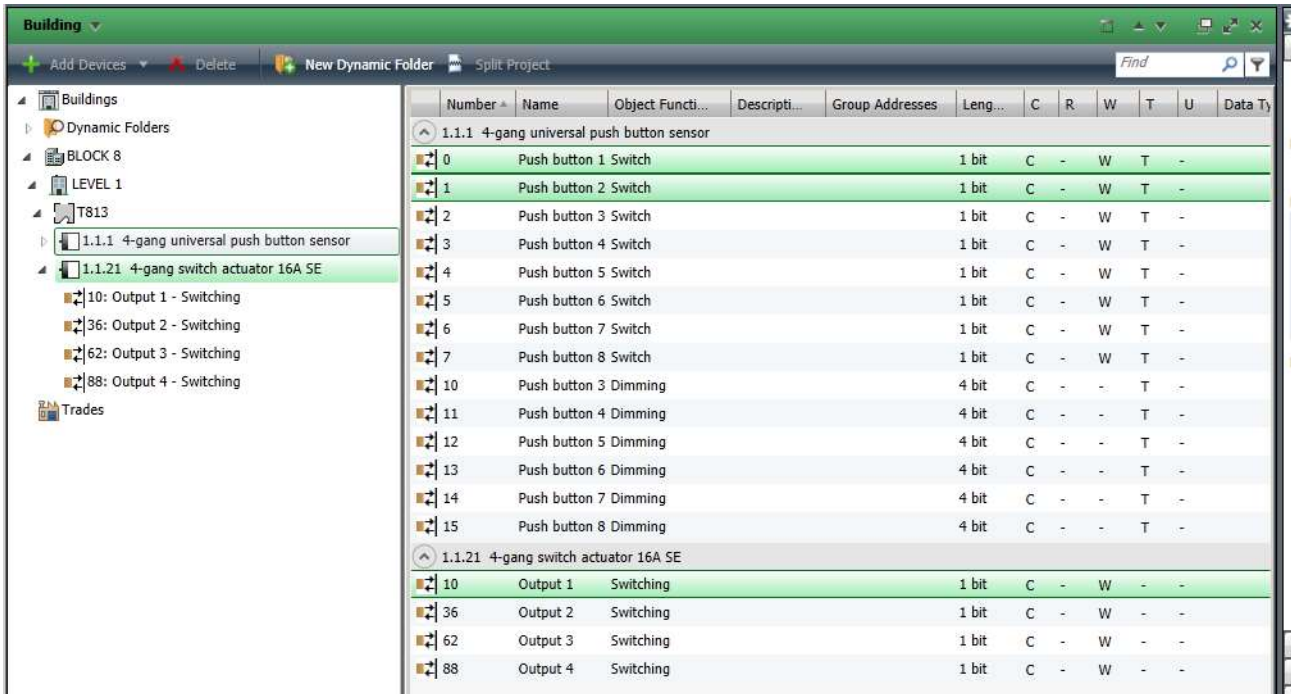
The next step would be to link the Push button 1, Push button 2 and Output 1 together so that Push button 1 will switch on the Output 1 and Push button 2 will switch off Output 1. This is done by grouping the three objects to a single group address as per diagram.



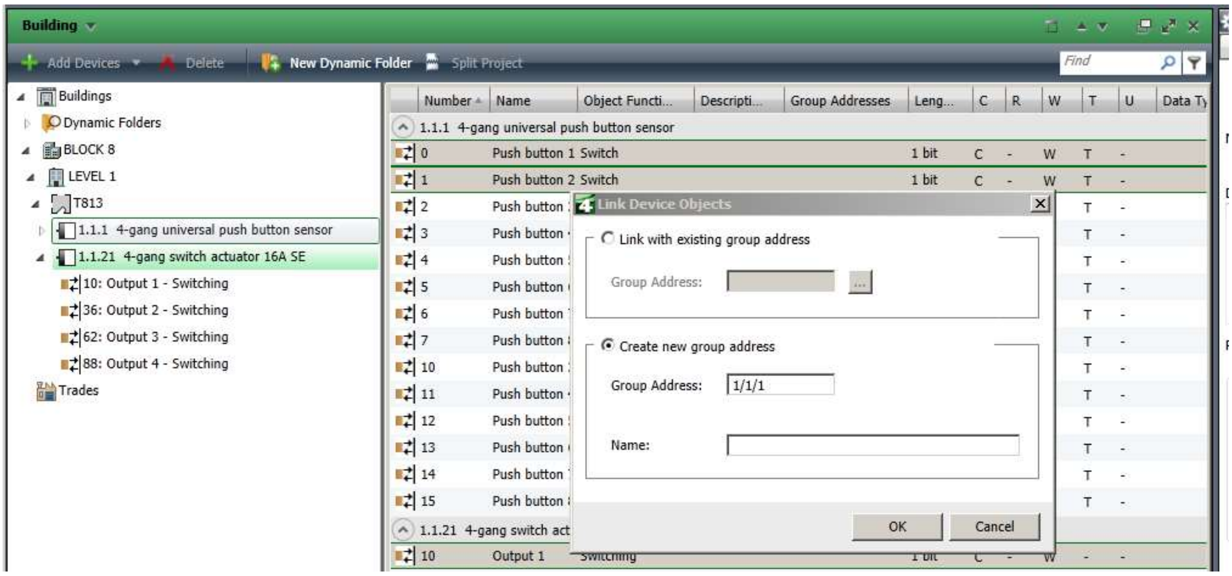
In the Building View Click on 1.1.1 4-gang universal push button sensor, hold down Ctrl button and click on 1.1.21 4-gang switch actuator 16A SE to show the group objects on the left panel.



Hold down the Ctrl key and click on Push button 1 Switch, Push button 2 Switch and Output 1 Switching to select all three objects.



Release Ctrl button after selecting these three objects, move mouse over any one of the selected object, right click to Link with, select Create new group address, type in 1/1/1 and click OK.



Right click on the individual objects to download the physical addresses and applications. Upon completion test that the push buttons 1 and 2 worked as designed.

3 Multiple Control Circuits

Edit the design to use push buttons 3 and 4 to control Output 2, Push buttons 4 and 5 to control Output 3 and Output 4. Show the result to your lecturer.

Notes:

Group addresses are very important in KNX projects.

There are several recommended ways to structure group addresses.

In this experiment, there are 4 circuits of light. Each circuit is actually an incandescent light bulb connected to an output of the 4-gang switch actuator (P.A: 1.1.21), for example [1.1.21]/Output-1, [1.1.21]/Output-2, etc.

There are 8 push buttons (4 pairs) from 4-gang universal push button sensor (P.A: 1.1.1), such as [1.1.1]/PB-1, [1.1.1]/PB-2, etc. Each pair of the push buttons controls a circuit of the light.

The relationship between an output on the actuator and push buttons on the sensor is a group address, such as [1/1/1], [1/1/2], etc.

For example,

[1.1.1]/PB-1, [1.1.1]/PB-2 control [1.1.21]/Output-1

[1.1.1]/PB-1 switches [1.1.21]/Output-1 “ON” by sending “ON” via [1/1/1]

[1.1.1]/PB-2 switches [1.1.21]/Output-1 “OFF” by sending “OFF” via [1/1/1]

Similarly,

[1.1.1]/PB-7, [1.1. 1]/PB-8 control [1.1.21]/Output-4

[1.1.1]/PB-7 switches [1.1.21]/Output-4 “ON” by sending “ON” via [1/1/4]

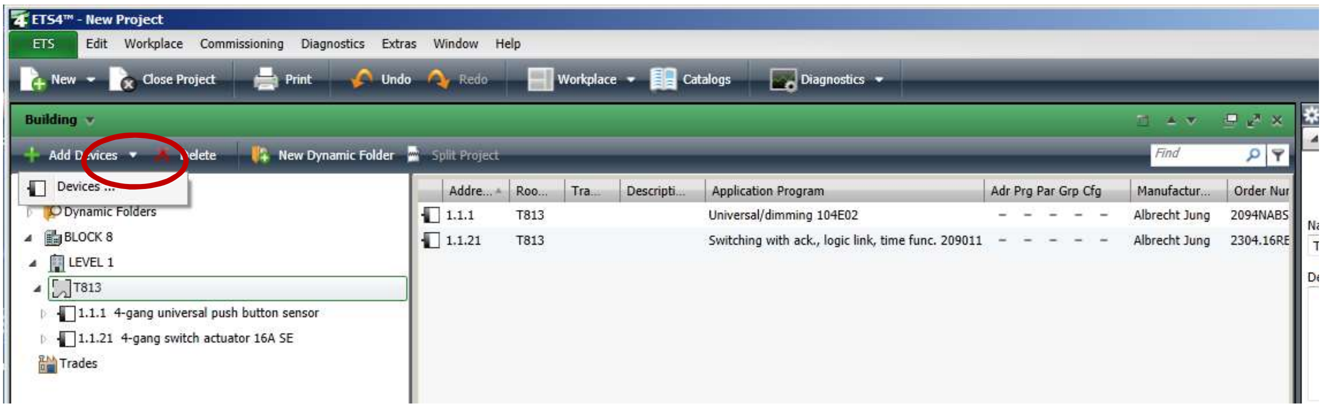
[1.1.1]/PB-8 switches [1.1.21]/Output-4 “OFF” by sending “OFF” via [1/1/4]

In KNX, commands like “ON” and “OFF” are of size 1-BIT.

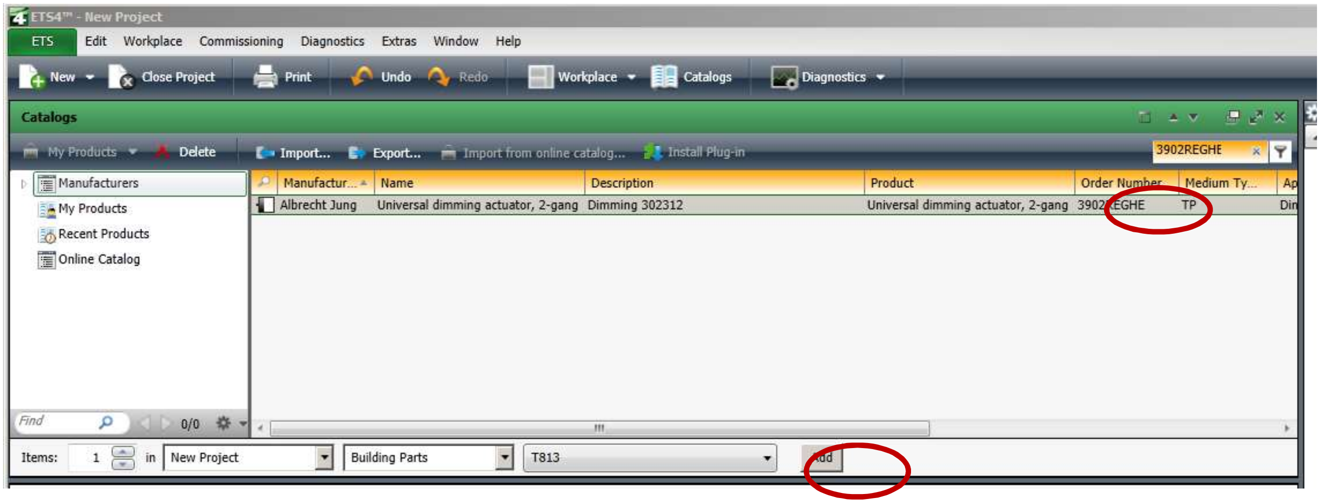
Hence, group addresses [1/1/1], [1/1/2] etc. are of size 1-BIT.

4 Dimming Function 1 (Incandescent Light)

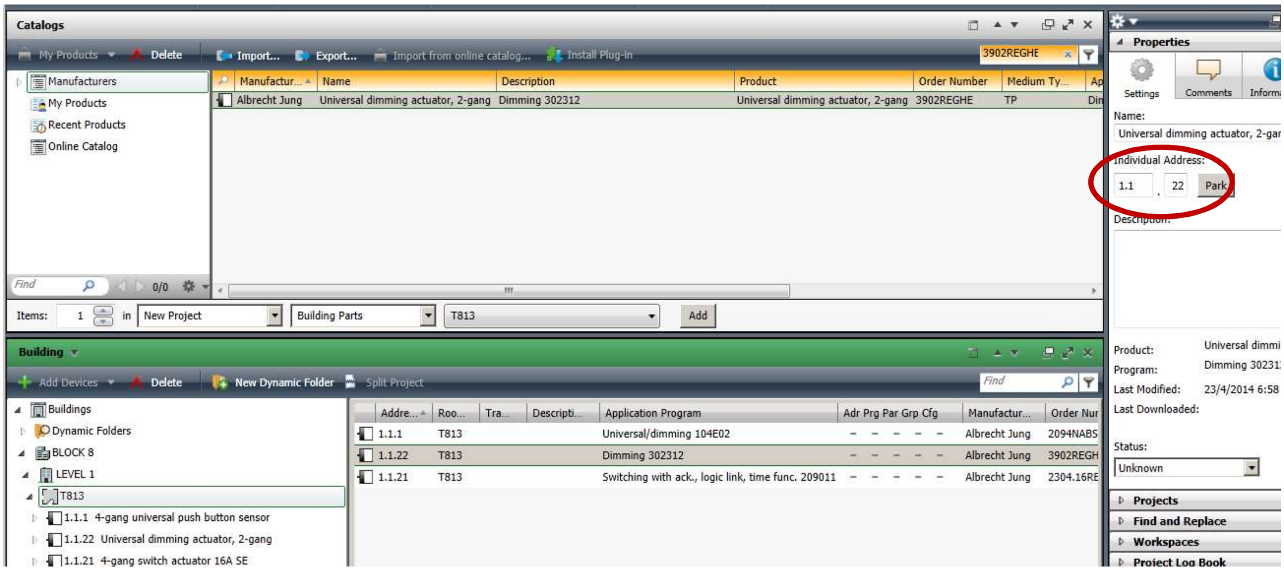
In the Building Node, select the node T813, then click on Add Devices



