Building Electrical Installation

Level-III

Based on October 2023, Curriculum Version II

Module Title: General Low Voltage Electrical Installations Cable and wire section

Module code: EIS BEI3 M02 1023

Nominal duration: 72Hour

Prepared by: Ministry of Labor and Skill

October, 2023

Addis Ababa, Ethiopia

Table of Contents

Acknowledgment

Ministry of Labor and Skills wish to extend thanks and appreciation to the many representatives of TVET instructors and respective industry experts who donated their time and expertise to the development of this Teaching, Training and Learning Materials (TTLM).

Acronym

LV -- Low Voltage

MV -- Medium Voltage

HV -- High Voltage

MLVS -- Main LV switchboard

PVC --- Polyvinyl-Chloride

XLPE --- Cross-Linked Polyethylene

RCD --- Residual Current Device

MCB -- Miniature Circuit Breakers

MCC -- Motor Control Centers

EPR-- Ethylene Propylene Rubber

NEC --- National Electrical Code

NM-B Cable-------------------------------------- Nonmetallic-sheathed cable

BX cable -- Armored cable

NFPA-- National Fire Protection Association

Introduction to the Module

In Building Electrical installation filed provides selecting wiring systems and cables for electrical installations operating at voltages. It encompasses knowledge and application of wiring systems and cable types, selecting wiring system compatible with the installation conditions, selecting cables that comply with required current-carrying capacity and voltage drop and earth fault-loop impedance limitations, coordination between protective devices and conductors and documenting selection decisions

This module is designed to meet the industry requirement under the Building Electrical Installation occupational standard, particularly for the unit of competency: **Selection of Wiring Systems and Cables for Low Voltage General Electrical Installations.**

This module covers the units:

- Basic concept of wiring systems and cables selection
- wiring systems and cables Selection for general electrical installations
- Electrical Installation Documentation

Learning Objective of the Module

- Identify and understand Basic concept of wiring systems and cables selection
- Select wiring systems and cables for general electrical installations
- Document & Report Electrical Installation

Module Instruction

For effective use this modules trainees are expected to follow the following module instruction:

- Read the information written in each unit
- Accomplish the Self-checks at the end of each unit
- Perform Operation Sheets which were provided at the end of units
- Do the "LAP test" giver at the end of each unit and
- Read the identified reference book for Examples and exercise

Unit One: Basic Concept of Wiring Systems and Cables Selection

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- safety and other regulatory requirements
- standard and cod of practice
- Factors that affects cable and wire selection
- Nature of electrical installation
- the route lengths of cables

This unit will also assist you to attain the learning outcomes stated in above unit. Specifically, upon completion of this learning guide, you will be able to:

- Identify and understand safety and other regulatory requirements
- Use standard and cod of practice
- Check Factors that affects cable and wire selection
- Identify Nature of electrical installation
- Understand the route lengths of cables

1.1 Safety and Regulation for Electrical Installation

1.1.1 Basic concept of wiring systems

A wiring system is a network of electrical conductors and associated hardware that connects electrical components to each other and to a power source. Wiring systems are used in a wide variety of applications, including homes, businesses, industrial facilities, and transportation vehicles.

The most basic wiring system is a single circuit, which consists of two conductors: a hot conductor and a neutral conductor. The hot conductor carries the electrical current from the power source to the load, and the neutral conductor carries the current back to the power source.

More complex wiring systems may consist of multiple circuits, each with its own hot conductor and neutral conductor. These circuits may be connected to a single power source, or they may be connected to multiple power sources.

1.1.2 Safety and other regulatory requirements When designing and installing a wiring system, it is important to follow all applicable safety and regulatory requirements. These requirements are designed to protect people and property from electrical hazards.

Some of the most important safety and regulatory requirements for wiring systems include:

- **Using the correct type of cable for the application:** The cable must be suitable for the type of environment in which it will be used and the type of load that it will be connected to.
- **Installing the cable properly:** The cable must be installed in a way that protects it from physical damage and prevents it from overheating.
- **Using the correct circuit breakers and fuses***:* Circuit breakers and fuses are designed to protect the wiring system from overcurrent conditions. It is important to use the correct type and size of circuit breaker or fuse for each circuit.
- **Having the wiring system inspected by a qualified electrician**: Once the wiring system is installed, it is important to have it inspected by a qualified electrician to ensure that it complies with all applicable safety and regulatory requirements.

1.1.3 Harmful Effects Against Electrical Installation Must Provide Protection

The design of an electrical installation must provide protection against various harmful effects to ensure the safety of people, property, and the electrical system itself. Some of the key harmful effects that need to be considered in the design include:

- **Electric shock:** Electrical installations must protect against electric shock, which occurs when a person comes into contact with energized parts. This can lead to serious injury or even death. Adequate insulation, grounding, and the use of residual current devices (RCDs) or ground fault circuit interrupters (GFCIs) are essential for preventing electric shock.
- **Fire hazards**: Electrical installations can pose a fire hazard due to factors such as overloaded circuits, short circuits, faulty wiring, or overheating equipment. The design should incorporate measures to prevent overloading, proper circuit protection devices like circuit breakers or fuses, and the use of fire-resistant materials.
- **Electrical burns**: Contact with high temperatures or electric arcs can cause burns. Protective measures, such as the use of proper electrical enclosures, insulation, and the selection of equipment with appropriate thermal ratings, should be included in the design to minimize the risk of electrical burns.
- **Electrical fires:** Faulty electrical installations can lead to electrical fires, which can cause extensive damage to property and endanger lives. The design should consider fire-resistant materials, adequate circuit protection, proper wire sizing, and the use of arc-fault circuit interrupters (AFCIs) or other advanced fire detection and suppression systems.
- **Overvoltage and power surges:** Voltage spikes or surges can damage electrical equipment and disrupt the normal functioning of electronic devices. Protection measures, such as surge protectors, voltage regulators, and transient voltage surge suppressors (TVSS), should be incorporated into the design to safeguard against overvoltage events.

These are some of the harmful effects that need to be addressed when designing an electrical installation. It is important to comply with relevant electrical codes, standards, and regulations to ensure a safe and reliable electrical system. Consulting with qualified electrical engineers or professionals is highly recommended for proper design and implementation.

1.1.4 Need for protection against injury from mechanical movement

Protection against injury from mechanical movement is essential in various industries and everyday activities. The potential risks associated with mechanical movement can lead to severe injuries, such as cuts, abrasions, crush injuries, fractures, and even amputations. Therefore, implementing appropriate protection measures is crucial to ensure the safety and well-being of individuals. Here are some common examples of protection against injury from mechanical movement:

- ✓ **Personal Protective Equipment (PPE)**
- ✓ **Machine Guards:**
- ✓ **Safety Interlocks:**
- ✓ **Training and Awareness:**

It's important to note that the specific protection measures required will depend on the type of machinery, industry, and applicable regulations. Consulting relevant safety guidelines and regulations is crucial to ensure comprehensive protection against injury from mechanical movement in specific contexts

- **UNDERSTANDING LOW VOLTAGE SUPPLY SYSTEM**

LV, MV, and HV stand for Low Voltage, Medium Voltage, and High Voltage, respectively.

- **Low Voltage (LV)** is a voltage range between 50 V and 1 kV. LV is used in most residential and commercial buildings, as well as in many industrial applications.
- **Medium Voltage (MV)** is a voltage range between 1 kV and 52 kV. MV is used in transmission and distribution of electricity, as well as in some industrial applications.
- **High Voltage (HV)** is a voltage range above 52 kV. HV is used in transmission and distribution of electricity, as well as in some industrial applications.

The following table summarizes the voltage ranges for LV, MV, and HV:

Voltage range	Voltage classification
50 V to 1 kV	Low Voltage (LV)
1 kV to 52 kV	Medium Voltage (MV)
Above 52 kV	High Voltage (HV)

Table 1 the voltage ranges for LV, MV, and HV

It is important to note that these are just general guidelines. The specific voltage ranges for LV, MV, and HV may vary depending on the country or region.LV, MV, and HV equipment are designed to operate at different voltage levels. It is important to use the correct type of equipment for the specific application.

- *For example, LV equipment should not be used in MV or HV applications, as this could be dangerous.*

- **LV, MV, and HV equipment:**
  - ✓ LV equipment: Lighting fixtures, appliances, power outlets, circuit breakers, fuses
  - ✓ MV equipment: Transformers, switchgear, circuit breakers, fuses, cables
  - ✓ HV equipment: Transformers, transmission lines, power substations

- **SUPPLY SYSTEM**
  - **Electricity Supply Specifications**

Electricity supply for domestic consumers, according to MS IEC 60038 standards, meets the following specifications: -

- ✓ Single phase supply with nominal voltage of 220V, range ±10%
- ✓ Three phase supply with nominal voltage of 380V, range ±10%
- ✓ Permitted frequency is 50 ±2.5%;

- An electric **power system** is a network of **electrical** components deployed to **supply**, transfer, and use electric **power**. The majority of these **systems** rely upon three-phase AC **power**. the standard for large-scale **power** transmission and **distribution** across the modern world.
- **In direct current (DC),** the electric charge (**current**) only flows in one direction.

Electric charge in alternating **current** (**AC**), on the other hand, changes direction periodically. The voltage in **AC** circuits also periodically reverses because the **current** changes direction.

1.2 Standard and cod of Practice

✓ **Standard is** a document that provides requirements, specifications, guidelines, or characteristics that can be used consistently as rules, conditions, or definitions to ensure that materials, products, processes, and services are fit for their purpose. Standards are developed by a variety of organizations, including governments, industry associations, and professional societies. They may be voluntary or mandatory.

Voluntary standards are adopted by organizations on a voluntary basis. Mandatory standards are required by law or regulation.

- ✓ **Code of Practice**

A code of practice is a document that provides guidance on how to comply with a standard. It may include specific procedures, methods, or examples. Codes of practice are often developed by the same organizations that develop standards.

Codes of practice are not legally enforceable, but they are widely used by organizations to demonstrate compliance with standards. They can also be used to train employees and to provide guidance to suppliers and contractors.

- ✓ **Relationship between Standards and Codes of Practice**

Standards and codes of practice are complementary documents. Standards provide the requirements that must be met, while codes of practice provide guidance on how to meet those requirements.

Standards are typically developed by technical experts, while codes of practice are often developed in consultation with a wider range of stakeholders, such as industry representatives, government officials, and consumers. This helps to ensure that codes of practice are practical and achievable.

Examples

Some examples of standards and codes of practice include:

- ISO 9001:2015: Quality management systems
- ISO 14001:2015: Environmental management systems
- OHSAS 18001:2007: Occupational health and safety management systems
- HIPAA: Health Insurance Portability and Accountability Act (United States)
- PCI DSS: Payment Card Industry Data Security Standard

These are just a few examples. There are many other standards and codes of practice that have been developed for a wide range of industries and activities.

Standards and codes of practice are important tools for improving the safety, quality, efficiency, and interoperability of products, processes, and services. They can also help to reduce costs and promote trade.

1.3. Factors that affects cable and wire selection

- ✓ **5 Key Factors in Choosing the Right Cable Size**

This unit principle in choosing the right cable size is how well your cable can carry the required current load in your installation environment without causing excessive voltage drop from your supply voltage. Once you know the load the cable will carry (Ampere), here are some conditions that would affect the ultimate cable size you choose. Going through the considerations below may bring you to different recommended conductor sizes. The key is that the minimum conductor size you select must at least be the minimum allowable cable size that can cover all the conditions you have looked into.

With that in mind, here are five questions we would typically ask:

- ✓ How are you planning to install these cables?
- ✓ What cable construction are you considering for the cables?
- ✓ What is your cable length?
- ✓ What is your ambient temperature?
- ✓ How many circuits will you be placing together?

1. Installation Method

This is the first thing we look at because how and where the cable will be installed directly affects whether a cable could be overloaded (e.g. in conduit, on cable tray, in free air, grouping, spacing, trefoil, laid flat).

2. Cable Material

Cable insulation material (the extruded layer after the conductor) is important in cable sizing because it directly affects your cable's maximum operating temperature. For your reference, we have placed common insulation materials: PVC, XLPE, and EPR in the guide.

In standard cable materials,

- ✓ PVC has a maximum operating temperature of 70˚C,
- ✓ XLPE 90 ˚C
- ✓ EPR 90 ˚C.

You may wonder why, for instance, we would choose PVC vs XLPE, given the lower maximum operating temperature for PVC. This relates to other material properties that work better in your installation environment.

- ✓ For instance, **PVC is much more flexible than XLPE** and may be a better choice where you would require the cable to **bend in tighter spaces.**

You may also choose between single-core or multi-core cables depending on the installation requirement, which would also affect the current carrying capacity of the cable.

- ✓ A **single-core cable** would be ***able to dissipate heat better*** than a multi-core cable and hence would ***have a higher current carrying capacity***.
- ✓ However, you may still choose the ***multi-core cable*** as installing the required conductors at **go *could be easier.***

3. Cable Length

We require cable length to assess Voltage Drop, which is the loss of electrical potential along your cable run. In Ethiopia, we follow the EBCS wiring regulations, where the ***voltage drop of a cable run must not exceed 4%.***

- ✓ For example, if a supply voltage is 415V, then the maximum acceptable voltage drop cannot exceed 4% of 415V = 16.6V
- ✓ if a supply voltage is 380=15.2V
- ✓ if a supply voltage is 220V=8.8V

The cable size and length of a cable line mainly determine the voltage drop of a circuit. The smaller the cable size or, the longer the cable length required for your circuit, the greater the voltage loss. If you find that the voltage drop of the circuit has exceeded the 4% stated, you would need to upsize your cable.

4. Ambient Temperature

Our tables assume a standard ***ambient temperature of 30˚C*** in free air or a ***ground temperature of 15˚C*** with a depth of 0.5m. Do note that cable routing and ventilation will directly affect your ambient temperature, so it is important to consider the installation condition along the entire length of the cable laid. If there is a deviation from the standard temperature, you must apply a correction factor to the current load your cable is expected to carry. The higher your ambient temperature from the standard, the larger your cable size may be needed to carry the required load.

5. Number of circuits

Our tables assume that you are laying one circuit single-phase or three-phase. If you intend to group circuits in your installation, it is crucial to apply a cable grouping correction factor so that you select the appropriate cable size that would prevent overheating issues. The more circuits you intend to group, the harder the heat dissipation; hence you may need to upsize the cables accordingly.

We hope this article has given you a general idea of some key factors to consider when determining the minimum allowable cable size. To reiterate, you may choose the minimum economic size to cover all the conditions you have looked into to ensure the cable does not get overloaded. To help with your cable size estimates, please reach out to our Sales team, who can take you through a step-by-step example and include cable sizing tables for your calculations.

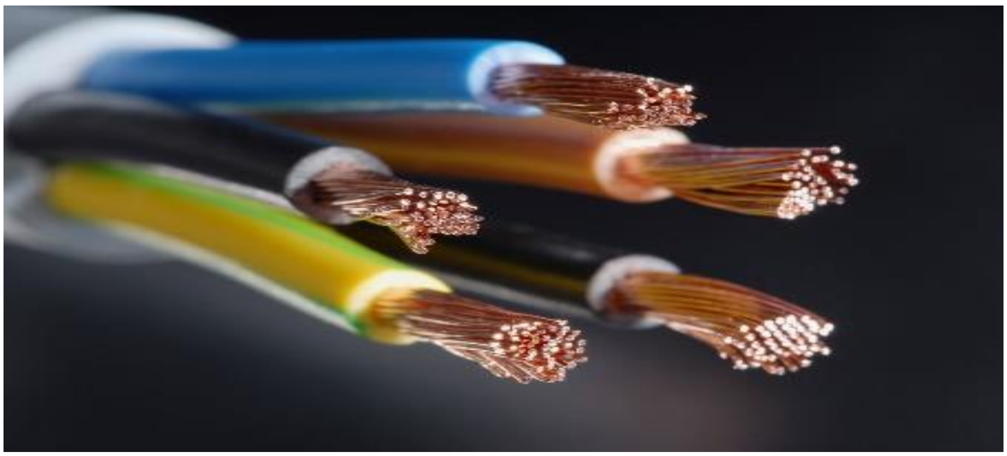


Figure 1.1: cables and wires

1.4. Nature of electrical installation

The extent and nature of the electrical installation is determined from the job specifications. The job specifications should describe the following:

- ✓ The type of installation (domestic, commercial, industrial)
- ✓ The size and type of building
- ✓ The number and type of electrical loads
- ✓ The environmental conditions
- ✓ The required level of protection

The job specifications should also include any specific requirements, such as the need for compliance with certain codes or standards.

