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Lecture Notes

Industrial Electrical Networks

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The objectives of the course

This course aims to provide students with an overview of industrial electrical networks (architectures, diagrams, and plans), followed by the information necessary to evaluate electrical installations and the principles to be followed for safe intervention on such installations.

By the end of this course:

Students will have:

The ability to understand any structure of an industrial electrical network;

Understanding the operation of industrial electrical networks;

Understanding the different components of an industrial electrical network;

Understanding the different types of disturbances in an industrial electrical network;

Understanding how to improve the quality of an industrial electrical network; Understanding the importance of the neutral grounding system in an industrial electrical network;

Understanding how to size an industrial electrical network (calculating cable cross-section and circuit breaker ratings).

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PREFACE

Preface

This document is a course handout for "Industrial Electrical Networks," developed in accordance with the official curriculum approved by the Ministry of Higher Education and Scientific Research. Its content is the result of several years of teaching this module in our department and also reflects the reading of numerous books and documents, the most important of which are cited in the bibliography.

This document is primarily intended for first-year Master's students in Electromechanical Engineering, but it will also be useful to other students in Electromechanical Engineering or Electrical Engineering.

Its overall objective is to provide students with an overview of industrial electrical networks (architectures, diagrams, and plans), followed by the information necessary to evaluate electrical installations and the principles to be followed for safe intervention on such installations. Through the content of the various chapters in this handout, the reader (student or otherwise) will have the opportunity to develop their knowledge of different network concepts, particularly those related to industrial electrical networks.

This handout is structured into six chapters:

Chapter 1 presents general information on standardization, voltage ranges, switchgear, and diagram symbols.

Chapter 2, entitled "Industrial Electrical Networks," deals specifically with the general structure of an industrial network, including delivery substations, main and sub-distribution boards, backup power, and uninterruptible power supplies (UPS).

Industrial electrical installations are covered in Chapter 3.

Chapter 4 extensively addresses grounding and safety in electrical installations, particularly low-voltage networks.

Chapter 5 presents the essentials of installation calculations, while the final chapter covers wiring and maintenance of electrical installations.

Hoping that this document will meet with the satisfaction and appreciation of my colleagues and students, I would be very happy to receive their comments and suggestions via email.

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CHAPTER I

GENERAL INFORMATIONS

General Objectives:

- To gain an overview of the electrical network

- To identify the main standards applied in electrical installations and the standards bodies involved.

- To understand the importance of standards.

- To know the voltage ranges

- To know the electrical symbols used in electrical diagrams (Power supply, Control devices, Loads, Connection devices, signaling devices).

Introduction

Industrial electrical networks are the natural extension of the distributor's network to which they connect, ensuring the power supply for industrial equipment such as electric motors, lighting, and various production machines, etc. Their design always begins with a technical study based on the electricity needs and ends with the construction of a vast network of lines, composed of cables, electrical delivery substations, protection devices, and control and disconnection systems.

1. Definition of the Electrical Network

A network is a set of works and equipment (overhead and underground lines, substations, cables, switchgear, transformers, surge arresters, etc.) which, assembled together, have the function of interconnecting production centers such as hydroelectric, thermal power plants, etc., with consumption centers (cities, factories, etc.).

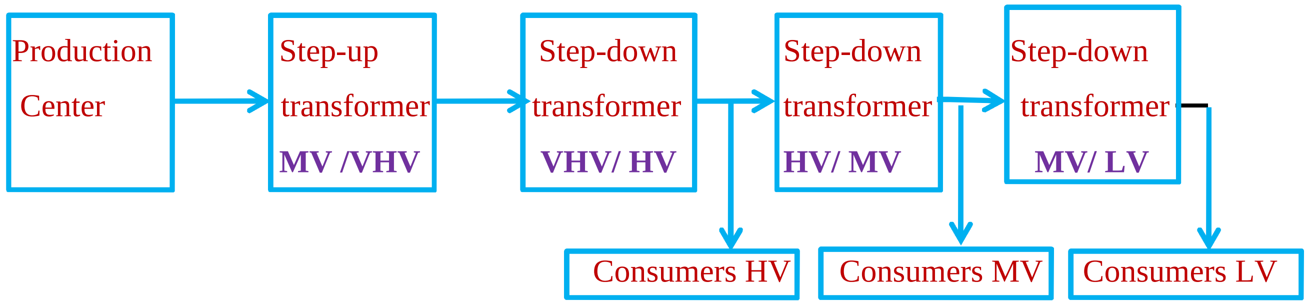


Figure I.1 Simplified diagram of an electrical network

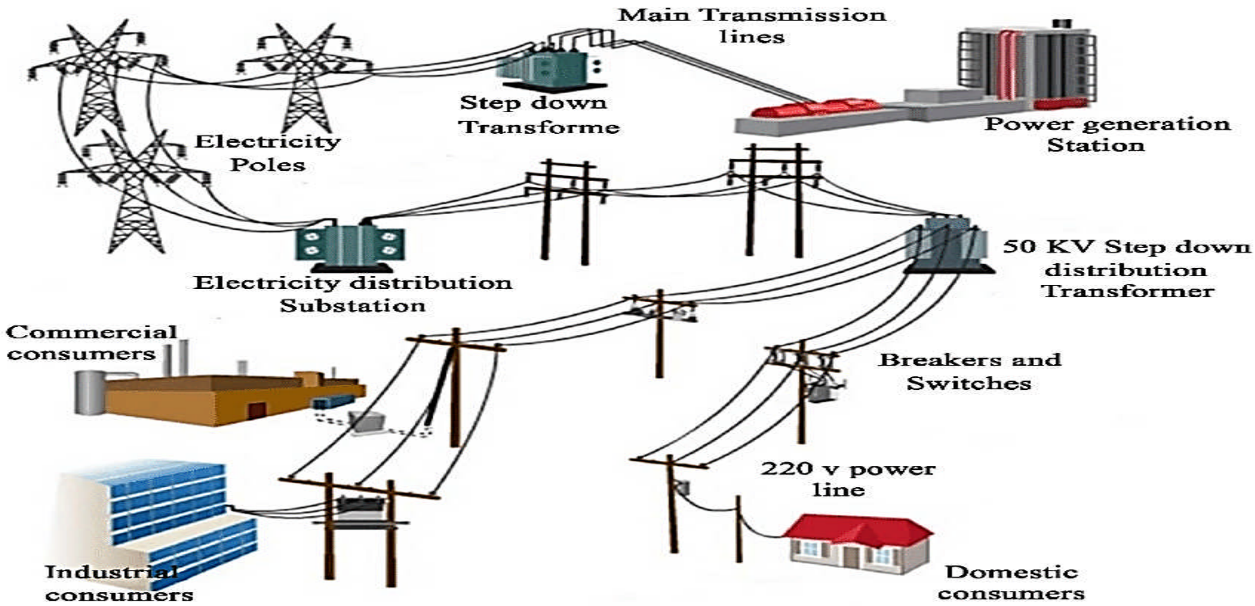


Figure I.2 Representative figure of an electrical network

2. Standardization

Standardization is an activity of general interest that aims to provide, by consensus, reference documents containing guidelines, rules, methods, and technical or quality specifications relating to products, methods, services, or practices. In other words, it serves to establish industrial norms and standards as a common reference intended to harmonize the activity of a sector.

It includes all the technical rules that allow:

- The specification and standardization of different devices,
- The uniformity of their graphic representation and wiring diagrams.

In electricity: An electrical diagram is a means of representing electrical circuits and installations; it is therefore a language that must be understood by all electricians. For this reason, representation rules must be followed. These rules are classified in international standards.

The objective of such international standardization is to establish a common language among electricians that facilitates the writing, reading, and understanding of electrical diagrams. The International Electrotechnical Commission (IEC), established in 1906, develops standards applicable to electricity and electronics.

2.1. The Standard

A standard is the result of an open process aimed at the common good, orchestrated by a duly authorized body on behalf of a group of interested parties.

"A document established by consensus and approved by a recognized body that provides, for common and repeated use, guidelines or characteristics for activities or their results, ensuring an optimal level of order in a given context." Any organization may or may not use or refer to it.

2.2. Role of Standards

Standards play a crucial role:

• They establish precise characteristics to define the limits of a product's use, taking into account the intended audience.

• They define the tests required to guarantee safe and non-polluting behavior throughout the product's entire life cycle, including its recycling.

2.3. The advantages of standardization

For the company:

• Produce according to predefined and recognized plans and programs.

• Enable operational efficiency.

• Reduce production costs, improve productivity and processes.

• Have technical standards as a selling point and consequently strengthen competitiveness.

For the consumer:

• Easier comparison and choice.

• Satisfying their needs and fulfilling the product's expected functions.

• Benefiting from guarantees of quality, consistency, safety, and interchangeability.

• Enjoying better value for money.

For public authorities:

• Simplify and accelerate the work of regulators.

• Support good regulatory practices.

• Limit, or even eliminate, technical barriers to trade.

• Improve the quality of life for consumers.

• Increase the competitiveness of businesses nationally and internationally.

• Enable better implementation of public policies.

• Address unfair competition.

2.4. International Standardisation Bodies:

1. ISO: International Organization for Standarization;
2. IEC: International Electrotechnical Commission;
3. CEN: Comité Européenne de Normalisation;
4. AFNOR: Association Française de Normalisation;
5. BSI: British Standards Institution;
6. DIN: Deutshes Institut fur Normung.

2.5. Standardization bodies in Algeria:

The organization and operation of Algerian standardization are governed by Executive Decree No. 464 of December 5, 2005, which defines the following standardization bodies:

1. The National Standardization Council (CNNOR);
2. The Algerian Institute for Standardization (IANOR);
3. The National Technical Committees (CTN);
4. The Standardization Bodies (OAN)

2.6. Some examples of standards:

IEC 27-1: Literal symbols for use in electrical engineering

IEC 617-2: Graphical symbols for diagrams, symbol elements, distinctive symbols and other symbols of general application

IEC 617-7: Graphical symbols for diagrams, switchgear and control and protection devices

NF C 13-100: Delivery substations located inside a building and supplied by a second-category public distribution network

NF C 13-200: High-voltage electrical installations

NF C 15-100: Low-voltage electrical installations

3. Voltage levels

Voltage levels are defined by IEC 60038 with the following definitions:

• Low Voltage (LV): From 0 to 1000 V.

Standard values are: 230 V (single-phase), 400 V (three-phase).

• Medium Voltage (MV): From 1 kV to 50 kV.

Standard values are: 3.6 kV, 7.2 kV, 12 kV, 24 kV, 36 kV, 40.5 kV

• High Voltage (HV): From 50 kV to 230 kV.

The standard values are: 110 kV, 145 kV, 220 kV

• Very High Voltage (VHV): From 230 kV to 500 kV

The standard values are: 300 kV, 400 kV, 500 kV

• Ultra High Voltage (UHV): Above 500 kV

The standard values are: 750 kV, 1100 kV

The new standard in force in France, UTE C 18-510, defines alternating voltage levels as follows:

- HV: for a line voltage greater than 50 kV
- MV: for a line voltage between 1 kV and 50 kV
- LV: for a line voltage between 500 V and 1 kV
- LV: for a line voltage between 50 V and 500 V
- ELV: for a line voltage less than or equal to 50 V

In Algeria, the voltage levels used are:

LV: 220/380V

MV: 30kV overhead, 30kV and 10kV underground

HV: 60kV, 90kV, 150kV, 220kV, 400kV.

4. Equipment

4.1. Definition

Electrical equipment is an element that ensures the protection and safe, uninterrupted operation of an electrical network.

Perfect control of electrical energy requires all the necessary means to command and control the flow of current in the circuits that run from power plants to consumers. This critical task falls primarily to electrical switchgear. It must be available at all times and able to operate flawlessly, to the point of being almost invisible.

4.2. Basic functions for equipment

Regulations define three basic functions for switchgear in the design of an electrical installation:

Isolation function

Control function

Protection function

4.2.1. Isolation Function

Isolators are designed to visibly open an electrical installation without loads at any point.

4.2.1.1. Disconnecting Devices

a- The Disconnector (isolator)

This device allows the upstream live section of an electrical circuit to be separated (isolated) from the downstream section. The circuit is isolated under no-load conditions by opening all the conductors of the electrical lines. The disconnect switch does not have breaking or making capabilities. Locking is achieved with a padlock**.**

Figure I.3 Disconnector (isolator)

b- The fuse-type disconnect switch

It allows the upstream live section of an electrical circuit to be isolated and protected from the downstream section.

Figure I.4 fuse holder switch

c- Disconnect Switch

It allows for the manual separation and interruption (opening or closing) of a circuit under load. It has a breaking capacity (Pdc).

Figure I.5 Disconnect Switch

4.2.2. Command function

There are two types of control: functional control and safety control.

Functional control (normal operation) ensures that an electrical system is switched on or off.

Safety control (emergency stop) ensures that an electrical system is switched off in the event of a danger to property or people.

4.2.2.1. Control Devices

a- The switch

It allows an electrical circuit to be established or interrupted (closed or opened) manually.

Figure I.6 Switch

b- The Contactor

A contactor is a mechanical switching device with a single rest position and a single working position. It is capable of making, carrying, and breaking currents under normal circuit conditions, including overload conditions during operation. The advantage of a contractor is its ability to be controlled remotely.

Figure I.7 Contactor

c- The commutator

It allows one or more electrical circuits to be manually established or interrupted. It has several operating positions (Open or Closed). There are several types of switches.

Figure I.8 Commutator

d- Electromagnetic Relay

An electromagnetic relay, in its switching principle, is similar to a mechanical switch, but its operation is not performed manually, but by passing a current through the relay's excitation circuit. This circuit consists of a coil called the excitation coil or control coil.

Figure I.9 Electromagnetic Relay

4.2.3. Protection function

It helps to limit the destructive or dangerous consequences of overcurrent's or insulation faults and to separate the defective part from the rest of the installation.

4.2.3.1. Protective Devices

Protective devices trip in case of anomalies (short circuit, overcurrent, etc.).

Breaking capacity (BC) is the maximum current a device can interrupt while preventing the formation of an electric arc that could dangerously delay the current interruption.

a- The Circuit Breaker

Thermal circuit breaker

It protects an electrical circuit against current overloads (overvoltage in an electrical network) or a high current surge when a motor starts.

Figure I.10 Thermal circuit breaker

Magnetic circuit breaker

It protects an electrical circuit against short circuits. The circuit breaker reacts to a change in current by the movement of a soft iron core, which mechanically opens the protected circuit.

Figure I.11 Magnetic circuit breaker

b- The Fuse

It protects an electrical circuit against short circuits by melting the active part of the fuse. It contains a silica beam to quickly extinguish the electrical arc and ensure insulation after the break. There are several types of fuses: gG cartridges (industrial use), aM cartridges (motor protection), and UR cartridges (ultra-fast, protecting electronic components).

Figure I.12 Fuse

c- Thermal Overload Relay

This is an overload protection device. The thermal overload relay consists of a bimetallic strip calibrated according to the relay's operating range. When current flows through the strip, the bimetallic strips deform, but in the event of an overload, the strips will deform so much that they will trigger the contact.

Figure I.13 Thermal Overload Relay

d- Residual Current Circuit Breaker and Switch

It protects people against indirect electric shocks (TT system against indirect contact), and also protects electrical equipment. It is characterized by: Rated voltage and current; frequency; temperature; and residual current**.**

Figure I.14 Circuit breaker

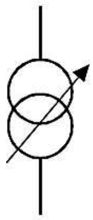
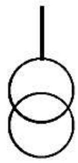
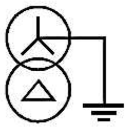
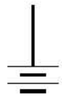
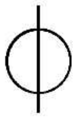
Figure I.15 Differential switch

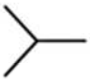
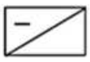
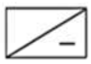
5. Abbreviations

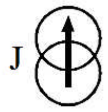
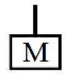
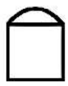
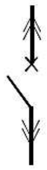
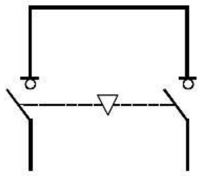
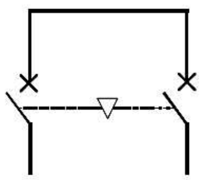
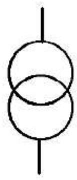
- UPS : uninterruptible power supply
- PIM : permanent insulation monitor
- RCD : residual current device
- IT : unearthed neutral and earthed exposed conductive part
- N : neutral
- NC : normally closed
- NO : normally open
- PE : protective conductor
- PEN : combined protective and neutral conductor
- Ph1, Ph2, Ph3 : phase 1, 2, and 3
- TN : earthed neutral and neutral-connected exposed conductive part

- TNC : earthed neutral, neutral-connected exposed conductive part, combined neutral and protective conductor
- TNS : earthed neutral, neutral-connected exposed conductive part, separate neutral conductor and protective conductor
- TT : earthed neutral and earthed exposed conductive part
- Z1//Z2 : signifies that impedances Z1 and Z2 are in parallel.
- LV Low voltage.
- MV Medium voltage.
- HV High voltage

6. graphic symbols of diagrams

	transformer fitted with an on-load tap changer		voltage transformer
	artificial neutral or earthing transformer		battery
	current transformer		A.C. generator or alternator
	asynchronous generator		motor

	three-phase line or cable		single-phase line or cable
	short circuit		earth electrode
	outgoing feeder		supply incoming feeder
	resistor		variable resistor
	reactor or transformer, motor or generator winding		iron core reactor
	capacitor		impedance (Z, R, L or C)
	star-connected winding		delta-connected winding
	varistor or surge arrester		spark gap or overvoltage limiter
	diode		thyristor
	inverter		rectifier

	source of current		metering
	measuring device		electrical power outlet
	switch disconnector		isolator
	fuse		switch-fuse
	circuit-breaker		circuit-breaker fitted with a (thermal) overload and (magnetic) short-circuit trip relay
	contactor		fuse contactor
	drawout circuit-breaker		changeover switch
	changeover circuit-breaker		transformer

Evaluation

Comprehension questions

1. List and discuss the advantages of standardization.
2. Give the symbol for a circuit breaker and state its function.
3. Give the symbol for a disconnect switch and state its function.
4. State the difference between a circuit breaker and a disconnect switch.
5. State the function of a limit switch and its symbol.
6. Give the symbol for a contactor and describe its components.
7. Why is electricity transmitted at high voltage?
8. Why has alternating current become widespread on electrical networks?
9 Why sinusoidal current?
10. Why is electricity transmitted in three-phase?

See the answers in Appendix A

CHAPTER II

INDUSTRIAL ELECTRICAL NETWORKS

General objectives:

- Identify the types of diagrams, tables, and charts used;
- Choose the most appropriate representation method for the application;

Introduction

An electrical grid is a set of infrastructure that transmits electrical energy from power generation centers to electricity consumers.

It consists of power lines operating at different voltage levels, connected to each other in substations. Substations distribute the electricity and convert it from one voltage to another using transformers.

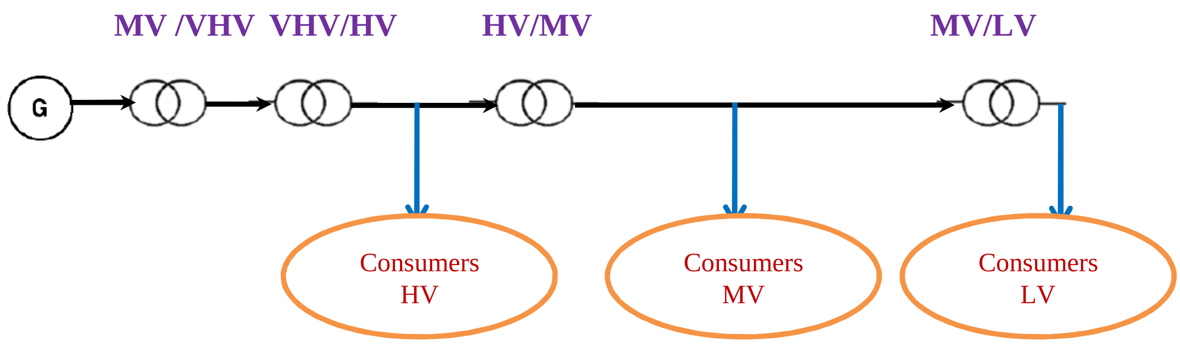
An electrical grid must also ensure the dynamic management of the entire production-transmission-consumption process, implementing adjustments to ensure overall stability.