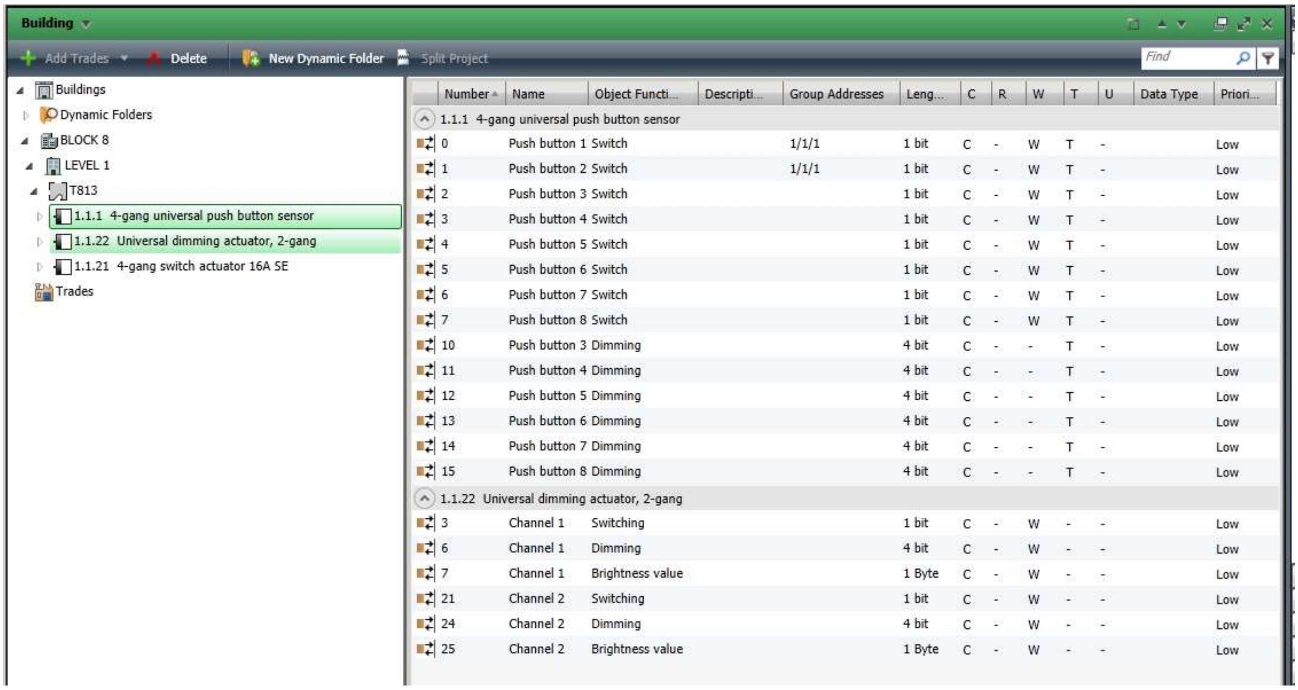
The Catalogue window will appear, type in the order number 3902REGHE in the search box, click the search button Ψ next to the box, the device will appear below.



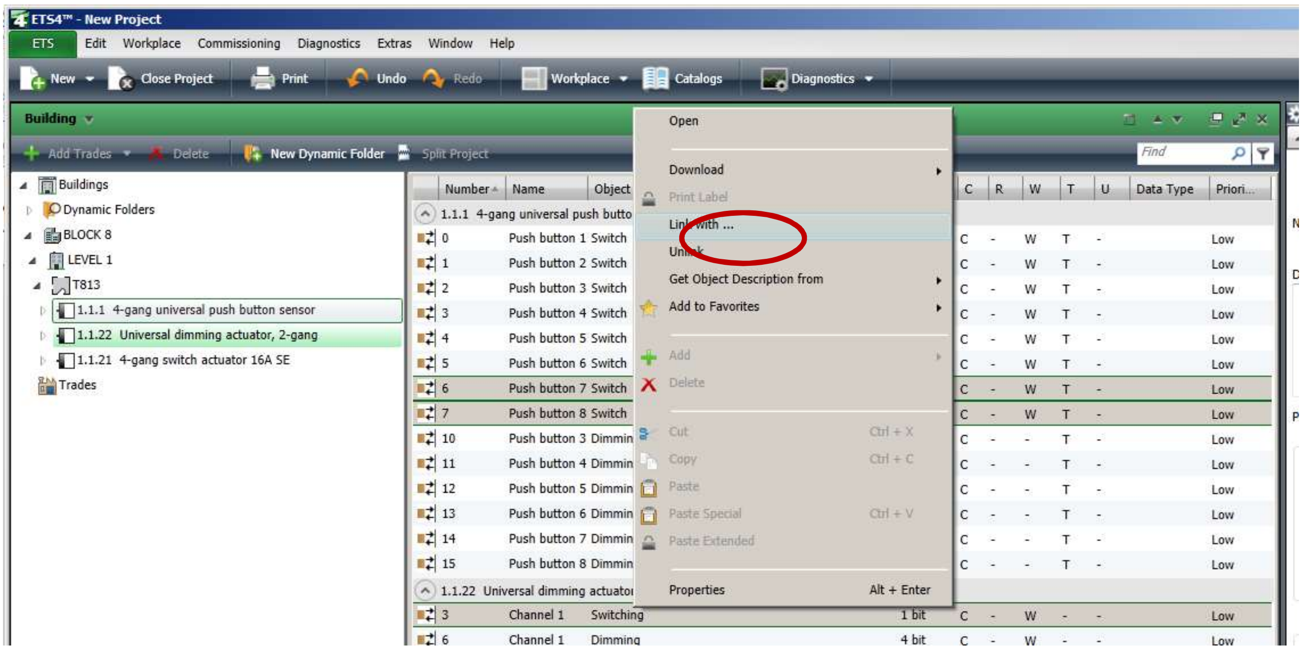
Click the Add button, the device will appear in the Building window, click to select the device and change the physical address to 1.1.22 in the Properties panel.



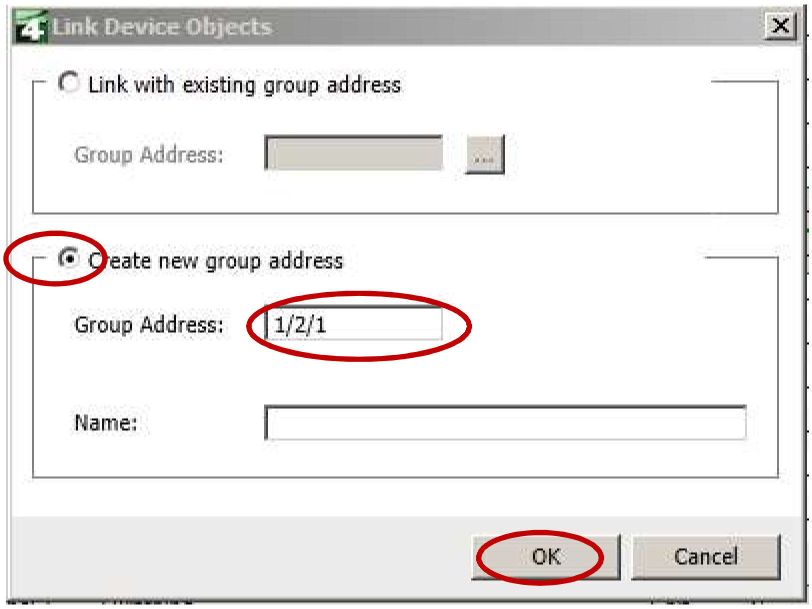
Next closed the Catalogs panel by clicking on the X closed button such that the Building panel can occupied the whole screen. First select device 1.1.1 4-gang universal push button sensor by clicking on it, next hold down Ctrl key and left click on 1,1,22 Universal dimming actuator to show all channels of both devices on the right panel.



Group Push button 7 Switch, Push button 8 Switch and Channel 1 Switching to Group address 1/2/1 (This is done by first left click on Push button 1 Switch, then hold down Ctrl key and left click Push button 8 Switch and Channel 1 Switching. Let go of mouse and Ctrl key, move mouse over any one of the selected device channel then right click to open dialogue box select Link with …



When the Link Device Objects dialogue box appears, select Create new group address and type in 1/2/1, click OK to complete the linking.



Similarly link Push button 7 Dimming, Push button 8 Dimming and Channel 1 Dimming to Group address 1/2/2. Once completed download the Universal Dimming actuator physical address, and the application for both the 1.1.1 and 1.1.22. The dimming function can then be tested.

KNX Technology (Expt 2)
Objective

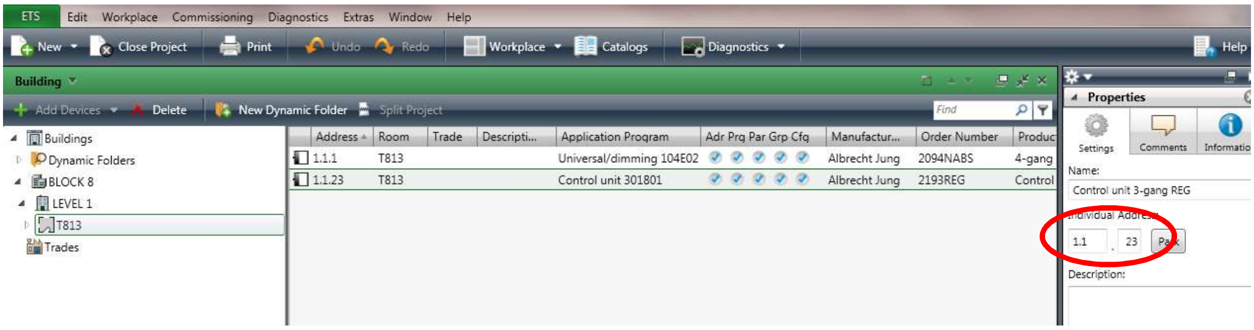
In this experiment, you will be able to learn about other actuators and advanced features of the KNX system.

Use the KNX software to design and commission the following:
Dimming On-Off Circuits for Fluorescent Light
Delayed On-Off Circuits
Filtered Circuits

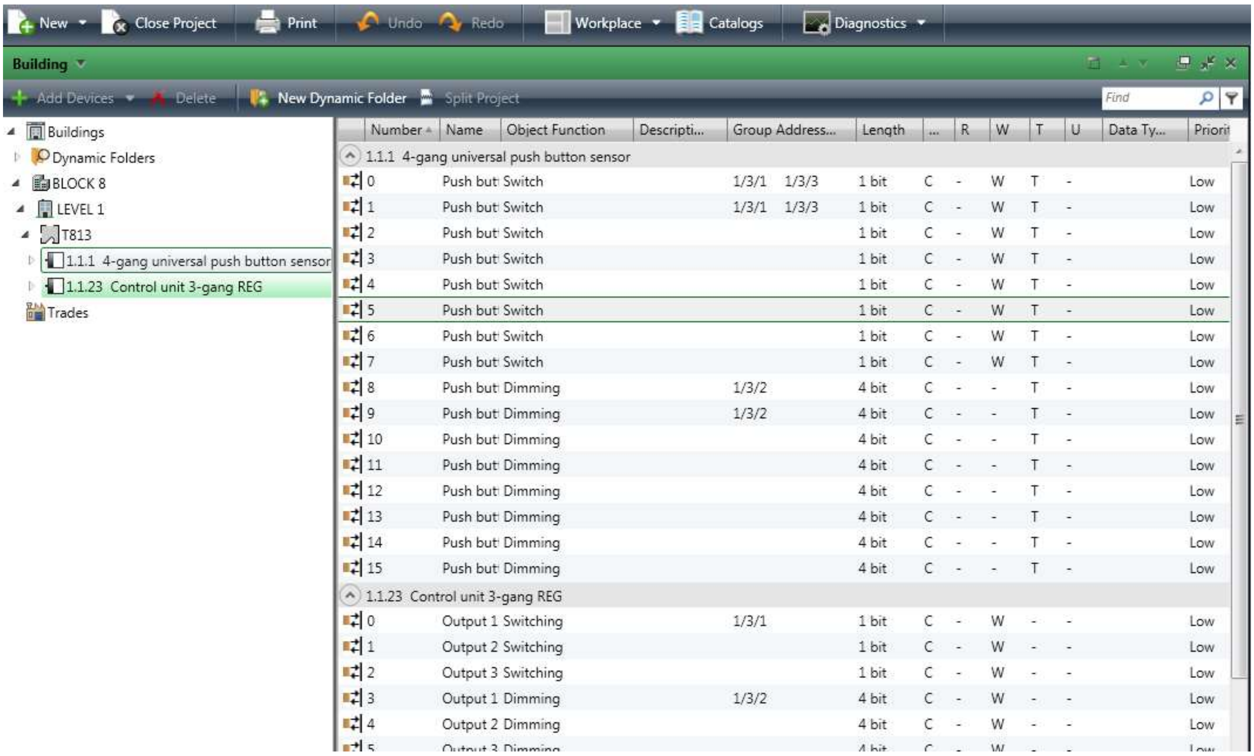
1 Dimming Function 2 (Fluorescent Lights)

Remove the device Universal dimming actuator 3902REGHE using the delete button.

Using the same method in section 4, add a new device Control Unit 3-gang 2193REG then change the physical address to 1.1.23 in the Properties panel.