Once the job specifications have been reviewed, the electrical engineer or electrician can develop a design for the electrical installation.

The design should include the following:

- ✓ The layout of the electrical circuits
- ✓ The type and size of wiring
- ✓ The location of all electrical outlets, switches, and fixtures
- ✓ The type and size of overcurrent protection devices
- ✓ The type and size of earthing system

The design should be approved by the client before any work is started on the electrical installation. The extent and nature of the electrical installation will vary depending on the job specifications.

For example, a small domestic installation will be much simpler than a large commercial or industrial installation.

Here are some examples of different types of electrical installations:

- ✓ **Domestic installation:** A domestic installation is an electrical installation in a residential property. Domestic installations typically include lighting, heating, appliances, and sockets for small electronic devices.

Figure 2 Domestic installation

- ✓ **Commercial installation:** A commercial installation is an electrical installation in a commercial property, such as an office, shop, or restaurant. Commercial installations typically include lighting, heating, ventilation, air conditioning, and power for a variety of electrical equipment.

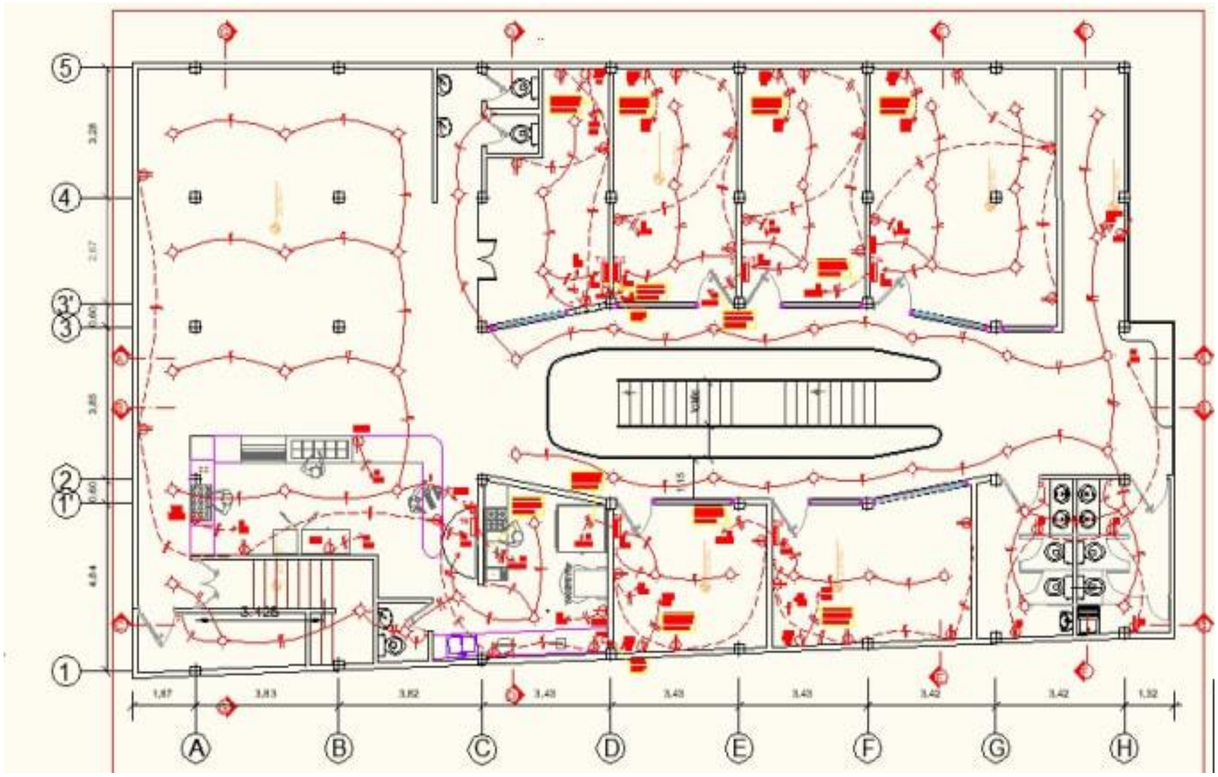


Figure 3 Commercial installation

- ✓ **Industrial installation:** An industrial installation is an electrical installation in an industrial property, such as a factory or manufacturing plant. Industrial installations typically include lighting, heating, ventilation, air conditioning, and power for a variety of industrial machinery. The electrical engineer or electrician will be able to assess the specific requirements of the job and design an electrical installation that meets those requirements safely and efficiently.

  Extent and nature of the electrical installation:

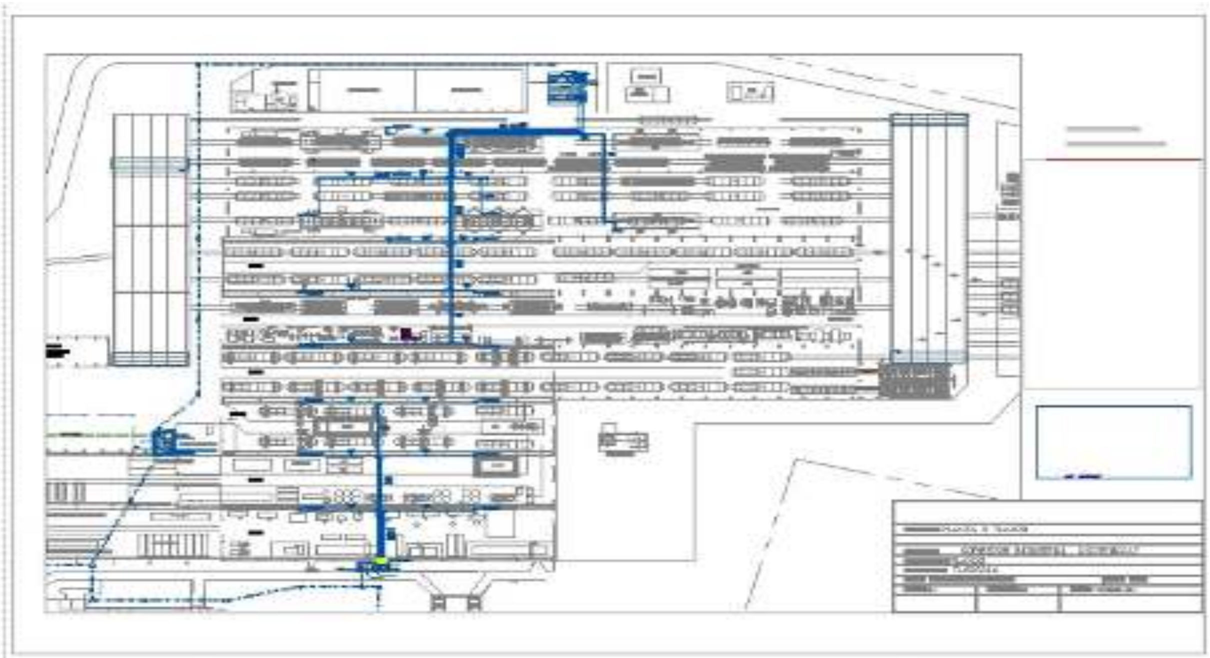


Figure 4 Industrial installation

The electrical installation for this home will need to include the following:

- ✓ A main service panel with circuit breakers for all of the electrical loads in the home.
- ✓ Wiring and outlets for lighting in all of the rooms.
- ✓ Wiring and outlets for appliances in the kitchen and laundry room.
- ✓ Wiring and outlets for HVAC equipment.
- ✓ Wiring and outlets for any other electrical devices that will be used in the home.

The electrical installation will also need to be inspected by a qualified electrician to ensure that it complies with all applicable codes and standards.

In addition to the above, the following factors may also need to be considered when determining the extent and nature of an electrical installation:

- The type of power source (e.g., grid power, solar power, etc.)
- The presence of any special requirements, such as emergency power backup or medical equipment
- The budget for the electrical installation

By carefully considering all of these factors, a qualified electrician can determine the extent and nature of an electrical installation to meet the specific needs of the client.

1.5. the route lengths of cables

The route lengths of cables and the conditions in which the wiring system is installed are important factors to consider when designing and installing an electrical system. The route length of a cable is the distance that it travels from the source of power to the load. The conditions in which the wiring system is installed include the ambient temperature, the presence of moisture or corrosive chemicals, and the mechanical stresses that the cables will be subjected to.

Figure 5 Heavy-duty cable tray

The route length of a cable will affect its voltage drop and current-carrying capacity. Voltage drop is the decrease in voltage that occurs as current flows through a cable. The longer the cable, the greater the voltage drop will be. Current-carrying capacity is the maximum amount of current that a cable can safely carry. The longer the cable, the lower the current-carrying capacity will be.

The conditions in which the wiring system is installed will also affect its voltage drop and current-carrying capacity. For example, cables that are installed in high-temperature environments will have a lower current-carrying capacity. Cables that are installed in wet or corrosive environments will be more likely to fail.

It is important to select the correct cable size and type for the route length and conditions in which the wiring system will be installed. The manufacturer's data sheets for the cable will provide information on the voltage drop and current-carrying capacity of the cable.

Here are some additional tips for selecting cables for the route length and conditions in which the wiring system will be installed:

- Use a cable with a larger cross-sectional area for longer cable runs.

- Use a cable with a higher insulation rating for high-temperature environments.
- Use a cable with a sheath that is resistant to moisture and corrosive chemicals for wet or corrosive environments.
- Use a cable with a higher mechanical strength rating for applications where the cable will be subjected to mechanical stresses.

It is also important to install cables in a way that minimizes voltage drop and prevents the cables from being damaged. Cables should be run in a straight line whenever possible. Cables should not be bent too tightly or twisted. Cables should be protected from physical damage.

Cable routing in the switchyard should provide the shortest possible runs to minimize voltage drops in the auxiliary power and control cables, and loss of signal in a communication cable, etc., as well as to reduce amount of cable required. Cables connected to equipment having comparable sensitivities should be grouped together and then the maximum separation should be maintained between groups. For cases where possible catastrophic failure of equipment leads to fire, all critical cables may be routed to avoid coincidental fire damage. This affects the proximity routing of trenches and the use of radial raceways rather than a grouped raceway.

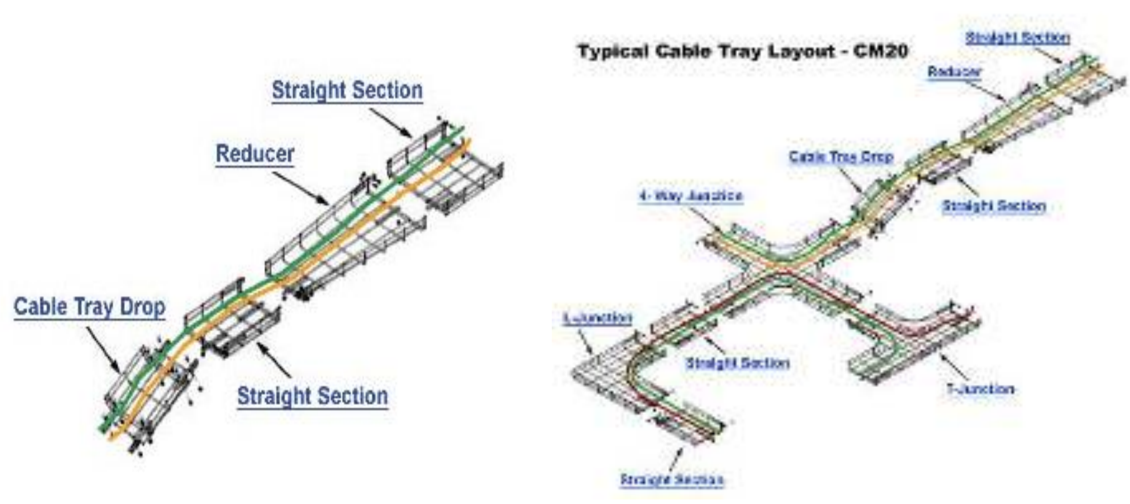


Figure 6 Typical Cable Tray Layout

Cable routes and route lengths:

The following cable routes will need to be considered for this home:

- From the main service panel to the distribution panels in each room.
- From the distribution panels to the lighting and outlets in each room.

- From the main service panel to the appliances in the kitchen and laundry room.
- From the main service panel to the HVAC equipment.

The route lengths of the cables will vary depending on the layout of the home. However, it is important to note that the cables should be routed in the most direct way possible to minimize voltage drop.

Conditions in which the wiring system will operate:

The wiring system in this home will operate in a typical residential environment. This means that the temperature range will be between **60°F and 80°F**, and the humidity will be between **30% and 70%.** The wiring system will not be exposed to any chemicals or other contaminants.

By considering all of these factors, a qualified electrician can determine the cable routes, the route lengths of cables, and the conditions in which the wiring system is to operate to meet the specific needs of the client.

Operating Conditions:

- Identify the environmental conditions in which the wiring system will operate, such as temperature, humidity, and exposure to chemicals or dust.
- Select cables and wiring methods that are suitable for the identified conditions, ensuring compliance with relevant standards and regulations.
- Consider any special requirements, such as fire resistance, hazardous location classification, or electromagnetic interference (EMI) protection.

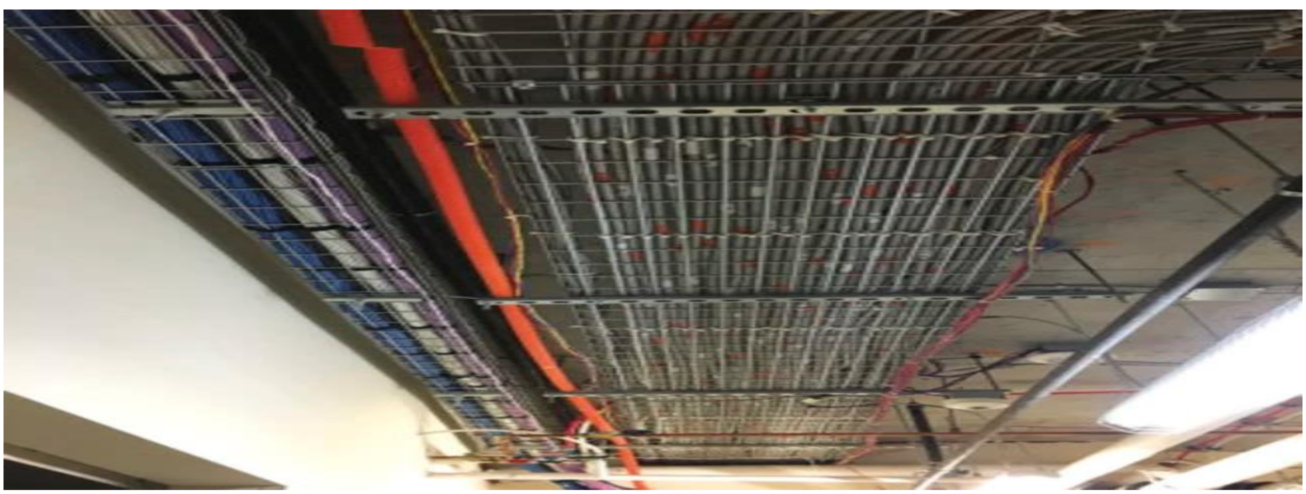


Figure 7 cable tray is used to support wiring as a main routing point down the corridor

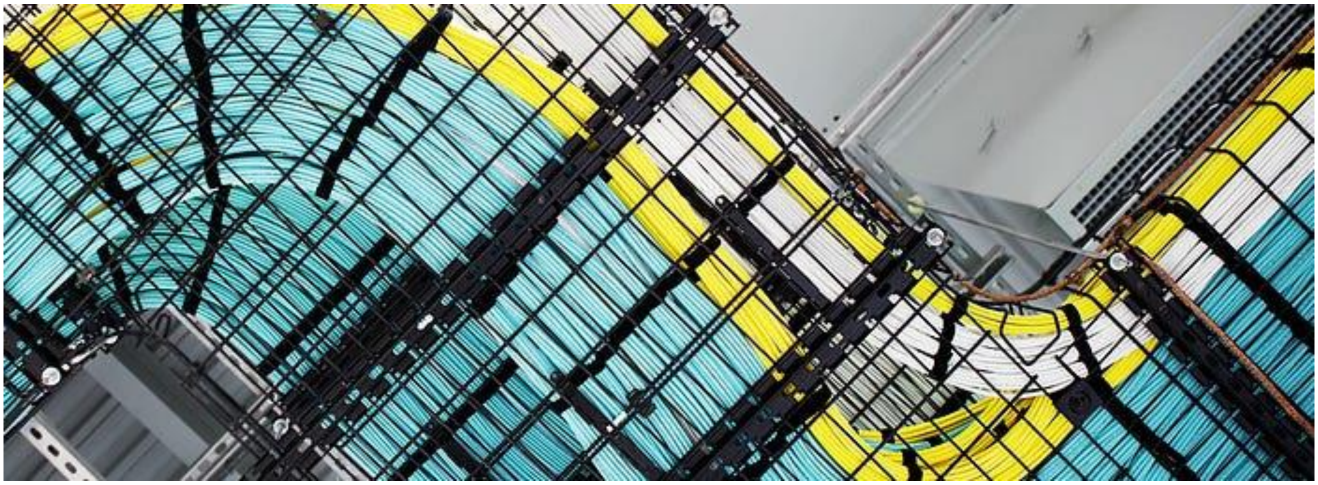


Figure 8 Cabling Pathway Types Overview

Figure 9 Underfloor Cable Tray

An underfloor cable tray is used primarily in data centers. It resembles much as overhead support pathway types. However, when using under floor cable tray systems, the air space may be a plenum air space, so all cable and patch cables would need to be plenum to ensure proper air flow.