The architecture of an industrial electrical distribution network varies in complexity depending on the voltage level, the power demand, and the required power reliability.

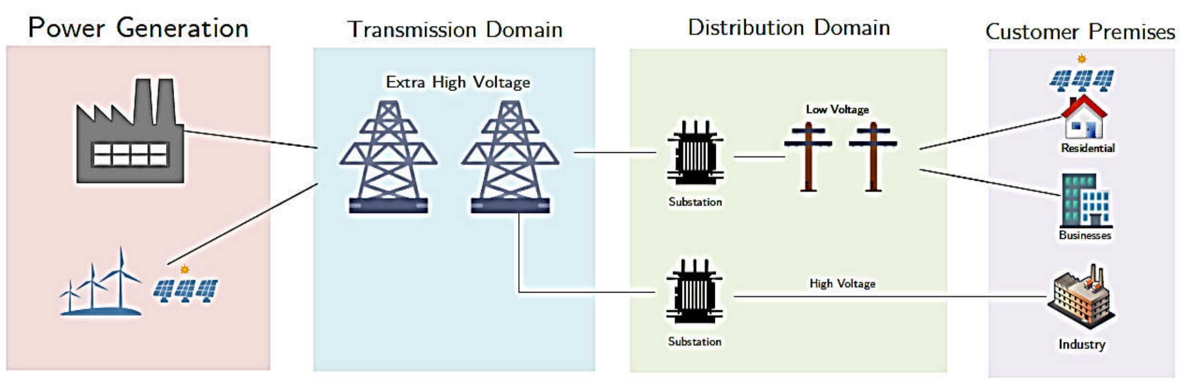
We will identify the different high-voltage (HV) and medium-voltage (MV) delivery substations, and the structure of MV and low-voltage (LV) networks.

1.General structure of a network

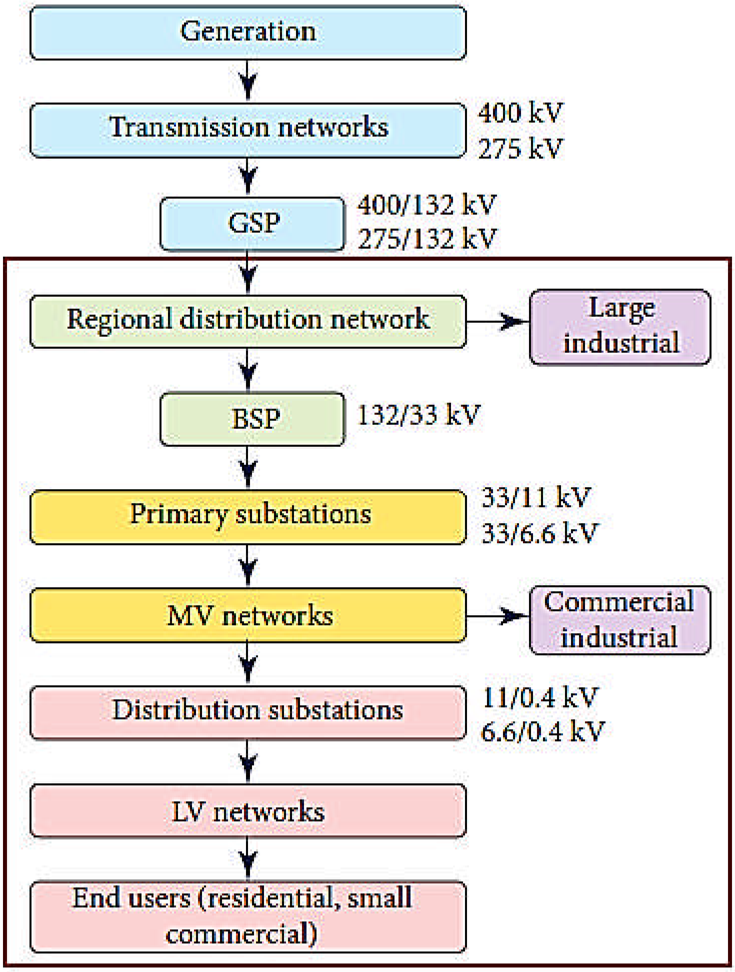
The following figures represent the general configuration of an electrical network with different shapes



(a)



(b)



(c)

Fig. 1: (a), (b), (c): A typical architecture of a power grid with different shapes

1.1 Large generation centers

A high amount of electric energy is generated using bulk generation units clustered in remote areas that are away from final consumption points.

Traditionally, various technologies have been used to generate bulk electric energy, such as nuclear, natural gas, coal, hydro, etc. The existing power systems were owned by one company. However, due to lower costs and the economies of scale, they were allowed to build such bulk power plants large, and some of them are still profitable.

1.2 Transmission network

Transmission network includes substations, lines, and equipment to connect large power plants to load centers where the consumption of power is mostly performed in cities and industrial areas. Transmission lines in transmission networks operate at high-voltage levels (above 220 kV) that can cover long distances and transport large quantities of energy; therefore, these lines operate at high-voltage levels.

1.2.1 Subtransmission network

A subtransmission network is considered as an intermediate link between distribution and transmission networks. Subtransmission network lines cover shorter distances compared to those of the transmission networks and that is why they operate at a lower level, i.e., 45, 66, and 132 kV. Voltage reduction is needed because of the voltage level differences in transmission network. Bulk load demands, such as big industries, can be directly connected to the subtransmission network.

1.3.1 Primary distribution network

The main part of the primary distribution network is the distribution substation that receives the energy delivered by the transmission and subtransmission networks and performs another voltage reduction. From medium voltage distribution lines, e.g., 11 and 25 kV, or distribution substation, the energy will be taken one step closer to end users; thus, bulk load demands can be connected to primary distribution networks.

1.3.2 Secondary distribution system (distribution substation)

Secondary distribution network includes medium voltage/low voltage (MV/LV) step-down transformers and LV lines, for example, 230 and 400 V, which deliver the power generated to LV commercial and residential consumers.

2. Industrial Network Structure

In general, an industrial network (or a private distribution network) comprises:

- A high-voltage (HV) delivery substation (60kV or 220kV) supplied by one or more sources, consisting of one or more busbars and protective circuit breakers;
- An internal generation source (for example, a generator set or a photovoltaic solar power system);
- One or more HV/MV transformers (60kV/30kV) (as required);
- A main MV distribution panel (30kV) consisting of one or more busbars;
- An internal MV (30kV) electrical distribution network supplying secondary electrical distribution panels or MV/LV transformer substations;
- MV loads;
- MV/LV transformer substations (30kV/380V);
- Low-voltage distribution panels and networks;
- Low-voltage loads.

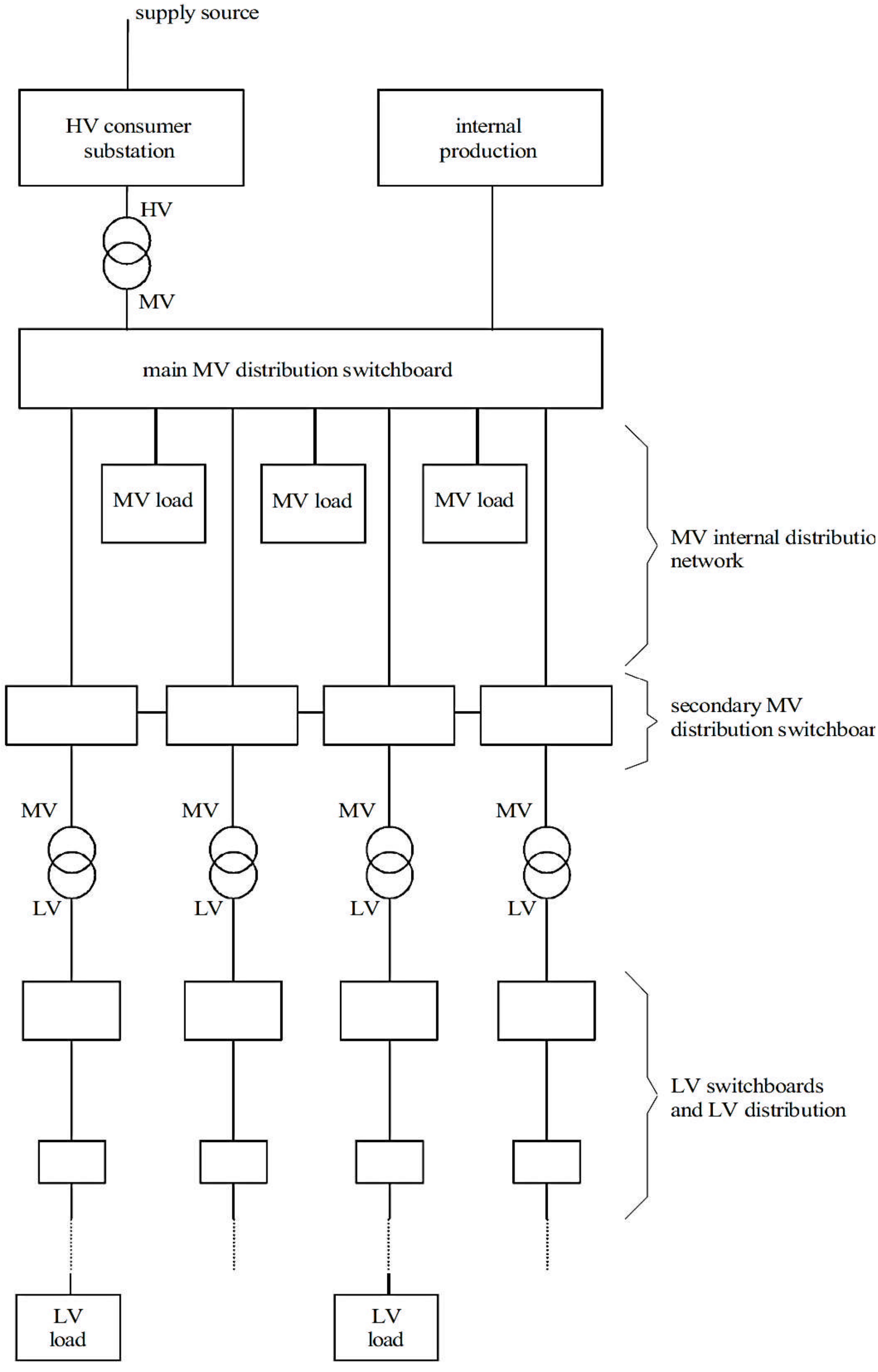


Figure.2: General structure of a private distribution network

2.1Power Supply Sources

In Algeria, industrial electrical networks can be powered by one of the following methods:

- High Voltage (HV): This means the voltage exceeds 50 kV, typically 60 kV, 90 kV, 150 kV, or 220 kV.
- Medium Voltage (MV): The voltage ranges from 1 kV to 50 kV, typically 30 kV in Algeria.
- Low Voltage (LV): The voltage is less than 1 kV, typically 380 V in Algeria.

2.2 Delivery Substations

2.2.1. High Voltage (HV) Delivery Substations

These generally concern power ratings above 10 MVA. The delivery substation installation is located between:

- On the one hand, the connection point to the HV distribution network
- On the other hand, the downstream terminal of the HV/MV transformer(s)

The electrical diagrams of the most commonly encountered HV delivery substations are as follows:

2.2.1.1 Single power supply

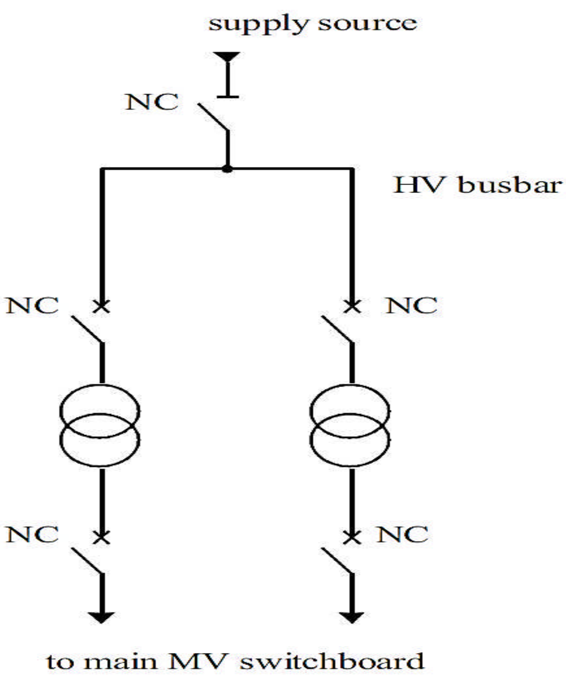


Figure 3: single fed HV consumer substation

Advantage: Reduced cost

Disadvantage: Low availability

2.2.1.2 Dual power supply

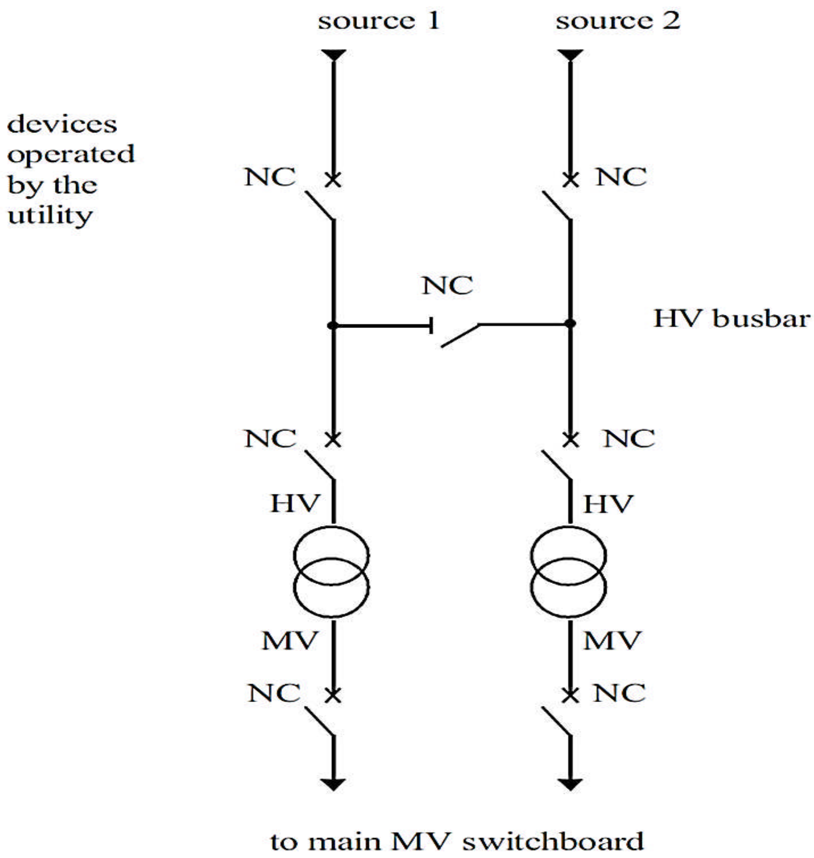


Figure 4: dual fed HV consumer substation

Advantages:

- good availability in that each source can supply the entire network
- maintenance of the busbar possible while it is still partially operating

Disadvantage:

- more costly solution than the single power supply system
- only allows partial operation of the busbar if maintenance is being carried out on it

2.2.1.3 Dual fed double bus system

Advantages :

- Good supply availability.
- Highly flexible use for the attribution of sources and loads and for busbar maintenance
- Busbar transfer possible without interruption (when the busbars are coupled, it is possible to operate an isolator if its adjacent isolator is closed).

Disadvantage:

- More costly in relation to the single busbar system

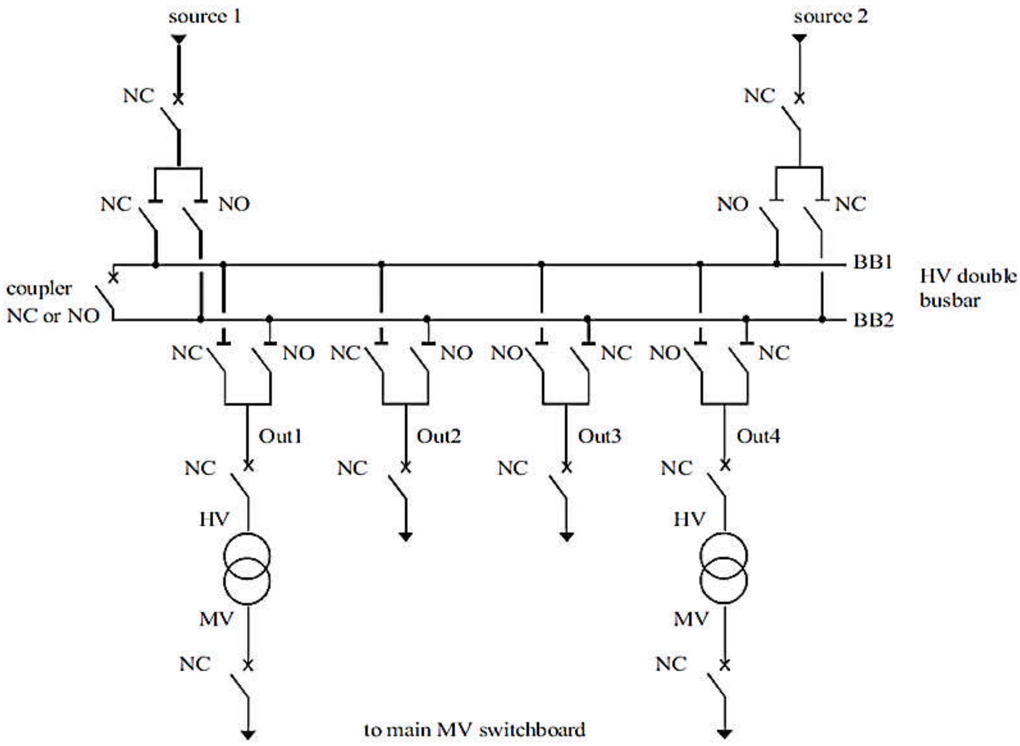


Figure 5: dual fed double bus HV consumer substation

2.3 MV power supply

We shall first look at the different MV service connections and then the MV consumer substation.

2.3.1. Different MV service connections

According to the type of MV network, the following supply arrangements are commonly adopted.

2.3.1.1 Single line service

The substation is fed by a single circuit tee-off from an MV distribution (cable or line). Up to transformer ratings of 160 kVA this type of MV service is very common in rural areas. It has one supply source via the utility

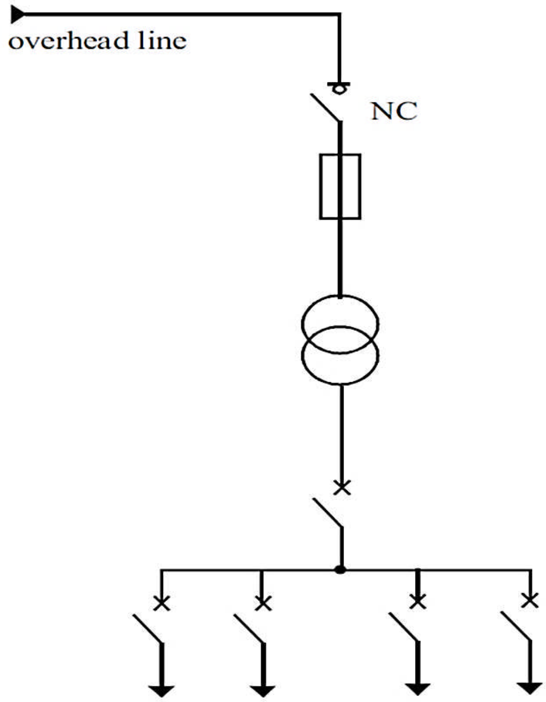


Figure 6: single line service

2.3.1.2 Ring main principle

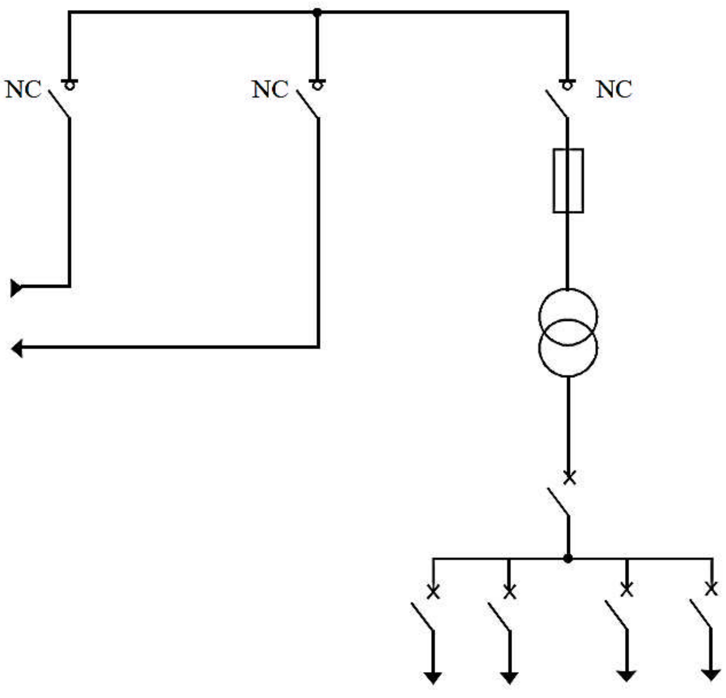


Figure 7: ring main service

Ring main units (RMU) are normally connected to form an MV ring main or loop

This arrangement provides the user with a two-source supply, thereby considerably reducing any interruption of service due to system faults or operational maneuvers by the supply authority. The main application for RMUs is in utility MV underground cable networks in urban areas.