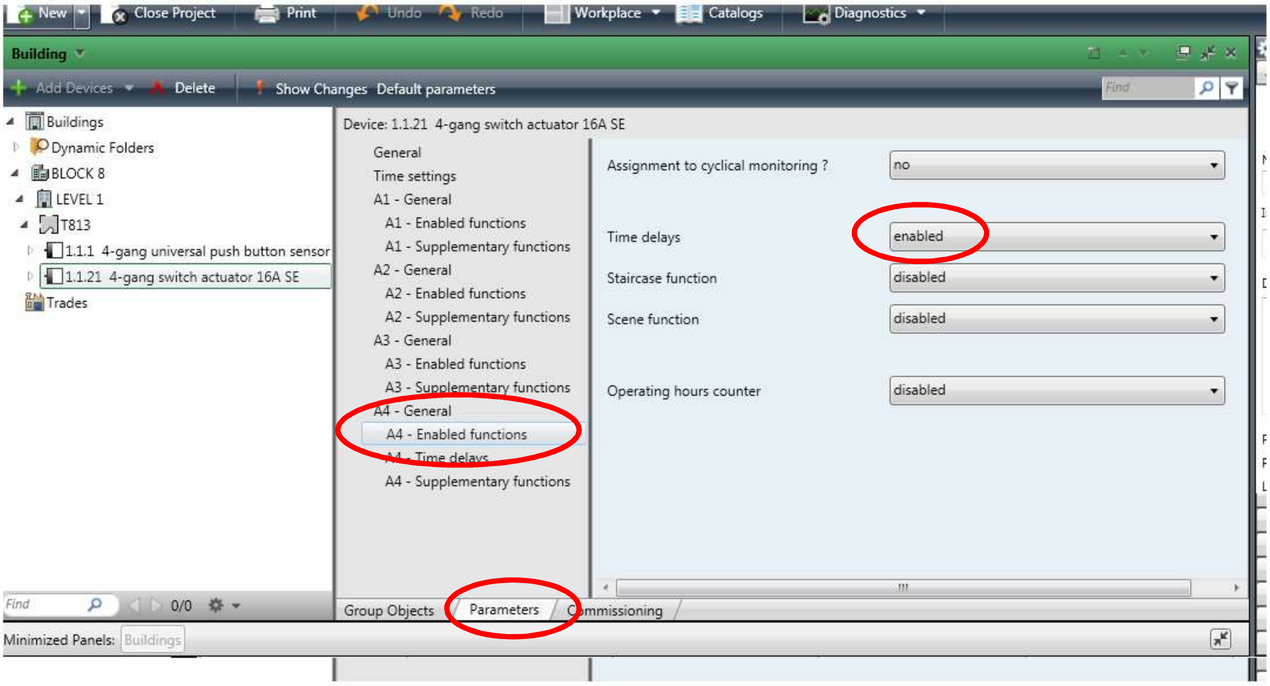
Proceed to link the Group Objects with the Group Addresses as shown in the following diagram. The dimming function for fluorescent lights can be tested



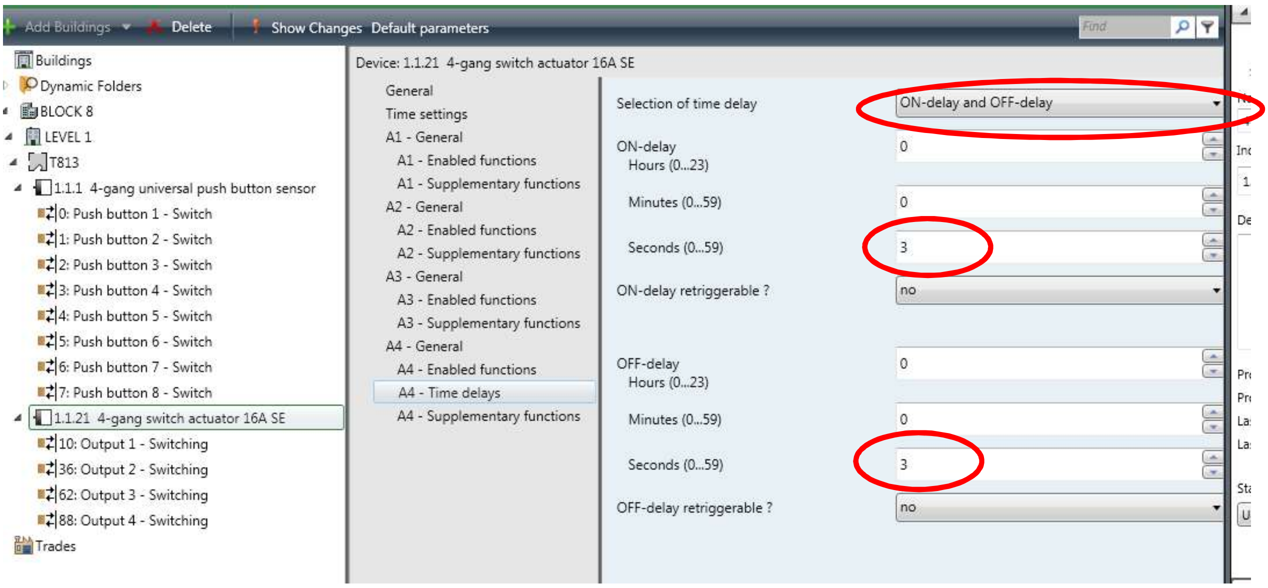
2. Delay Function

The delay function can enable a toilet lamp to be switched on by a pushbutton, and an exhaust fan to be automatically switched on after 5 seconds if the toilet lamp is not switched off. The exhaust fan if switched on shall continue to be on after the light is switched off (supposedly used to exhaust the foul smell) and will automatically switch off after 5 seconds.

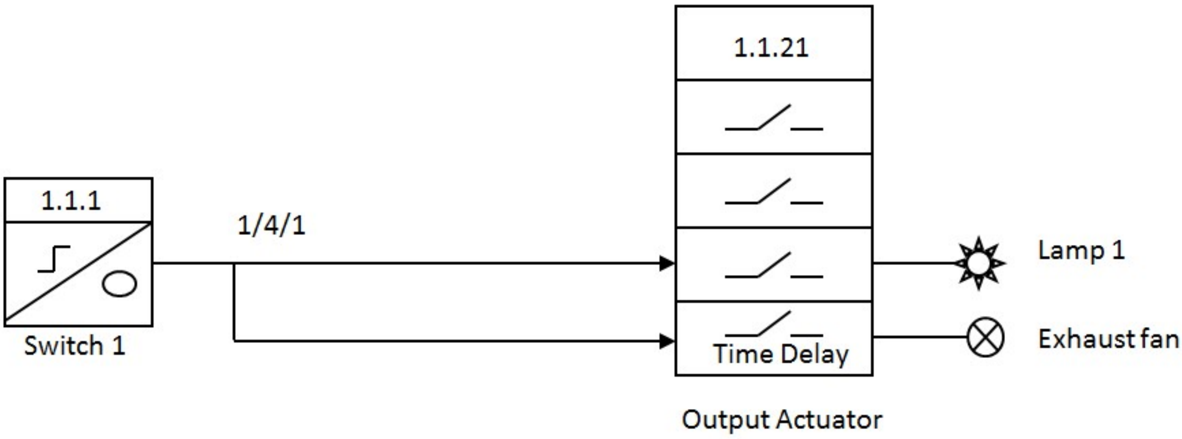
The 4-gang switch actuator 16A SE can be used for delay function. The 3rd and 4th gangs will be used. Go to Parameters and enable the Time Delay function of the 4th gang.



Click on A4-Time Delay, select ON-delay and Off-delay and change the time to 5 secs.

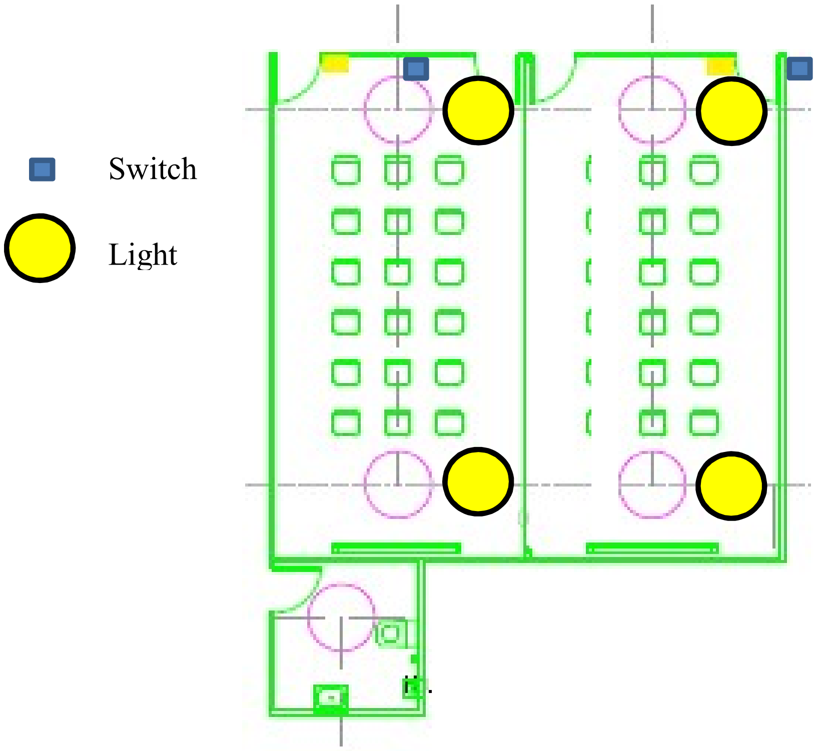


Proceed to link the Group Objects with the Group Addresses as shown in the following diagram. The delay function can be tested

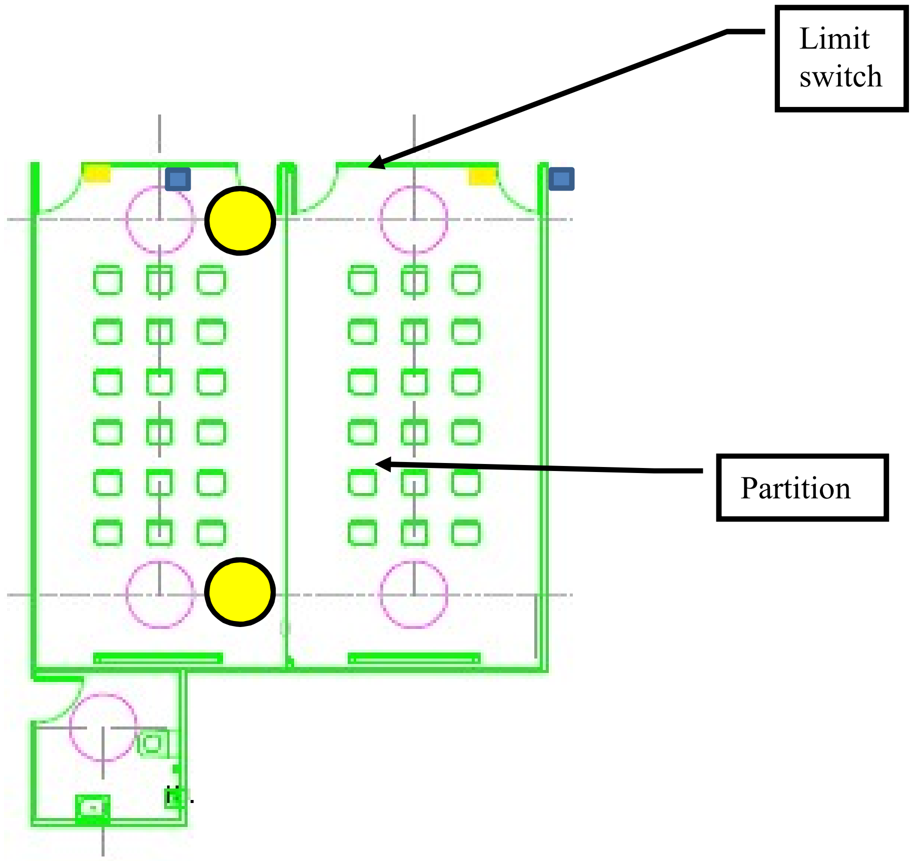


3 Logic Function

A conference room has a movable partition wall, and two pushbutton switches at the two entrances as shown below. When the partition wall is opened, either pushbutton can be used to switch on-off all lights in the conference room (made of two rooms).



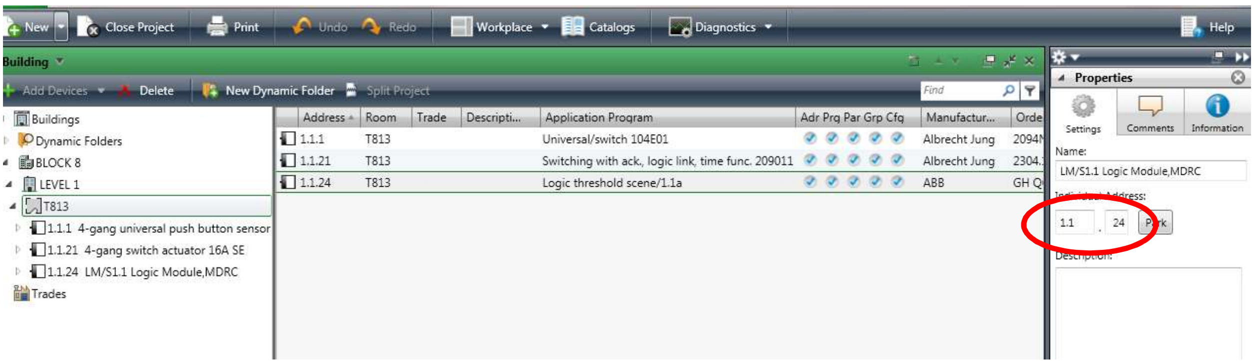
However, when the partition wall is closed, detected by a limit switch (you shall use one of the sub-channels in a switch to simulate this), the pushbuttons automatically switch the lights in the respective rooms only.



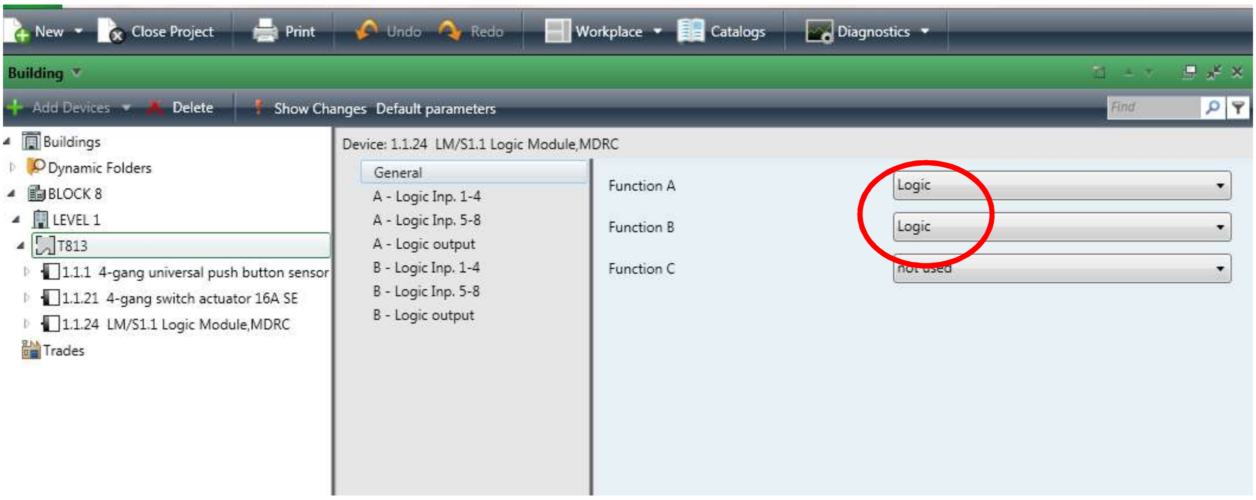
Implement the project using a logic controller to filter the telegrams from the pushbuttons, depending of the status of the limit switch.