- **Raceways** are special types of conduits used for surface mounting horizontal cables. They are usually pieced together in a modular fashion with vendors providing connectors that do not exceed the minimum bend radius. Raceways are mounted on the outside of a wall in places where cable is not easily installed inside the wall. They are commonly used on walls made of brick or concrete where no telecommunications conduit has been installed.

Self-Check 1

Name: ______________________________ Date: ____________________________

Time started: ________________________ Time finished: _____________________

Instructions: choose the correct Answer all the questions listed below.

1. Safety requirements for electrical wiring works have to be followed to eliminate any accidents which can result____________

   A, Physical damage b. Loss of life c. property d. all

2. Which of the following is Safety requirements have to be followed whenever electrical works are undertaken in a residential building?

   a. Personal safety b. safety at work place c. a and b

3 _______________in the switchyard should provide the shortest possible runs to minimize voltage drops in the auxiliary power and control cables.

   a. Cable routing b. cable support c. cable installation d. all

4 Mineral-insulated cables shall be run neatly on the surface of the___________________ in a vertical or horizontal direction, and at least 150mm clear of all plumbing and mechanical services.

   a. Walls b. Columns c. beams d. ceilings e. all

5.___________shall be provided throughout the entire cable route at regular intervals.

   a. Saddle b. Load c. weighs down d. burden e. all

6.Which of the following used as cable support in installation?

   a. Routing clip b. plastic clip c. C shape clip d. all

7. Which of the following is the nominal voltage of Single phase supply for Ethiopia?

   a. 220V ±10% b. 230V ±10% c. 240V ±10% d. 250V ±10%

8 Which of the following is the nominal voltage of three phase supply for Ethiopia?

   a. . 420V ±10% b. 380V ±10% c. 440V ±10% d. 600V ±10%

9.Which of the following power supply supplies a constant voltage to its load?

   a. DC power supply b. AC power supply c. Direct current power supply d. a and c

10.Which of the following power supply supplies a alternative voltage to its load?

   b. DC power supply b. AC power supply Direct current power supply d. a and b

11. Which of the following is the Range of low-voltage supply?

a. 0 V to 1000 V in AC. and from 0 V to 1500 V in DC

b. 0 V to 1500 V in DC and from 0 V to 1000 V in AC

c. Below 50V AC

d. a and b

Part three: Instructions: Answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers. Write your answers in the sheet provided in the next page.

1. Explain low voltage supply system. (3 points)
2. Explain DC and AC power supply system. (2 points)

Unit Two: wiring systems and cables Selection for general electrical installations

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Wiring system and Cable conductor sizes Selection
- Circuit protective devices Selection
- Layout/schedule of circuits for given installations
- Earthling systems and MEN system Selection

This unit will also assist you to attain the learning outcomes stated in above unit. Specifically, upon completion of this learning guide, you will be able to:

- Determine Wiring system and Cable conductor sizes Selection
- Determine Circuit protective devices Selection
- Understand Layout/schedule of circuits for given installations
- Determine Earthling systems and MEN system Selection

2.1 Wiring system and Cable conductor sizes Selection

the wiring system and cable conductor sizes selection is a critical process in electrical design and installation. It is important to select the correct wire size for each circuit to ensure that the wiring can safely carry the required current load and to prevent overheating.

- **The Critical Role of Cable Size in Electrical Efficiency**

Electricity is an essential element in our daily lives, powering everything from our homes to our workplaces.

✓ **What Is Cable Size?**

Cable size refers to the cross-sectional area of the conductor inside an electrical cable. It is measured in American Wire Gauge (AWG) or square millimeters (mm^2) in metric systems.

A larger cable size means a larger diameter of copper wire, resulting in lower resistance and higher current-carrying capacity.

- **Impact of Cable Size On Electrical Performance**

The size of the cable used in electrical systems has a significant impact on their performance.

A larger cable size means lower resistance and a higher current-carrying capacity. This results in better performance, higher efficiency, and less energy loss.

A larger cable size also reduces voltage drop and heat generation, leading to a longer lifespan and safer electrical systems.

Choosing the right cable size is essential to ensure the proper functioning and safety of electrical systems, and factors such as current load, voltage drop, distance, and ambient temperature should be considered.

2.1.1 Selecting Wiring System Suitable for Operating the Environment.

A network of wire connecting various accessories for distribution of electrical energy from the supply board to the numerous electrical energy consuming device such as lamps, fans, refrigerators, washing machine, juice maker, oven, stove and other domestic appliances through controlling and safety (protecting) device is known as residential wiring.

Electrical installations in residential or non-industrial buildings are determined by which factors of the suitability of a particular system or building, type and nature of building, its ultimate use and cost of the installation. In general, the wiring system selected depends up on the type of service required. The points to be considered while selecting the type of wiring will include:

- Expected life of the installation
- Expected future alterations of extensions
- Type of construction of the building
- Fire hazard
- Atmospheric hazards like fumes (smoke), dampers etc

Graphical symbols are used to show the components of the installation and measurements are given to show the position of each component.

Definitions

Electrical Equipment: Any item used for such purposes as generation, conversion, transmission, distribution or utilization of electrical energy, such as machines transformers. apparatus, measuring instruments, protective devices, equipment for wiring systems and appliances.

Electrical Installation: An assembly of associated electrical equipment, to fulfill a specific purpose or purposes and having coordinated characteristics.

Accessory: A device, other than current-using equipment, associated with such equipment or with the wiring of an installation.

Ambient Temperature: The temperature of the air or other medium where the equipment is to be used.

Appliance: Any device that utilizes electricity for a particular purpose, excluding a luminaries or an independent motor.

Insulation: Non-conducting material enclosing, surrounding or supporting a live part.

Insulated conductor: A conductor having only basic protection against shock, consisting of a covering of insulation.

Cable: An insulated conductor with an outer protective covering against external influences.

External Influences: Any influence external to an installation which affects the design or safety of the installation.

Fixed Wiring or Cable: Wiring or cable mounted on a fixed support so that its position does not change.

Flexible Wiring or Cable: Wiring or cable that may be moved in normal service between its points of termination.

Conduit: A system of tubing intended to enclose cables and wires in order to protect them from mechanical damage, and to allow them to be drawn-in and withdrawn.

Cable Trunking System: A factory-made system for enclosing cables and insulated wires, normally of rectangular cross-section, one side of which can be removed, and forming part of the wiring system.

Neutral Conductor (symbol N): A conductor connected to the neutral point of a system for the purpose of transmitting electrical energy.

Phase Conductor: A conductor of an AC system, other than a neutral conductor, intended for the transmission of electrical energy (also called "line conductor").

Cable Coupler: A means enabling the connection, at will, of two flexible cables. It consists of a connector and a plug.

Enclosure: A part providing an appropriate degree of protection of equipment against certain external influences and, a defined degree of protection against direct contact with live parts.

Building Void: A space within the structure or components of a building, which may be accessible at certain points.

2.1.2 selecting cable conductor size to meet current-carrying Capacity requirements.

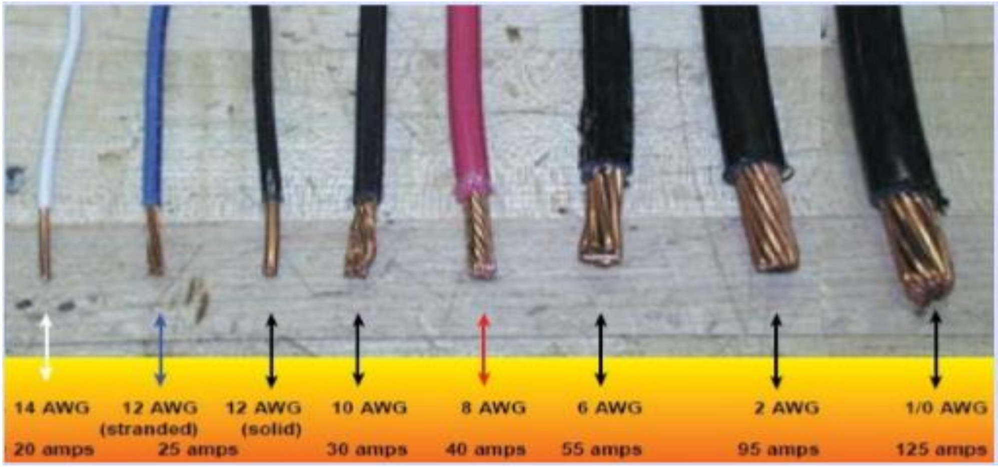
- ✓ **Wire and Cable**

The terms wire and cable are used more or less synonymously in house wiring. Strictly speaking single wire, may be bare or covered with insulation is known as a **wire** and several wires stranded together is known as a **cable.** But in practice bare conductors, whether single or stranded together are termed as **wire** and conductors covered with insulation are termed as

- ✓ **Wire size is measured in AWG (American Wire Gauge)**

- The AWG number identifies the size of the conductors the smaller the number the larger the diameter (AWG 0000 –0.46 in, AWG 18 – 0.04 in)
- NEC defines process for calculating wire size based on Current, Voltage and length of wire
- . Changes in routing may require a change in the wire used to cabinets or field elements.
- Most household wiring is usually 12 or 14 AWG Wire Size
- DOT Signal, Lighting and ITS wires range from 18 AWG for communications interconnect to 00+ for power service.

AWG # wire can be either solid or stranded



2.1 Measured in (AWG)

Determining Conductor Size

- ✓ Typically, ampacity and sizing is determined by the designer and provided on the plans
- ✓ conductors may need to be determined if the cable routing is revised by field personnel or final job layout
  - Derating process is documented in the NEC. Generally, requires a review of installation conditions and cable rating.

I. Cables.

- Cable requirements:
  - ✓ Has to efficiently conduct electricity.
  - ✓ It has to be cheap- i.e. not too small so as almost no voltage drop if possible, not to large so as it isn't costly.
  - ✓ Safe- i.e. the insulator must prevent leakage of current and this to minimize risk of fire and shock.

The three parts that constitute a cable are:

a) Conductor or core- wire or strand to carry the current.
b) Insulation or dielectric- a cover to avoid leakage of current.
c) Protective cover- to protect the insulator from mechanical damage.

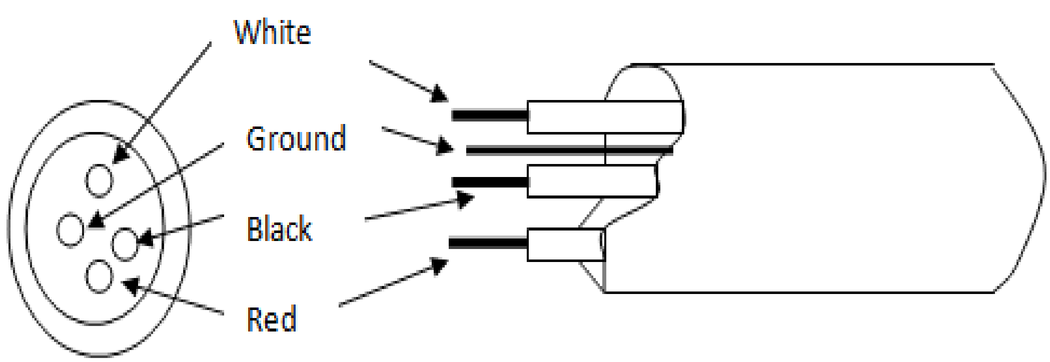
- **Conductor or core: -** copper and aluminum is the most widely used conductor in power and lighting circuits. Even if gold and silver are the best conductors, they are seldom used because of their high cost. Aluminum conductors mostly used for long distance power distribution.

Tungsten, because of its high resistivity, is used mainly in heating elements and light-bulb filaments.

- **Insulating materials-** those have to be highly resistive to the flow of electricity through them. Insulating materials have to give the following properties:
  - (i) Resistance
  - (ii) High flexibility
  - (iii) Highly resistive to moisture, acids or alkalis.
  - (iv) Capability to withstand high rupturing voltages and high temperature without must deterioration.

No one insulating material possess the all above mentioned qualities, so the type of insulating material used in a cable depends upon the service for which the cable is repaired.

Mechanical protection – uses steel tap, steel wire armor or aluminum sheath to protect the wire against mechanical damage.



2.2 Constitutes of cables

Types and Sizes of Cables

Cables may be divided into different groups

✓ *According to conductor material.*

- **Gold** Good conductor.
  - ✓ Used to plate contacts.
  - ✓ Does not corrode.
  - ✓ Expensive.
- **Silver** Best conductor material.
  - ✓ Used to plate contacts to expensive.
  - ✓ Ensure good electrical contact.
  - ✓ Soft and easily shaped.
- **Copper** Very good conductor.
  - ✓ Used extensively as a Soft and easily drawn into wires.

- ✓ Conductor material in cables easy to joint and solder.
- ✓ Good conductor of heat

- **Aluminum** Good conductor.
  - ✓ Used to manufacture Low cost and weight.
  - ✓ Larger cables and bus- bars.
  - ✓ Soft and easily shaped.
  - ✓ Overhead cables with steel core.
  - ✓ Not as flexible as copper.
  - ✓ High resistance to Corrodes.
- **Tungsten** Easily drawn into very fine wires.
  - ✓ Lamp filaments.
  - ✓ Very high melting point.
- **Brass** an alloy of copper and zinc.
  - ✓ Used to manufacture cable
  - ✓ Easily machined. Glands, terminals, plug pins, Resists corrosion.
  - ✓ some conduit fittings, nuts, bolts and washers.
- **Steel** Reasonably easy to shape.
  - ✓ Used to manufacture conduit, trucking, tray, enclosures and various fittings.
  - ✓ May be galvanized.
- **Tin** Resists corrosion.
  - ✓ Used to manufacture solder.
  - ✓ Coating on copper cables insulated with vulcanized rubber.
- **Lead** Does not corrode.
  - ✓ Used to manufacture solder, easily shaped.
  - ✓ Sheaths of cables, platesin lead-acid cells.
- **Mercury** Liquid at normal temperature.
  - ✓ Used in tilt switches.
- **Nichrome** is an alloy of nickel and chromium elements.
  - ✓ Hard and resists corrosion
- **Carbon** Good conductor. Brushes for electrical machines.
  - ✓ Hard wearing - self lubricating
  - ✓ negative temperature co-efficient of resistance.

➢ According to voltage grading. i.e., the voltage that the insulation can withstand.
  - ✓ 220/380 volts and
  - ✓ 650/ 1,100 volts' cable.