2.3.1.3 Parallel feeder

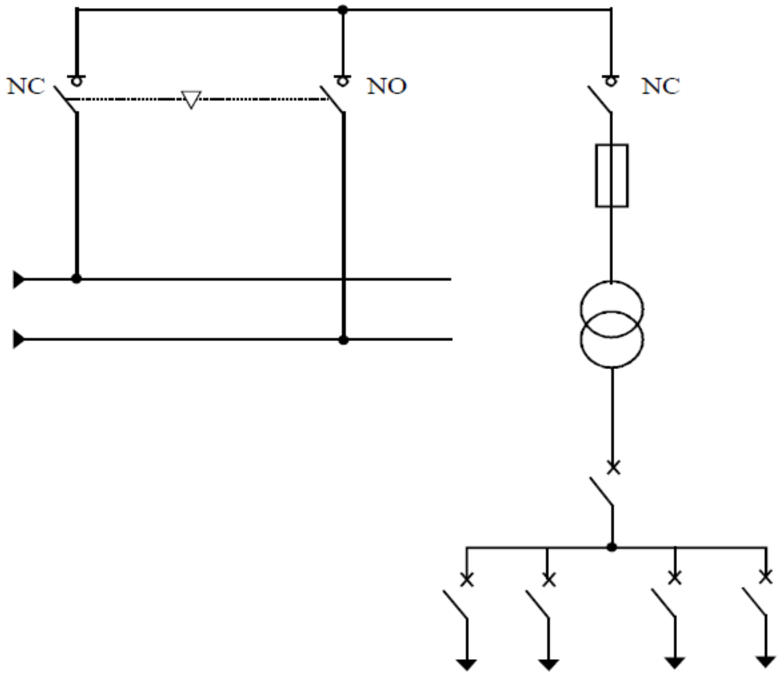


Figure 8: duplicated supply service

When an MV supply connection to two lines or cables originating from the same busbar of a substation is possible, a similar MV switchboard to that of an RMU is commonly used .

The main operational difference between this arrangement and that of an RMU is that the two incoming switches are mutually interlocked, in such a way that only one incoming switch can be closed at a time, i.e. its closure prevents that of the other.

On loss of power supply, the closed incoming switch must be opened and the (formerly open) switch can then be closed. The sequence may be carried out manually or automatically. This type of switchboard is used particularly in networks of high load density and in rapidly expanding urban areas supplied by MV underground cable systems.

2.4 LV Distribution networks:

2.4 .1 LV network topologies

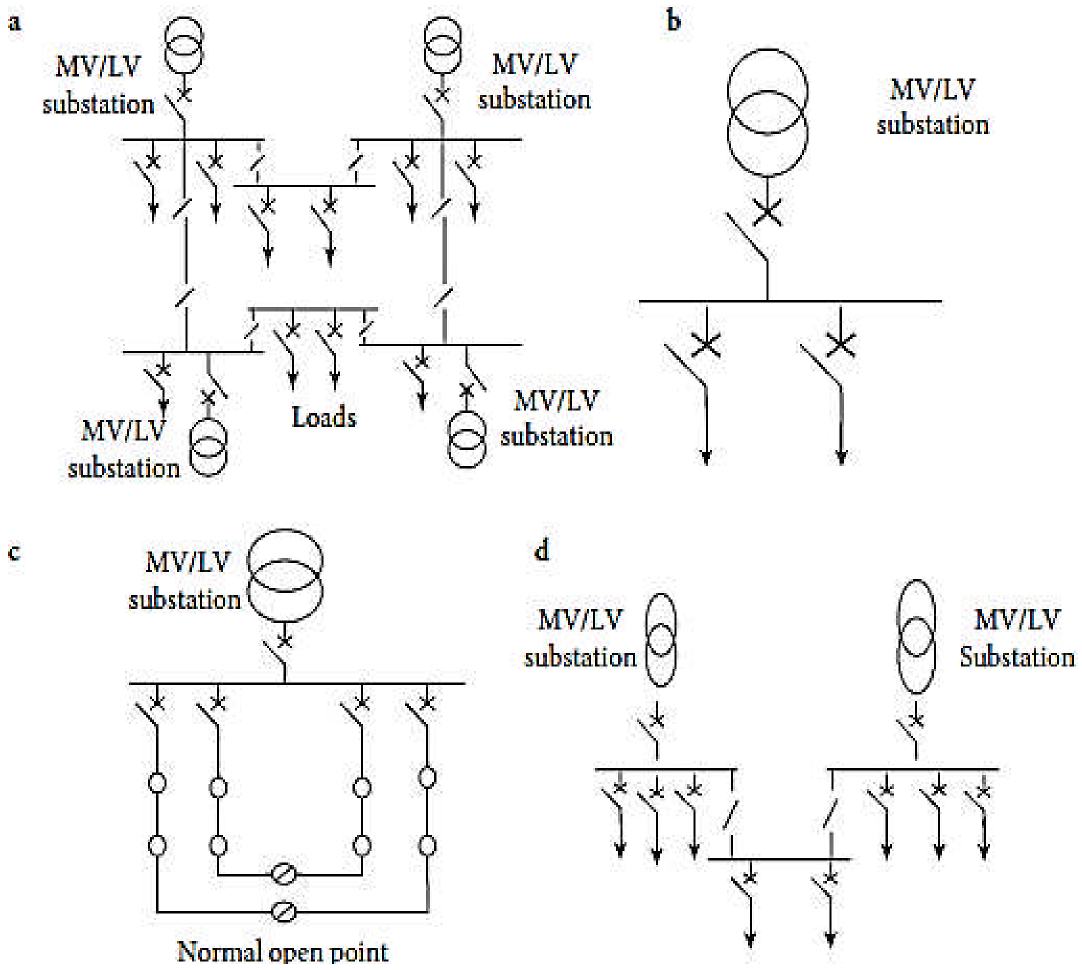


Figure 9: LV network topologies: (a) loop or ring mesh arrangements, (b) radial arrangement, (c) open loop arrangements,(d) parallel interconnected arrangements.

2.4 .2 LV network characteristics

Based on the above investigation, the main characteristic of the LV distribution network is listed as follows:

*1. **Large number of buses***: the LV network is to supply many domestic consumers.

*2. **The network is not monitored***: a significant part of the metering system, particularly the household meter, is still without a communication system with the network operators or smart meters. The advanced metering infrastructure (AMI) is still in the early stage of installation, which leads to the lack of understanding of the LV networks' real state and, thus, a high number of uncertainties.

*3. **Operated in radial or weakly meshed topology***: the majority of LV network configurations is radial, and this simplifies the power flow analysis.

*4. **High R/X ratios compared with HV and MV networks***: especially in the case of underground cables, which makes resistance a very important factor in determining the voltage, where the voltage angle is approximately constant at the LV network.

5. ***Highly violated load pattern***: the load pattern is unbalanced with a high level of uncertainty

3 Electrical Substations

An electrical substation is a component of the electrical grid used for both the transmission and distribution of electricity. It allows the voltage to be increased for transmission and then reduced for consumption by users (residential or industrial). Electrical substations are therefore located at the ends of transmission or distribution lines.

According to the definition of the International Electrotechnical Commission, an electrical substation is "the part of an electrical grid, located in a single place, comprising mainly the ends of transmission or distribution lines, electrical equipment, buildings, and, possibly, transformers."

Figure 10: Electrical Substations

3.1 Function of Electrical Substations

3.1.1 Directing Electricity

The electrical substation directs electricity according to the needs of consumers and the transmission capacity of the power lines.

3.1.2 Voltage Increase or Decrease

The voltage of the electricity supplied by the grid is modified by one or more transformers housed in a substation. The highest transmission voltage is generally 400,000 volts. Then, at electrical substations, it is successively reduced from one voltage level to another, down to the operating voltage of the distribution network (230 volts between phases and neutral for homes and small businesses).

3.1.3 Protection (Circuit Breakers)

In the event of a fault on the protected line, the current is interrupted;

Figure 11: Circuit Breakers

3.1.4 Isolation (disconnectors)

When a line is short-circuited by an environmental hazard (lightning, tree, etc.), the malfunctioning section is quickly isolated from the healthy network by a monitoring system located in the electrical substations;

3.1.5 Safety

Grounding;

3.1.6 Possible conversion of the electrical signal

From alternating current to direct current or vice versa.

3.2 Types of Electrical Substations

There are several types of electrical substations:

• **Power plant output substations**: the purpose of these substations is to connect a power plant to the grid;

• **Interconnection substations**: the purpose is to interconnect several power lines;

• **Step-up substations**: the purpose is to increase the voltage level using a transformer;

3.3 Distribution substations: the purpose is to reduce the voltage level to distribute electrical power to residential or industrial customers.

The appearance of electrical substations varies greatly depending on their function. Substations can be located above ground within an enclosure, or underground, within the buildings they serve.

3.3.1 Substation Components

Primary equipment includes:

• Electrical transformer

• Electrical autotransformer

• High-voltage circuit breaker

• Disconnect switch

• Grounding switch

• Surge arrester

• Current transformer

• Voltage transformer

• Combined current and voltage meter

• Busbars

• Capacitor bank

• Shunt reactance

Secondary equipment includes:

• Protection relays

• Monitoring equipment

• Control equipment

• Remote control system

• Energy metering

• Auxiliary power supplies

• Telecommunications equipment

• Status recorder.

Figure 12: Substation Components

4 Electrical Panels

An electrical panel is a distribution board containing various types of equipment associated with one or more outgoing electrical circuits supplied by one or more incoming electrical circuits, as well as terminals for the neutral and protective conductors.

Depending on the size of the installation, this assembly can be a simple box (apartment, house), a cabinet, or an entire room with various cabinets and boxes.

Figure 13: Electrical Panel

4.1Types of Electrical Panels

4.1.1 Main Panel

The main panel is the heart of any electrical installation. It is the first point of electricity distribution after the meter and plays a crucial role in protecting the entire electrical system. This panel houses the main protective devices, such as main circuit breakers, residual current devices (RCDs), and, in some cases, energy management devices. It is designed to ensure efficient and safe distribution of electricity to the various circuits in the house or building.

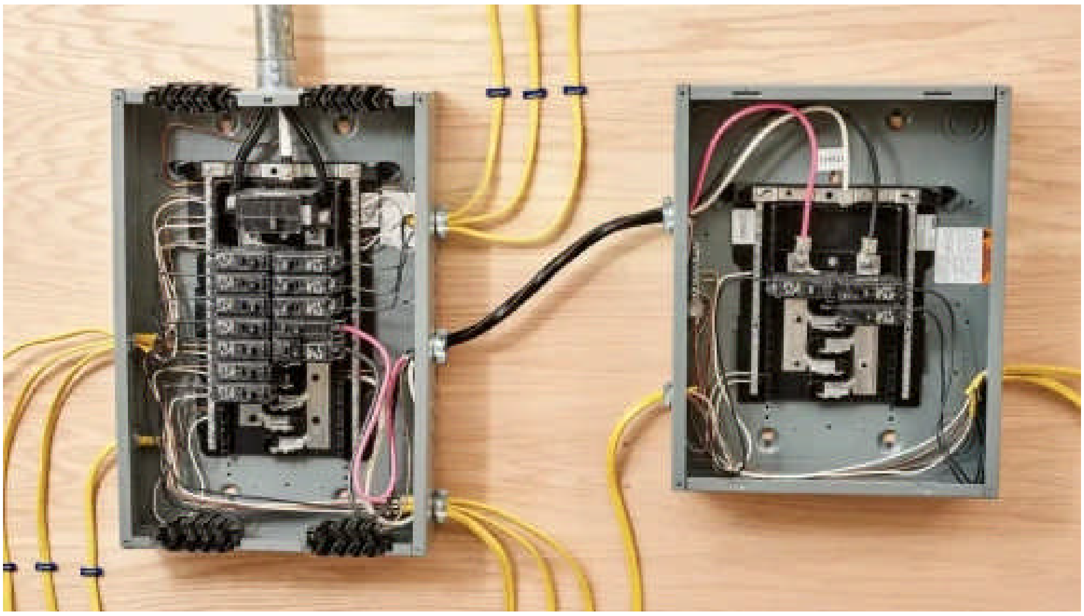


Figure 14: Main Panel

4.1.2 Sub-Panel

The sub-panel, often used in conjunction with the main panel, allows for secondary electrical distribution within an installation. It is particularly useful in large installations or buildings with diverse electrical needs across different floors or zones. The advantages of a sub-panel include the ability to segment the power supply for better management, simplified maintenance, and a reduced risk of overloading the main panel.

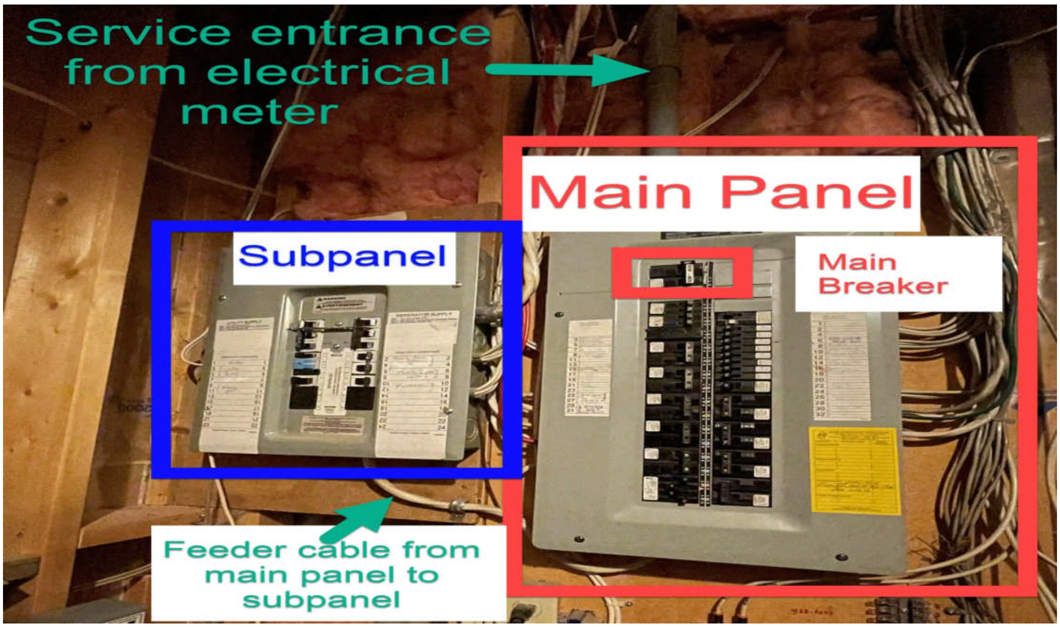


Figure 15: Sub-Panel

4.1.2.1What is the purpose of a sub-panel?

In short, in addition to and powered by the main electrical panel, the sub-panel is a branch of the main electrical installation. It is used to supply electricity to equipment that doesn't fit on the main panel or to supply electricity to a specific area of the home located far from the main panel.

Therefore, under no circumstances can the sub-panel replace the main panel. It is solely a secondary panel.

4.1.2.2 What does an electrical panel consist of?

The sub-panel is generally composed of one row and is protected upstream by an independent circuit breaker located on the main distribution board.

To meet standards, the sub-panel must be connected to the main board by electrical conductors whose length and cross-section depend on the upstream protection chosen.

It must also comply with standard NF C 15-100, notably respecting the rule that nothing other than electrical wiring should run within the space of the new electrical panel. Furthermore, the sub-panel's protective devices must be located at a height between 1 m and 1.80 m. In addition, the lowest row of the panel must not be located below 50 cm from the finished floor.

It is important to design your sub-panel correctly because, in the event of an incorrect calculation of the main supply cross-section, tripping and even fires can occur.

4.1.2.3 When should you install a sub-panel?

Generally speaking, the main reason for installing a sub-panel in a home is when it includes an annex, an extension, or a space separate from the main dwelling (shed, pool, cabin, apartment, etc.).

In this context, creating a secondary electrical panel has two clear advantages:

Firstly, the geographical distance from the main electrical panel has no impact on the transmission of electricity and is even advantageous when you need to control the electrical circuits in this area; Secondly, it allows you to efficiently meet the electrical needs of the new space (lighting, outlets, heating, etc.) without overloading the main panel, which probably doesn't have enough free slots. Also, in the case of a very spacious home, it can be advantageous to install this type of equipment to access controls located in a specific area (upstairs, for example) without having to go all the way to the main electrical panel. In practical terms, in the event of a tripped circuit breaker or a power outage, this can prove convenient because the electrical panel is potentially closer.

4 Backup Power Supply

4.1 What is a backup power supply?

A backup power supply is an electrical supply that takes over in case of an emergency, that is, in the event of a main power outage. Backup power supplies are primarily used for buildings or infrastructure that require a continuous power supply. Indeed, some sites, such as hospitals, ships, or nuclear power plants, cannot withstand a prolonged interruption of the power supply. These power outages can have dramatic consequences and must therefore be avoided at all costs.

Similar solutions now exist for individuals (UPS, uninterruptible power supply, generator, etc.) that allow, for example, the operation of heating systems for several hours or even a whole day if needed.

This type of device allows you to have power in the event of a widespread power outage.

Today, our comfort, safety, and sometimes even our health depend on devices powered exclusively by electricity. In the event of a prolonged power outage, a backup power supply allows you to ensure the comfort of your loved ones.

It is advisable to call upon a professional electrician for the selection and installation of your backup power system, in compliance with safety standards. They will be best able to advise you on the type of device best suited to your home.

These devices are generally used in situations where an interruption of the power supply leads to serious consequences or financial losses. For example, in hospitals, industry, airports, data centers, etc.

4.2 Generator Sets:

We implement tailored solutions for backup power supply of electrical installations.

We regularly install fixed generator sets for our industrial clients such as EDF and the CEA in Cadarache. Upon request, we can also design and install backup power supply units for mobile generator sets.

Figure 16: Generator Sets

4.3 Inverters:

We implement tailored solutions for maintaining power supplies.

Applications are highly diverse in terms of power requirements. They range from a simple UPS for a computer to prevent data loss, to backup systems for critical networks requiring continuous power supply, such as hospital operating rooms and many other high-risk applications.

These solutions can be classified into two categories based on the acceptable power outage duration for the loads.

Installations with short outages (0.5 to 30 seconds) (e.g., supermarkets, industrial facilities) allow for the startup of a backup diesel generator.

Installations without interruption (e.g., data centers, hospitals, electronics industry) are where micro-outages are prohibited.

Our expertise allows us to partner with several manufacturers and industrial partners to implement static (UPS) or rotating (zero-time generators) UPS systems of all power ratings.