Remove the device Control Unit 3-gang 2193REG using the delete button.

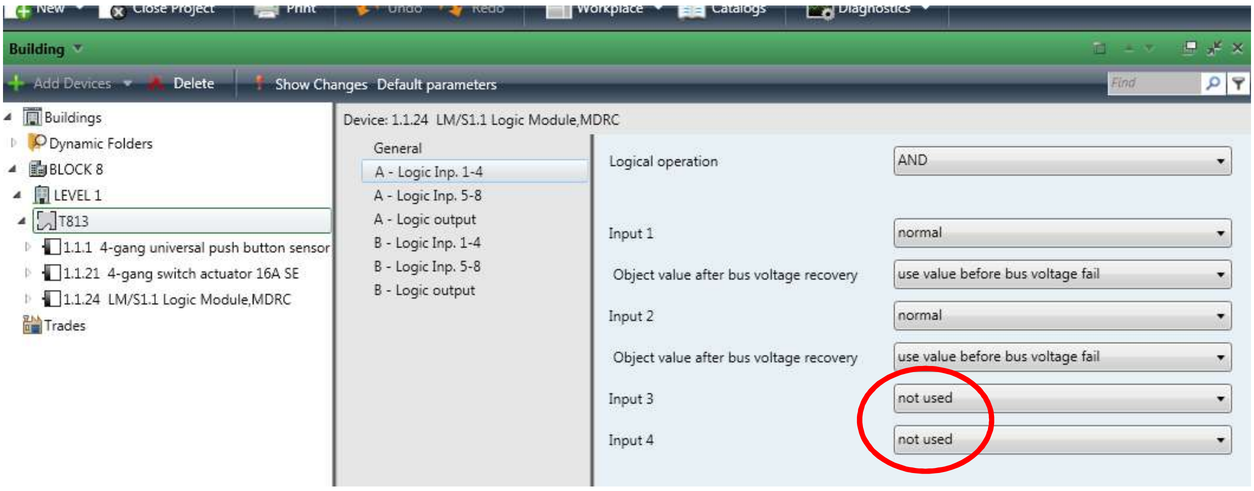
Add a new device Logic Threshold scene/1.1a GH Q631 0080 R0111 LM/S1.1 Logic Module then change the physical address to 1.1.24 in the Properties panel.



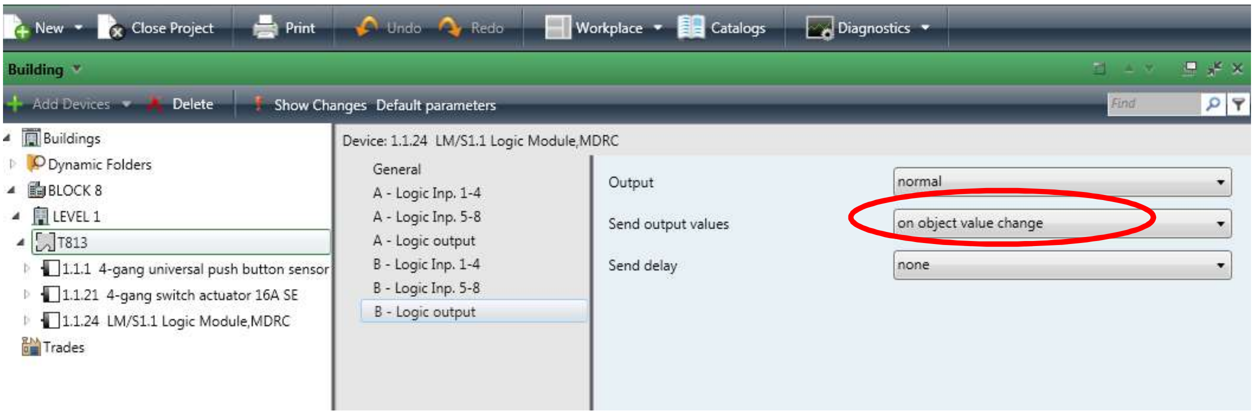
Go to Parameters of the Logic Module and change both Function A and Function B to Logic



Click on A-Logic Inp. 1-4. Disable inputs 3 and 4 by changing from 'normal' to 'not used'.

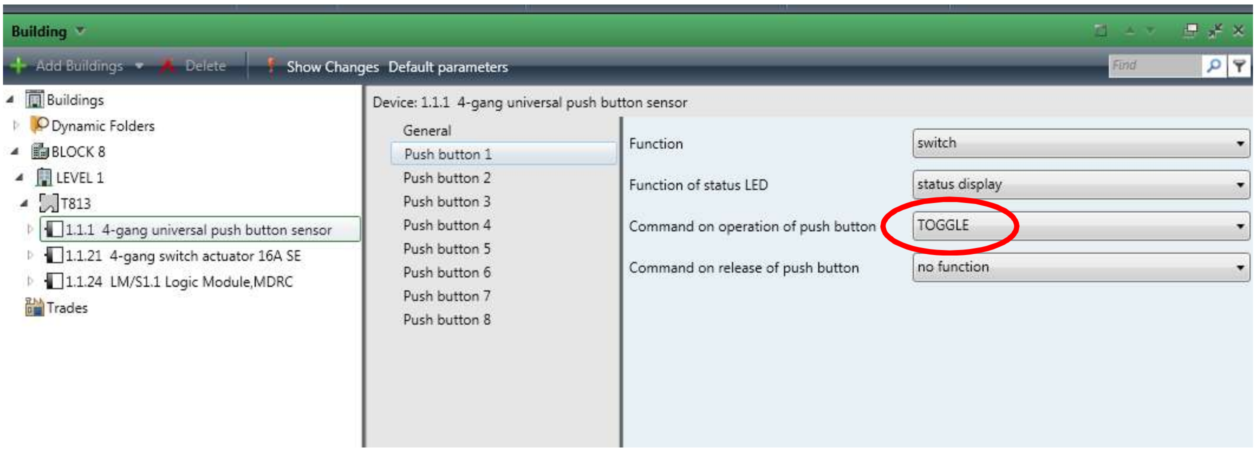


Click on Logic Output and change 'Send output values' to 'on object value change'.

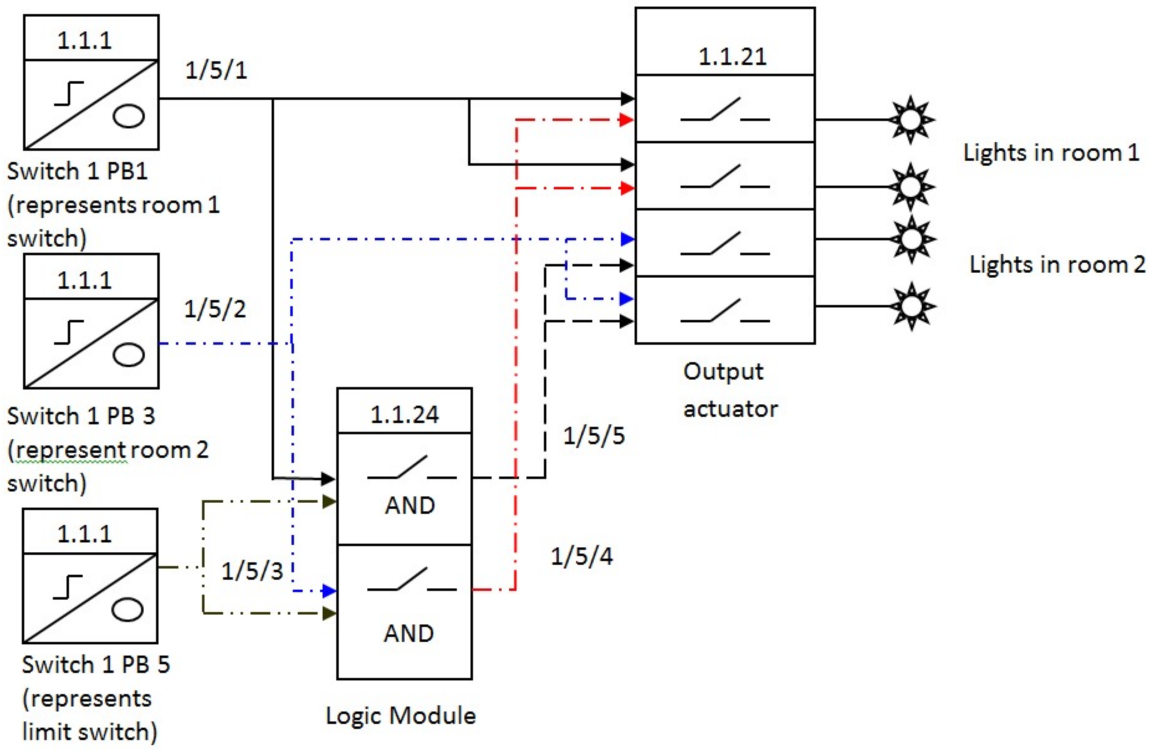


Do the same for Function B.

For this case, the push buttons of the 4-gang universal push button sensor shall have the toggle function. This means that the ON and OFF operations are done on the same switch. Using push buttons 1, 3 and 5, proceed to enable the toggle function of the three switches.



Use the configuration diagram below; proceed to link the Group Objects with the Group Addresses.



Singapore Polytechnic
School of Electrical and Electronic Engineering

Experiment : Three phase A.C. supply, Neutral, and Protection Against Indirect Contact

Objectives: **After completing the experiment, the students should be able to:**

a) Using three phase AC supply and understand single phase load distribution on three phase supply.

b) The importance of neutral in three phase supply particularly for single phase loads

c) Describe the anatomy of an electric shock by listing the four basic components. Using current data from industry standards, illustrate the physiological effects of electricity on the human body.

d) Understand the three most common measures of Protection Against indirect contact when using ac low voltage mains.
  - Earth equipotential bonding and automatic disconnection of supply
  - Use of Class II Equipment
  - Electrical Separation of Supply

e) Understand the use of the RCCD as an additional protection against electric shock – DEMO using 13A SSO with built-in 30mA and 10mA RCD

f) Observe and understand the tripping characteristics of MCB, in particular Type B (thermal and magnetic tripping) and cable burning as a result of overcurrent.

Components :
100W filament lamps
Multi-meter, tong meter
Electric kettle
Probe with 8K resistor and 6K resistor
Isolation transformer, Current injection test set
Hair dryer

Three phase supply

Three phase supply in Singapore is connected in star with the star point as the neutral. This part of the experiment will demonstrate balanced load using filament lamps and the need for neutral when the load is unbalanced.

Electrical shock

Electrical shock occurs when the human body becomes part of a path through which current can flow. The resulting effect on the human body may be injury or death. This effect may result from direct or indirect contact with an electrical voltage source or by involuntary reaction, such as falls from ladders or scaffolds.

Anatomy of an Electrical Shock

Current flow through the human body follows the same rules of circuit analysis as any circuit. Kirchoff's Laws and Ohm's Laws apply.

1. Electric current must have a complete path from the high side of the voltage source back to the low side of the voltage source.
2. Most current takes the path of least resistance.
3. The human body can provide a path for current to flow.
4. Current flow will be limited by the resistance of the body.

Moisture, oil, or abrasions on the skin at contact points reduces the resistance of the total path resulting in more damage.

Current flowing through the highly sensitive central nervous system can, under certain conditions, cause serious injury or death.

Physiological Effects of Electric Currents

Current at 50 HZ	Physiological Effect on 68 kg Person
<1 mA	None
1 mA	Perception Threshold
1 - 3 mA	Mild Sensation
3 - 10 mA	Painful Sensation
10 mA	Paralysis Threshold of Arms
30 mA	Respiratory Paralysis
75 mA	Fibrillation Threshold (0.5 %)
250 mA	Fibrillation Threshold (99.5 %)
4 A	Heart Paralysis Threshold (No Fibrillation)
>5 A	Tissue Burning

Your nervous system is an electrical network that uses extremely low currents. An electric shock--with even very low current--can disrupt normal functioning of muscles--most significantly, your heart. This is why a person receiving a shock is frequently unable to "let go," and his or her heart may lose its coordination. Currents that produce no noticeable heating of tissue or visible injury can cause these effects.

Electric shock by Indirect Contact

Electric shock happens when the body becomes part of an energized electrical path and energy is transferred between parts of the body, or through the body to ground or the earth. In order for shock to occur, a potential difference or stored electrical charge must be present to cause the current to flow.

Figure 1 shows that a person may suffer electric shock as a result of touching the casing of the electric kettle. (Indirect contact.) This is due to a fault where the live cable is shorted to the casing of the kettle.

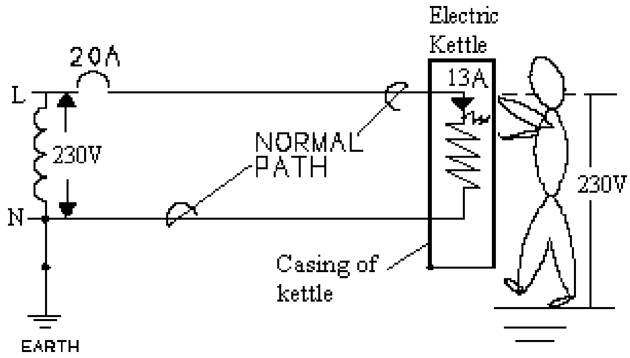


Figure 1

There are five measures used for protection against indirect contact:

a) Earthed equipotential bonding and automatic disconnection of supply
b) Use of class II Equipment or equivalent insulation.
c) Electrical separation
d) Non-conducting location
e) Earth-free local equipotential bonding

The laboratory demonstration will focus on the first three measures.