➢ According the No. of cores
  - ✓ single core cable
  - ✓ twin core and so forth

➢ According to insulating material

Generally, cables are specified according to complete information below.

a) size of cable
b) type of cores that the cable consists
c) voltage grading
d) type cable with clear description regarding insulation, taping and compounding.

All conductors have resistance that prevents an unlimited flow of current and of course voltage drop. For any given load, you must select a size of conductor that limits voltage drop to a reasonable value.

Copper Conductors

Figure 2.3 Copper Cable XLPE Insulation 4 cores

Copper conductor is being used in many electrical industries and applications, such as ***electrical motors*** transformers ***generators*** windings, power cables, small wiring wires, and so many applications.

The mix of hardness, strength, and flexibility of copper makes it very easy to work with in electrical installations, no special tools are needed for copper wiring.

- **Copper Conductivity**

The measure of how well any material transports electric charges is known as electrical conductivity.

Copper has the best and highest electrical conductivity of all metals except precious metals.

- **Is Copper a Good Conductor of Electricity?**

Yes, copper is an excellent conductor of electricity. In fact, copper is one of the most widely used materials for electrical conductors due to its exceptional electrical conductivity properties. It has several advantages that make it an ideal choice for conducting electricity:

1. **High Conductivity:** Copper has a high electrical conductivity, meaning it allows electric current to flow with minimal resistance. This property makes it very efficient for transmitting electricity.
2. **Low Resistance:** Copper offers low electrical resistance, reducing energy losses as electrical current flows through it. This makes it particularly valuable for ***power transmission*** and distribution.
3. **Ductility:** Copper is highly ductile, meaning it can be easily drawn into thin wires without breaking. This property is essential for producing fine and flexible copper wires used in various applications.
4. **Corrosion Resistance:** Copper is resistant to corrosion, which helps maintain its conductivity over time. It forms a protective oxide layer that prevents further corrosion.
5. **Heat Conductivity:** Copper also has excellent thermal conductivity, which makes it suitable for applications where heat dissipation is important, such as in electrical circuits and heat exchangers.
6. **Malleability:** Copper is malleable and can be shaped into various forms, making it versatile for different applications.

Due to these favorable properties, copper is commonly used in electrical wiring, power cables, electrical components, and many other applications where efficient and reliable electrical conductivity is essential.

- ✓ **Aluminum Conductor**

Aluminum is a conductor of electricity, but it is not as good a conductor as copper. Copper is the preferred material for most electrical wiring and applications due to its higher electrical conductivity.

Figure 2.4 Aluminum Conductor

However, aluminum does have some electrical conductivity properties and is used in certain situations for its advantages, such as lower cost and lower weight. Here are some key points about aluminum as a conductor of electricity:

1. **Lower Conductivity:** Aluminum has lower electrical conductivity compared to copper. This means that, for a given cross-sectional area, aluminum will have higher electrical resistance, leading to more energy losses in the form of heat when conducting electricity.
2. **Lightweight:** Aluminum is lighter than copper, which can be advantageous in certain applications, such as in overhead power lines, where the weight of the conductor affects the overall structure.
3. **Cost-Effective:** Aluminum is typically less expensive than copper, making it a cost-effective choice for large-scale electrical applications, such as power transmission lines.
4. **Corrosion Resistance:** Aluminum forms a thin oxide layer on its surface, which provides some resistance to corrosion. This can be advantageous in outdoor and high-humidity environments.
5. **Expansion and Contraction:** Aluminum has a higher coefficient of thermal expansion compared to copper, which means it expands and contracts more with temperature changes. This property must be considered in some applications.

While aluminum is a suitable conductor of electricity and is widely used in various applications, including power transmission lines, it is important to note that special connectors and considerations are often required when using aluminum conductors to mitigate some of its limitations, such as its lower electrical conductivity and increased thermal expansion.

➔ ***In many residential and smaller-scale electrical applications, copper conductors remain the preferred choice due to their superior conductivity and performance.***

✓ **Power Cables**

A power cable is an electrical cable, an assembly of one or more electrical conductors, usually held together with an overall sheath. The assembly is used for transmission of electrical power. Power cables may be installed as permanent wiring within buildings, buried in the ground, run overhead, or exposed. Power cables that are bundled inside thermoplastic sheathing and that are intended to be run inside a building are known as NM-B (nonmetallic sheathed building cable).

All cables shall be of multi-strand construction and of copper conductor unless otherwise specified.

The minimum cross sectional area of any cable core shall be 2.5 mm^2 except for:

- current transformer wiring which shall be a minimum of 4 mm^2; and
- Lighting circuits, which may be a minimum of 1.5 mm^2.

Where not otherwise specified, the Contractor shall select required cables in accordance with the following:

➔ For sizes between 1.5~6 mm^2 they shall be minimum Cu 450/750 V, V-90 PVC/PVC insulated and sheathed,

➔ For sizes 10~16 mm^2 they shall be Cu 0.6/1 kV, V-90 PVC/PVC insulated and sheathed,

➔ LV Power Cables with cross sectional area greater than 16 mm2 shall be Cu 0.6/1 kV, X-90 XLPE/PVC insulated and sheathed,

➔ VSD Motor Cables shall be min 2.5 mm^2 Cu 0.6/1 kV, X-90 insulated, 3C+3E, PVC bedded, Cu tape screened, PVC sheathed (Olex 'Varolex' or approved equivalent).

Figure 2.5 Power Cables

- **Control Cables**

  Control cables which are required to operate at low voltages shall be stranded PVC insulated PVC sheathed copper conductor cables manufactured in accordance with AS/NZS 5000 and having a minimum conductor cross sectional area of 1.0 mm^2.

  Control cables which are required to operate at extra low voltage shall be rated for the voltages and currents with which they have to carry. Conductor cross sectional area shall be not less than 0.50 mm^2.

  Multi-core cables shall be provided with a number of spare cores, not less than two, or 20% of the total number of installed cores, rounded to the next higher whole number, whichever is the greater. The application of mixed voltages (LV and ELV) within the same multi-core cable is not permitted.

Figure 2.6 Control Cables

- **Solid core conductors: -** are either circular or rectangular in cross- section and are used for fixed wiring. Circular conductors- are restricted mainly to cable cores up to 2.5 $mm^{2.}$ Rectangular conductor usually called bus bars-are used in distribution boards to allow many different circuits to be tapped off.

Figure 2.7 Solid core conductors

- ## CABLE SIZE DESIGN PROCEDURE

The correct choice of cable size for any installation is dependent upon fundamental aspects of

(a) Environmental conditions and characteristics of protection,

(b) Current-carrying capacity of the cable and

(c) Voltage drop of the cable.

When current flows through a conductor, the resistance offered by the conductor produces heat. The increase in heat is proportional to the cable resistance, which in turn depends upon the cross-sectional area of the cable. Since overheating damages the insulation, the conductor size must be of adequate size to prevent this from occurring.

The requirements of IEE Regulations make it clear that circuits must be designed and the design data made readily available. How then can we begin to design? Clearly, plunging into calculations of cable size is of little value unless the type of cable and its method of installation is known. This in turn will depend on the installation's environment. At the same time, we would need to know whether the supply was single or three phases, the type of earthing arrangements, and so on. Here then is our starring point. Having ascertained all the necessary details, we can decide on an installation method, the type of cable, and how we will protect against electric shock and over currents. We would now be ready to begin the calculation part of the design procedure. Basically, there are eight stages in such a procedure. These are the same whatever the type of installation, be it a lightening circuit, cooker circuit or a sub main cable feeding a distribution board in a factory. Here then are the eight basic steps in a simplified form:

1. Determine the design current Ib.
2. Select the rating of the protection In
3. Select the relevant correction factors (CFs).
4. Divide In by the relevant CFs to give cable current-carrying capacity
5. Choose a cable size to suit Iz
6. Check the voltage drop
7. Cheek for shock risk constraints
8. Cheek for thermal constraints.

- **CHOOSING CABLE SIZE**
  - ✓ **How to choose the correct size cable?**

A standard electrical system is essential for the correct use of all the equipment present in a *house, an office or any other building.*

When we are building or renovating our electrical system, one of the biggest doubts we can run into is choosing the correct size of electrical cables. *Specifically, the electric cables must meet the requirements of the local building regulations* and *must have the right section to avoid the dangerous overheating of the system.* Other aspects involved and factors to be taken into consideration are ***current absorption***, ***the type of laying***, ***the insulation***, ***the length of the line***, and the ***environmental conditions*** because cables can be used either for indoor or outdoor installations.

However, when we are dealing with small or medium-sized works, the main factor is certainly the current absorption, expressed in **amperes**.

In other words, sizing a cable means defining the section based on the intensity of the current flowing through it.

In the market there are ***electric cables*** of different sections, from ***1.5 mm² to 35mm²;*** this data represents the section of an electric cable and indicates the area expressed in square millimeters made up of the copper wires that pass inside it.

Normally 6 mm² are used for the uprights, 2.5 mm² for the circuits that power the sockets or fixed appliances such as the air conditioner and 1.5 mm² for the light circuits.

Continuing with general information, the larger the section of an electric cable, the greater the current that will pass. Sizing the electrical cables properly means less loss of dissipated energy and therefore optimizing the efficiency of our electrical system.

- **THE VOLTAGE DROP METHOD**

The criteria to be considered for this procedure are essentially two. First, it is necessary to know the power used as a consequence we also **know the current circulating in the line**. To manage the sizing, the allowable voltage drop is imposed and the corresponding section is ***calculated, choosing the section of the cable immediately higher than the calculated one***. To make sure that the operation is correct, **we must compare the section of the cable to the effective voltage drop**: if this value is higher than the allowed one, it is necessary to increase the section and choose a larger cable.

- **THE FLOW METHOD**

When we use this method we know both the ***power used and the current circulating in the line***, as well as the type of cable, insulation, laying and the number of active cables present in the common conduit is known.

We select the size by a table considering the section of the cable characterized by a capacity immediately higher than the current actually circulating.

Also, the final check is still referred to the table. Note the section, if it is lower than the circulating current, the section of the cable must be increased.

The main sections for correct sizing of electrical cables

Size	Application
0.5 mm²	used for service connections; prohibited for 230 V mains power supply
0.75 mm²	used in the wires of some low-power lamps; prohibited for 230 V mains power supply
1.5 mm²	light points and electrical outlets up to 10 amps

2.5 mm²	light points and electrical outlets up to 16 amps
4 mm²	total absorption up to a maximum of 25 amps
6 mm²	total absorption up to a maximum of 32 amps

- ✓ ***If we install cables in outdoor areas, double insulation cables must be used*** which can consist of one or more conductors such as uni-polar cable, bipolar cable (neutral and phase), tri-polar (neutral, phase, earth), multi-polar cables, up to ***4 cores (2 phases, 1 neutral, 1 earth)*** and one with ***5 cores (3 phases, 1 neutral, 1 earth).***

  In conclusion, the choice of a section of cable that is too small, in fact, would involve a high risk in the safety of both the system itself and, obviously, of the people and things close to it, since we would be in the presence of a high current passing on a section of cable too small. This could generate high heat along the cable (the so-called Joule effect) and as a consequence short circuits and fires.

Table 2.1 The following table shows the minimum wire size requirements for common residential circuits, based on the NEC:

Circuit Type	Current Load (Amps)	Wire Size (AWG)
15-amp branch circuit	15	14
20-amp branch circuit	20	12
30-amp branch circuit	30	10
40-amp branch circuit	40	8
50-amp branch circuit	50	6
60-amp branch circuit	60	4

- **CURRENT-CARRYING CAPACITY**

The formula for how to calculate ***current carrying capacity of copper cable*** is as follows:

I = KA/L.

Here,

- ✓ I stand for the maximum current load in amperes (amps),
- ✓ K is a constant that depends on the type of material used in the cable,
- ✓ A stands for the cross-sectional area of the cable in square millimeters (mm2), and L stands for length in meters (m).

Example 1. if you're using standard annealed copper wire with a cross-sectional area of 1 mm2 and a length of 10 m, K would equal 0.0175 ohms per meter (Ω/m).

Therefore, your equation would become **I = 0.0175 * 1 / 10 = 0.00175 amps or 1.75mA.**

This means that your maximum current load would be **1.75 milliamps (mA).**

Formula to Calculate Cable Current Rating

The current rating of a copper cable depends on various factors such as the cross-sectional area of the cable, the type of insulation used, and the installation conditions. A commonly used formula on ***how to calculate cable current rating*** is as:

Current Rating = (K * √ (Cable Cross-Sectional Area)) / Cable Resistance

Where:

- K is a constant that depends on the installation conditions and other factors. It can be obtained from relevant standards or engineering references.
- Cable Cross-Sectional Area is the area of the copper conductor in square millimeters (mm^2).
- Cable Resistance is the resistance of the copper cable per unit length, which can be determined using the resistivity of copper and the length of the cable.

It's important to note that this formula provides an estimate, and actual current ratings may vary based on specific installation conditions, temperature rise limits, and other factors. It is always recommended to consult with relevant standards, engineering guidelines, or a qualified electrical engineer for accurate current rating calculations for a specific application.

Cable size (AWG)	Current carrying capacity (amps)
14	15
12	20
10	30
8	40
6	55
4	70
3	85
2	100
1	125

Table 2.2 Cable size with Current carrying capacity

Conductor material	Insulation type	K
Copper	PVC	16
Copper	XLPE	20
Aluminum	PVC	12
Aluminum	XLPE	16

Table 2.3 Conductor material with Insulation type

For example, the current-carrying capacity of a 10 mm² copper conductor with PVC insulation at an ambient temperature of 30 degrees Celsius is:

$$I = 16 * 10 / 1 = 160 \text{ A}$$

- ✓ **VOLTAGE DROP**

Voltage drop is the decrease in voltage that occurs as current flows through a conductor. The voltage drop is determined by the length of the wire, the wire size, and the current load. A larger wire size will reduce the voltage drop. This is because a larger wire has a lower resistance, which allows more current to flow through the wire with less voltage drop.

It is essential to provide the correct voltage to ensure correct use and quality of the electricity service. It is therefore important to check that the cumulative voltage drop from the source up to any point in the installation does not exceed the required values.

If the voltage drop is greater than the permitted limits, it is advisable to increase the cross-section of the conductors until the voltage drop is below the specified values.

When the main wiring systems of the installation are longer than 100 m, the permitted voltage drop limits can be increased by 0.005% per meter above 100 m, but this additional amount must not itself exceed 0.5%.

- ***Permitted voltage drop limits according to Standard of IEC 60364-5-52 recommends a maximum value of 4%.***

This value applies to normal operation, and does not take account of devices, such as motors, that can generate high inrush currents and voltage drops.

If the installation supplies motors, it is advisable to check the voltage drop under starting conditions. To do this, simply replace current ib in the formula opposite with the starting current of the motor and use the power factor on starting. in the absence of more accurate data, the starting current can be taken as being 6 x in. the voltage drops, taking account of all the motors that may start at the same time, must not exceed 15%. Apart from the fact that too high a voltage drop can hinder other users of the installation, it may also prevent the motor starting.

More restrictive values may be required for the link between the transformer and the main breaking or protection device.

The unit voltage drop v (in volts per ampere and for 100 m), can be determined directly from the tables on the following pages, according to the:

- Cross-section (in mm^2) and type of core (copper or aluminum)
- Linear reactance of the conductors, λ (in mΩ/m), connected with their relative arrangement

➔ CABLE VOLTAGE DROP (VD) CALCULATIONS

1. Calculate the voltage drop (Vd) using the following formula:

Vd = I * R * L

where:

- ✓ Vd is the voltage drop in volts (V)
- ✓ I is the current in amperes (amps)
- ✓ R is the resistance of the cable in ohms per meter (Ω/m)
- ✓ L is the length of the cable in meters (m)

The resistance of the cable can be found in tables in electrical engineering handbooks.

2. Once you have calculated the voltage drop, you can choose the minimum size of the cable using the following formula:

A = Vd / (V * K)

where:

- ✓ A is the cross-sectional area of the cable in square millimeters (mm^2)
- ✓ Vd is the voltage drop in volts (V)
- ✓ V is the voltage in volts (V)
- ✓ K is a factor that depends on the type of cable insulation used. For PVC insulated cables, K = 100. For XLPE insulated cables, K = 120.