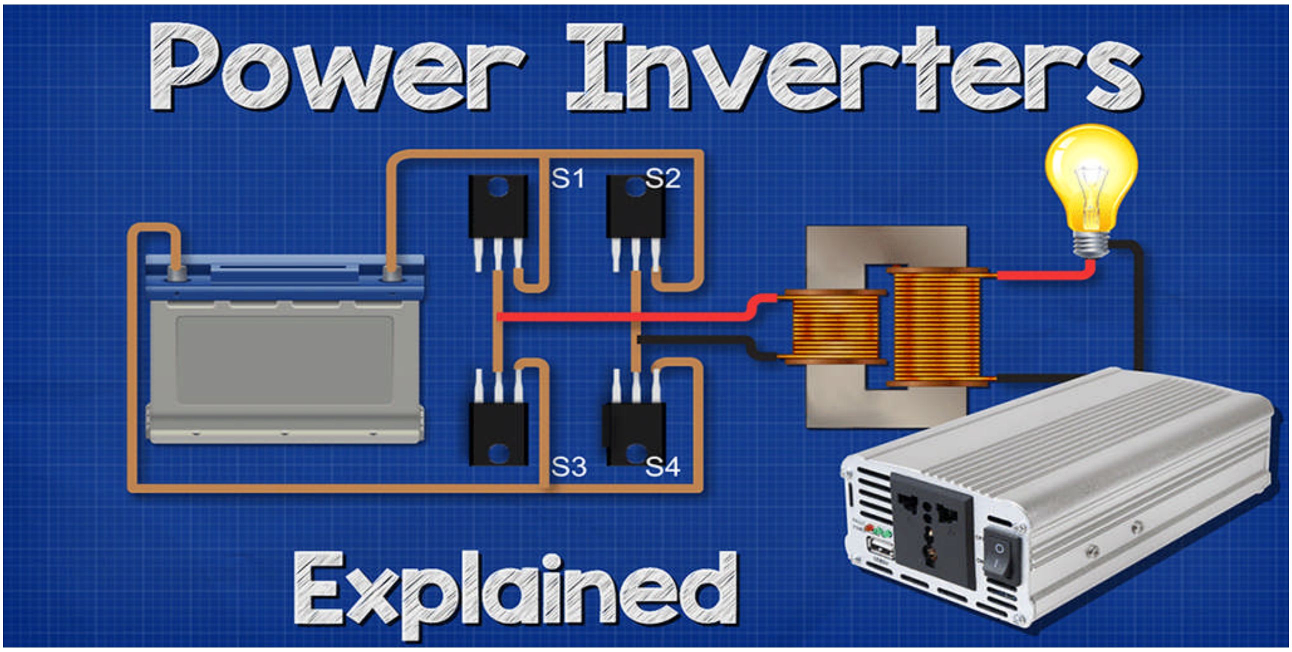


Figure 17: power inverter

5 Uninterruptible Power Supply (UPS)

An uninterruptible power supply (UPS), also known as a static uninterruptible power supply (SUP),

or simply an inverter (named after one of its components), is a power electronics device that provides a stable alternating current free from interruptions or micro-interruptions, regardless of what occurs on the electrical grid.

The latest generation of UPSs also maximizes the power factor as seen from the grid and delivers high-quality output power, all independent of the input grid (fixed frequency and RMS voltage, low total harmonic distortion).

Some UPSs have operating modes capable of compensating for harmonics in the currents drawn from the grid.

The term "inverter" is frequently used, somewhat inaccurately, to refer to the entire device. This is the case for the "inverters" that are inserted between the distribution network and the servers in a data center.

It relies on cascading the following devices:

• An AC-to-DC converter called a rectifier;

• An energy storage device (battery, supercapacitors, flywheel, etc.);

•an AC converter (for the device's output), called an inverter or "transformer," operating at a fixed frequency;

And, if necessary, an external power source (for example, a generator) if the power outage lasts longer than the capacity of the intended storage device.

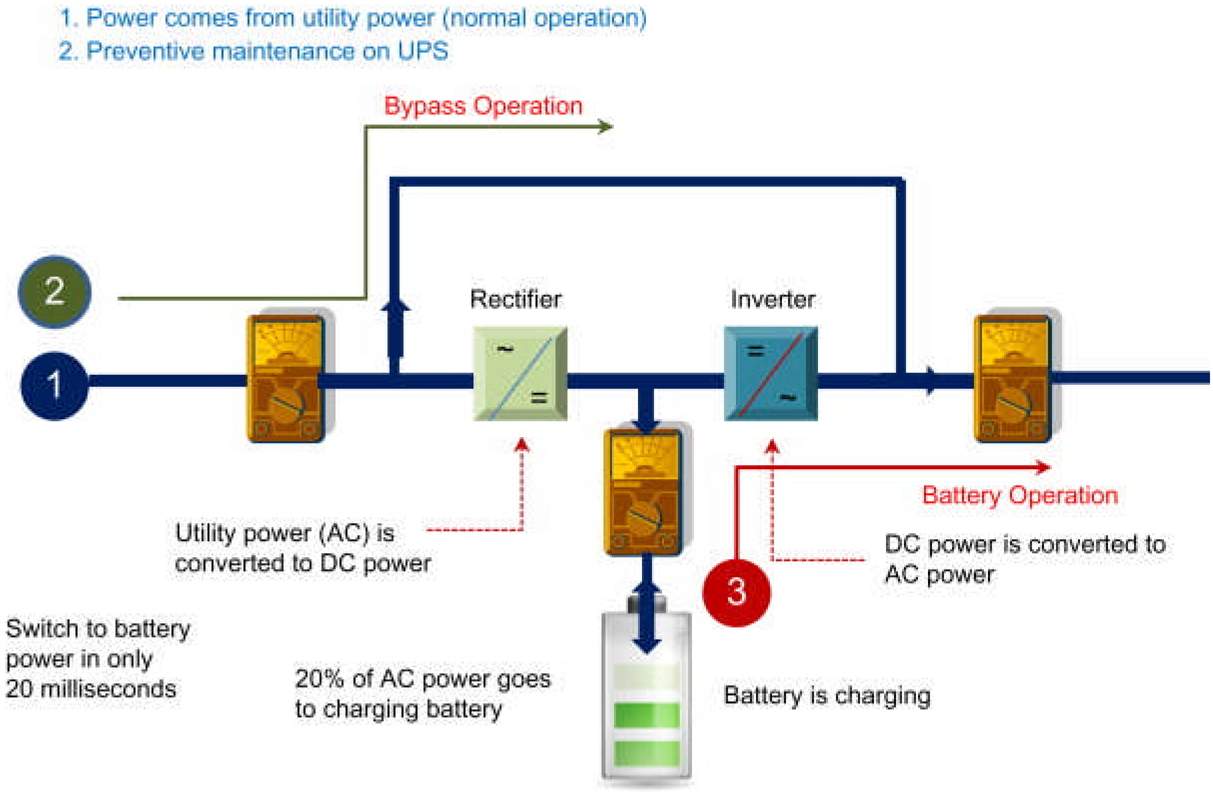


Figure 18: Uninterruptible Power Supply

6 Examples of architecture

Various examples of architecture are illustrated below;

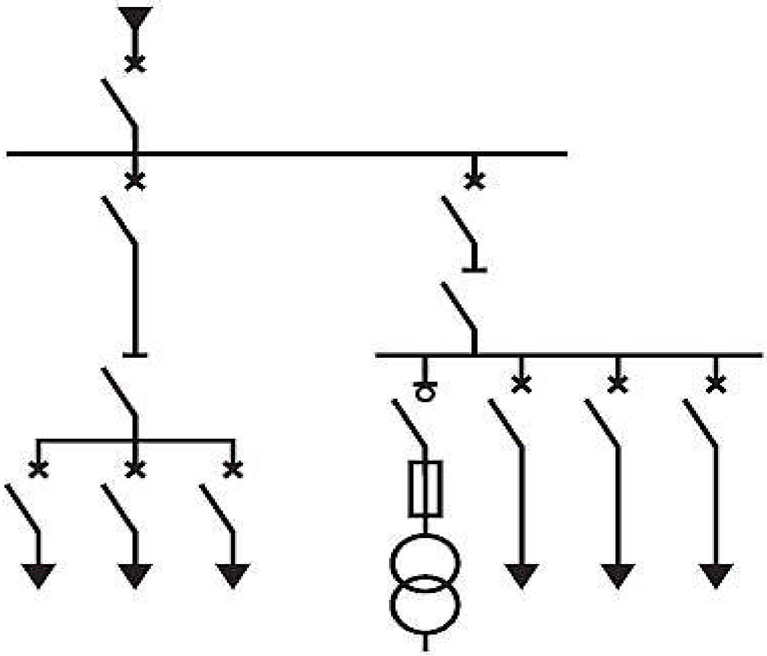


Figure 19: Single antenna network

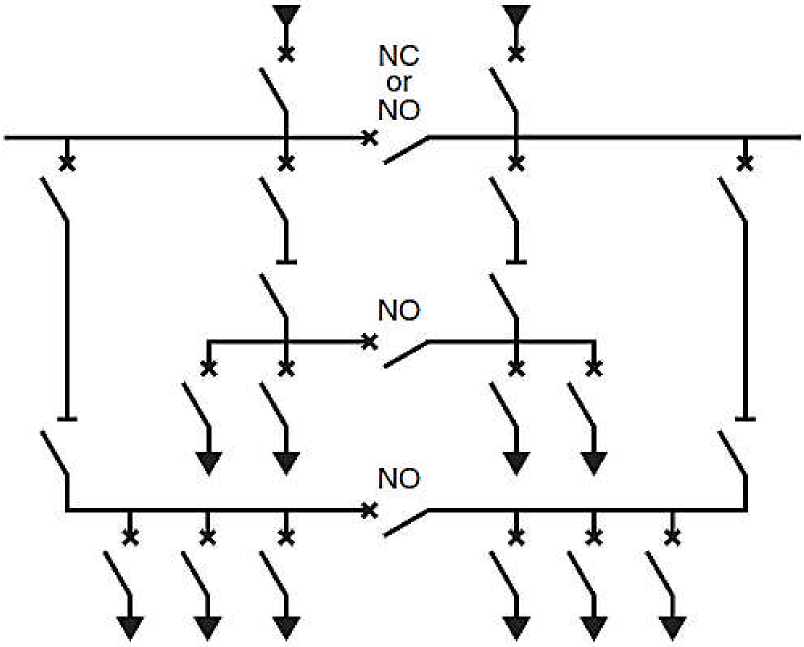


Figure 20: Dual-antenna network

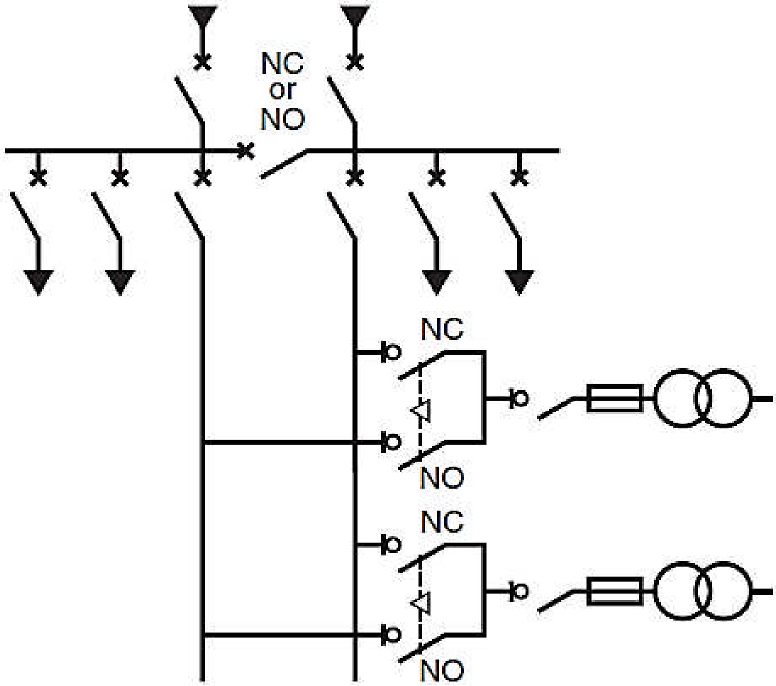


Figure 21 : Dual-branch network

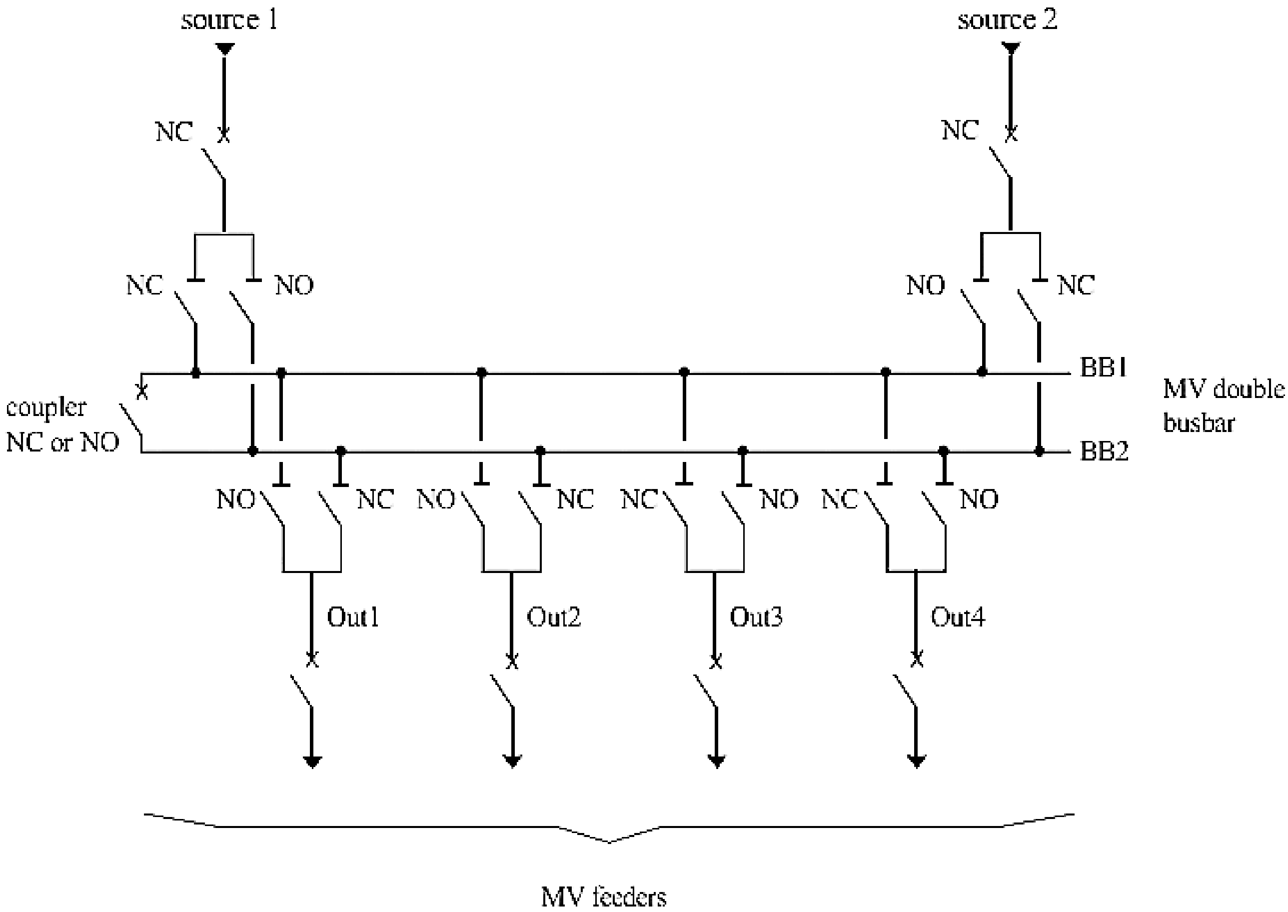


Figure 22: Dual-power network with dual busbars

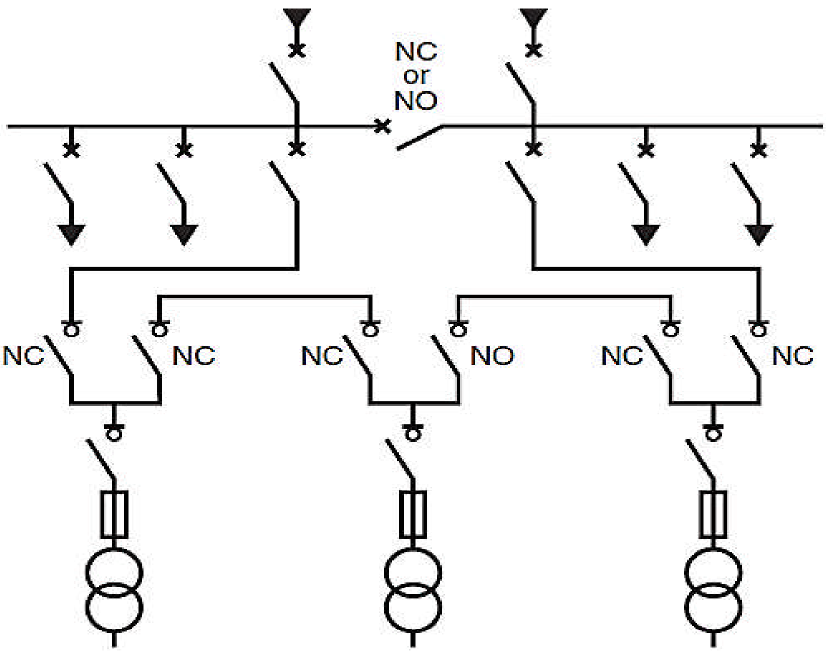


Figure 23: Open-loop closed network

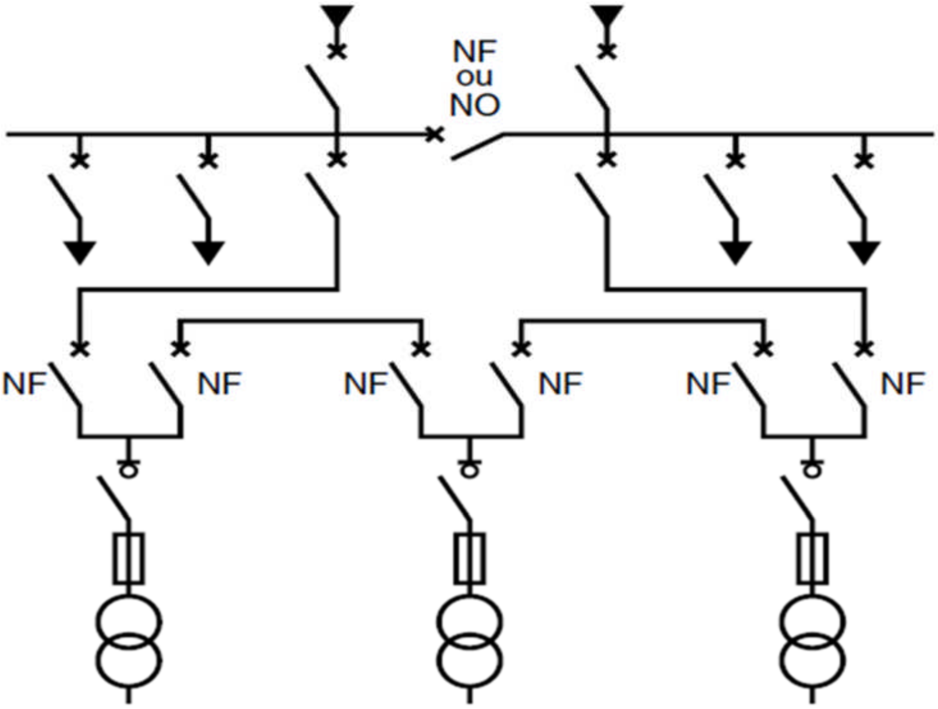


Figure 24: Closed-loop network

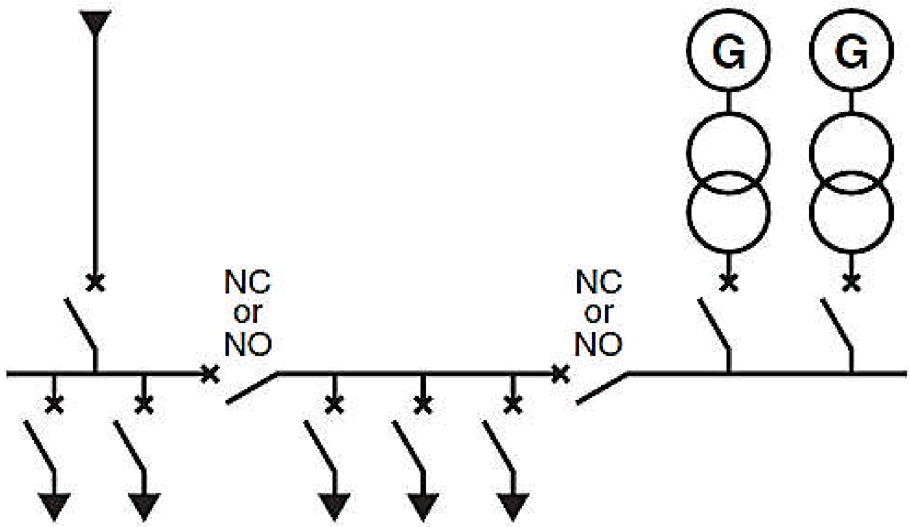


Figure 25: Network including internal energy production with local generation units

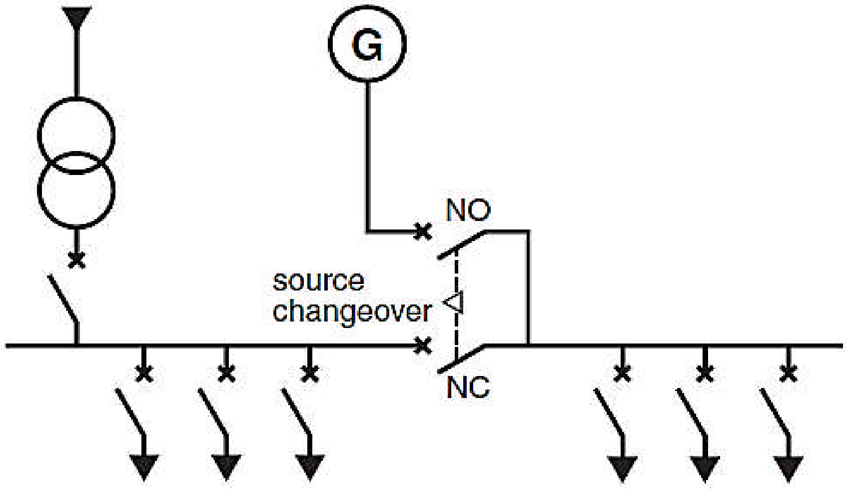


Figure 26: Network including internal energy production with backup generators

Evaluation

1. List out the components of station output system.

2. What are the protections provided for 220 kV lines and bus bars?

a. Bus bar differential protection.

b. Distance protection.

c. Over current protection.

d. Earth fault protection.