Earthed equipotential bonding and automatic disconnection of supply

In this measure the exposed conductive part of the equipment is bonded to earth so that in the event of a fault where the live conductor is shorted to exposed conductive part, a complete path will be set up for a fault current to flow. As this is a short circuit current, the circuit breaker protecting the circuit will trip to isolate the supply (**automatic disconnection of supply**). Though unlikely, people may be holding or touching the exposed conductive part when an earth fault occurs, other conditions such as time of disconnection of supply and maximum allowable touch voltage must be met for a circuit to be considered to be protected against indirect contact using this measure. This is evident from the physiological effect of electric shock. This measure can be used when the source of supply is solidly earthed. (Lecturer to demonstrate this measure using the electric kettle with a simulated earth fault.)

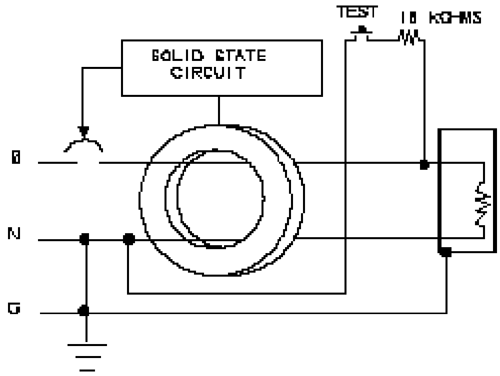
Use of Class II Equipment or equivalent insulation.

In this measure it is recognised that in certain equipment, although the equipment casing or certain part of it may be metallic, it is possible to provide an additional layer of insulation (called the supplementary insulation) to the area where the supply (230V) is used such that even if the cable insulation failed, the supplementary will ensure that 230V will not be shorted to the metallic casing.
(Lecturer to show the difference between Class II equipment and totally insulated appliance.)

Electrical Separation of Supply

This measure uses an isolating transformer where the secondary is not earthed to prevent electric shock through contact with exposed-conductive parts which might be energised by a fault in the basic insulation of the cable. Shave outlet in hotel room toilet uses this measure.
(Lecturer to demonstrate the difference between this and the first measure.)

Earth Leakage Protection (Use of Residual Current Circuit Breaker)



Residual Current Circuit Breaker

The residual current circuit breaker is an inexpensive device used to protect personnel against electrical shock. The SS638:2018 and Energy Market Authority mandates the used of the RCCD in residential premises and for all 13A switched socket outlets circuits. (Lecturer explained and demonstrate the operation of the RCCD.

Questions to think about: Ω

Three phase supply:

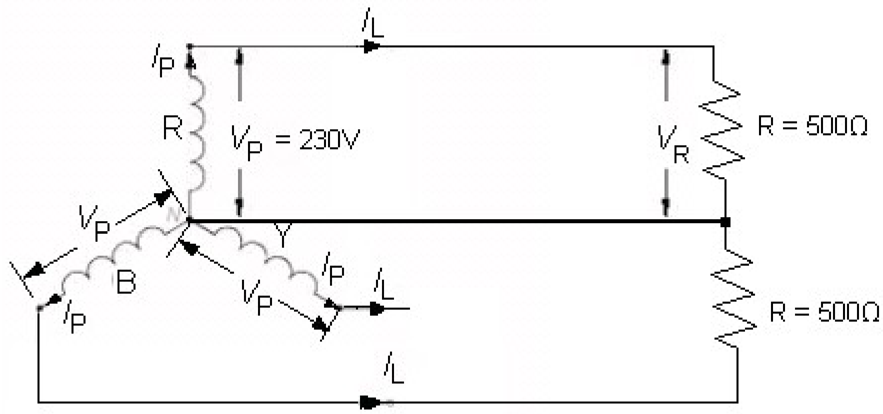


Figure 2 with neutral

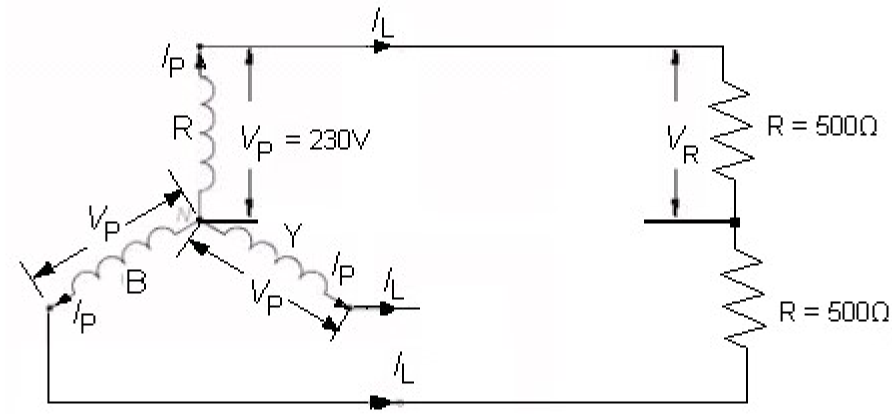


Figure 2a without neutral

State the voltage V_R and calculate the current I_L on Figure 2 and Figure 2a

Figure 2 V_R = ____________________ , I_L = _______________________

Figure 2a V_R = ____________________ , I_L = _______________________

Electric Shock

1) **List the four rules that comprise the anatomy of an electric shock:**

a)____

b)

c)

d)

2) What are the two most common measures used in Singapore for protection against indirect contact?

3) Why equipotential bonding and automatic disconnection of supply cannot be used when the neutral of the source of supply is not solidly earthed?

4) Explain why Class II equipment must not be earthed?

5) When a person touches the phase conductor with one hand and touches the neutral conductor with the other hand will the protective device such as the circuit breaker, fuse or RCCD operate to protect him/her? Give your reason in arriving at the conclusion.

6) Explain the main difference between the overload and short circuit tripping mechanism of Type B MCB.

Singapore Polytechnic
School of Electrical and Electronic Engineering

Experiment : Briefing on ETEIN, PBIL Project and ONLINE QUIZ

Objectives :

1) Use E-Tein to further their understanding of Electrical Installation
2) Start on the PBIL project on Electrical Installation
3) Do the ONLINE Quiz on Topic2 (5%)

Equipment : Students are required to bring their Laptops (or they may use their smart phone of the online quiz) for this session.

Singapore Polytechnic
School of Electrical and Electronic Engineering

Experiment : **Lighting and Power Points Wiring**

Objectives : After carrying out the experiment, the students will be able to:

1) **Understand the technique of cutting, shaping and fixing PVC trunking for lighting and power points wiring**
2) **Acquire sufficient skills to wire up lighting and power points from the consumer unit.**
3) **Familiarise with tools and components used for wiring and the test procedures before energising.**

Components : PVC trunking
Flat file, handsaw and nails
Light switch
13A switched socket outlet
Lamp-holder
Single-core PVC cables
Consumer unit
Lamp bulbs

Test Equipment: Insulation /continuity tester
Ring main tester

Information :

PVC trunking is commonly used for surface wiring and can be conveniently altered or replaced without the hacking of walls as in the case of concealed wiring. PVC trunking give protection against mechanical damage of wires.

Lighting circuits are separated from power circuits because of the nature of loads. Socket outlets are provided as convenience to serve portable appliances. Each lamp or a number of lamps can be controlled from one or more switches. Each circuit is connected to a separate way in a consumer unit. Circuit wires i.e. the live, neutral and protective conductors belonging to the same circuit can be readily identifiable by labels in the consumer unit. This will make it safe and convenient to be able to identify the correct circuit conductors for testing.

Sharing a return neutral or protective conductor is prohibited. There must not be any jointing of wires between terminations unless special proprietary jointing materials are used and the joint is located in a junction box.

Procedures :

1. Study the general arrangement as shown in the LAYOUT DIAGRAM
2. Mark the position of the fittings and the routing of the PVC trunking on the wall or ceiling with chalk using dimensions given by the lecturer if it differs from the drawing. Check for squareness relative to both horizontal and vertical planes.
3. Before cutting off the PVC trunking, pay special attention to angles and tee joints. Allowance for the width of the trunking after a bend should be taken into consideration when marking off. Ensure that there is no interference for removal of the cover at any point.

4. The trunking and outlet boxes must be completely fixed before wires are run.
5. Run wires usually from outlet or the end point backwards, leaving sufficient length for final connections. When terminating, identify the *colour-codes* or markings on the outlet to ensure correct termination.

   Note: if the phase and neutral wires are not colour coded except the protective conductor, then connect the conductor to be identified temporarily at one end to the protective conductor and use a multimeter or the insulation tester/continuity tester to identify this wire at the other end. Repeat until all wires are identified. You can mark the identity of the wires by colour insulation tape.
6. Cut smaller pieces of the pvc cover to hold up wires along the route and carefully close up trunking. Cut off excess wires at the ends and complete terminations.

Testing

1. Continuity test can be conducted by shorting temporary the live to neutral conductors at the source end and verify using a continuity tester at the load end. Complete by shorting the neutral to earth connections and likewise verify at the load end. For lighting circuit, the lighting switch should be turned “on”. After the test, terminate the conductors to the appropriate terminals at the consumer unit according to the single line diagram.

   Note: For Edison screw lamp-holder, the continuity test would also proof that the live conductor is connected to the centre terminal and not to the screwed portion of the lamp-holder.

2. Using the insulation tester, check insulation resistance between phase conductor and neutral and between phase conductor and earth. Before the test, also check that all switches are closed, and no devices are connected to the outlets. The insulation resistance should exceed 0.5 MΩ

3. Place a lamp in the lamp-holder and energised the lighting circuit to ensure it is functioning correctly. Check toggle position of the light switch.

4. Check the polarity of the 13A socket outlet using a socket outlet tester.

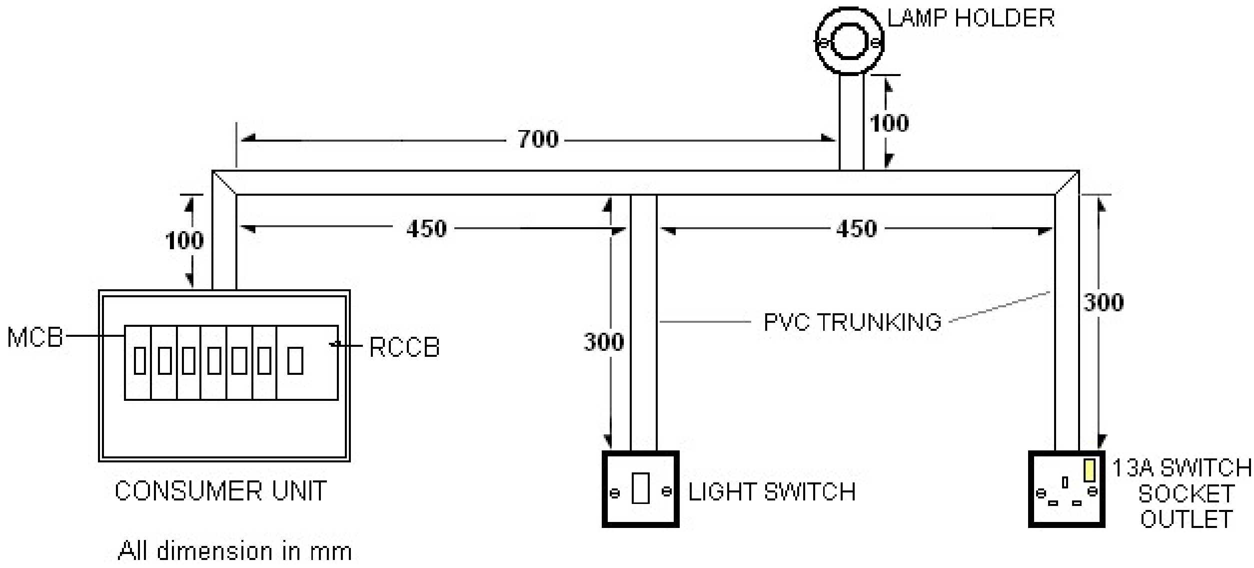
State the results of the Insulation Test below:

Live to Neutral _______________

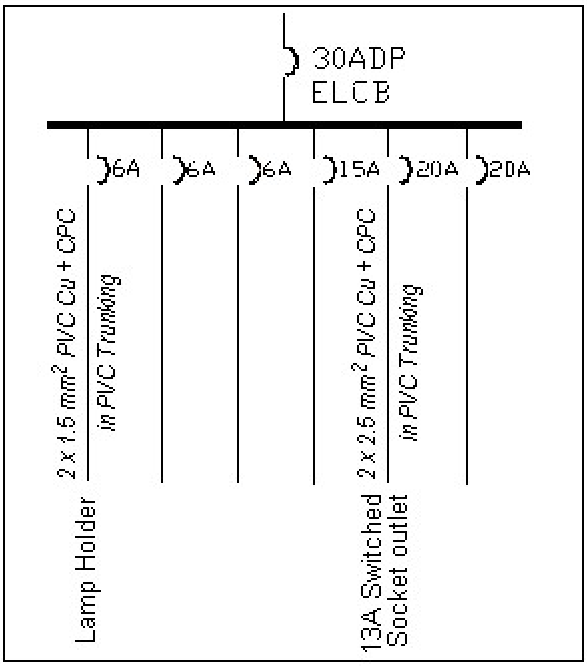
Live to Earth _______________

Neutral to Earth _______________

Polarity check of socket outlet: __________________



LAYOUT DIAGRAM



SINGLE LINE DIAGRAM

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Experiment : Industrial Controls using Relays/Timers

Objectives : After completing the hands-on, the students will be able to:

1) understand the operation of a relay/timer
2) identify relay/timer contacts (N.O. & N.C.) and coil terminals
3) read and interpret control schematics using timing circuits

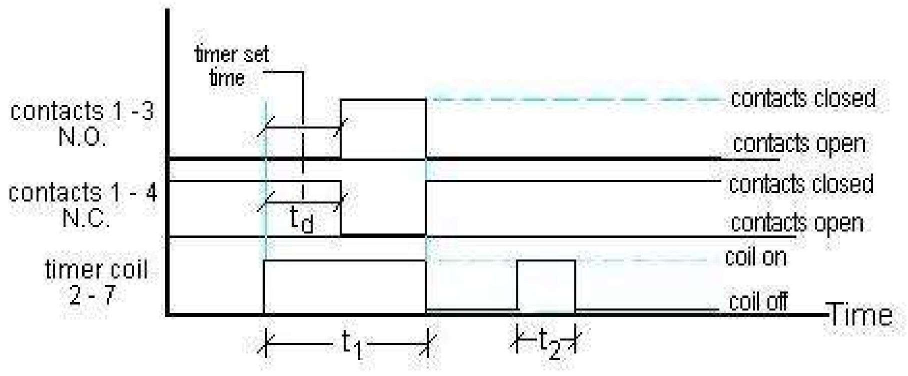
Components :

On-delay timer	Indicating lamps
Off-delay timer	N.C. pushbutton
N.O. pushbutton	General purpose control relay

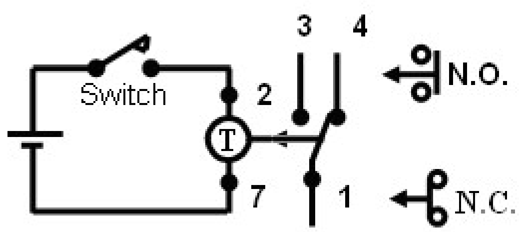
Information : Timers are commonly used for timing control for industrial processes, motor circuits and control systems where the control action is to be delayed for a predetermined period. There are two types of timers : the on-delay and the off delay timer. Volt free contacts are provided to relay the action of the timer. In the case of the on delay timer, the N.O. contacts are kept opened until the preset time expires i.e. from the moment of energisation of the timer. The N.C. contacts act in a similar manner i.e. timed open.