3. Select the cable size that is equal to or greater than the cross-sectional area calculated in step 2.

Here is an example of how to determine the minimum size of a cable based on voltage drop: Suppose you are designing a new electrical circuit for a residential building. The circuit will be used to power a number of outlets and lights. The maximum current that will flow through the circuit is 20 amps. The circuit will be approximately 100 feet long and will be installed in a PVC conduit.

The voltage drop of the circuit should **not exceed 5%.**

To calculate the voltage, drop, we use the following formula:

Vd = I * R * L

Assuming that the resistance of the cable is 0.01 Ω/m, we can calculate the voltage drop as follows:

Vd = 20 A * 0.01 Ω/m * 30.48 m (100 ft)

Vd = **6.096 V**

To choose the minimum size of the cable, we use the following formula:

A = Vd / (V * K)

A = 6.096 V / (120 V * 0.01)

A = 5.08 mm²

Therefore, the minimum size of the cable is 12 AWG.

It is important to note that this is just an example. The specific cable size that you need will vary depending on the specific requirements of your application. It is always best to consult with a qualified electrician to determine the appropriate cable size for your specific application.

Example:

You need to select the conductor size for a 240-volt circuit that will carry 100 amps for a distance of 250 feet. The ambient temperature is 77 degrees Fahrenheit.

✓ **Step 1:** Calculate the voltage drop.

Voltage drop = (100 amps * 250 feet) / (240 volts * 1000) = 0.104167 volts

Step 2: Use the voltage drop chart to determine the correct conductor size.

For a 240-volt circuit with a voltage drop of 0.104167 volts, the correct conductor size is #4 AWG copper or 3/0 AWG aluminum.

Tips:

- ✓ Always use a conductor size that is larger than the minimum required size. This will help to prevent the conductor from overheating and causing a fire.
- ✓ If the cable run is long, you may need to use a larger conductor size to compensate for the voltage drop.
- ✓ When installing cables in a hot environment, you may need to use a larger conductor size to prevent the conductor from overheating.
- ✓ If the cable will be exposed to the elements, you need to use a cable with the appropriate insulation type.

- **Examples**

a. A 12-volt system at 10% drop with a 40’ circuit x 45 amps = 1800 F amps.

A wire size of 8 is required.

b. A 24-volt system at 3% drop with a 10’ circuit x 100 amps = 1000 Famps. A wire size of 6 is required.

- **Example:**

Calculate the voltage drop for an installation which is supplied at 240V by a single core 16mm2 PVC insulated cable in conduit with a length of 23 m and the current flow to the load of 33 A.

Solution:

Find the value of the voltage drop for the size of the cable by using the third column in Table 4D1B.

Cable size = $16mm^2$

From Table 4D1B,

Voltage drop = 2.8 mV/A/m

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

$$V_d = \frac{2.8 \times 33 \times 23}{1000}$$

$$= 2.125 \text{ Volt}$$

The voltage drop in the cable is 2.125 Volt when a cable of 16 mm^2 is used. As this does not exceed the 9.6 Volt as specified, the most suitable cable size to be used is 16 mm^2.

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

Conductor cross-sectional area	2 cables d.c	2 cables, single-phase a.c									3 or 4 cables, three-phase a.c											
		Reference Method 3 & 4 (Enclosed in conduit etc. in or on a wall)			Reference Method 1 & 11 (clipped direct or on trays, touching)			Reference Method 12 (spaced*)			Reference Method 3 & 4 (Enclosed in conduit etc. in or on a wall)			Reference Method 1, 11 & 12 (in trefoil)			Reference Method 1 & 11 (flat and touching)			Reference Method 12 (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	0.40	0.31	0.51

Table 2.4 Voltage drop table

✓ EARTH FAULT-LOOP IMPEDANCE

Earth fault-loop impedance (EFLI) is the total impedance of the circuit path between the live conductor and the earth. The EFLI is important for safety because it determines the magnitude of the current that will flow in the event of an earth fault.

A lower EFLI will result in a higher current flow in the event of an earth fault. This is because a lower impedance provides a less restrictive path for the current to flow.

The NEC requires that the EFLI for certain types of circuits be below a certain threshold. This is to ensure that a sufficiently high current will flow in the event of an earth fault to operate the circuit protection device and disconnect the circuit.

- **Earth fault-loop impedance calculation and formula**

Earth fault loop impedance (Zs) is the total impedance of the path that a current takes from the phase conductor to the earth during an earth fault. It is an important safety parameter, as it determines how quickly a protective device will operate to clear the fault and prevent serious injury or damage.

The following formula can be used to calculate the earth fault loop impedance:

$$Zs = Ze + (R1 + R2)$$

where:

Zs is the earth fault loop impedance in ohms (Ω)

Ze is the external earth loop impedance in ohms (Ω)

R1 is the resistance of the phase conductor in ohms (Ω)

R2 is the resistance of the protective conductor in ohms (Ω)

The external earth loop impedance (Ze) is the impedance of the path that the current takes from the point of fault to the earth electrode. It is typically measured by a qualified electrician using a specialist test instrument.

The resistance of the phase conductor (R1) and the protective conductor (R2) can be measured using a simple resistance meter.

Example:

Calculate the earth fault loop impedance for a circuit with the following parameters:

External earth loop impedance (Ze) = 0.5 Ω

Phase conductor resistance (R1) = 0.2 Ω

Protective conductor resistance (R2) = 0.1 Ω

Solution:

Zs = 0.5 + (0.2 + 0.1) = 0.8 Ω

Therefore, the earth fault loop impedance for the circuit is 0.8 Ω.

It is important to note that the earth fault loop impedance should be kept as low as possible. This is because a lower earth fault loop impedance will result in a higher fault current, which will cause the protective device to operate more quickly.

In general, the earth fault loop impedance for a circuit should be less than 1 Ω. However, there may be specific requirements for certain types of circuits or installations. It is always best to consult with a qualified electrician to determine the correct earth fault loop impedance for a particular application.

1. Choosing the minimum size of the cable in case of earth fault loop impedance.

chooses the minimum size of the cable in case of earth fault loop impedance, you can use the following steps:

1. Calculate the earth fault loop impedance (Zs) using the following formula:

$$\mathbf{Zs = Ze + Zc + R1 + R2}$$

where:

- ✓ Ze is the external loop impedance, which is the impedance of the path from the source of the earth fault to the point where the cable enters the building. This value can be obtained from the electricity utility company.
- ✓ Zc is the impedance of the protective conductor (earth wire). This value can be found in tables in electrical engineering handbooks.
- ✓ R1 is the resistance of the line conductor from the point where the cable enters the building to the point of the earth fault. This value can be calculated using the following formula:

$$\mathbf{R1 = \rho * l / A}$$

where:

- ✓ ρ is the resistivity of the conductor material (e.g., copper or aluminum).
- ✓ l is the length of the line conductor.
- ✓ A is the cross-sectional area of the line conductor.

- ✓ R2 is the resistance of the protective conductor from the point of the earth fault to the earth electrode. This value can be calculated using the same formula as for R1.

2. Once you have calculated the earth fault loop impedance, you can choose the minimum size of the cable using the following formula:

A = Zs * If / (V * K)

where:

- ✓ A is the cross-sectional area of the cable in square millimeters (mm^2)
- ✓ Zs is the earth fault loop impedance in ohms (Ω)
- ✓ If is the fault current in amperes (amps)
- ✓ V is the voltage in volts (V)
- ✓ K is a factor that depends on the type of earthing system used. For TN earthing systems, K = 1.5. For TT earthing systems, K = 2.

3. Select the cable size that is equal to or greater than the cross-sectional area calculated in step 2.

Here is an example of how to choose the minimum size of a cable in case of earth fault loop impedance:

Suppose you are designing a new electrical circuit for a home. The circuit will be used to power a number of outlets and lights. The maximum fault current for the circuit is 100 amps. The circuit will be approximately 100 feet long and will be installed in a TN earthing system. The external loop impedance (Ze) is 0.5 Ω. The impedance of the protective conductor (Zc) is 0.1 Ω. To calculate the earth fault loop impedance, we use the following formula:

Zs = Ze + Zc + R1 + R2

Since the lengths of the line conductor and the protective conductor are the same, we can assume that R1 = R2.

To calculate R1, we use the following formula:

R1 = ρ * l / A

Assuming that the line conductor is made of copper and has a cross-sectional area of 12 AWG, we can calculate R1 as follows:

R1 = (1.68 * 100) / (5.31) = 31.9 Ω

Therefore, the earth fault loop impedance is:

$$Zs = 0.5\ \Omega + 0.1\ \Omega + 31.9\ \Omega + 31.9\ \Omega = 64.4\ \Omega$$

To choose the minimum size of the cable, we use the following formula:

$$A = Zs * If / (V * K)$$

Assuming that the voltage of the circuit is 120 V, we can calculate the cross-sectional area of the cable as follows:

$$A = 64.4\ \Omega * 100\ A / (120\ V * 1.5) = 35.7\ mm^2$$

Therefore, the minimum size of the cable is 8 AWG.

It is important to note that this is just an example. The specific cable size that you need will vary depending on the specific requirements of your application. It is always best to consult with a qualified electrician to determine the appropriate cable size for your specific application.

- **To select the correct wire size, we need to consider the following factors:**

✓ **Current-carrying capacity:** The wire size must be sufficient to carry the maximum current load of 15 amps.

✓ **Voltage drop**: The wire size must be large enough to minimize voltage drop.

Conductor type: We will use copper conductors.

✓ **Ambient temperature:** The ambient temperature is 30 degrees Celsius.

Based on the table above, we can see that a 14 AWG copper conductor has a current-carrying capacity of 15 amps at an ambient temperature of 30 degrees Celsius. This means that a 14 AWG copper conductor would be suitable for this circuit.

- **Earth fault-loop limitation.**

The path made or followed by the earth fault current is called the earth-fault loop or phase-earth loop. It is termed impedance because part of the circuit is the transformer or generator winding, which is inductive. This inductance, along with the resistance of the cables to and from the fault, makes up the impedance.

- **Design current calculation**

Design current is the maximum amount of current that a circuit is designed to carry safely. It is an important parameter to consider when designing and installing electrical circuits, as it ensures that the circuit components are not overloaded and that the risk of fire and other hazards is minimized.

The following formula can be used to calculate the design current for a circuit:

$$I = P / V$$

where:

I is the design current in amperes (A)

P is the total power consumption of the circuit in watts (W)

V is the voltage of the circuit in volts (V)

➾ **Example:**

Calculate the design current for a circuit with a total power consumption of 1000 W and a voltage of 240 V.

Solution:

I = 1000 / 240 = 4.17 A

Therefore, the design current for the circuit is *4.17 A*.

It is important to note that the design current is typically higher than the maximum load current that the circuit will ever carry. This is to provide a safety margin and to account for factors such as starting currents and diversity.

In general, the design current for a circuit should be at least 25% higher than the maximum load current. However, there may be specific requirements for certain types of circuits or installations. It is always best to consult with a qualified electrician to determine the correct design current for a particular application.

2.2 Circuit protective devices Selection

to ensure the safety of electrical circuits, it is important to select circuit protective devices that are properly coordinated with the current-carrying capacity of the conductors. This means that the protective device must be able to safely interrupt any overcurrent condition that may occur in the circuit without damaging the conductors.The following factors must be considered when selecting circuit protective devices for coordination with conductor current-carrying capacity:

- ✓ **Current rating**: The current rating of the protective device must be greater than the maximum current that will flow through the circuit.

- **Type of protective device:** The type of protective device must be selected based on the type of overcurrent condition that it is intended to protect against. For example, fuses are typically used to protect against overload and short-circuit currents, while circuit breakers are typically used to protect against short-circuit currents only.
- **Interrupting rating**: The interrupting rating of the protective device must be greater than the maximum short-circuit current that can flow in the circuit.

Example:

Consider a circuit with a maximum current of 20 amps and a maximum short-circuit current of 100 amps. To properly coordinate the circuit protective devices with the conductor current-carrying capacity, the following devices would be selected:

- **Conductor**: A conductor with a current-carrying capacity of at least 20 amps would be selected.
- **Overload protection:** A fuse or circuit breaker with a current rating of 20 amps would be selected.
- **Short-circuit protection:** A fuse or circuit breaker with an interrupting rating of at least 100 amps would be selected.

It is important to note that coordination of circuit protective devices is a complex topic and there are many other factors to consider when selecting protective devices. It is always best to consult with a qualified electrician to ensure that the correct protective devices are selected for a particular application.

- ***To calculate the circuit protective devices required to coordinate with the conductor current-carrying capacity, the following steps can be taken***:

1. Determine the maximum current that will flow through the circuit. This can be done by adding up the current ratings of all of the loads that the circuit will be supplying.
2. Determine the conductor current-carrying capacity. This can be found in the manufacturer's data sheets for the conductor.
3. Select a circuit protective device with a current rating greater than the maximum current that will flow through the circuit.
4. Select a circuit protective device with an interrupting rating greater than the maximum short-circuit current that can flow in the circuit.

Circuit protective devices are devices that are used to protect electrical circuits from overcurrent conditions. Overcurrent conditions can occur when too much current flows through a circuit, which can cause the wires to overheat and start a fire. Circuit protective devices work by interrupting the flow of current when an overcurrent condition is detected.

Circuit breakers are the most common type of circuit protective device. They are designed to be reusable and can be reset after they have tripped.

- **Circuit breakers** typically contain a bimetallic strip and a magnetic trip unit. The bimetallic strip heats up when current flows through it, and it will bend and trip the circuit breaker if the current is too high. The magnetic trip unit will trip the circuit breaker if there is a sudden increase in current, such as a short circuit.

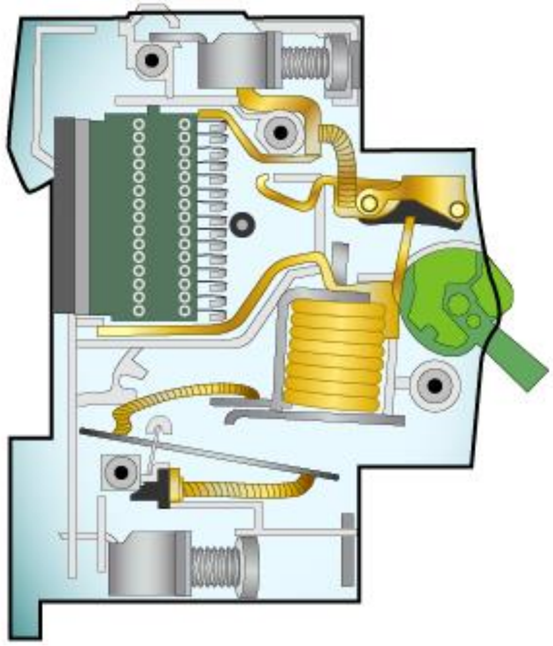


Figure 2.8 Circuit breaker

- **Electronic fuses** are a type of circuit protective device that uses electronic components to detect and interrupt overcurrent conditions. Electronic fuses are typically faster than circuit breakers and can provide more precise protection. However, they are also more expensive and cannot be reset.

Figure 2.9 Electronic fuse

Fuse holders are devices that are used to hold fuses in place. Fuse holders come in a variety of sizes and styles, and they can be used in both indoor and outdoor applications.

Figure 2.10 Fuse holder

Circuit protective devices are an important part of any electrical circuit. They help to protect the circuit from overcurrent conditions, which can prevent fires and other damage. It is important to select the correct circuit protective devices for a particular application and to install them properly.

CONDUCTORS AND PROTECTION DEVICES.

Conductors are wires or cables that carry electricity. They are made of a variety of materials, including copper, aluminum, and steel. Conductors are typically covered in an insulating material to prevent them from touching each other and causing a short circuit.

Protection devices are used to protect conductors from overcurrent conditions. Overcurrent conditions can occur when too much current flows through a conductor, which can cause it to overheat and start a fire. Protection devices work by interrupting the flow of current when an overcurrent condition is detected.