3. What are the main sources of power supply to 6.6 kV buses?

a. Unit transformer which steps down the generated voltage to 6.6 kV from the generator.

b. Startup transformer, which steps down the grid voltage to 6.6 kV

4. List some important loads to 6.6 kV buses.

a. Auxiliary transformers.

b. PHT motors.

c. BFP motors.

d. CEP motors.

e. CCW motors.

f. Chiller motors.

g. Pressuring pump motors.

5. For how long 220 V DC batteries can supply power UPS?

6. Mention the commissioning tests on breaker and bus bars.

Breaker

a. Milli volt drops test between the interrupting contacts and between the isolator contacts.

b. Closing and opening timing of the breaker for 5 times.

c. Checking whether the breaker trips or closes when the logics are fulfilled.

Bus bars

a. Millivolts drop test for the contact resistance value.

b. Tightness of the joints.

c. IR values between phase to phase and phase to ground.

6. Should I choose a single-phase or three-phase electrical panel for my home?

7. How do I know if I need a sub-panel?

8. What is the difference between a main distribution board and a sub-distribution board?

9. How do I maintain my electrical panel?

10. What type of electrical panel do you recommend for an industrial installation?

11. How do I add an extra circuit to my electrical panel?

12. Is it necessary to hire a professional to change the type of electrical panel?

CHAPTER III

INDUSTRIAL ELECTRICAL WORKS

(INSTALLATIONS AND SWITCHBOARDS)

Introduction

An electrical installation is a coherent set of electrical circuits and their associated wiring and equipment, installed according to a specific diagram. It serves to supply and distribute electrical energy to various loads, it can be located in a building or used for: authorization, industrial, commercial, or office purposes. It must be installed in accordance with legislation.

1 Environmental Conditions

The characteristics of the equipment and materials are given for standard environmental conditions. Knowledge of the parameters relating to the actual site conditions allows the designer to introduce correction or derating factors for the equipment.

Among the environmental conditions, the designer will consider:

• The risks of explosion in the presence of flammable gases or products in the atmosphere, which determines the level of protection required for the equipment

• The risks of earthquakes

• The altitude

• The average and maximum temperatures

• The soil resistivity

• The presence of frost, wind, and snow

• The keraunic level of the region (the keraunic level is the number of times thunder has been heard in a year, denoted "Nk") for protecting the installation against lightning hazards

• Air pollution (dust, corrosion, humidity levels)

• Site regulations (public buildings, high-rise buildings, etc.).

2 Structures and Pipelines

2.1 Definitions

2.1.1 Conductor

A conductor consists of a simple metallic core with or without an insulating sheath.

2.1.2 Cable

A cable consists of a number of conductors, electrically separated but mechanically joined, usually encased in a flexible protective sheath.

2.1.3 Cable trays

The term cable tray refers to the installation of conductors and/or cables with a connotation of support and protection, for example: the terms cables on shelves, cable ladders, cables in trunking, cables in channels, etc.... are all referred to as "cable trays".

2.1.3 Conductor Identification

The identifications always comply with the following three rules:

Rule 1

The dual green-and-yellow coloring is reserved exclusively for the protective conductors PE and PEN.

Rule 2

When a circuit includes a neutral conductor, it must be identified in light blue (or by the number 1 for cables with more than 5 conductors).

When a circuit does not include a neutral conductor, the light blue conductor may be used as a phase conductor if it is part of a cable with more than one conductor.

Rule 3

Phase conductors may be identified by any color except:

• Green and yellow,

• Light blue (see rule 2).

2.2 Installation Methods Based on Different Types of Cables or Conduits

The different possible installation methods are indicated in the following table, depending on the different types of conductors or cables

Conductors and cables		Installation method							
		Without fixing	Direct fixing	Conduit system	Trunking systems	Profiled duct systems	cable trays	On insulators	Carrier cable
Bare conductors		-	-	-	-	-	-	+	-
Insulated conductors [b]		-	-	+	+**[a]**	+	-	+	-
Cables in sheaths	Multi-conductor	+	+	+	+	+	+	0	+
	Mono-conductor	0	+	+	+	+	+	0	+

+ : Admitted.

– : Not admitted.

0: Not applicable, or not used in practice

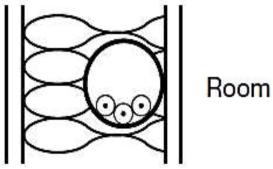
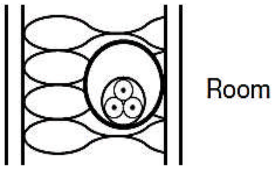
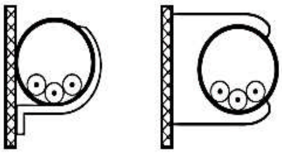
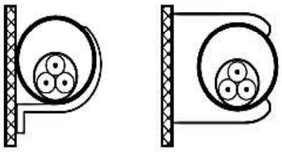
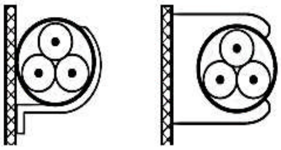
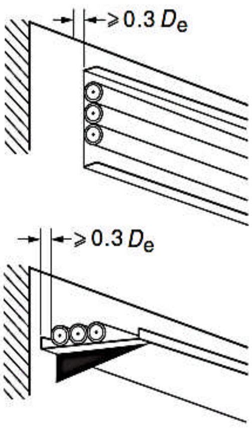
[a] Insulated conductors are permitted if the trunking system has at least an IP4X or IPXXD protection rating and if the cover can only be removed with a tool or by deliberate action.

[b] Insulated conductors used as protective or equipotential bonding conductors may be installed using either method and do not require installation in a conduit, duct, or trunking system.

2.3 Example of pipe laying methods and their reference method

Table 3.2 illustrates some of the laying methods for different types of pipes among the many methods that exist.

Installation methods are grouped by reference (a letter code from A to G): for installation methods which have the same characteristics for the calculation of permissible currents of the pipes, the same calculation method is used.

Item No.	Methods of installation	Description	Reference method of installation to be used to obtain current-carrying capacity
1		Insulated conductors or single-core cables in conduit in a thermally insulated wall	A1
2		Multi-core cables in conduit in a thermally insulated wall	A2
4		Insulated conductors or single-core cables in conduit on a wooden, or masonry wall or spaced less than 0,3 x conduit diameter from it	B1
5		Multi-core cable in conduit on a wooden, or mansonry wall or spaced less than 0,3 x conduit diameter from it	B2
20		Single-core or multi-core cables: - fixed on, or sapced less than 0.3 x cable diameter from a wooden wall	C
30		On unperforated tray	C

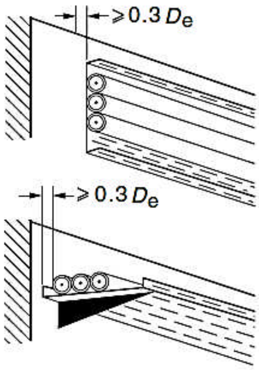
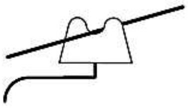
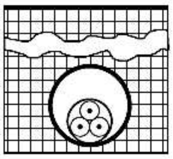
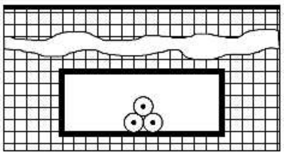
Item No.	Methods of installation	Description	Reference method of installation to be used to obtain current-carrying capacity
31		On perforated tray	E or F
36		Bare or insulated conductors on insulators	G
70		Multi-core cables in conduit or in cable ducting in the ground	D
71		Single-core cable in conduit or in cable ducting in the ground	D

Table 3.2: Examples of installation methods

3-1. Electrical disturbances and their origins:

Electrical disturbances affecting one of the following four parameters:

+ The angular frequency of the three voltages;

+ The amplitude of the three voltages;

+ The waveform of the three voltages;

+ The symmetry of the three-phase system;

Disturbances can manifest as distortion of the fundamental frequency, thus affecting the amplitude of the quantities of interest (voltage or current), namely, a voltage dip, a break or surge, a voltage fluctuation, or an imbalance in the three-phase system. They also manifest as the appearance of harmonic currents at frequencies that are multiples of the fundamental frequency, adding to the fundamental component and thus causing distortion of the waveforms of the quantities of interest.

3.2. Disturbances related to frequency fluctuations

Since the frequency is closely dependent on the angular velocity imposed on the synchronous machine in power plants, it is clear that this type of disturbance is rarely observed except in exceptional circumstances, such as certain faults in energy production or transmission. Under normal operating conditions, the average value of the fundamental frequency should be within the range of 50 Hz ±1% or 60 Hz ±1%.

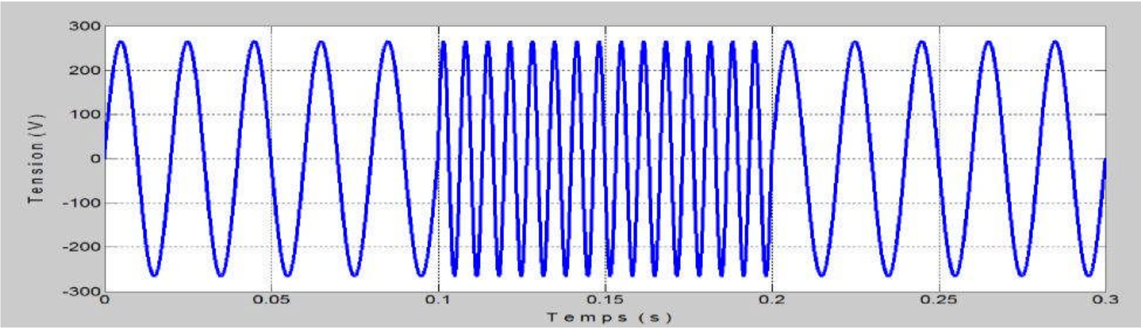


Fig. 3.1. Disturbances related to frequency fluctuations

3-3. Disturbances related to the amplitude of the three voltages:

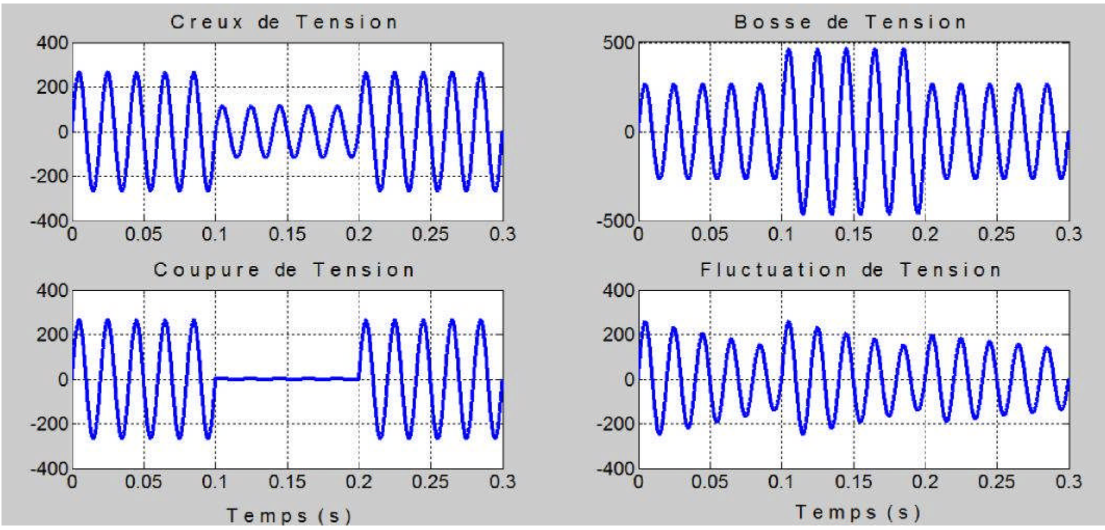


Fig. 3.2 Disturbances related to voltage amplitude

Voltage amplitude disturbances are defined according to standards (IEC 61000-2-1 and IEEE 1159).

a) Voltage dips:

A voltage dip is a sudden drop in voltage at a point in an electrical power network, conventionally between 1% and 90% or between 10% and 90% of a reference voltage

(Uref), followed by a restoration of voltage after a short period of time between half the fundamental cycle of the network (10 ms at 50 Hz) and one minute.

Voltage dips are caused by natural phenomena such as lightning, or by faults in the installation or the network. They also occur during switching operations involving high currents (motors, transformers, etc.).

b) Voltage Outage

Outages are a specific type of voltage dip with a depth greater than 90% (IEEE) or 99%. Brief outages last less than 3 minutes, or one minute, and are often caused by slow automatic reclosing designed to prevent prolonged outages (set between 1 and 3 minutes). Figure 3.2 shows an example of a voltage dip and an outage.

c) Voltage Surge or Overvoltage:

This is a very brief increase in the amplitude of the network voltage, from 1.1 to 1.8 times the nominal voltage, as shown in Figure 3.2. It manifests as a voltage surge that can cause conductors to overheat and sometimes leads to the destruction of electrical equipment. It is often caused by atmospheric phenomena such as lightning and during the switching on of large loads.

d) Voltage Fluctuations:

These fluctuations result in variations in the peak value with an amplitude of less than 10% of the nominal voltage and current intensity, visible under lighting conditions, which causes visual discomfort. These fluctuations cause cyclic or random flickering of the supply voltage envelope, often called "flicker." These fluctuations are mainly due to rapidly changing industrial loads such as welding machines, arc furnaces, and rolling mills. An example of voltage fluctuation and overvoltage is shown in Figure 3.2.

3.4. Disturbances related to the symmetry of the three-phase system:

When the three voltages are equal in amplitude and phase-shifted by 120° relative to each other, the system is said to be balanced. The system is subject to an imbalance disturbance when the amplitudes are not the same and/or the phase shift is different between the three phases. The imbalance is generally due to poor load distribution across the three phases, insulation faults, or a break in the neutral conductor. It can also encompass both the variation in amplitude and the distortion of the waveform of the three voltages.

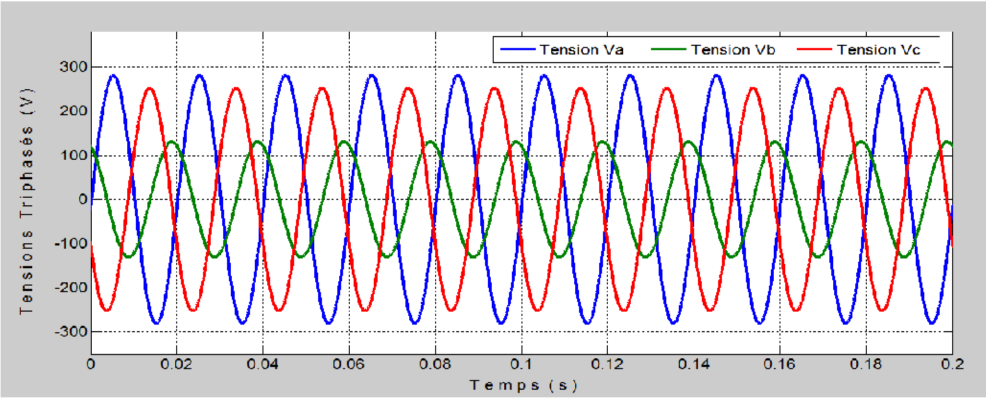


Fig. 3.3. Three-phase system imbalance

3.5. Waveform distortion of the three voltages:

The waveform distortion is primarily due to the superposition of harmonics on the fundamental wave. These harmonics are sinusoidal waves with frequencies that are integer multiples of the fundamental frequency of 50 Hz. Figure (3.4) shows the superposition of the 3rd and 5th harmonics on a fundamental voltage with a frequency of 50 Hz. The main source of harmonics in electrical networks is the increasing use of power electronics equipment with semiconductor components, namely diodes, GTO thyristors, IGBT transistors, MOSFETs, etc.

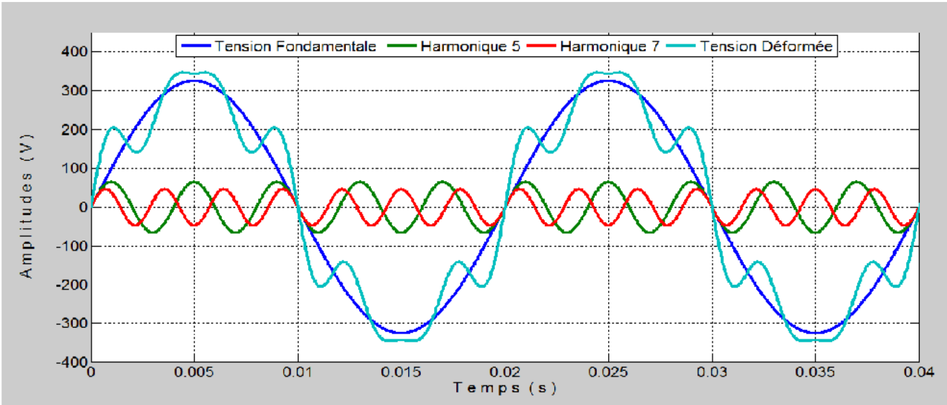


Fig. 3.4 Influence of the h5 and h7 harmonics on the fundamental frequency

3-6 Harmonic disturbances:

a- Origin of harmonics:

Harmonics are periodic quantities that vary at frequencies that are multiples of the fundamental frequency and that combine to form a distorted signal. This signal is generally composed of several harmonics, often presented as a spectrum, as in Figure 3.5.

Interharmonics, with frequencies that are not multiples of the fundamental frequency, are also distinguished from infraharmonics, with frequencies lower than the fundamental frequency.

Interharmonics are superimposed on the fundamental waveform but are not integer multiples of the grid frequency. Interharmonics originate from frequency converters, variable speed drives, and other similar equipment. Generally, the shape of the three voltages depends on the nature of the electrical loads, as these are found in consumers in two types: linear and non-linear loads. Linear loads, such as standard light bulbs, heating systems, resistive loads, motors, and transformers, contain no active electronic components, only resistors (R), inductors (L), and capacitors (C).

They absorb purely sinusoidal currents, with the same waveform as the voltage except for a phase shift. The harmonic current spectrum has only one component at 50 Hz, the fundamental component; the Total Harmonic Distortion (THD) of the current in this case is almost zero. Figure (3.6) clearly shows the waveform of the current absorbed by a linear load and its harmonic spectrum.