Off delay timer operates the contacts instantaneously upon energisation. However, a delay action takes place upon de-energisation of the timer.

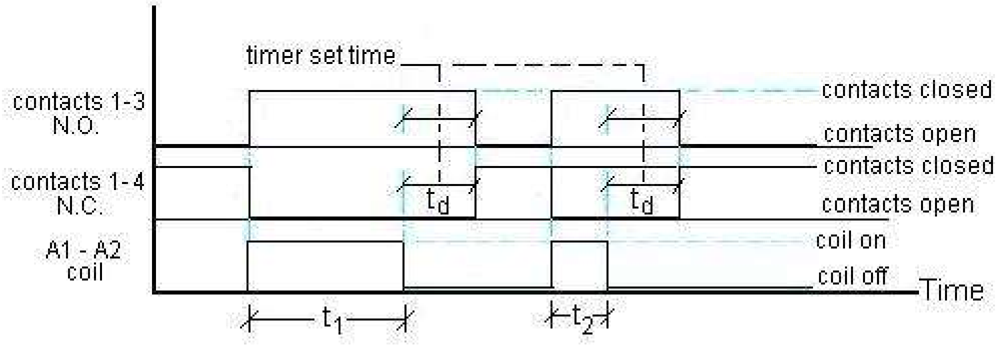
On-delay Timer – Timing Chart



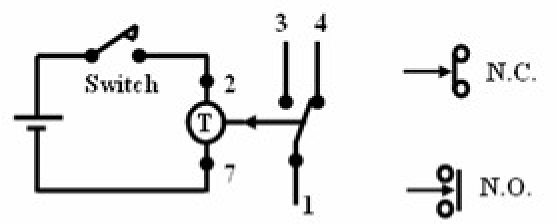
Timing diagram for on-delay timer



Off-delay Timer – Timing Chart



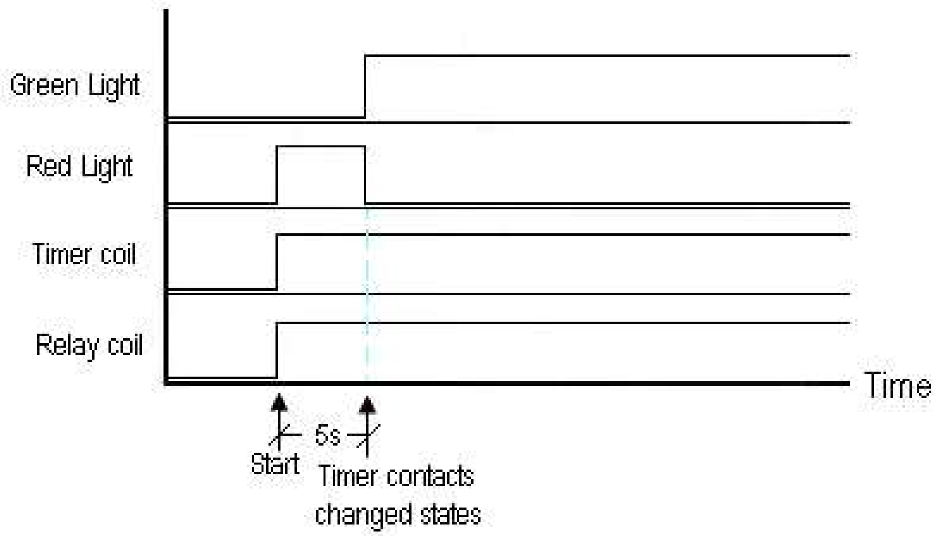
Timing diagram for off-delay timer



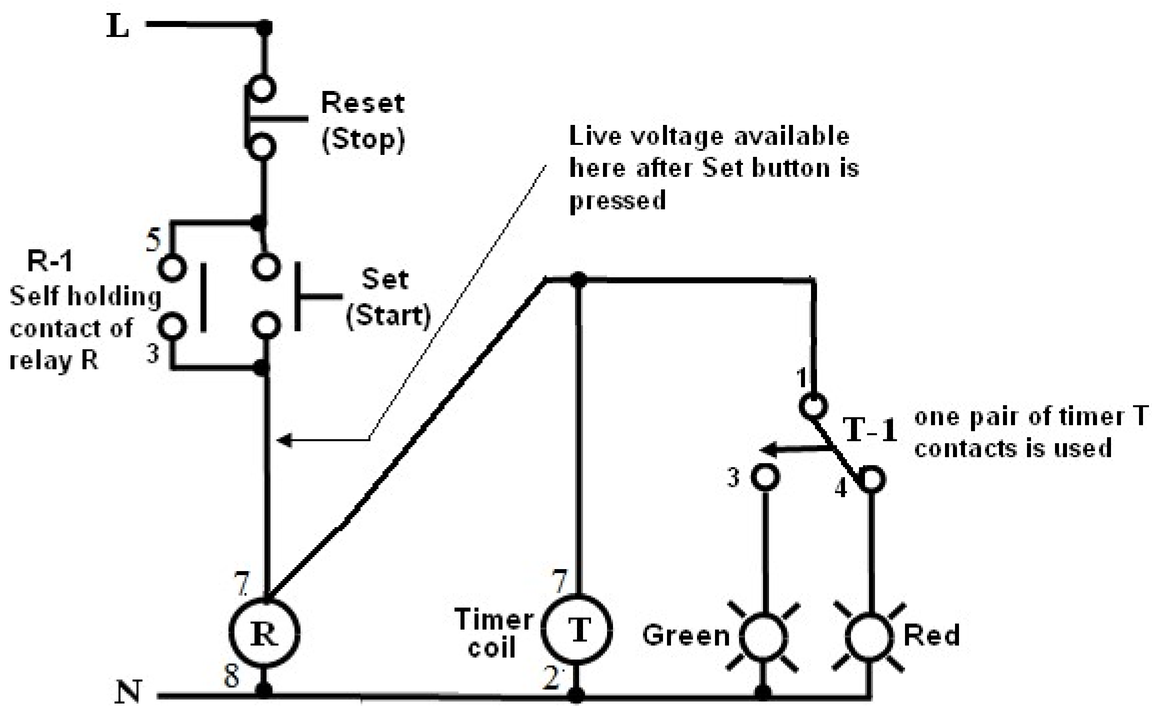
Characteristics of the on-delay and off-delay timers

Procedures :

1. Connect the wirings to components as per Circuit 1
2. Set the "on delay" timer to 5 sec
3. Switch on the electricity supply, press the Start pushbutton and observe the outputs of the timer shown by the status of the indicating lamps. Check its operation by timing the lights from the time of activating the pushbutton.
4. Switch off the supply and replace the "on delay timer" with the "off delay" timer
5. Set timer to 5 sec and switch on the supply
6. Operate the Start pushbutton and observe the timer operation
7. Operate the Stop pushbutton and observe the response of the indicating lights



Timing diagram for Circuit 1 (on-delay)

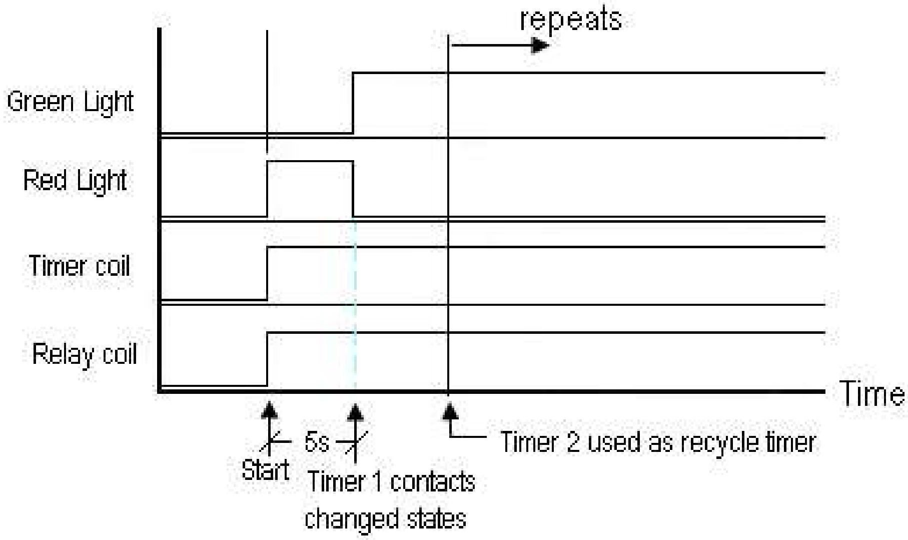


Circuit 1

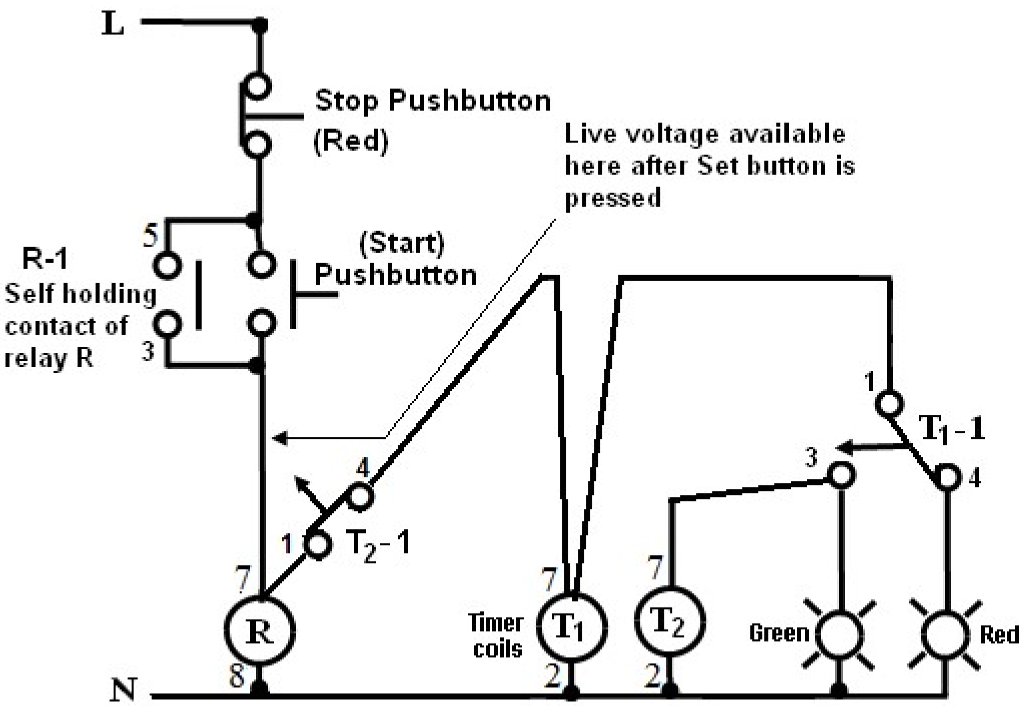
Flickering circuit with 2 on-delay timers

If Circuit 1 is to be modified such that the lights will cycle forever, another timer is required and is used as the *recycle timer*.

1. Connect Circuit 2 and verify its operation.



Timing diagram for Circuit 2



Circuit 2

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Experiment : **Full Voltage Motor Starter (Direct-On-Line Starter)**

Objectives : After completing the workshop, the students will be able to:

1) Translate the motor schematic diagram to actual wiring.
2) Know the component parts of a Full Voltage Starter.
3) Translate the working of a motor starter from the control circuit.
4) Carry out preliminary checks to ensure that the starter could be energised safely

Components: 3-pole main circuit breaker

3-pole contactor with add-on auxiliary contact blocks

1 No. N.O. pushbutton

1 No. N.C. pushbutton

Red and Green indicating lights

Thermal overload relay

Terminal blocks and mounting rail

Control Operation:

Turn on the supply to the panel by closing the main circuit breaker. The "*Stop*" (Red) indicating light is activated by the N.C. auxiliary contact M-2 of the contactor.

The motor starter, contactor M is energised by the *start* pushbutton.

N.O. auxiliary contact M-1 closes instantly and latches the control supply to the contactor.

N.O. auxiliary contact M-3 also closes the supply to the "*Run*" indicating light (green). The Motor runs when the contactor is energised.

Operating the "*Stop*" pushbutton trips the contactor. The supply to the motor is cut off and the status of the indicating lights reverts to the condition prior to starting.

The thermal overload relay can be manually activated to check for tripping function under overload condition.

Procedures :

With a multimeter (set function switch to a suitable Ohm range), carry out the preliminary checks to identify the terminals and the status of the contacts of the control devices. Insert the identification labels or terminal reference onto the schematic diagram to facilitate wiring.