Figure 2.11 Some common types of protection devices include:

- **Fuses:** Fuses are the simplest type of protection device. They contain a thin wire that melts when too much current flows through it. This interrupts the flow of current and prevents the conductor from overheating.
- **Circuit breakers:** Circuit breakers are more complex than fuses, but they can be reset after they have tripped. Circuit breakers typically contain a bimetallic strip and a magnetic trip unit. The bimetallic strip heats up when current flows through it, and it will bend and trip the circuit breaker if the current is too high. The magnetic trip unit will trip the circuit breaker if there is a sudden increase in current, such as a short circuit.
- **Ground fault circuit interrupters (GFCIs):** GFCIs are designed to protect people from electric shock. They work by detecting a difference in current between the hot and neutral wires. If a difference in current is detected, the GFCI will interrupt the flow of current. GFCIs are typically used in kitchens, bathrooms, and other areas where there is a risk of electric shock.
- **Arc fault circuit interrupters (AFCIs):** AFCIs are designed to protect against electrical fires caused by arcing faults. Arcing faults occur when there is a loose connection or damaged wire. AFCIs work by detecting the high-frequency signals that are produced by arcing faults. If an arcing fault is detected, the AFCI will interrupt the flow of current.

It is important to select the correct protection devices for a particular application and to install them properly. Protection devices can help to keep you and your home safe from electrical hazards.

- **Breaker and Wire Size Chart**

The following breaker and wire size chart can be used as a guide when calculating the appropriate breaker and wire size based on the load current and circuit requirements:

Load Current Range	**Breaker Size**	**Wire Size (Copper)**	**Wire Size (Aluminum)**
0-15 amps	15 amps	14 gauge	12 gauge
16-20 amps	20 amps	12 gauge	10 gauge
21-30 amps	30 amps	10 gauge	8 gauge
31-40 amps	40 amps	8 gauge	6 gauge
41-50 amps	50 amps	6 gauge	4 gauge
51-60 amps	60 amps	4 gauge	2 gauge
61-80 amps	80 amps	3 gauge	1 gauge

Table 2.5 ***Breaker and Wire Size Chart***

- **How Circuit Breaker and Wire Size can be calculated**

To calculate current draw & circuit breaker size, you must know the load's power rating and the circuit's voltage. Once you have this information, you can use Ohm's law that states current (I) equals power (P) divided by voltage (V):

$$I = P / V$$

For example, let's say you have a 120-volt circuit with a load that has a power rating of 1000 watts. Using Ohm's law, the current draw can be calculated as follows:

$$I = 1000 / 120 = 8.33 \text{ amps}$$

So, the load current in this example is 8.33 amps.

Select a breaker with a current rating greater than or equal to the load current to determine the appropriate circuit breaker size. For a load current of 8.33 amps, a 10-amp circuit breaker would be appropriate. However, if there are no 10-amp breakers available, the next size up (i.e., 15 amps) can be used.

- **Circuit Breaker Size Calculation for Single Phase Supply**

To determine the appropriate size of circuit breaker for single phase supply, it depends on multiple factors like type of load, cable material and environment temperature etc.

The general rule of thumb is that circuit breaker size should be 125% of the ampacity of cable and wire or the circuit which has to be protected by the CB. Let see the following solved examples:

Example

Suppose, a 12-gauge wire is used for 20 amperes lighting circuit having 120V single phase supply. What is the best size of circuit breaker for that 20 A circuit?

Solution:

Circuit Current: 12A

Circuit Breaker Size?

CB size should be 125% of the circuit current.

= 125% x 20A

= 1.25 x 20A

Circuit Breaker Size = 25A

Example

Following Loads are connected in a building: -

Sub-Circuit 1

- 2 lamps each o 1000W and
- 4 fans each of 80W
- 2 TV each of 120W

Sub-Circuit 2

- Lamps each of 80W and
- sockets each of 100W
- 4 lamps each of 800W

If supply voltages are 230 V AC, then **calculate circuit current** and **Cable size for each Sub-Circuit**?

Solution: -

Total load of Sub-Circuit 1

= (2 x 1000) + (4 x 80) + (2×120)

= 2000W + 320W + 240W = 2560W

Current for Sub-Circuit 1 = I = P/V = 2560/230 = **11.1A**

Total load of Sub-Circuit 2

= (6 x 80) + (5 x 100) + (4 x 800)

= 480W + 500W + 3200W= **4180W**

Current for Sub-Circuit 2 = I = P/V = 4180/230 = **18.1A**

Therefore, ***Cable suggested for sub circuit 1*** = **3/.029**" (**13 Amp**) or **1/1.38 mm** (**13 Amp**)

Cable suggested for Sub-Circuit 2 = **7/.029**" (**21 Amp**) or **7/0.85 mm (24 Amp)**

Total Current drawn by both Sub-Circuits = 11.1A + 18.1A = **29.27 A**

So ***cable suggested for Main-Circuit*** = **7/.044″ (34 Amp)** or **7/1.04 mm (31 Amp**)

➯ **Example**

What is the appropriate size of circuit breaker for 2000W, single phase 120V Supply?

Solution:

- Load: 2000W
- Voltage: 120V (Single Phase)

Circuit Current:

According to the ohm's law,

I = P / V

I = 2000W / 120V

I = 16.66 A.

Circuit Breaker Size:

Simply, Multiply 1.2 or 1.25 to the load current.

1.2 x 16.66 A

Circuit Breaker Size = 20 A

➯ **Example**

What is the suitable size of circuit breaker for 230V, 1840kW load single phase circuit?

Solution:

Current = Power / Voltage

I = 1840W / 230V

I = 8A

The minimum rating of circuit breaker should be **8A.**

The recommended size of circuit breaker should be **8A x 1.25 = 10**

➾ **Example** Which size circuit breaker is needed for 6.5kW, three phase 480V load?

Solution:

Power in Three Phase: P = V x I x √3

Current: P / V x √3

I = 6.5kW / (480V x 1.732) … (√3 = 1.732)

I = 6.5kW / 831.36

I = 7.82A

The recommended size of circuit breaker is

1.25 x 7.82A = 9.77A

The next closest standard of circuit breaker is 10A.

➾ **Example:** Find the appropriate size of CB for 3-Phase 415V, 17kW load?

Solution:

Current = Power / (Voltage x √3)

I = 17000W / (415V x 1.732)

I = 23.65A

Recommended Size of Circuit Breaker: 1.25 x 23.65A = 29.5A. The next closest value is **30A**.

2.3 Layout/schedule of circuits for given installations

The layout/schedule of circuits for given installations is a plan that shows how the electrical circuits in a building will be arranged. It includes the location of all of the electrical outlets, switches, and fixtures, as well as the size and type of wiring that will be used. The schedule of circuits also includes a list of all of the loads that will be connected to each circuit.

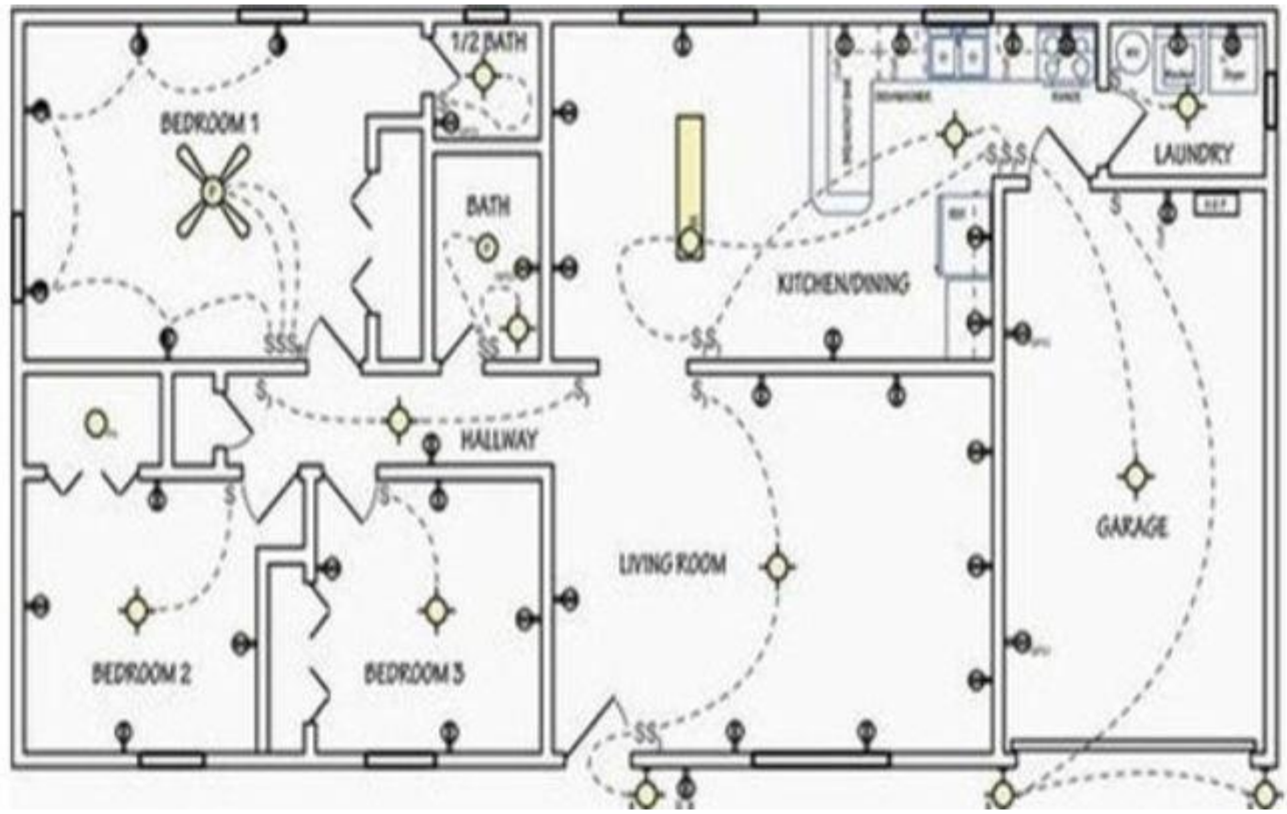


Figure 2.12 Layout/schedule of circuits for given installations

The layout/schedule of circuits is typically created by an electrician or electrical engineer. It is an important part of any electrical installation, as it helps to ensure that the circuits are properly sized and arranged to safely handle the electrical load.

To create a layout/schedule of circuits, the electrician or electrical engineer will first need to determine the type and size of the electrical loads that will be connected to each circuit. This includes the wattage of all of the lights, appliances, and other electrical devices that will be used on the circuit. Once the electrical loads have been determined, the electrician or electrical engineer can then select the appropriate size and type of wiring for each circuit.

The electrician or electrical engineer will also need to determine the location of all of the electrical outlets, switches, and fixtures. This is typically done by creating a floor plan of the building and marking the location of all of the electrical devices on the plan. Once the location of the electrical devices has been determined, the electrician or electrical engineer can then route the wiring from the electrical panel to each device.

The layout/schedule of circuits is an important document that should be kept on file for future reference. It can be used for troubleshooting electrical problems, adding new electrical circuits, or making repairs to existing circuits.

- **Layout a main switchboard for an installation supplied with single phase single tariff whole current metering.**

The main switchboard for an installation supplied with single phase single tariff whole current metering should have the following layout:

Single phase single tariff whole current metering switchboard layout

✓ **Components:**

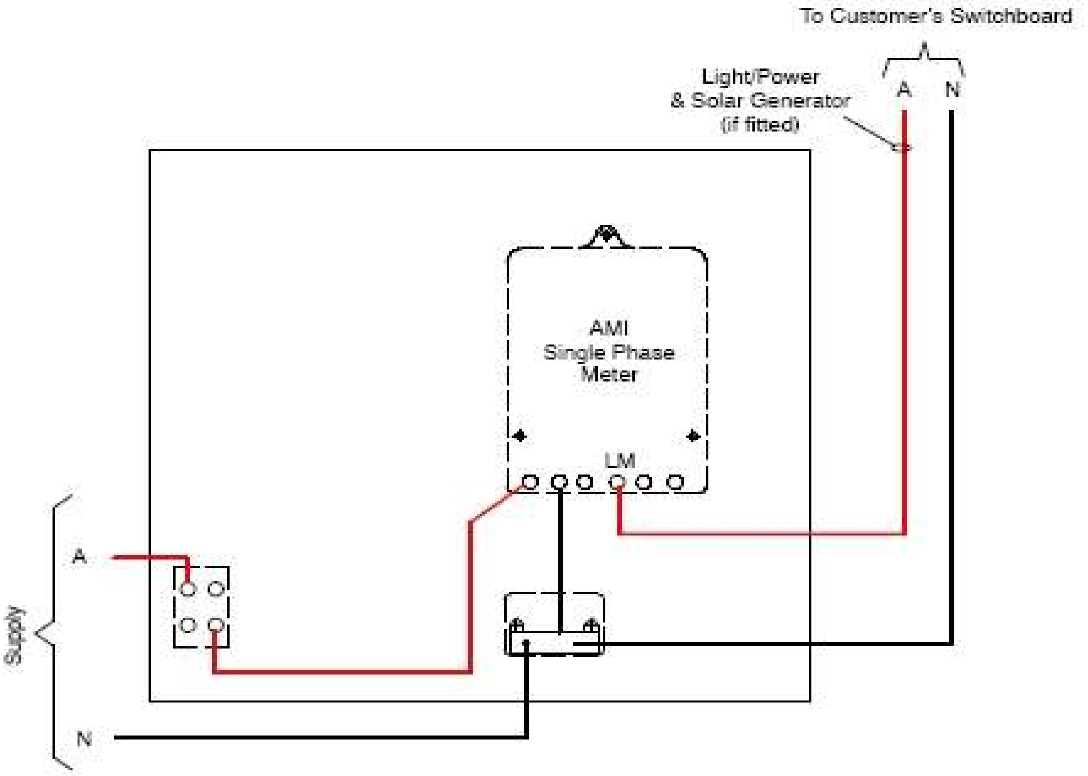
- Main incoming isolator
- Electricity meter
- Main circuit breaker
- Outgoing circuit breakers (one for each circuit in the installation)
- Busbar
- Neutral bar
- Earth bar

✓ **Layout:**

The main incoming isolator should be located at the top of the switchboard. This is followed by the electricity meter, which should be easily accessible for meter readers. The main circuit breaker should be located below the electricity meter. The outgoing circuit breakers should be located below the main circuit breaker. The busbar, neutral bar, and earth bar should be located at the bottom of the switchboard.

- The switchboard should be made of a non-combustible material.
- The switchboard should be enclosed in a metal cabinet with a lockable door.
- The switchboard should be installed in a clean and dry location.
- The switchboard should be properly labeled and identified.
- All wiring connections should be tight and secure.

It is important to note that this is just a general layout for a single phase single tariff whole current metering switchboard. The specific layout of your switchboard may vary depending on the specific requirements of your installation.



Notes

1. Available to all "New", "Add/Alt", and "PFIT" customers in Citipower and Powercor
2. Refer to VSIR Figure 8.6 for meter panel layout
3. Solar Generator (if fitted) connected to Light/Power circuits in customer's main switch board
4. Meter panel fuse not required where an arial service line is provided
5. Refer figure AMT–1 for Meter Terminal Drawing

Figure 2.13 Layout a main switchboard single phase single tariff whole current metering.

It is always best to consult with a qualified electrician to ensure that your switchboard is properly designed and installed. Layout a main switchboard for an installation supplied with single phase multiple tariff whole current metering with image. The main switchboard for an installation supplied with single phase multiple tariff whole current metering should have the following layout:

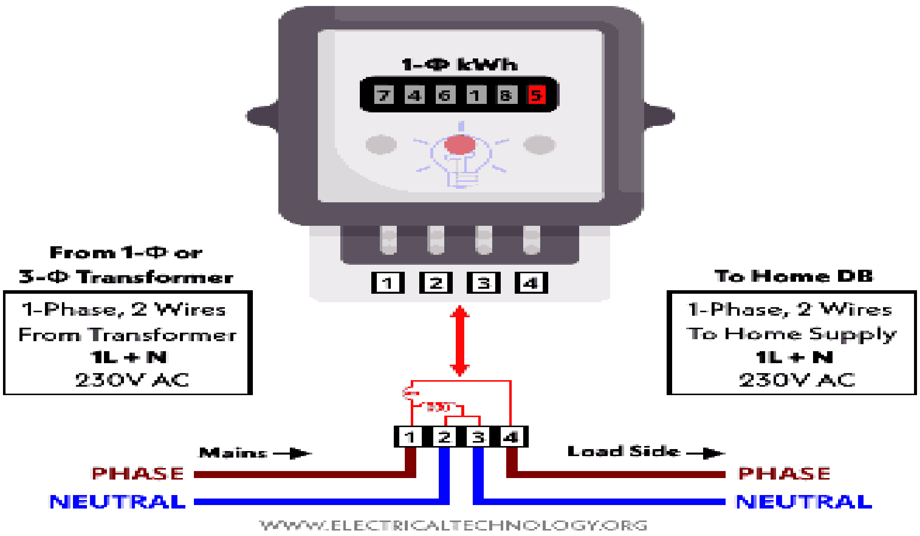


Figure 2.14 Single phase multiple tariff whole current metering switchboard layout

The tariff control unit is responsible for switching between the different tariffs. It does this by monitoring the time of day and the day of the week. The tariff control unit is also responsible for sending the appropriate tariff information to the electricity meter.