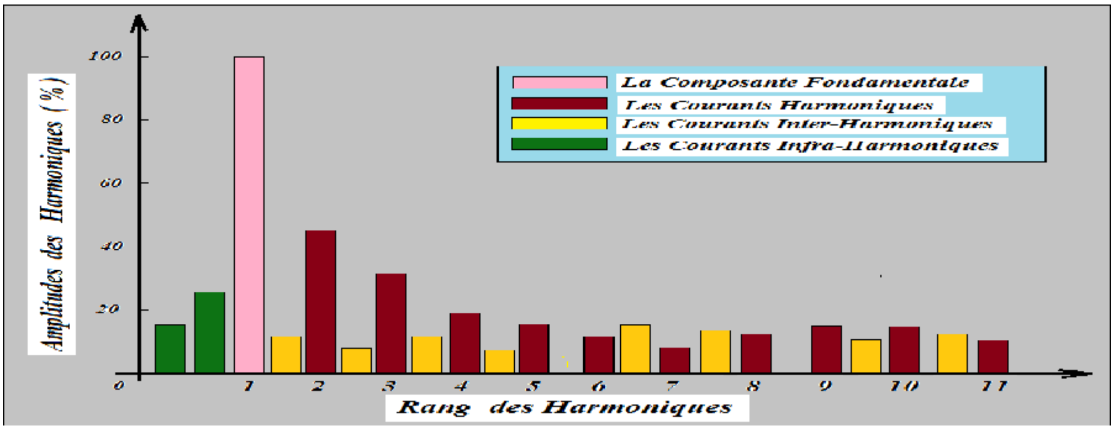


Fig. 3.5. Different types of harmonics

b-Remedies for disturbances

- Use of UPS (uninterruptible power supply)
- Use of voltage stabilizers
- Rebalancing of voltages by returning to alternators
- Use of filters (passive / active / hybrid) to cancel harmonics and produce a sinusoidal waveform.

Evaluation

1. What are the major impacts of environmental conditions on electrical equipment?
2. How to choose the right equipment for a corrosive environment?
3. What is the impact of temperature on electrical cables?

4- What are the main types of disturbances?

5. What are the impacts of these disturbances on the installations?
6. What are the problems in station operation due to grid under voltage?

7. What are the problems in station operation due to grid under frequency?

8. What causes harmonics in an electrical system?

9. What are the effects of electrical harmonics?

10. What is a non-linear load?

11. What are the visible symptoms of high harmonic pollution?

12. How is harmonic pollution measured?

13- How to mitigate harmonics in an installation?

14- How to protect installations against disturbances?

15. What to do in case of a disturbance?

See the answers in Appendix A

CHAPTER IV

GROUNDING AND SAFETY IN INSTALLATION

OBJECTIVES:

By the end of the session, the student should be able to:

- *Define the neutral system;*
- *Recognize the different neutral systems;*
- *Determine fault currents;*
- *Establish the appropriate protective equipment for each neutral system.*

1. Introduction

In any medium or low voltage three-phase system there are three single-phase voltages which are measured between each phase and a common point called the "neutral point". In balanced operating conditions these three voltages are phase shifted by 120° and have the value: U / √3 U being the phase-to-phase voltage measured between phases

From a physical point of view, the neutral is the common point of three star-connected windings. It may or may not be accessible, may or may not be distributed and may or may not be earthed, which is why we refer to the *earthing system*.

The neutral may be connected to earth either directly or via a resistor or reactor. In the first case, we say that the neutral is solidly (or directly) earthed and, in the second case, we say that the neutral is impedance-earthed.

When there is no intentional connection between the neutral point and earth, we say that the neutral is isolated or unearthed.

The earthing system plays a very important role in a network. On occurrence of an insulation fault or a phase being accidentally earthed, the values taken by the fault currents, touch voltages and overvoltages are closely related to the type of neutral earthing connection. A solidly earthed neutral helps to limit overvoltages; however, it generates very high fault currents. On the other hand, an isolated or unearthed neutral limits fault currents to very low values but encourages the occurrence of high overvoltages.

In any installation, service continuity in the presence of an insulation fault also depends on the earthing system. An unearthed neutral allows continuity of service in medium voltage, as long as the security of persons is respected. On the other hand, a solidly earthed neutral, or low impedance-earthed neutral, requires tripping to take place on occurrence of the first insulation fault.

The extent of the damage to some equipment, such as motors and generators having an internal insulation fault, also depends on the earthing system.

In a network with a solidly earthed neutral, a machine affected by an insulation fault suffers extensive damage due to the high fault currents.

On the other hand, in an unearthed network or high impedance-earthed network, the damage is reduced, but the equipment must have an insulation level compatible with the level of overvoltages able to develop in this type of network.

The earthing system also has a considerable amount of influence on the nature and level of electromagnetic disturbances generated in an electrical installation.

Earthing systems which encourage high fault currents and their circulation in the metallic structures of buildings are highly disturbing.

On the other hand, earthing systems which tend to reduce these currents and which guarantee good equipotential bonding of exposed conductive parts and metallic structures are not very disturbing.

The choice of earthing system, as much in low voltage as in medium voltage, depends both on the type of installation and network. It is also influenced by the type of loads, the service continuity required and the limitation of the level of disturbance applied to sensitive equipment.

2. Different earthing systems

The different types of neutral point connection to earth are shown in table 4-1. We can make a distinction between:

- The solidly (or directly) earthed neutral,
- The unearthed neutral, or high impedance-earthed neutral,
- Resistance earthing
- Reactance earthing
- Petersen coil earthing.

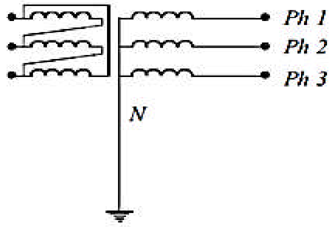
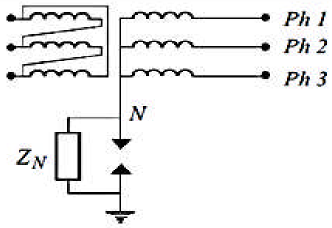
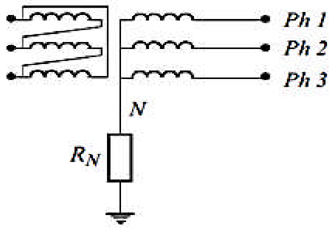
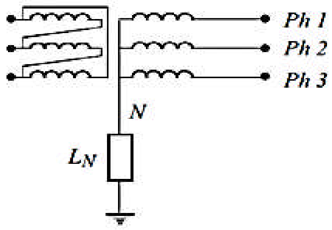
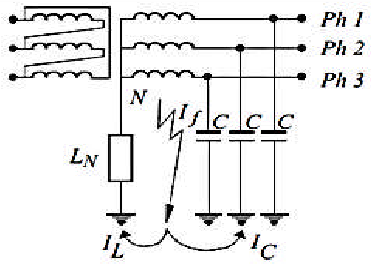
Solidly earthed neutral An electrical connection is intentionally made between the neutral point and earth.	
Unearthed neutral There is no electrical connection between the neutral point and earth, except for measuring and protective devices. **High impedance earthing** A high impedance is inserted between the neutral point and earth.	
Resistance earthing A resistor is inserted between the neutral point and earth	
Reactance earthing A reactor is inserted between the neutral point and earth.	
Petersen coil earthing A reactor tuned to the network capacitances is inserted between the neutral point and earth so that if an earth fault occurs, the fault current is zero.	 $\vec{I}_f = \vec{I}_L + \vec{I}_C = \vec{0}$ I_f : fault current I_L : current in the neutral earthing reactor I_C : current in the phase-earth capacitances

Table 4.1: neutral point connection methods

3 Touch voltages

3.1 Touch voltage - non-dangerous limit voltage

Any person entering into contact with a live part is subjected to a difference in potential: the person therefore risks being electrified (i.e. receiving a non-lethal electric shock). There are two types of contact: direct contact and indirect contact.

Direct contact

This is the contact of a person with a live part of a piece of equipment that is energized. Contact may occur with a phase or with the neutral

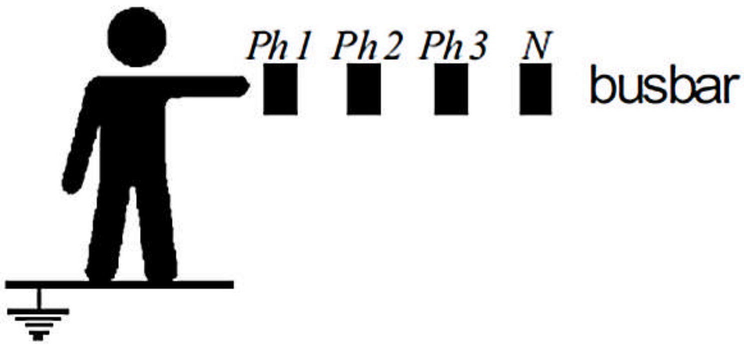


Figure 4.1: direct contact

Indirect contact

This is the contact of a person with the exposed conductive part of a load which is accidentally live following an insulation fault

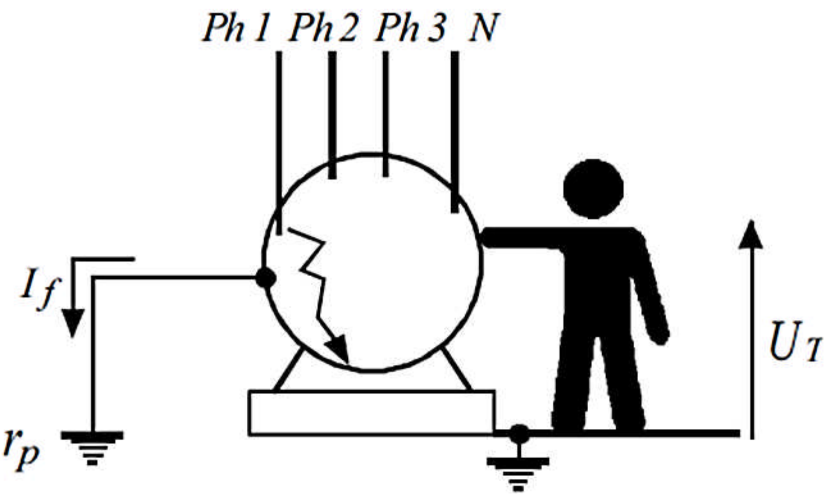


Figure 4.2: indirect contact

Contrary to what is generally believed, the risk for persons is not only related to the value of the voltage applied to the human body, but also to that of the current likely to go through it and the contact time. The current and voltage are related by Ohm's law: $I = U/R$; where R is the impedance of the human body.

This impedance varies in relation to the touch voltage, the state and dampness of the skin, as well as the path that the current takes inside the human body.

IEC publication 479 gives the human body impedance values in relation to the touch voltage to which it is subject

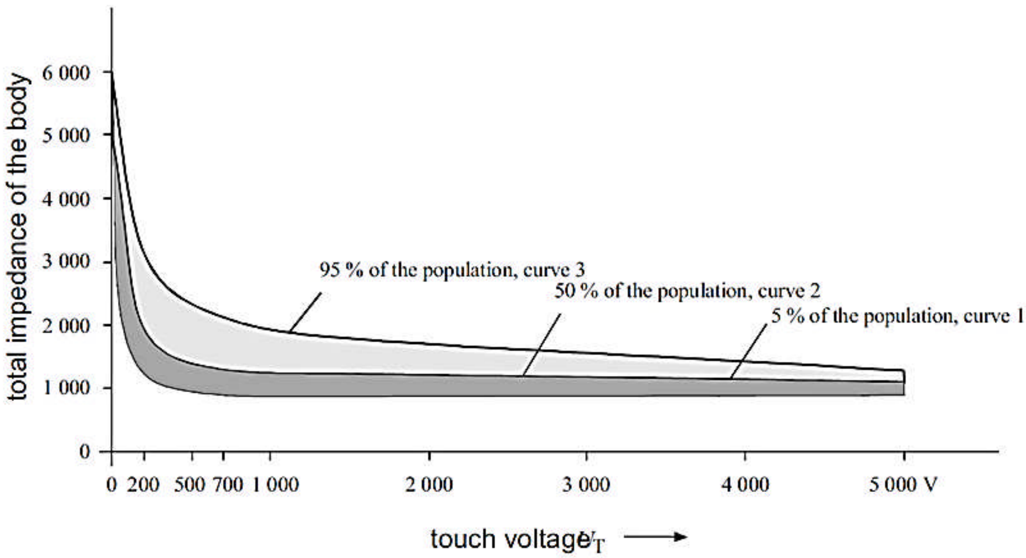


Figure 4.3: statistical values of the total impedances of the human body for a hand-to-hand or hand-to-foot current trajectory

This publication also gives the effects of electrical current on persons in relation to its value and duration. These effects are shown in figure 4.5 for alternating current at 50 or 60 Hz.

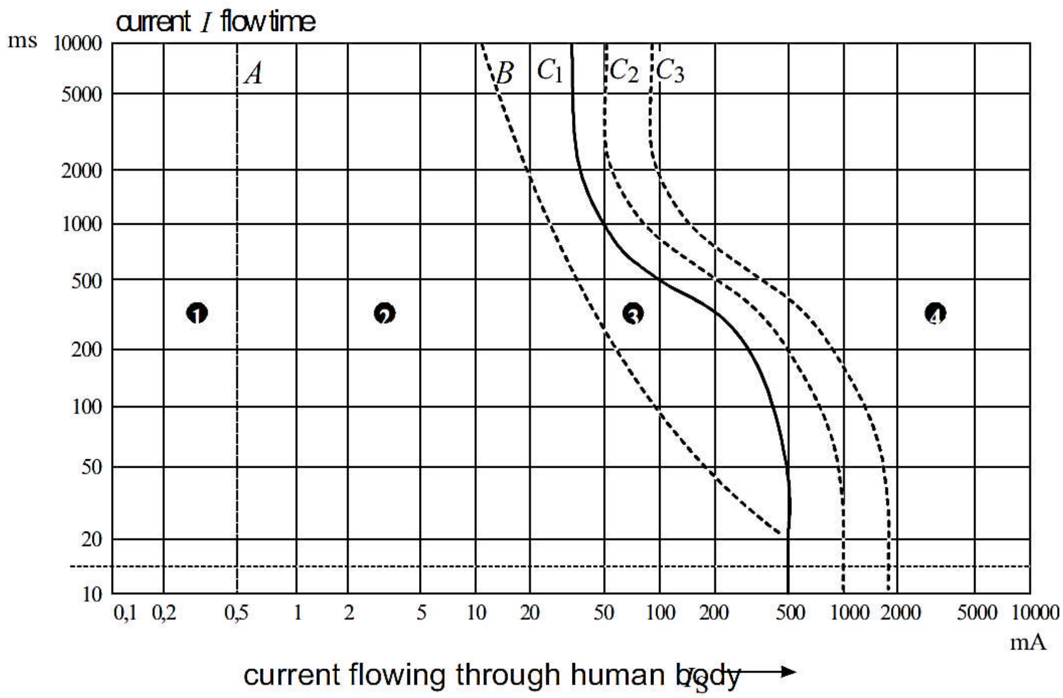


Figure 4.5: effects of 50/60 Hz electrical current

❶ : not noticeable

❷ : noticeable

❸ : reversible effects - muscular contraction

❹ : possible irreversible effects, risk of death

Curve C1 defines the time-current limit of exposition to an electric shock, which must not be exceeded.

The disconnection times to be used in practice and the protections to be implemented for disconnecting the power supply depend on the earthing systems (*TT*, *TN*, *IT*)

Prospective touch voltage (V)	**Maximum disconnecting time of the protective device (s)**	
	AC	**DC**
<50	5	5
50	5	5
75	0.60	5
90	0.45	5
120	0.34	5

150	0.27	1
220	0.17	0.40
280	0.12	0.30
350	0.08	0.20
500	0.04	0.10

Table 4.2: maximum prospective touch voltage holding time in dry premises (U L = 50 V)

Prospective touch voltage (V)	Maximum disconnecting time of the protective device (s)	
	AC	**DC**
25	5	5
50	0.48	5
75	0.30	2
90	0.25	0.80
110	0.18	0.50
150	0.12	0.25
230	0.05	0.06
280	0.02	0.02

Table 4.3: maximum prospective touch voltage holding time in damp premises (U L = 25 V)

Earthing systems used in low voltage

In low voltage, earthing systems are governed by international IEC standard 364-3. Three systems are considered. Each one is defined by two letters.

The first letter defines the situation of the neutral point in relation to earth.

T: solidly earthed neutral

I: unearthed or high impedance earthed neutral.

The second letter defines the connection method of the electrical installation's exposed conductive parts:

T: the exposed conductive parts are interconnected and solidly earthed, regardless of whether the neutral point is earthed or not

N: the exposed conductive parts are directly connected to the neutral conductor.

4.2. Solidly earthed neutral (*TT earthing system*)

The neutral point is directly earthed (first letter *T).*

The exposed conductive parts of the loads are interconnected, either altogether, or in groups, or individually, and are earthed (second letter *T*). Protection is ensured by residual current devices. All the exposed conductive parts protected by the same protective device must be connected to the same earth electrode.

The neutral earth electrode and that of the exposed conductive parts may or may not be interconnected or the same. The neutral may or may not be distributed.

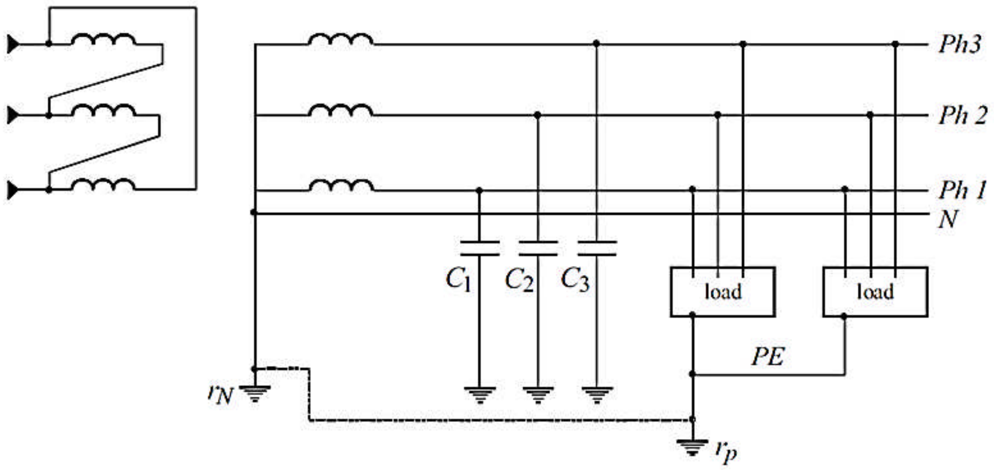


Figure 4.6: solidly earthed neutral (TT earthing system) in low voltage

4.1. Unearthed or impedance earthed neutral (*IT earthing system*)

The neutral is unearthed or earthed via high impedance (first letter *I).*

Impedance between 1000 and 2000 Ω is frequently used.

The exposed conductive parts of loads are interconnected, either altogether, or in groups. Each interconnected group is connected to an earth electrode (second letter *T).* It is possible for one or several exposed conductive parts to be separately earthed. Where possible, it is advisable to interconnect all the exposed conductive parts of the same installation and connect them to the same earth electrode. It is nonetheless possible for exposed conductive parts which are far away from each other, or located in different buildings, not to be. In this case, each group of exposed conductive parts connected to the same electrode and each individually earthed exposed conductive part must be protected by a residual current device.

The earth electrodes of the exposed conductive parts and the neutral may or may not be interconnected or the same.

It is not advantageous to distribute the neutral which results in the maximum length of wiring systems being reduced

Installing an overvoltage limiter between the neutral point of the MV/LV transformer and earth is compulsory. If the neutral is not accessible, the overvoltage limiter is installed between one phase and earth. It protects the low voltage network against rises in voltage due to flashover between the transformer medium voltage and low voltage windings

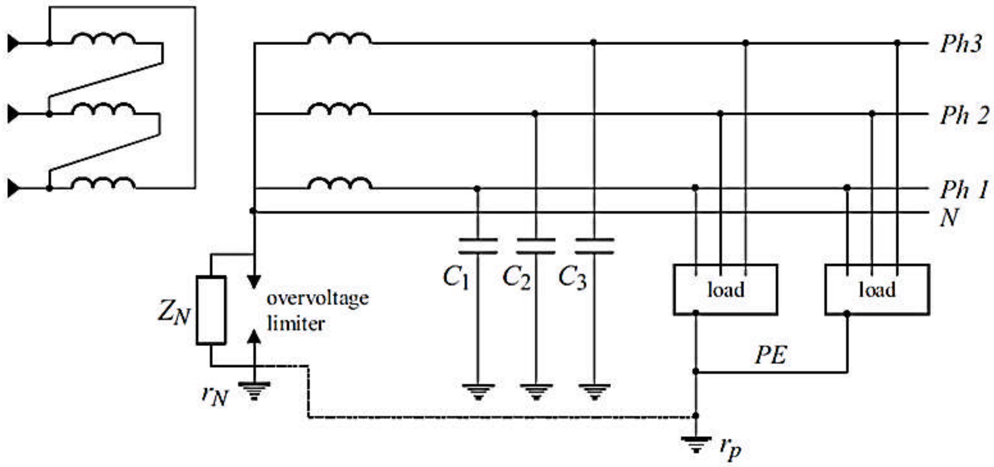


Figure 4.7: unearthed or impedance earthed neutral (IT earthing system) in low voltage

4.3. Neutral earthing (*TN earthing system*)

The neutral point is directly earthed (first letter *T).*

The exposed conductive parts of the loads are connected to the neutral conductor (second letter *N).*

There are two possible systems depending on whether the neutral conductor (*N*) and protective conductor (*PE*) are one and the same or not

Case one

The neutral and protective conductors form a single conductor called the *PEN.* This system is identified by a third letter *C* and is called the *TNC* system

- It is advisable to regularly connect the *PEN* to earth

- This system must not to be used for cross-sectional areas below 10 mm² for copper or 16 mm² for aluminum, as well as for mobile wiring systems. It is also forbidden downstream of a *TNS* system.