Check that *the colour-coded wires are correct*. Each wire must be carefully stripped to sufficient length. Excessive stripping of insulation thereby exposing the bare conductor is incorrect. Wires must be secured firmly.

Ensure the interconnections between terminations are not excessively long and are run squarely on the panel. If your circuit has terminals with different colour wires terminating at the same point, then recheck the polarity of the circuit.

Testing:

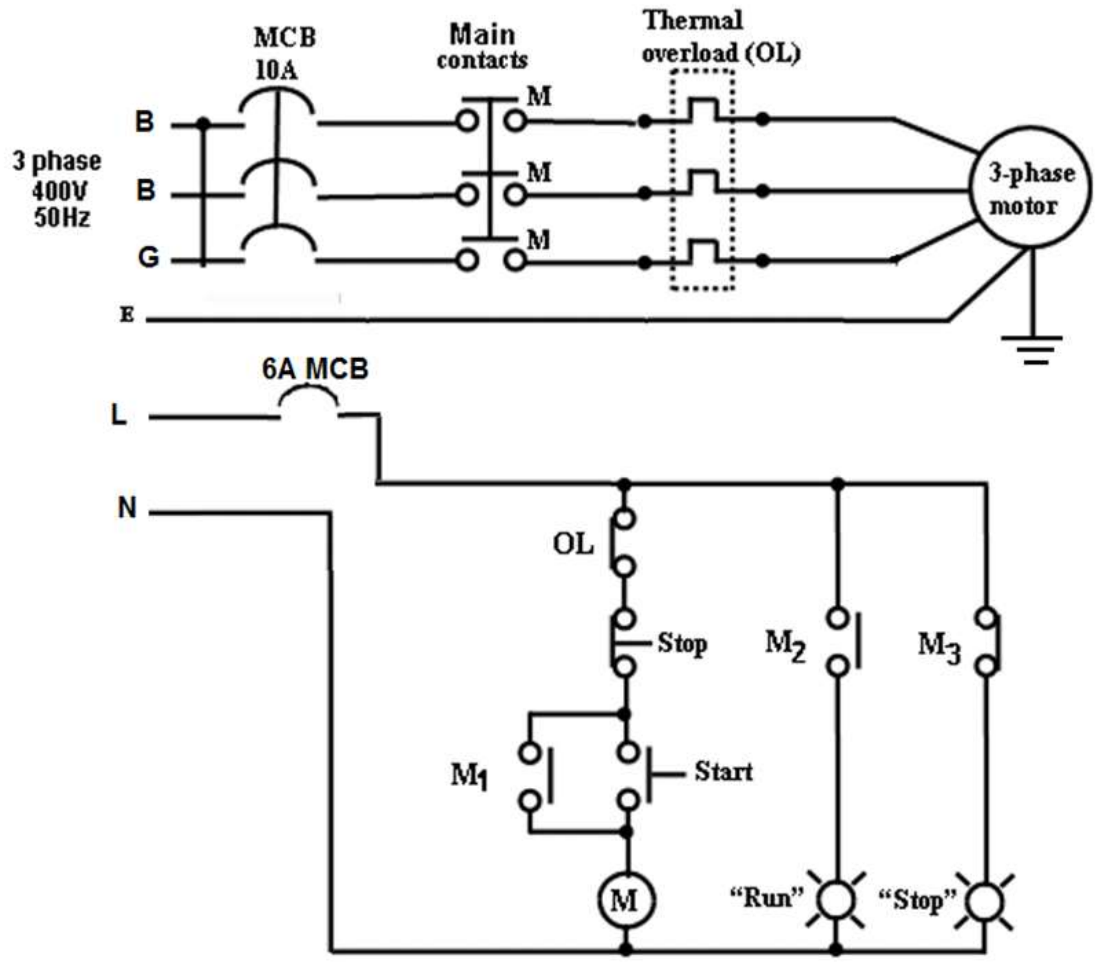
With the main circuit breaker in off position, and the meter set to measure low resistance, the impedance registered will be the impedance of the indicating light. Pressing the start button will reduce this resistance to include the impedance of the coil of the contactor. This can only confirm that there is no direct short circuit across the control supply.

To verify the continuity of the power circuit, manually close the main contacts by pressing on the armature lever of the contactor and then measure across the load side of the main circuit breaker and the terminals for the outgoing cables to the motor individually for each of the 3-phase.

After completing the non-energised testing, the circuit is ready for operation by the lecturer.

Possible failures

- Single phasing (also motor runs with a loud hum)
- Latching circuit not in because of wrong wiring
- If motor starts even without pressing the start button: check that the type of auxiliary contact and the type of pushbutton connected.
- If motor cannot stop: check that the latching circuit is not connected directly to the source i.e. before the stop button.



Singapore Polytechnic
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Experiment : Laboratory Test

Objectives :

(1) To assess students hands-on performance individually and to award test marks following the criteria given.
(2) To test students ability to translate the schematic diagram to actual wiring and to complete it within a given time.
(3) To allow students to apply what they have learned in the previous laboratory hands-on and build their confidence in circuit design and wirings.

Instructions :

(1) Each student will be assigned one set-up to carry out the hands-on individually
(2) Test duration is 1 hours and 40 minutes
(3) Assessment will be based on the Assessment Criteria given below
(4) All required tools will be provided
(5) Revise your previous hands-on prior to sitting for the test
(6) Lab teaching staff shall provide the necessary briefing to prepare students psychologically one or two weeks prior to the test

Assessment Criteria :

(1) Wiring Completion
- extend of circuit completion
- correct colour code of wirings
- correct and tightness of terminations
- connection to earth all exposed conductive parts

(2) Skill & Workmanship
- neatness/orderliness of wirings
- perform dry test before energising

(3) Function Test
- circuit operates successfully as designed
- test performance of overload relay

(4) Distinction Test
If operation is correct, answer the questions in the test paper for testing understanding.

Singapore Polytechnic
School of Electrical and Electronic Engineering

Experiment : **Testing and Measurement of Final Circuits**

Objectives : After carrying out the experiment, the students will be able to:
1) Know the procedures necessary for carrying out the various tests.
2) Know the use of various test instruments.
3) Understand the purpose of the various tests carried out on the electrical installation.

Information :

Every installation, on completion prior to being energized, shall be inspected and tested in accordance with the SS638. The purpose is to ensure that the installation works are properly carried out in compliance with the regulations and practices governing the safe operation and protection against hazards to persons or property and the proper functioning of the equipment.
The various tests to be performed are given in Part 7 and Appendix 6L of SS638:2018. The tests shall be carried out in the following sequence to verify the integrity of the installation.

1. Non-Energised Test

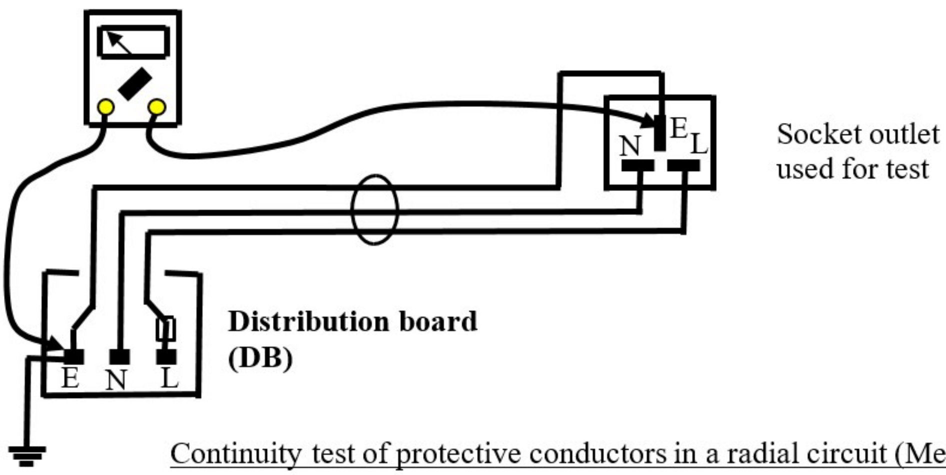
Testing Continuity of Protective Conductors

The continuity tester is being used for checking the continuity of the protective conductors.

Step 1: Connect one terminal of the continuity tester to a long test lead and connect this to the consumer's earth terminal.

Step 2: Connect the other terminal of the continuity tester to a short lead and use this to make contact with the protective conductor at various points on the installation, testing such items as switch boxes and socket outlets.

Connected Load	Protective Conductor (Ω) (Tick if continuity and record value)
(i) Fluorescent Lamp Circuit	
(ii) 13A Switched Socket Outlet (Radial)	
(iii) Instantaneous Water Heater	



Continuity test of protective conductors in a radial circuit (Method 1)

Ring Circuit Continuity Test

***The continuity tester is being used for checking the continuity of ring circuits*.**

Step 1: With the ring opened at its ends, measure resistances between ends of protective conductor, phase conductor and neutral conductor respectively, say A, B and C ohms.

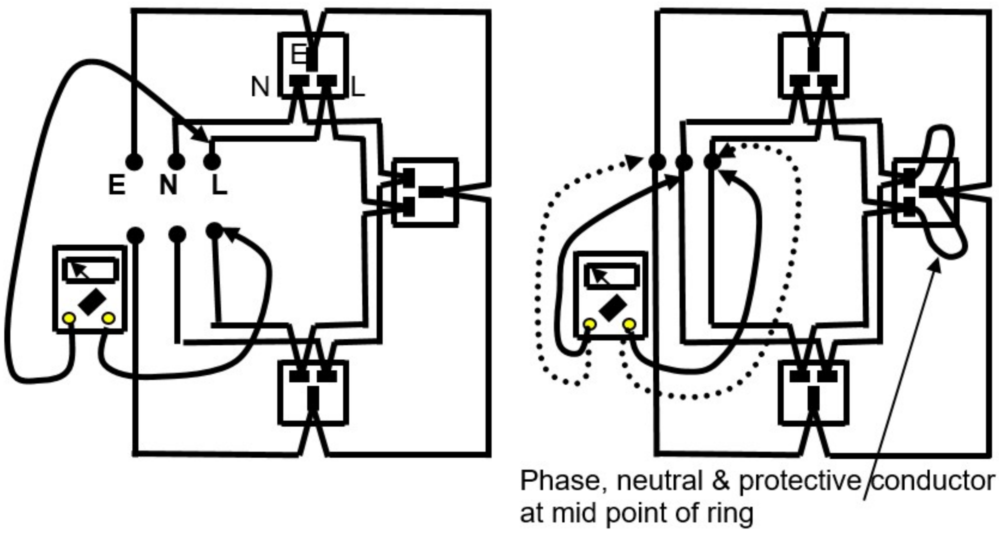
Step 2: Connect the ends of the ring, measure between phase and neutral with mid-point conductors short circuited and check that the resistance value is

$$\frac{B}{2}=\frac{C}{2}$$

Step 3: Measure between phase and protective conductor with mid-point short-circuited and check that the resistance value is:

$$\frac{A}{4}+\frac{B}{4}$$

Phase Conductor, R_P (Ω)	**B =**
Neutral Conductor, R_N (Ω)	***C* =**
Protective Conductor , R_{CPC} (Ω)	**A =**
Phase & Neutral Conductors R_{P-N} (Ω)	$\frac{B}{2}=\frac{C}{2}$
Phase & Protective Conductors R_{P-CPC} (Ω)	$\frac{A}{4}+\frac{B}{4}$

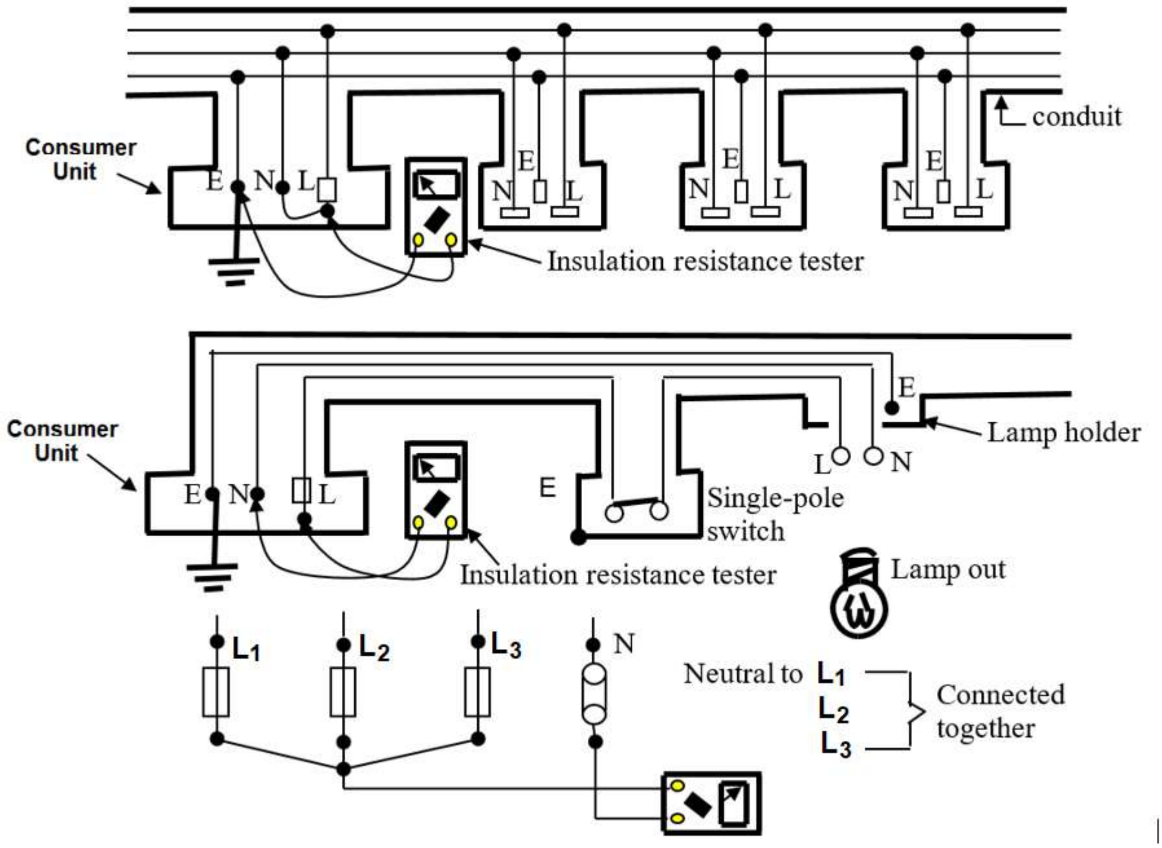


Step 1 ***Step 2 & 3 (shown by dotted line)***

Continuity test of ring circuit (Method 2)

Insulation Resistance Test

The insulation resistance test is carried out to prove the integrity of the insulating materials at each point in the installation. The minimum acceptable value of insulation resistance as per SS638:2018 is to be greater than **1.0 MΩ** between phase or between phases and earth. Failure of the insulation material and short circuits can be deduced from the readings.
Prior to carrying out the I.R Test, ensure that *all fuses shall be in, switches and circuit breakers closed, where practicable, any lamps removed*, appliances and fixed equipment disconnected.