The electricity meter then uses this tariff information to calculate the energy consumption for each tariff. The energy consumption for each tariff is displayed on the electricity meter display.

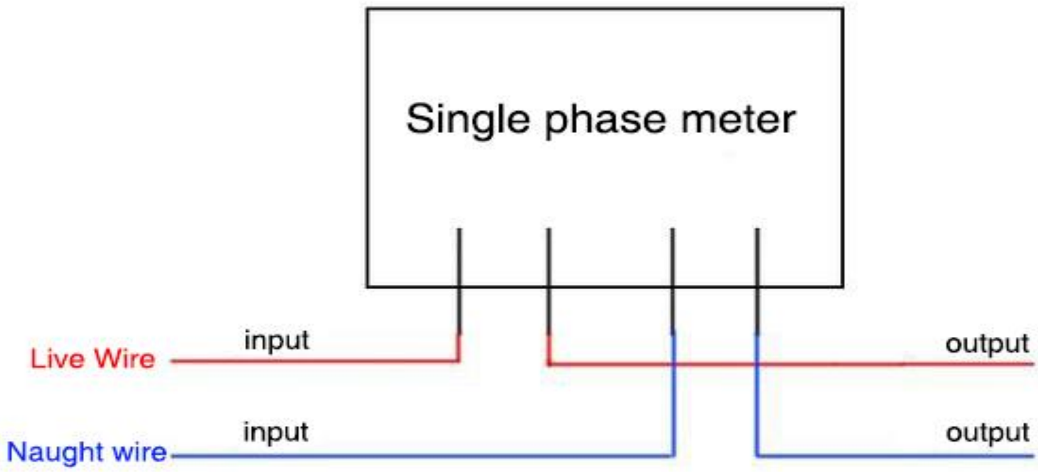


Figure 2.14 single phase meter wiring diagram

Layout a main switchboard for an installation supplied with multiphase single tariff whole current metering

- **Three phase energy meters:** Three phase energy meter is used for commercial or industrial application. As in the industries we have huge amount of current so to protect it we will use current transformer. It will step down the current to isolate energy meters from high current.

The three phase energy meters have three phase wires and one neutral wire. The output three wires go to the main db. One unit means 1000-watt hour. The three phase electro meters available in metal case or polycarbonate body.

Three phase energy meters are used for the power above the 10KW power. This meter is also called poly phase meters. This means it can be used to record energy consumption for more than one phase simultaneously. The same parameters are present in the three phase meters which are present in the single phase energy meter. There a few differences and changes in usage in the three phase meter. The three phase meter also records consumption in kVAH and kVArH. With this we are able to check on the meter how much load the consumer has actually used on the site and how much power factor has been used. There are advanced types of three phase meter which has advanced features like it is tamper proof, it has such features that if someone tries to remove the top cover and it gets opened, there is immediate display showing a cover open symbol along with the data and time stamping. If meter is immune from any magnetic influence and radio frequency influence or even if anyone try to used electrostatic discharge the meter will display the tampering done.

Figure 2.15 Three phase energy meters

In the three phase meter there are 8 terminals to meet the 3 phase 4 wire distribution system requirement. The eight terminals are in arranged in such way that four wires incoming in which three are phase wires and one is neutral wire

2.4 Earthling systems and MEN system Selection

EARTHING SYSTEM

Choosing the right Earthing system for your power supply is crucial to protecting both people and property. And to make the right choice, you must understand how the different Earthing systems affect electromagnetic compatibility.

An electrical installation's Earthing system determines how a power supply's (usually a transformer) neutral is connected to earth. Earthing systems were developed decades ago to protect people and property and fix the potential reference for the electrical source. In terms of electromagnetic compatibility, the different Earthing systems can cause disturbances or over voltages. This is why it is important to choose the right Earthing system when designing an electrical installation.

1.1 The four Earthing systems:

- TT: The protective earth connection is independent from that of the installation.
- IT: Neutral is isolated to the protective earth or connected by impedance.
- TN-C: Neutral and protective earth are combined.
- TN-S: Neutral and protective earth are independent.

TT system (earthed neutral)

One point at the supply source is connected directly to earth. All exposed- and extraneous-conductive-parts are connected to a separate earth electrode at the installation. This electrode may or may not be electrically independent of the source electrode. The two zones of influence may overlap without affecting the operation of protective devices.

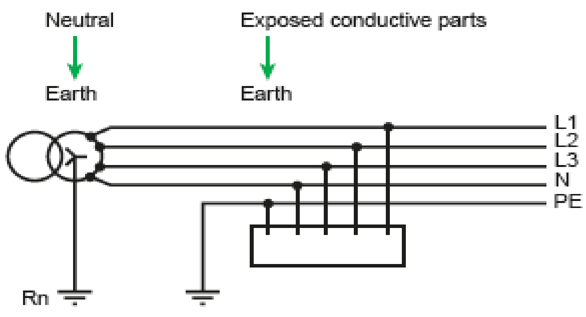


Figure 2.16 show TT system (three phase)

Earthing Arrangements Using a TT System

a. The first alphabet indicates the earthing arrangements from the supply side.
b. The second alphabet indicates the earthing arrangement in the consumer's installation.

T – First: Indicates that the supply system has its own earthing arrangements

T – Second: Indicates that all metallic frames of the electrical appliances, etc. are connected directly to earth.

The Earthing arrangement using a TT system is as shown in Figure 7.1.

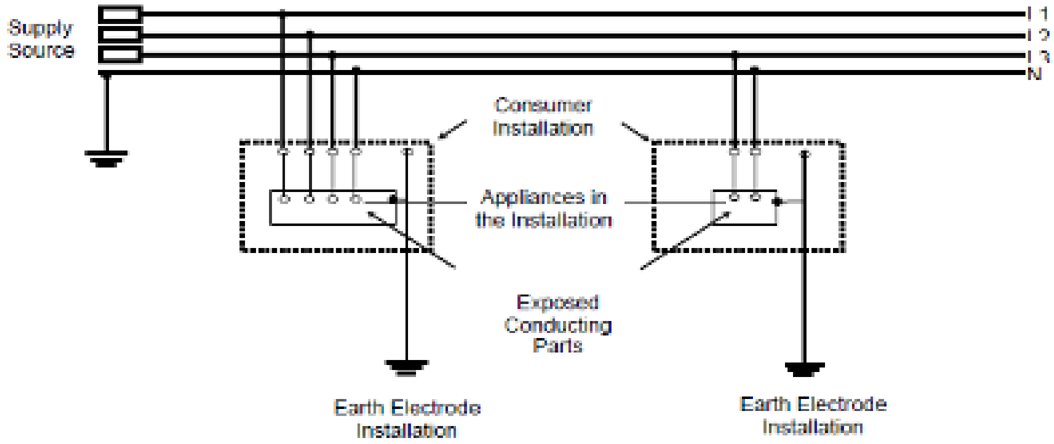


Figure 2.17: TT System Earthing (three phase and single phase)

The TT system:

- ✓ *Technique for the protection of persons: the exposed conductive parts are earthed and residual current devices (RCDs) are used*
- ✓ *Operating technique: interruption for the first insulation fault*

TN systems (exposed conductive parts connected to the neutral)

The source is earthed as for the TT system (above). In the installation, all exposed and extraneous-conductive-parts are connected to the neutral conductor. The several versions of TN systems are shown below.

TN-C system

The neutral conductor is also used as a protective conductor and is referred to as a PEN (**P**rotective **E**arth and **N**eutral) conductor. This system is not permitted for conductors of less than 10 mm^2 or for portable equipment.

The TN-C system requires an effective equipotential environment within the installation with dispersed earth electrodes spaced as regularly as possible since the PEN conductor is both the neutral conductor and at the same time carries phase unbalance currents as well as 3^{rd} order harmonic currents (and their multiples).

The PEN conductor must therefore be connected to a number of earth electrodes in the installation.

Caution: In the TN-C system, the “protective conductor” function has priority over the “neutral function”. In particular, a PEN conductor must always be connected to the earthing terminal of a load and a jumper is used to connect this terminal to the neutral terminal.

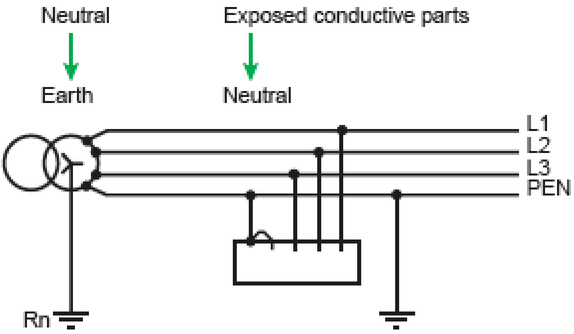


Figure 2.18 TN-S system

The TN-S system (5 wires) is obligatory for circuits with cross-sectional areas less than 10 mm^2 for portable equipment.

The protective conductor and the neutral conductor are separate. On underground cable systems where lead-sheathed cables exist, the protective conductor is generally the lead sheath. The use of separate PE and N conductors (5 wires) is obligatory for circuits with cross-sectional areas less than 10 mm^2 for portable equipment.

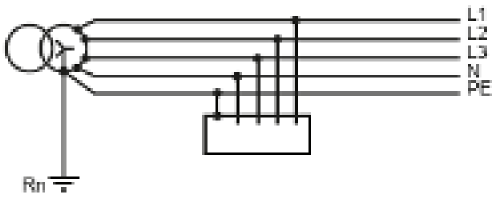


Figure 2.19 The TN-C and TN-S systems

The TN-C and TN-S systems can be used in the same installation. In the TN-C-S system, the TN-C (4 wires) system must never be used downstream of the TN-S (5 wires) system, since any accidental interruption in the neutral on the upstream part would lead to an interruption in the protective conductor in the downstream part and therefore a danger.

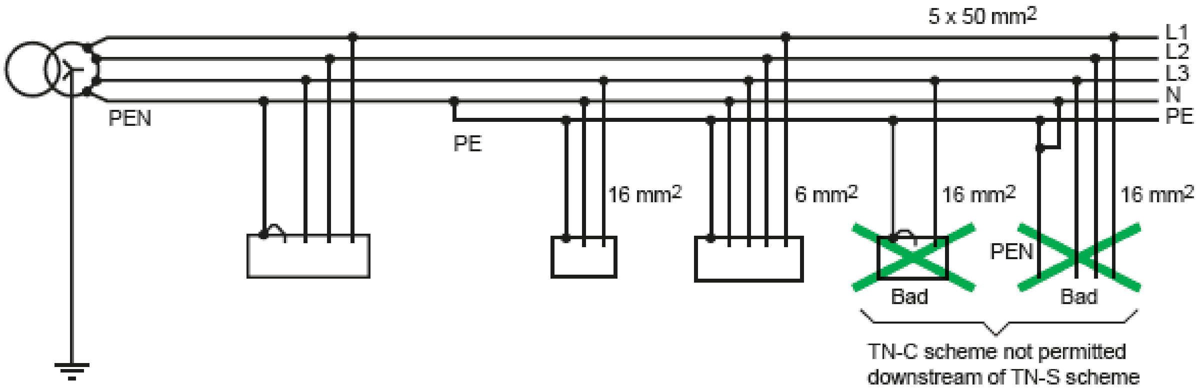


Figure 2.20 *TN-C-S system*

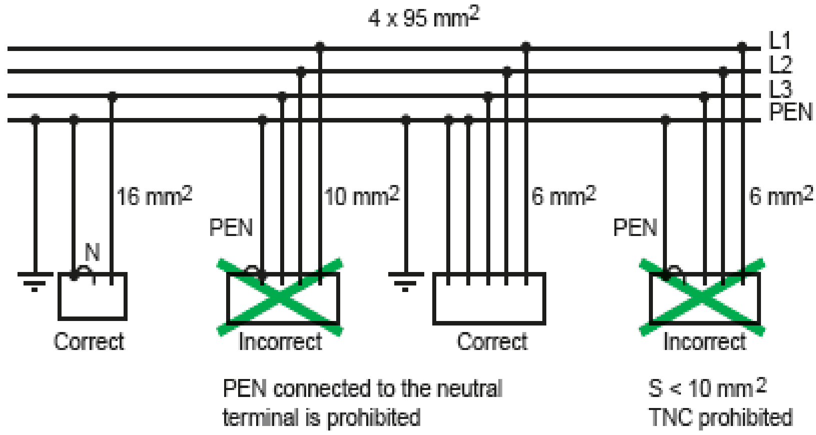


Figure 2.21 Connection of the PEN conductor in the TN-C system

The TN system:

- ✓ *Technique for the protection of persons:*
  - ✓ *Interconnection and earthing of exposed conductive parts and the neutral are mandatory*
  - ✓ *Interruption for the first fault using over current protection (circuit breakers or fuses)*
  - ✓ *Operating technique: interruption for the first insulation fault*
- **IT system (isolated or impedance-earthed neutral)**
- ✓ **IT system (isolated neutral)**

No intentional connection is made between the neutral point of the supply source and earth.

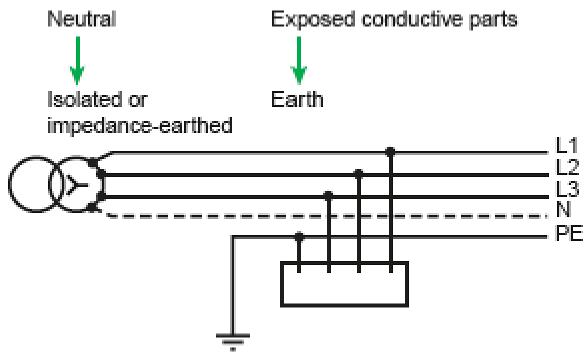


Figure 2.22 IT system (isolated neutral)

Exposed- and extraneous-conductive-parts of the installation are connected to an earth electrode.

In practice all circuits have leakage impedance to earth, since no insulation is perfect. In parallel with this (distributed) resistive leakage path, there is the distributed capacitive current path, the two paths together constituting the normal leakage impedance to earth (see Figure 2.23).

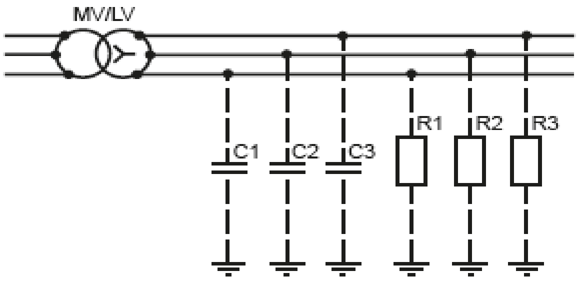


Figure 2.23: IT system (isolated neutral)

In a LV 3-phase 3-wire system, 1 km of cable will have leakage impedance due to C1, C2, C3 and R1, R2 and R3 equivalent to neutral earth impedance Zct of 3000 to 4000 Ω, without counting the filtering capacitances of electronic devices.

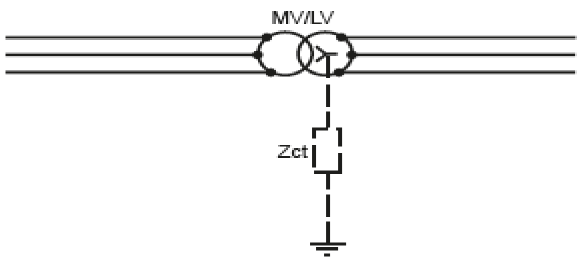


Figure 2.24: Impedance equivalent to leakage impedances in an IT system

IT system (impedance-earthed neutral)

Impedance Zs (in the order of 1000 to 2000 Ω) is connected permanently between the neutral point of the transformer LV winding and earth (see Figure 2.25).