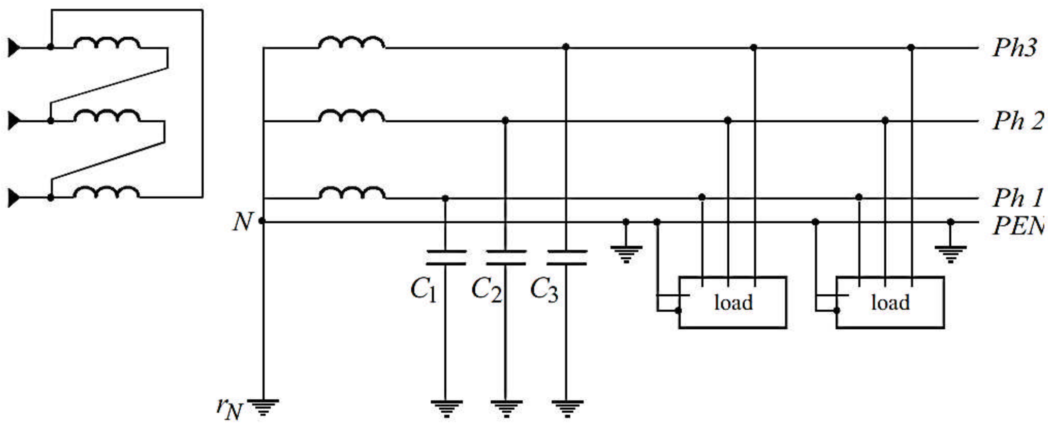


Figure 4.8: TNC earthing system

Case two

The neutral conductor and protective conductor are separate. The system is then identified by a the third letter S and is referred to as the *TNS* system

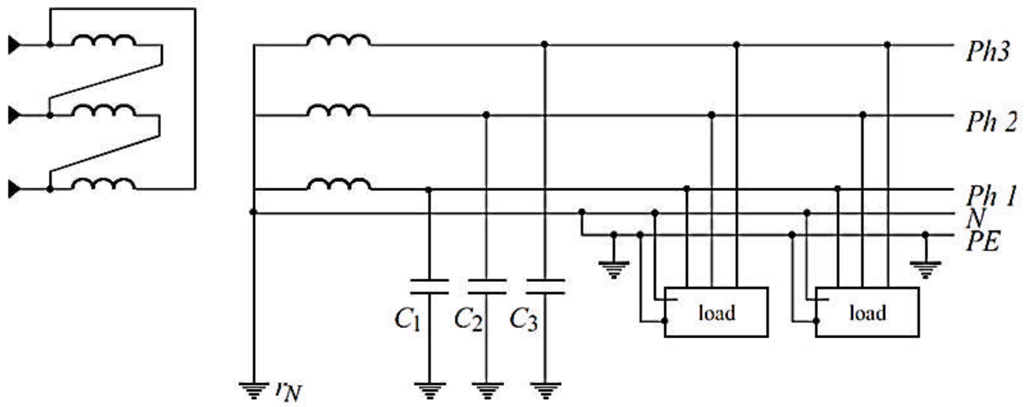


Figure 4.9: TNS earthing system

As for the TNC earthing system, it is advisable to regularly connect the protective conductor to earth.

This earthing system is compulsory for cross-sectional areas below 10 mm² for copper or 16 mm² for aluminium, as well as for mobile wiring systems. It must not be used upstream of a *TNC* earthing system.

5. Comparison of different low voltage earthing systems - choice

5.1.Comparison of different earthing systems

5.1. 1.TT earthing system

- This is the simplest solution to implement. In France, it can be used for installations directly supplied by the low voltage public distribution network

- It does not require any specific monitoring although a regular inspection of the residual current devices may be necessary
- Protection is ensured by residual current devices (RCD) which also make it possible for fire risks to be prevented when the device sensitivity is ≤ 500 mA
- Each insulation fault leads to disconnection. This disconnection can be limited to the only faulty circuit by setting up an appropriate selectivity
- Loads or installation parts, which generate high earth leakage currents, must be fitted with suitable RCD in order to avoid spurious tripping.

5.1.2. TN earthing system

- It requires earthing of the protective conductor at regular intervals
- It requires the operation of the protective devices against phase-to-phase faults to be checked for an insulation fault
- It requires any modification or extension to be carried out by qualified personnel fully conversant with implementation rules
- On occurrence of an insulation fault, it may lead to considerable deterioration of the windings of rotating machines and sensitive equipment,
- In premises where there is a risk of fire, it may be dangerous due to the high value of the fault currents.

The TN − C earthing system:

- Installation savings may be made since one pole and one conductor are removed
- It involves the use of fixed and rigid wiring systems
- It is forbidden in premises where there is a risk of fire
- During insulation faults it generates a high level of electromagnetic disturbances which may damage sensitive electronic equipment or disturb their operation
- Unbalance currents, third harmonics and multiples of third harmonics circulate in the PEN protective conductor and may be the cause of multiple disturbances.

The TN − S earthing system:

- This can be used even in the presence of flexible conductors or wiring systems with a small cross-sectional area
- Through the separation of the neutral and protective conductor it allows good equipotential bonding of the exposed conductive parts to be maintained and the level of electromagnetic disturbances to be reduced. It is thus recommended for computing premises
- It is compulsory in premises where there is a risk of fire, if the installation has a TN earthing system.

5.1.3. IT earthing system

- It is the solution that ensures the best continuity of service
- signaling of the first insulation fault followed by its location and clearance allows any interruptions in power supply to be systematically prevented
- It requires maintenance personnel for monitoring and operation
- It requires network insulation to be maintained in good condition
- Any modification or extension must be carried out by qualified personnel fully conversant with implementation rules
- It involves dividing up the network if it is very widespread and loads with a high earth leakage current being fed by an insulating transformer
- It requires the operation of protective devices against phase-to-phase faults to be checked for a double insulation fault.

5.2. Choice of earthing system

5.2.1. Earthing system performances

The performances of earthing systems can be assessed according to the following six criteria:

- Protection against electric shocks
- supply continuity
- Protection against overvoltages
- Protection against electromagnetic disturbances
- Implementation requirements.

■ **implementation requirements**

The TT earthing system, as well as the $TN-S$ earthing system when it is installed with residual current devices, are the simplest to implement.

The $TN-S$ earthing system without residual current devices and the $TN-C$ and IT earthing systems require operation of the protective devices against phase-to-phase faults to be checked. This leads to the maximum lengths of wiring systems being limited and requires the intervention of qualified personnel to carry out extensions and modifications to the installation.

5.2.2. Choice and recommendations for use

When it is possible to choose the earthing system, the choice is carried out cases by case, based on the requirements relating to the electrical installation, the loads, the user's needs and regulations.

It is often advantageous not to choose one system for the entire installation.

- **the *TT* earthing system is recommended for installations with little monitoring and future extensions**

Indeed, this is the simplest earthing system to implement and use.

- **the *IT* earthing system is recommended if there is a service continuity requirement**

Indeed, the *IT* earthing system guarantees better energy availability. On the other hand, it requires:

- Implementation rules to be respected
- problems generated by earth leakage currents to be taken into account
- a qualified maintenance service for the location and clearance of the first insulation fault as well as for installation extensions and modifications.

- **the *TN – S* earthing system is recommended for installations with few future changes**

It is generally set up without any residual current device.

The currents generated by an insulation fault are high and may cause:
- temporary disturbances
- Risks of extensive damage
- Fires.

Like the *IT* earthing system it requires the implementation rules to be respected. **If medium-sensitivity residual current devices are installed**, they provide this earthing system with better protection against fires and flexibility in design and use.

	TNC	TNS	TT	IT
Loads sensitive to fault currents	NR	NR	P	R
Loads sensitive to electromagnetic disturbance	NR	R	P	P
Premises where there is a risk of fire	F	NR(1)	P(1)	R(1)
Installation with frequent modifications	NR	NR	R	NR
Installation where the continuity or earth circuits is uncertain (work sites)	NR	P	R	NR
Need for service continuity	NR	NR	NR	R
Network, loads with high leakage currents	R	R	P	NR

Table 4.4: choice of earthing system

(1) The use of a < 500 mA sensitive RCD is compulsory

R: Recommended

P: Possible

NR: Not Recommended

F: Forbidden

Evaluation

1. Why is grounding mandatory?
2. What causes poor grounding?
3. What are the consequences of poor grounding?
4. What do the letters in TT, TN, and IT stand for?
5. What is the main use of the TT system?
6. What protective device is mandatory in a TT system?
7. What happens in the event of an insulation fault?
8. What is the difference between TN-C and TN-S?
9. What is the advantage of the TN system?
10. What is the main benefit of the IT system?
11. How do you choose the neutral system?
12. What is the most common neutral system?
13. Where does the neutral current go?

See the answers in Appendix A

CHAPTER V

INSTALLATION CALCULATIONS

Introduction

In this chapter, we will examine the steps involved in sizing and selecting the components of a low-voltage electrical installation, namely:

✓ Calculating the power balance;

✓ Calculating the operating current (IB);

✓ Calculating the permissible current (IZ);

✓ Determining conductor cross-sections and equipotential bonding conductors;

✓ Verifying the voltage drop;

✓ Selecting the protection device.

1.Determining conductor cross-sectional areas and choosing protective devices in low voltage

2.Definition of terms relating to low voltage wiring systems

(Insulated) cable

Assembly comprising:

- one or more insulated conductors
- their eventual individual screening
- any eventual assembly protection
- any eventual protective shielding

It may also comprise one or several bare conductors.

Multi-core cable

Cable comprising more than one conductor, which may eventually include bare conductors.

Note: the term three-core cable is used to designate the cable making up the phases of a three-phase system.

Single-core cable

Cable comprising a single insulated conductor.

Note*: the term single-core cable is especially used to designate a cable making up one of the phases of a three-phase system.*

Wiring system

Assembly made up of one or more electric conductors and the devices ensuring their fixation and, if necessary, their mechanical protection.

Cable channel

Ventilated or enclosed duct located above or in the ground, having dimensions preventing persons from moving around inside it but allowing access to the cables over their entire length during and after installation.

Note: *a cable channel may or may not form part of the building construction.*

Cable tray

Holder made up of a base and sides but no cover.

Note: *A cable tray may be perforated or unperforated.*

Electrical circuit (of an installation)

All the electrical equipment of the installation fed from the same source and protected against over currents by the same protective device(s).

(Insulated) conductor

Assembly comprising the conductor, its insulating envelope and eventual screens.

(Circular) conduit

Enclosed envelope, having a circular cross-section, designed for the installation or the replacement of insulated conductors or cables by capstan, in electrical installations.

Ducting

Assembly of closed envelopes having a non-circular cross-sectional area, designed for the installation or the replacement of insulated conductors or cables by capstan, in electrical installations.

Brackets

Horizontal cable supports fixed at one of their ends, arranged from point to point and on which the cables rest.

Design current of a circuit

Current to be carried in a circuit in normal service

(Continuous) current carrying capacity of a conductor

Maximum value of the current that, in given conditions, can continuously flow in a conductor without its steady-state operating temperature being higher than the specified value.

Cable ladder

Cable support made up of a series of non-touching elements firmly fixed to main vertical rods.

Sleeve (or tube)

Element surrounding wiring and providing it with extra protection in building passages (walls, partitions, floor, ceiling) or in buried passages.

Sheath

Enclosure located above ground level having dimensions preventing persons from moving around inside it but allowing access to the cables over their entire length. A sheath may or may not be built into the masonry.

Trough

Assembly of envelopes closed by a cover and ensuring mechanical protection of insulated conductors or cables not installed or removed by a capstan and which allow other electrical equipment to be added.

Building void

Space in a structure or building parts which is only accessible at certain places.

Note: *- Spaces in walls, supported floors, ceilings and certain types of window or door frames and jamb linings are examples of building voids.*

- Specially built building voids are also called "ducts".

3. Determining Low-Voltage Conductor Cross-Sections

The power balance is the first essential step in the design study of an industrial electrical network. It must identify and geographically locate the values of active and reactive power.

Depending on the site's size, the installed power, and its distribution, the installation will be divided into several geographical zones. The active and reactive power balance will then be calculated for each zone by applying the specific utilization factors for each load to the installed power.

3.1. Method principle

In compliance with the recommendations of IEC 364-4-43, the cross-sectional area of wiring systems and the protective device must be chosen to meet several conditions necessary for the security of the installation.

The wiring system must:

- carry the maximum design current and its normal transient peaks
- Not generate voltage drops above the allowed values.

The protective device must:

- protect the wiring system against any over currents up to the short-circuit current
- ensure the protection of persons against indirect contact.

The logigram in figure V-1 sums up the principle of the method which may be described by the following stages:

1st stage:

- using the load power, the maximum design current I_B is calculated and the rated current I_n of the protective device is deduced from this
- The maximum short-circuit current I_{sc} at the origin of the circuit is calculated and the breaking capacity of the protective device is deduced from this.

2nd stage:

- Depending on the installation conditions (installation method, ambient temperature, etc.), the overall correction factor f is determined
- The suitable conductor cross-sectional area is chosen in relation to I_n and f.

3rd stage:

- The maximum voltage drop is checked
- The thermal withstand of the conductors in the event of a short circuit is checked
- For TN and IT systems, the maximum length relating to the protection of persons against indirect contact is checked.

The conductor cross-sectional area meeting all these conditions is then chosen.

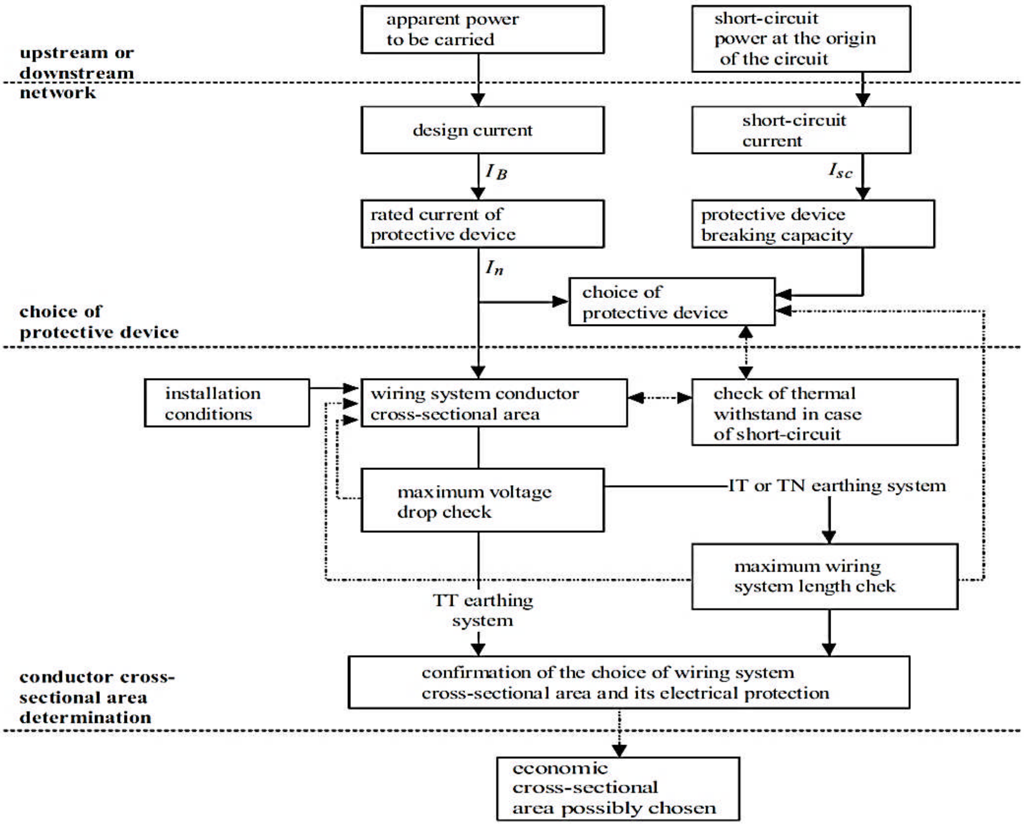


Figure V-1: wiring system cross-sectional area and protective device choice logogram

4.Cross-sectional area of *PEN* conductors

In the case of a *TNC* earthing system, the protective conductor also plays the role of the neutral conductor.

In this case, the cross-sectional area of the *PEN* must be at least equal to the greatest value resulting from the following requirements:

$$- S_{PEN} \geq \begin{cases} -10\ mm^2 & \text{for copper} \\ -16\ mm^2 & \text{for aluminium} \end{cases}$$

- meet the conditions relating to the *PE* conductor
- meet the conditions required for the neutral conductor cross-sectional area.

5.Cross-sectional area of the neutral conductor

- The neutral conductor must have the same cross-sectional area as the phase conductors in the following cases:

. Single-phase circuit

. Three-phase circuit having phase cross-sectional areas smaller than or equal to 16 mm² for copper or 25 mm² for aluminium.

- For three-phase circuits having a phase cross-sectional area greater than 16 mm² for copper or 25 mm² for aluminium, the neutral cross-sectional area may be smaller than that of the phases as long as the following conditions are met:

The maximum current likely to continuously circulate in the neutral is lower than the current-carrying capacity of the chosen cross-sectional area. The unbalance of single phase loads and third and multiples of third harmonics which may require the use of a cross-sectional area greater than the phases must be taken into account

The neutral conductor is protected against overcurrent by a fuse or a circuit-breaker trip setting suitable to its cross-sectional area.

The cross-sectional area of the neutral conductor is at least equal to 16 mm² for copper or 25 mm² for aluminium.

Evaluation

Exercise 1:

Design the conductor cross-section for a 35 km long, 36 kV overhead line using an Al, Mg, Si (alloy) conductor carrying 10 MW of power (inductive power factor 0.9). The projected lifespan is 20 years (T), and the annual power increase is 3% (α). The conductor alloy has a resistivity of 0.357 × 10^{-7} Ω·m at 20°C and a temperature coefficient α of 0.004 C^{-1}.

• Network data: We know that the short-circuit power to be considered will never exceed 700 MVA for 1.5 seconds.

• Electrical constraints: We will allow a maximum voltage drop of 9%.

We request:

1. Select the cross-section of the phase conductors to meet the sizing criteria according to the theory. The operating temperature is approximately 70°C, and the maximum temperature is approximately 250°C.

For the inductance, we will consider "X = 0.4 Ω/km" as the starting value. No reactive power compensation is planned.

Exercise 2:

Sizing (conductor cross-section selection) for a 70kV overhead line using AMS conductors (Al, Mg, Si alloy; ρAMS, 20°C = 3.57 x 10^{-8} Ω·m; α = 4 x 10^{-3} $°C^{-1}$) over a distance of 50 km, designed to carry 10MW of power (inductive power factor 0.9). Projected lifespan: T = 20 years; annual power increase: a = 3.5%.

• Network data: We know that the short-circuit power to be considered will never exceed 1 GVA for 0.3 seconds.

• Electrical constraints: We will allow a maximum voltage drop of 10%.

We request:

1. Select the cross-section of the phase conductors to meet the design criteria according to the theory. The operating temperature is approximately 70°C, and the maximum temperature is approximately 250°C. We consider X = 0.4 Ω/km as the starting value. No reactive power compensation is planned.