Insulation Resistance Test Results

Circuit No.	Connected Load	Between Conductors L1-L2, L1-L3, L2-L3 or L1L2L3-N		All Conductors to Earth L1,L2,L3 & N-E	
L1S1	Fluorescent Lamp	L1-N	MΩ	L1-E	MΩ
L2S1	Filament Lamp	L2-N	MΩ	L2-E	MΩ
L1P2	Ring 13A S.S.O	L1-N	MΩ	L1-E	MΩ
L3P2	Radial 13A S.S.O	L3-N	MΩ	L3-E	MΩ
L1P3	15A S.S.O	L1-N	MΩ	L1-E	MΩ
L2P3	3kw Water Heater	L2-N	MΩ	L2-E	MΩ
L1L2L3P1	3-phase Isolator & Terminal Box	L1L2L3-N	MΩ	L1-E	MΩ
		L2L3N-L1	MΩ	L2-E	MΩ
		L1L3N-L2 L1L3N-L2	MΩ MΩ	L3-E N-E	MΩ MΩ

2. Energised Test (or Live Test)

Instruction : Energised test is to be conducted by teaching staff by way of demonstration. These energised tests should only be performed on the designated energised test panel).

As a measure to protect against indirect contact by earthed equipotential bonding and automatic disconnection of supply (SS638:2018 413.1 & 413.3), the earth loop impedance at every *socket outlet* is such that the disconnection time occurs within *0.4s*

The maximum value of earth loop impedance Z_S can be measured using an earth loop impedance tester at the furthest point of socket outlet circuits. The value of this impedance is compared with the permissible value of the impedance based on SS638:2018 Table 41.3L.

Table 41.3L Maximum Earth Fault Loop Impedance (Z_S) for Socket Outlet and Fixed Equipment.

Type B Miniature Circuit Breaker

Rating (amperes)	6	10	16	20	32	40	50	63	100	I_N
Z_S (ohms)	7.67	4.6	2.87	2.3	1.44	1.15	0.92	0.73	0.46	$\frac{46}{(I_N)}$

RCCB Test

1. Energise the single-phase supply to the Small Electrical Installation Panel.
2. With the supply switch on, press the test button on the RCCB. If the device does not trip, carry out check to rectify the problem before proceeding.
3. Using the RCCB test instrument plugged into one of the socket outlets, carry out the test as per table requirements.

Test Current	**Trip Time (Actual)**	**Max Allowable Trip Time**
15 mA (x ½ of $I_{\Delta N}$)		RCD should not trip
30 mA (x 1 of $I_{\Delta N}$)		100 ms
150 mA (x 5 of $I_{\Delta N}$)		40 ms

Prospective Short-circuit Current Test

The prospective short-circuit current at a particular point in an electrical installation is calculated to include all impedances upstream from that point and the short-circuit is of negligible impedance. The total impedance at the point of fault will depend on the size and length of the conductor from the source. The value of the prospective short-circuit current will fall as the fault is further away from the source. On the other hand, the value will be greater if the point of fault is closer to the protective device or source.

$$I_{PSC} = \frac{V_s}{Z_T}$$

Singapore Polytechnic
School of Electrical and Electronic Engineering

Experiment : Testing and Troubleshooting of Final Circuits

Objectives : After carrying out the experiment, the students will be able to:

1) Approach an electrical problem systematically to isolate the cause of the malfunction and determine the proper procedure to correct it.
2) Learn the use of various test instruments.
3) Acquire the necessary knowledge and skill in electrical troubleshooting.
4) Develop a sense of safety consciousness in doing electrical testing/repair/maintenance works.

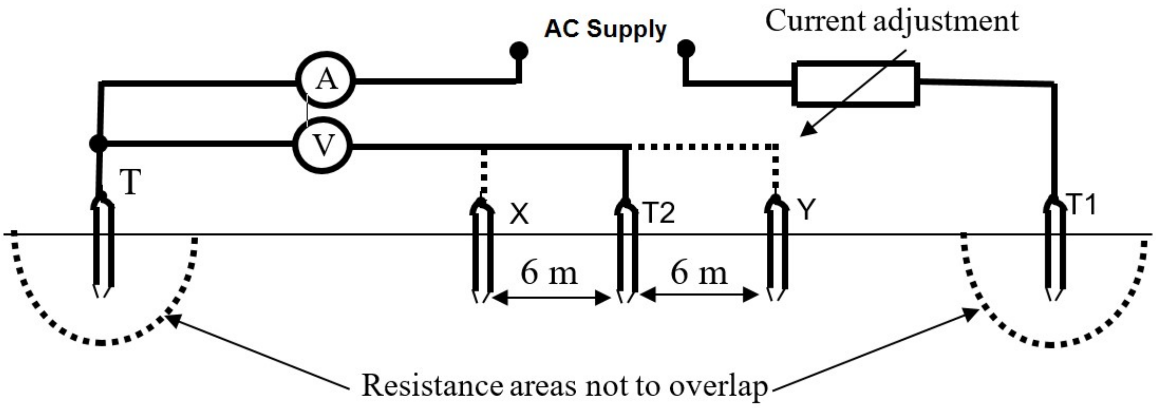
Information :

Troubleshooting is the process of first identifying the cause of an electrical malfunction and then fixing the faulty circuit/component so that the malfunction is removed.
Taking a simple example; when a new bulb is used and it does not light up, it cannot be assumed that something must be wrong with the existing circuit and that the new bulb is good. Try another bulb known to be in working order to confirm the bulb is good and the existing circuit is faulty. Sometimes, it can be the problem, as in the case of Edison screw-type incandescent lamp, of the centre contact is pushed too far down to cause open circuit in the electrical supply to the lamp.

Earth Electrode Resistance Test

The test is carried out to measure the resistance of the electrode buried in the ground. The "fall of potential method" is used for small electrode system consisting of one or two rods or plates. In this method, the current spike is driven into the ground some 30m away from the earth electrode under test to ensure that the resistance area does not overlap. The potential spike is driven mid-way in direct line with them. The tester is then operated, and the reading taken.

Two further readings are to be taken by repositioning the potential spike 6m on each side from the mid-point. The ***average resistance would be $R_a = (R_1+R_2+R_3)/3$.*** The maximum deviation of either R_1, R_2 or R_3 from the average is $\Delta R/R_a \times 100\%$. If the value of the percentage deviation approaches 10% , it implies that the earth resistance curve is more of a straight line with the positive slope rather than the horizontal plateau. The tests have to be repeated with greater distance to the current spike.



Non-energised Troubleshooting

Insulation Resistance Fault Finding

The insulation resistance test is carried out to prove the integrity of the insulating materials at each point in the installation. The minimum acceptable value of insulation resistance as per SS638:2018 is to be greater than **1.0 MΩ** between phase or between phases and earth. Failure of the insulation material and short circuits can be deduced from the readings.

1. The final circuits for I.R measurement are identified as per table below
2. Turn on all circuit breakers, switches, isolator, etc and remove lamps
3. Using the I.R. tester, measure at the consumer terminal and record low I.R. values in Table 1 – Summary of Non-compliant Test Results.

Circuit No.	**Connected Load**	**Between Conductors L_1-L_2, L_1-L_3, L_2-L_3 or $L_1L_2L_3$-N**	**All Conductors to Earth L_1,L_2,L_3, & N-E**
L1S1	Fluorescent Lamp	**L_1**-N	L_1-E
L2S1	Filament Lamp	**L_2**-N	L_2-E
L3P2	Radial 13A S.S.O	**L_3**-N	L_3-E
P3L_1 L_2 L_3	3-phase Isolator & Terminal Box	**$L_1L_2L_3$-N**, **L_1-L_2**, **L_1-L_3**, & **L_2-L_3**	**$L_1L_2L_3$,N** - E

Radial and Ring Fault Simulation

The possible faults on the 13A socket outlet are as follows:

(i) L & N reverse
(ii) L & E reverse
(iii) N & E reverse
(iv) L, N & E open-circuit
(v) L & N short-circuited
(vi) L & E short-circuited
(v) N & E short-circuited
(vii) L, N & E short-circuited

Using a continuity meter, check for the possible faults for all the socket outlets in the radial and ring final circuits. Record the abnormalities in Table 1 – Summary of Non-compliant Test Results.

Name: ________________________________ Class Group: ______________

________________________________ Date:

Panel No : 6A (FOR EXAMPLE.)

Table 1 – Summary of Circuit Fault/Non-compliant Results

Circuit No.	**Connected Load**	Remarks (Record low I.R. value/Radial & Ring Faults/Lamp Polarity Faults)
L1S1	Fluorescent light	
L2P2	Cooker control Unit with 13A S/S/O	

Example of Result Tabulation
Table 1 – Summary of Non-compliant Test Results

Circuit No.	**Connected Load**	Remarks (Record low I.R. value/Radial & Ring Faults/Lamp Polarity Faults)
L1S1	Fluorescent light	E open
L3P2	4 Nos S/S/Os (Radial cct)	L, N reverse
L1P3	1 no 15A S/S/O	N open
L2P3	Instantaneous Water Heater	No fault

Engineering @ SP

The School of Electrical & Electronic Engineering at Singapore Polytechnic offers the following full-time courses.

1. Diploma in Aerospace Electronics (DASE)

The Diploma in Aerospace Electronics course aims to provide students with a broad-based engineering curriculum to effectively support a wide spectrum of aircraft maintenance repair and overhaul work in the aerospace industry and also to prepare them for further studies with advanced standing in local and overseas universities.

2. Diploma in Computer Engineering (DCPE)

This diploma aims to train technologists who can design, develop, setup and maintain computer systems; and develop software solutions. Students can choose to specialise in two areas of Computer Engineering & Infocomm Technology, which include Computer Applications, Smart City Technologies (IoT, Data Analytics), Cyber Security, and Cloud Computing.

3. Diploma in Electrical & Electronic Engineering (DEEE)

This diploma offers a full range of modules in the electrical and electronic engineering spectrum. Students can choose one of the six available specialisations (Biomedical, Communication, Microelectronics, Power, Rapid Transit Technology and Robotics & Control) for their final year.

4. Diploma in Energy Systems & Management (DESM)*

The Diploma in Energy Systems & Management course aims to equip students with the knowledge and expertise in three specialisations: clean energy, power engineering and energy management, so as to design clean and energy efficient systems that will contribute to an economically and environmentally sustainable future.

5. Diploma in Engineering Systems (DES)*

The Diploma in Engineering Systems course aims to provide students with a broad-based engineering education to support activities and future challenges requiring interdisciplinary engineering systems capabilities. The course leverages on the experience and expertise of two schools, namely the School of Electrical & Electronic Engineering and the School of Mechanical & Aeronautical Engineering.

6. Diploma in Engineering with Business (DEB)

Diploma in Engineering with Business provides students with the requisite knowledge and skills in engineering principles, technologies, and business fundamentals, supported by a strong grounding in mathematics and communication skills, which is greatly valued in the rapidly changing industrial and commercial environment.

7. Common Engineering Program (DCEP)

In Common Engineering Program, students will get a flavour of electrical, electronics and mechanical engineering in the first semester of their study. They will then choose one of the 8 engineering courses specially selected from the Schools of Electrical & Electronic Engineering and Mechanical & Aeronautical Engineering.

*Course is applicable only for AY2018 intake and earlier

School of Electrical & Electronic Engineering

More than **60** Years of solid foundation	**8 Tech Hubs**	Unique **PTN** Scheme	**SP-NUS SP-SUTD** Programmes	More than **35,000+** Alumni

SINGAPORE POLYTECHNIC SP

Electives offered by SP SCHOOL OF ELECTRICAL & ELECTRONIC ENGINEERING

All SP students, including EEE students are free to choose electives offered by ANY SP schools, subject to meeting the eligibility criteria.

Like all schools, School of Electrical and Electronic Engineering offers electives for:

- EEE students only
- *and* for all SP students

EEE students are required to complete 3 electives, starting from Year 2 to Year 3 (one elective per semester).

Electives Choices for All SP students

Mod Code	Module Title
EP0400	Unmanned Aircraft Flying and Drone Technologies
EP0401	Python Programming for IoT*
EP0402	Fundamentals of IoT*
EP0403	Creating an IoT Project*
EP0404	AWS Cloud Foundations
EP0405	AWS Academy Cloud Architecture
EP0406	Fundamentals of Intelligent Digital Solutions
EP0407	Technology to Business

Certificate in IoT (Internet of Things)

*** A certificate in IoT would be awarded if a student completes the 3 modules: EP0401, EP0402 and EP0403**

Electives Choices for EEE students

Mod Code	Module Title
EM0400	Commercial Pilot Theory
EM0401	Autonomous Electric Vehicle Design
EM0402	Artificial Intelligence for Driverless Cars
EM0403	Autonomous Mobile Robots
EM0404	Smart Sensors and Actuators
EM0405	Digital Manufacturing Technology
EM0406	Linux Essential
EM0407	Advanced Linux
EM0408	Linux System Administration
EM0409	Rapid Transit System
EM0410	Rapid Transit Signalling System
EM0412	Data Analytics
EM0413	Mobile App Development
EM0414	Client - Server App Development
EM0415	Machine Learning & Artificial Intelligence
EM0416	Solar Photovoltaic System Design
EM0417	Energy Management and Auditing
EM0418	Integrated Building Energy Management System
EM0419	Digital Solutioning Skills
EM0423	Independent Study 1