All exposed- and extraneous-conductive-parts are connected to an earth electrode.

The reasons for this form of power-source earthing are to fix the potential of a small network with respect to earth (Zs is small compared to the leakage impedance) and to reduce the level of over-voltages, such as transmitted surges from the MV windings, static charges, etc. with respect to earth. It has, however, the effect of slightly increasing the first-fault current level.

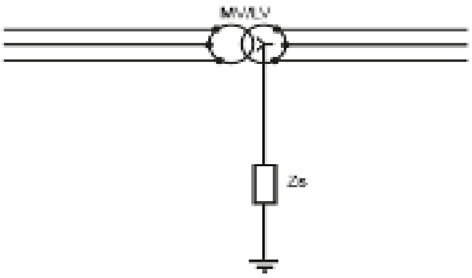


Figure 2.25: IT system (impedance-earthed neutral)

IT system:

- ✓ *Protection technique:*
  - ✓ *Interconnection and earthing of exposed conductive parts*
  - ✓ *Indication of the first fault by an insulation monitoring device (IMD)*
  - ✓ *Interruption for the second fault using overcurrent protection (circuit breakers or fuses)*
- ✓ *Operating technique:*
  - ✓ *Monitoring of the first insulation fault*
  - ✓ *Mandatory location and clearing of the fault*
  - ✓ *Interruption for two simultaneous insulation faults*

✓ **The main characteristics of the four earthing systems:**

	TT	TN-S	IT	TN-C
Protection of people	Good Residual current device are required	Good Protective earth connections throughout the installation required		
Protection of property	Good Medium fault current, in the tens of amps or less	Poor High fault current, in the thousands of amps	Good Low fault current on first fault, in the tens of milliamps; but high fault current on second fault	Poor High fault current, in the thousands of amps
Energy availability	Good	Good	Very good	Good
Electromagnetic compatibility	Good Risk of overvoltage Equipotential issues Must manage devices with high leakage current	Very good Few equipotential issues Must manage devices with high leakage current High fault currents (transitory disturbances)	Poor (not recommended) Risk of overvoltage Common mode filters and surge protectors must withstand phase-phase voltage Residual current monitors are very sensitive due to the leakage currents from EMC filters TN on second fault	Poor (to be avoided) Neutral and PE are combined 50/60 Hz and harmonics currents circulate in the earthing and grounding structures Poor equipotential situation High current fault levels

EARTHING OF ELECTRICAL INSTALLATIONS

Earthing

Earthing is a connection system between the metallic parts of an electrical wiring system and the general mass of the earth. This will provide an easy path with a low impedence or resistance to earth to enable the protection system to operate effectively. It will thus ensure safety to human beings/consumers from the dangers of electric shocks if earth leakage currents are present. In general, an electrical installation is earthed because of: -

1. Safety reasons.
2. Protection system requirements.
3. Need to limit over voltages.
4. Need to provide a path for electrical discharge.
5. Legal requirements.

Classification of Earthing

Generally, earthing can be divided into 2 parts, namely: -

i. **System Earthing**

a) To isolate the system under fault conditions;

b) To limit the potential difference between conductors which are not insulated in an area.

c) To limit the occurrence of over voltages under various conditions.

ii. Equipment Earthing

Equipment earthing is undertaken to protect human beings/consumers. If a live source comes into contact with the equipment body, electrical energy will flow to the earth, without flowing through the human being/ consumer's body. This is because of the fact that the human body has a greater resistance compared with the resistance to earth.

Types and Functions of Earthing Accessories

Earthing accessories are as follows: -

i. **Earthing Electrode: -** Copper jacketed steel core rods are used as electrodes for domestic wiring.

ii. **Equip-potential Bonding: -**This is the conductor which is connected between the consumer Earthing point and the exposed metallic part. The minimum cable size for this purpose is 10 mm^2.

iii. **Protection Conductor:**-This is the conductor which connects the consumer earthing point with other parts of the installation which needs earthing. Its size is as follows:-

iv. **Use of Protection Conductor Minimum Cross Sectional Area Rating**

The following table shows the protection conductor minimum cross sectional area in comparison with the phase conductor cross sectional area:

Phase conductor cross sectional area (S) mm^2	Protection conductor minimum cross sectional area mm^2
$S \leq 16$	S
$16 < S \leq 35$	16
$S > 35$	S/2

Parts that are required to be earthed

- All metallic structures in the wiring system (noncurrent carrying) such as metallic covers, conduits, ducts, the armour of catenary wires, etc.;
- A secondary winding point in a transformer; and
- Frame of metal roof truss.

Parts that are not required to be earthed

- Short, isolated metallic parts for mechanical protection of cables which have nonmetallic sheaths other than conduits which are connected at entry points between the building and conduits which protect discharge lamp cables;
- Cable clips for installing cables;
- Metallic covers for lamps;
- Small metallic parts such as screws and name plates which are isolated by means of insulation;
- Metallic lamp parts for filament lamps in water proof floors.

Termination to Earth

The termination to earth is done as shown in Figure below.

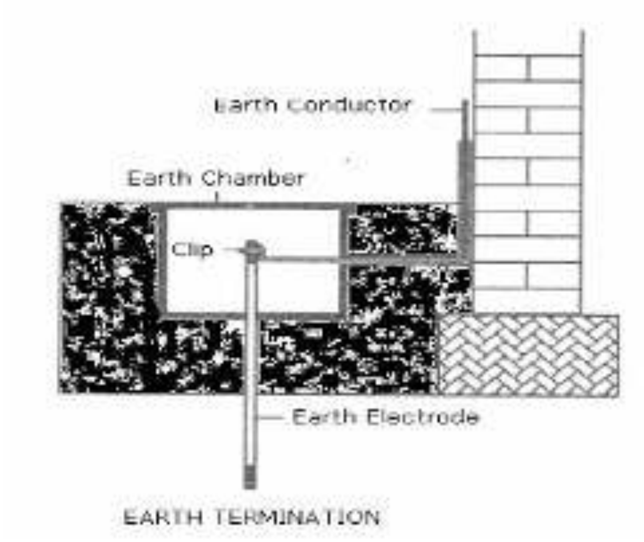


Figure show Termination to Earth

This is an essential element in protection against lightning: all the exposed conductive parts, which are themselves interconnected, must be connected, and the system must be capable of discharging the lightning current, avoiding a voltage rise in the earthing system itself and the surrounding ground.

Although it must be low enough (< 10 Ohm), the low frequency resistance value of the earthing electrode is less important than its shape and size as far as the discharge of the high frequency lightning current is concerned.

As a general rule, each down conductor must end in an earthing electrode which can consist of conductors (at least three) in a crow's foot layout buried at least 0.5 m deep, or earth rods, preferably in a triangular layout. The earth chamber is of concrete or PVC while the earth electrode is of copper jacketed steel core rod type.

Earth Electrode Resistance

The maximum permitted earth electrode resistance for different types of installations is as shown in the Table below:

Earth electrode for installations protected by RCDs of sensitivity 100mA	10 ohm
Lightning arrestor earth electrode	10 ohm

- **Select compliant earthling system components**

To select compliant Earthing system components, you can follow these steps:

1. Identify the requirements of the earthing system. What are the specific requirements of the earthing system? Consider the following factors:
    - The type of installation
    - The environment in which the earthing system will be installed
    - The applicable codes and standards
2. Research different earthing system components. There are a variety of different earthing system components available, each with its own advantages and disadvantages. Consider the following factors when selecting earthing system components:
    - The suitability of the components for the environment in which the earthing system will be installed
    - The cost of the components
    - The ease of installation and maintenance
    - The durability of the components
3. Select earthing system components that meet all of the requirements. This may involve iterating through different components to find a combination that meets all of the requirements.:

Self-Check -2

Name: ______________________________ Date: ____________________________

Time started: ________________________ Time finished: _____________________

Instructions: choose the correct Answer all the questions listed below.

1.Which of the following are the types of earthing system?

a. TT b.TN-C c.TN-S d. IT e. all

2.Which of the following are the types of earthing system in which the Neutral and protective earth are independent?

b. TT b. IT c. TN-C d. TN-S

3.Which of the following are the types of earthing system in which the Neutral and protective earth are combined?

a. TT b. IT c. TN-C d. TN-S

4.Which of the following are the types of earthing system in which the Neutral is isolated to the protective earth or connected by impedance?

a. TT b. IT c. TN-C d. TN-S

5.Which of the following are the types of earthing system in which the protective earth connection is independent from that of the installation?

a. TT b. IT c. TN-C d. TN-S

6.In general, an electrical installation is earthed because of: -

a. Safety reasons b. Protection system requirements c. Need to limit over voltages

d Need to provide a path for electrical discharge e. Legal requirements f. all

7. Which of the following are earthing accessories?

a. Earthing Electrode b. Equi-potential Bonding c. Protection Conductor d. all

Operation sheet 2.: **calculate voltage drop**

Operation Title: calculating voltage drop

Purpose: To determines the general state of **calculate voltage drop** condition quickly

Conditions or situations for the operations:

- ✓ Safe working area
- ✓ Properly operated tools and equipment

- ✓ Appropriate working cloths fit with the body

Equipment Tools and Materials:

- ✓ pepper
- ✓ calculator
- ✓ pencil

Steps in doing the task

1. Formula writing
2. calculating voltage drop
3. cheek

Quality Criteria: Assured performing of all the activities according to the procedures

Precautions:

- Wearing proper material
- Make working area hazard free
- Read and interpret manual which guide you how to use tools and equipment

UNIT Three : Electrical Installation Documentation

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- evidence from manufacturers/suppliers
- Document reasons for selections
- evidence of electrical equipment selections.

This unit will also assist you to attain the learning outcomes stated in above unit. Specifically, upon completion of this learning guide, you will be able to:

- Obtaining evidence from manufacturers/suppliers
- Documenting selection reasons of cable size, including calculations.
- . Documenting wiring systems and selected items with full specification

3.1 Obtaining Evidence from manufacturers/suppliers

Documentation is a set of documents provided on paper, or online, or on digital or analog media, such as audio tape or CDs. Examples are user guides, white papers, on-line help, and quick-reference guides. Paper or hard-copy documentation has become less common. Documentation is often distributed via websites, software products, and other on-line applications.

There are two main types of product documentation:

- ✓ System documentation represents documents that describe the system itself and its parts.
- ✓ User documentation covers manuals that are mainly prepared for end-users of the product and system administrators

In general, the evidence of different products and services obtained from the manufacturers and from the supplier's interns of the hard copy or in the electronically system.

For as long as we've had tools we need help using (and language to talk to each other), we've had technical documentation. Technical documentation can quickly go from "here's how to use this if you're unfamiliar and have limited experience one's going to get you using the product right away, while the other will make you go cross-eyed.

- . **Evidence from manufacturers/suppliers**

Here is some evidence from manufacturers/suppliers on the importance of selecting the correct wire size:

- ✓ **Evidence from Southwire:**

Southwire is a leading manufacturer of electrical wire and cable. They provide the following evidence on the importance of selecting the correct wire size:

The correct wire size is essential for ensuring the safe and efficient operation of your electrical system. If a wire is too small, it can overheat and cause a fire. If a wire is too large, it will waste energy and increase your energy costs.

Southwire also provides a wire size chart that can be used to select the correct wire size for a given circuit. The chart takes into account the following factors:

- ✓ Circuit type (e.g., branch circuit, feeder circuit, service entrance circuit)
- ✓ Current load (amps)
- ✓ Wire length (feet)
- ✓ Ambient temperature (°C)

The correct wire size is essential for the safety and reliability of your electrical system. It is important to select the correct wire size for each circuit in your system, taking into account the circuit type, current load, wire length, and ambient temperature. If you are unsure of the correct wire size to use, it is always best to consult with a qualified electrician.

3.2 Document reasons for selections

Here are some reasons for selecting the correct wire size:

- ✓ Safety: The correct wire size is essential for the safety of your electrical system. If a wire is too small, it can overheat and cause a fire. Overheated wires can also damage electrical equipment.
- ✓ Reliability: The correct wire size will ensure that your electrical system is reliable and can operate efficiently. Undersized wires can cause voltage drop, which can lead to problems for sensitive electronic equipment. Oversized wires can also cause problems, such as overheating and difficulty in installation.
- ✓ Cost: Selecting the correct wire size can help you save money in the long run. Undersized wires may need to be replaced sooner than oversized wires. Oversized wires can also increase your energy costs.

Here is an image that shows the relationship between wire size, current load, and voltage drop:

Relationship between wire size, current load, and voltage drop

3.3 Evidence of Electrical Equipment Selections.

There are several ways to find evidence of electrical equipment selections. Some common sources of evidence include:

- ✓ Engineering drawings: Engineering drawings typically show the type and size of electrical equipment that will be used in a project.
- ✓ Equipment specifications: Equipment specifications provide detailed information about the specific equipment that will be used in a project, including the manufacturer, model number, and electrical characteristics.
- ✓ Purchase orders: Purchase orders show the type and quantity of electrical equipment that has been ordered for a project.
- ✓ Installation records: Installation records show the type and location of electrical equipment that has been installed in a facility.
- ✓ Maintenance records: Maintenance records show the type and condition of electrical equipment that has been maintained in a facility.

In addition to these sources of evidence, it is also possible to find evidence of electrical equipment selections by interviewing the personnel who were involved in the selection and installation of the equipment. This may include engineers, electricians, and contractors.

Here are some specific examples of evidence of electrical equipment selections:

- ✓ A copy of the engineering drawings for a new commercial building, showing the type and size of electrical equipment that will be used in the building.
- ✓ A copy of the equipment specifications for a new industrial plant, showing the manufacturer, model number, and electrical characteristics of the electrical equipment that will be used in the plant.
- ✓ A copy of a purchase order for a new electrical panel, showing the type and quantity of electrical equipment that has been ordered.
- ✓ A copy of an installation record for a new electrical circuit, showing the type and location of the electrical equipment that has been installed in the circuit.
- ✓ A copy of a maintenance record for an electrical transformer, showing the type and condition of the transformer.

It is important to note that the specific evidence that is required to support a claim of electrical equipment selection will vary depending on the specific circumstances of the claim. For example, if a claim is being made that a particular type of electrical equipment is not suitable for a particular application, then engineering evidence may be required to support the claim.

If you are unsure whether you have sufficient evidence to support a claim of electrical equipment selection, it is always best to consult with a qualified professional.

Self-Check -3

Name: ______________________________ Date: ____________________________

Time started: ________________________ Time finished: _____________________

Instructions: choose the correct Answer all the questions listed below.

1. Which of the following is the way we obtain evidence document from the manufacturers or suppliers?

   a. on paper b. online c. on CDs d. all

2. Now a day evidence document for different product and services are distributed via__________

   a. Websites b. software products c. online applications d. all

3. Which of the following are the types of product documentation?

   a. System documentation b. User documentation c. both

4. Which of the following are the types of product documentation mainly prepared for end-users of the product and system administrators?

   a. System documentation b. User documentation c. technical documentation d. all

Developer's Profile

No	Name	Qualification (Level)	Field of Study	Organization/ Institution	Mobile number	E-mail
1	Mengistu Abiyu	MSc	Industrial Automation & Control Management	Lideta Manufacturing College	0913948480	menabiy@gmail.com
2	Samuel Bekele	MSc	Industrial Automation & Control Management	Haramaya PTC	910082977	samuelbekele460@gmail.com
3	Yidnekachew Seboka	BSc	Electrical Automation & Control Technology	Akaki PTC	920137899	www.yidne23@gmail.com
4	Zegeye Girma	BSc	Electrical Automation & Control Technology	Addis Ketema In.College	**926805563**	zegeyegirma2@gmail.com
5	Bacha Wake	MSc	Industrial Automation & Control Management	Hawassa Tegibarid PTC	**987065251**	bachawake@gmail.com

የሥራና ክህሎት ሚኒስቴር
Ministry of Labor and Skills