2. The operating temperature is approximately 70°C, and the maximum temperature is approximately 250°C. We consider X = 0.4 Ω/km as the starting value. No reactive power compensation is planned.

CHAPTER VI

CABLING AND MAINTENANCE

1. Introduction

Today, in industry, electricity users are concerned with ensuring continuity of service, given the often enormous losses caused by a shutdown of their equipment.

To this end, all equipment manufacturers systematically offer their customers a first level of preventive maintenance, known as routine maintenance. This is carried out at regular intervals to guarantee minimum performance throughout the equipment's lifespan, provided it is used under normal conditions.

Power outages and technological failures can be disastrous. Given the heavy reliance on computers and other digital equipment in a business, for example, the inability to access them poses serious problems for the company. Data loss, power cuts, and operational interruptions are just some of the difficulties this entails. Therefore, to avoid them, it is necessary to know exactly what they are and how they occur. Here are five of the most common electrical problems in commercial facilities.

2 What are the most common electrical problems?

2.1 Electrical leaks and grounding

Electrical leaks are often the cause of high electricity bills. These types of electrical problems can be caused by moisture, poor-quality electrical items, or faulty installation.

Electrical outlets, light fixtures, conduits, and other electrical components must be grounded to prevent electric shock when using electrical equipment.

Figure 1: grounding

2.2 Exposed Wiring

Whether exposed to the environment or human contact, faulty wiring can present a number of complications in any commercial installation. Loose connections can lead to overloads and fires. Of course, it's difficult to know their condition, as they are often hidden behind walls, which is why they must be inspected by a team of professional electricians. Grounding can also be a hidden problem; therefore, an inspection is necessary to prevent major issues.

Figure 2: Exposed Wiring

2.3 Flickering

This may seem trivial, but it is one of the most common electrical problems in commercial facilities; the negative effects will quickly be felt by staff. Flickering is often the result of a loose connection, which can become a serious problem if not addressed promptly. Constant flickering lights will be a source of distraction and irritation for everyone on the premises, impacting productivity and customer service. If the flickering does not disappear after changing the bulbs, a lighting maintenance program will be necessary.

Figure 3: Screen Flickering

2.4 Manufacturing Defect

A manufacturing defect in the electrical panel may necessitate a complete replacement. The maintenance company will determine if this is necessary. Failures are usually limited to fuses and circuits, as these are the components most likely to be damaged if not installed correctly.

2.5 Power Outages

A sudden power outage can be disastrous; the consequences vary depending on the industry. The only solution is to wait if the problem is caused by a general grid issue; however, in some cases, the problem originates within the company itself. Generally, the issue is caused by a simple tripped safety switch. It could be a faulty circuit breaker in the area if the power loss is not widespread throughout the entire building or complex. This is due to information overload. If the power comes back on after resetting the switch, it's time to call in an expert.

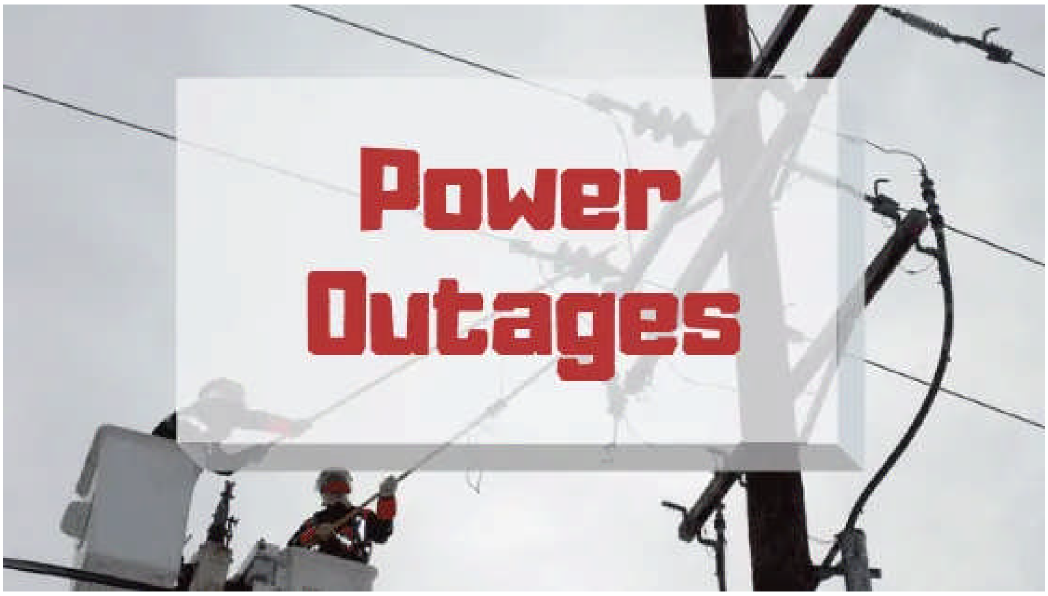


Figure 4: Power Outages

2.6 Fires

A typical workplace or building contains a large number of electrically powered devices that operate almost continuously throughout the day. This can lead to excessive energy consumption and overload the circuit breaker, causing it to trip. This is especially dangerous if the wiring is inadequate or unsuitable for the intended use. Ignoring this problem can result in an electrical fire.

Figure 5: fire in an electrical panel

3 What are the main causes of failure for electrical cables?

There are many possible causes of failure for electrical cables, the worst consequences being fire, as well as other types of serious damage.

Here are the most frequent causes of failure:

3 .1 Aging

The service life of a cable can be significantly reduced if it is operated outside the optimal operating conditions for which it was designed. The aging process typically leads to embrittlement, cracking, and eventual failure of the insulation and sheathing materials, exposing the conductor and creating a potential short circuit, a likely cause of electrical fires.

3 .2 Application type

If the selected cable is not suitable for the application, it is likely to fail in service. A cable that is insufficiently robust for the environment either mechanically resistant to wear and abrasion or chemically resistant to ambient conditions is more likely to fail than a cable whose composition is suited to the installation environment.

3 .3 Mechanical failure

If the cable is damaged during installation or subsequent use, the cable's integrity will be affected and its lifespan will be reduced.

Figure 6: Mechanical failure

3 .4 Electrical Cable Sheath Degradation

Several factors can cause the outer sheath of a cable to degrade, such as excessive heat or cold, harsh weather conditions, or abrasion. All of these factors can lead to electrical cable failure because the conductors are no longer properly insulated and protected by the outer sheath originally designed for this purpose.

3 .5 Moisture penetration into insulation

Moisture penetration can cause significant problems, including short circuits and corrosion of copper conductors.

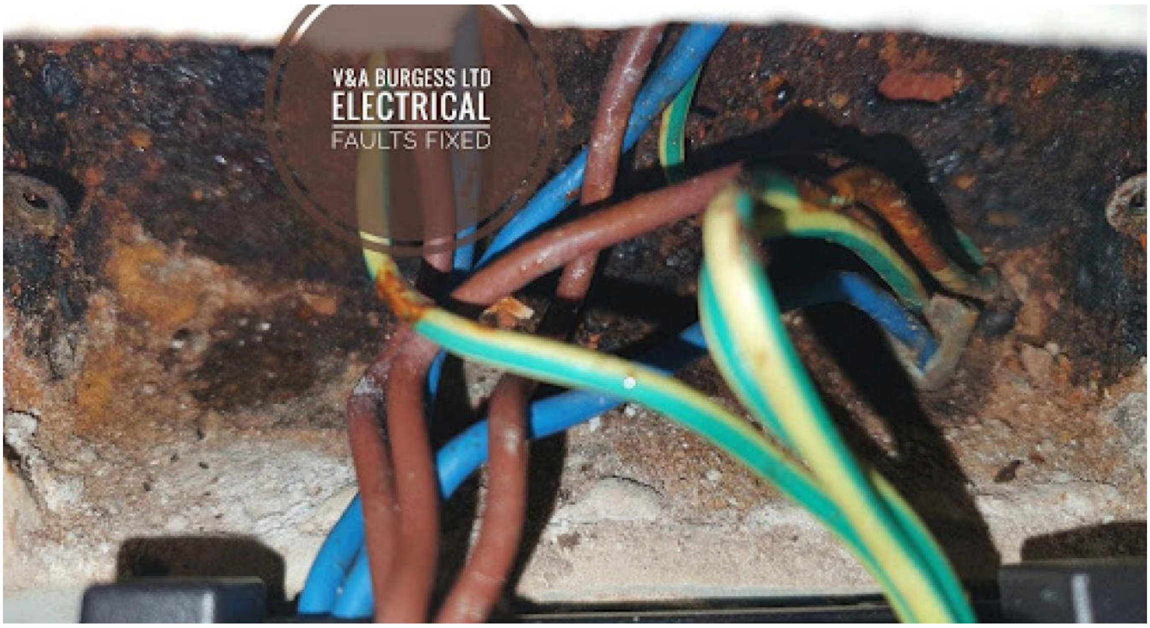


Figure 7: Moisture penetration into insulation

3 .6 Overheating of electrical cables

Overheating of a cable leads to degradation of the insulation material and outer sheath, as well as premature failure. The heat can originate from an external source or be generated by resistance as current flows through the conductor, a failure that is likely to occur when the cable is overloaded and/or undersized for the application.

Figure 8: Overheating of electrical cables

3 .7 Electrical Overload

In principle, electrical overload occurs when a cable is undersized for the application or if it is subjected to too much load. In domestic applications, this is often the result of plugging too many devices into the same outlet and overloading the wiring on that individual outlet, extension cord, or group outlet.

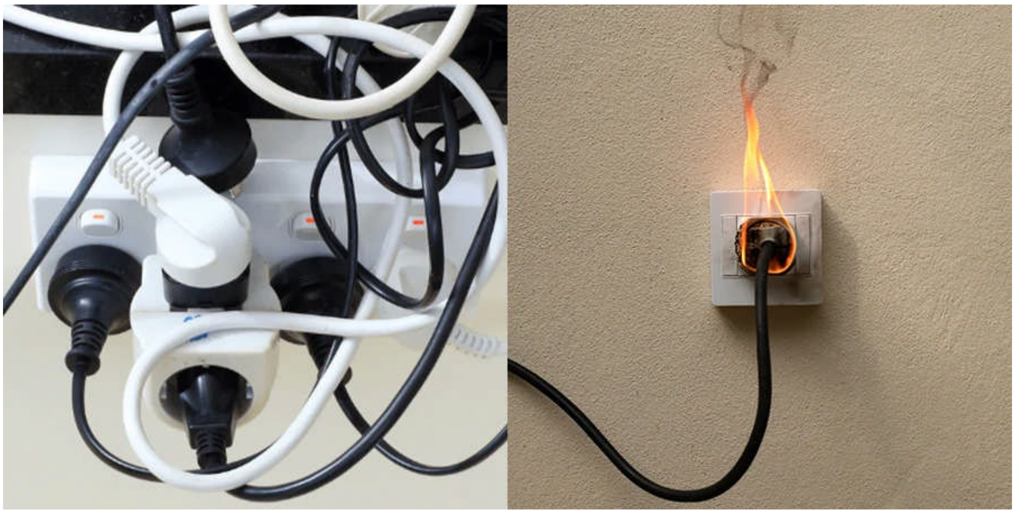


Figure 9: Electrical Overload

3 .8 Rodent attacks

The outer sheaths of cables can be susceptible to rodent attacks. This damage can be significant, considerably reducing the cable's sheathing or insulation properties, and can be another potential source of electrical fires.

Figure 10: Rodent attacks

3 .9 UV Exposure

UV exposure can significantly affect the insulation and sheathing of electrical cables. Cables likely to be exposed to UV radiation must be made of UV-resistant materials with an appropriate carbon black content, or protected from exposure with a protective coating, for example, by being installed inside a cable conduit, and therefore not in direct sunlight. UV exposure frequently causes cracks in the insulation and therefore potential short-circuit failures.

3 .10 Environment/Pollution

This category includes causes of failure related to the environment in which the components of an electrical installation are located.

A humid environment promotes the oxidation of metal parts in the installation. Dust or corrosive environments can corrode electrical contacts. This causes an increase in the resistance of the contaminated contacts.

Figure 11: electric corrosion

3 .11 Connection Defects

These connection defects include improperly tightened cable and busbar connections. They also include poor connections due to unsuitable screws. A connection defect will result in increased electrical resistance at the connection.

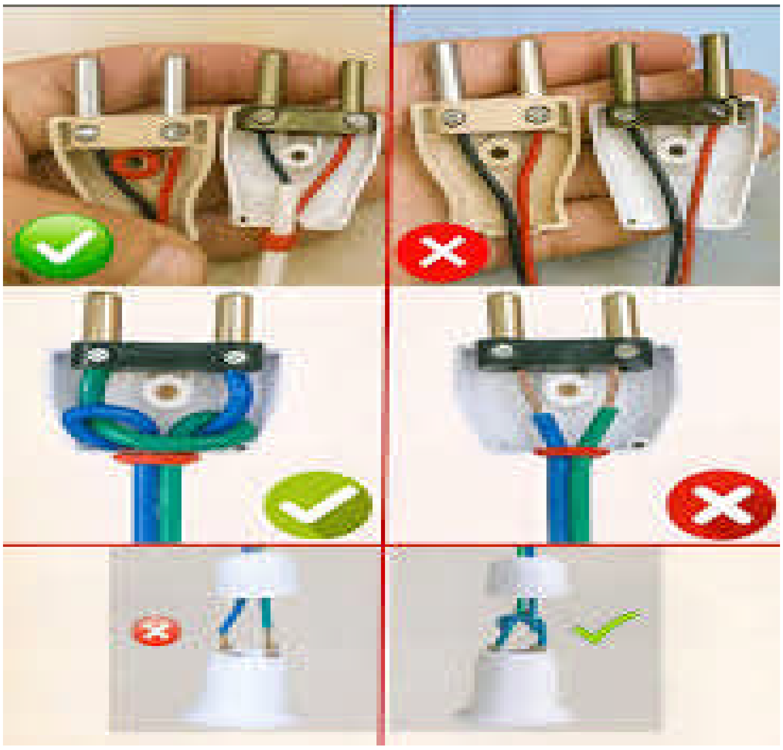


Figure 12: Connection Defects

4 Detection and Diagnosis of Electrical Installation Faults by Temperature Measurement

4.1 Thermal Monitoring: Yesterday and Today

Today, these two methods are still widely used to predict the risk of electrical installation failure caused by excessive heating; they are:

a • Regular inspections utilize the five human senses;

We typically see the maintenance technician walking through the electrical installation, opening and inspecting cabinets, looking for melted wires, a busbar that is changing color, or to detect the smell of a burning or overheating component. Therefore, the most commonly used senses are sight, smell, and touch.

Figure 13: human inspection

b • Regular inspections using infrared thermography.

Infrared thermography allows for the localization of hot spots using a photothermal image. Any object at normal temperature (above absolute zero) emits radiation in the infrared range, the intensity of which depends on its temperature. This property is used by the electronics of infrared detectors to determine the temperature of an object by capturing the infrared energy it emits.

Figure 14: thermography inspection

4.2 Thermal monitoring of tomorrow

If we want continuous monitoring of the electrical installation, for us

it will allow us to more effectively analyze potential deviations and plan predictive maintenance. We must use detection and diagnostic tools that will rely on the data acquisition logistics chain via the web. This chain consists of communicating elements:

• Micrologics communication: components integrated into the circuit breaker for current measurement;

• Power meters for measuring current, voltage, and harmonic distortion;

• Wireless temperature sensors;

• A data storage server.

4.3 Operation of an Industrial Electrical Installation

Operating an electrical installation means activities aimed at maintaining its functionality, primarily involving the control, monitoring, inspection, maintenance, and execution of electrical and other work.

• The person in charge of an electrical installation prepares the operating plan and inspects the installation;

• Performs operational work in accordance with the law;

• Visually inspects the electrical installation and checks its cleanliness.

4.4 Inspection of electrical distribution equipment and switchboards:

➢ Verification of the presence of stickers and markings, safety signs;

➢ Verification of the presence of electrical diagrams for the switchboards and their conformity to the actual situation;

➢ Monitoring of vibration and noise from contactors and relays;

➢ Checking for any signs of overheating;

➢ Checking the tightness of contacts;

➢ Checking the condition of protective switches;

➢ Checking the condition of cable markings and their conformity to the actual situation;

➢ Checking the conformity of protective equipment to requirements;

➢ Checking the condition of nut-and-bolt connections;

➢ Verification of the presence of all necessary earth cables and inspection of their condition;

➢ Check the cleanliness of the control panels and equipment during operating work, and clean them if necessary.

4.4.1 Lighting installation inspection:

➢ Check the condition of light fixtures and light sources, replacing light sources if necessary;

➢ Check the operation of lighting equipment and the timely switching of light fixtures;

➢ Monitor the cleanliness of light fixtures and make suggestions for storage;

4.4.2 Inspection of power cables and grounding system installation:

➢ Visually inspect the installation and make suggestions for its organization;

➢ Check the tightness of cable end contacts and tighten them if necessary;

➢ Inspect programmable timers and electricity consumption meters;

➢ Visually check the accuracy of programmable timers;

➢ Visually check the condition of electricity consumption meters;

➢ Maintain and file an inspection log;

➢ Maintain the lightning protection system in accordance with regulations;

➢ Operate the emergency lighting system and test the leakage current protection system in accordance with regulations; perform maintenance work;

➢ Carry out electrical measurements and technical inspections.

5 Industrial Maintenance

In general, the maintenance philosophies adopted in industrial electrical installations can be classified as belonging to one of the following categories:

5.1 Corrective or Curative Maintenance

Corrective maintenance, sometimes called curative (a non-standard term), aims to restore lost qualities to equipment necessary for its use.

According to standard NF EN 13306, corrective maintenance can be:

• ***Deferred***: corrective maintenance that is not performed immediately after the detection of a fault, but is delayed in accordance with given maintenance rules.

• ***Emergency***: corrective maintenance performed immediately after a fault is detected to avoid unacceptable consequences.

This is commonly applied to smaller components where repair is more expensive than replacement, and where the loss of the particular component during operation does not disrupt electrical power generation.

5.2 Preventive maintenance

Maintenance performed at predetermined intervals or according to prescribed criteria, designed to reduce the probability of failure or degradation of an asset's operation. It aims to prevent equipment failures during operation. Cost analysis must demonstrate a benefit compared to the failures it prevents.

5.2.1 Systematic preventive maintenance

Preventive maintenance performed at predetermined time intervals or according to a defined number of units of use, but without prior inspection of the equipment's condition.

While time is the most common unit, other units can be used, such as: the quantity of products manufactured, the length of products manufactured, the distance traveled, the mass of products manufactured, the number of cycles performed, etc.

This intervention frequency is determined from the date of commissioning or after a complete or partial overhaul.

5.2.2 Condition-based preventive maintenance

Preventive maintenance based on monitoring the operation of the asset and/or significant parameters of that operation, incorporating the resulting actions. Monitoring of operation and parameters can be performed according to a schedule, on demand, or continuously.

Note:

Condition-based maintenance is therefore experience-dependent and relies on real-time data.

Condition-based preventive maintenance is characterized by the identification of weaknesses. Depending on the situation, it is advisable to monitor these weaknesses and, based on this monitoring; decide on intervention when a certain threshold is reached. However, checks remain systematic and are part of non-destructive testing methods.

All equipment is concerned. This condition-based preventive maintenance is carried out through relevant measurements on equipment in operation.

5.2.3 Preventive Electrical Maintenance

With a preventive maintenance program, potential hazards that could lead to equipment failure or an interruption of electrical service can be identified and corrected.

Properly maintained equipment reduces downtime by minimizing catastrophic failures. To ensure the proper functioning of electrical equipment and devices, it is necessary to implement an effective preventive maintenance program.

5.2.4 Preventive Maintenance Strategies

Much of effective preventive maintenance of electrical equipment can be summarized by four rules:

- Keep it dry.
- Keep it clean.
- Keep it cool.
- Keep it tight.

There are several traditional philosophical approaches to electrical maintenance, such as fail-on, fail-as-needed, scheduled maintenance, and predictive maintenance.

5.2.5 General Criteria for Effective MPE

Efficient electrical equipment and MPE and subsystem testing programs must meet the criteria listed below.

First and foremost, a structured MPE program should actually exist.

In other words, an MPE program must be carried out as follows:

• Under formal management control

• In accordance with defined practices and schedules

• By clearly designated personnel

More specifically:

• Management must assign high priority to MPE.

• MPE activities must be prioritized according to the criticality of the systems and equipment involved.

• The MPE program must be carried out according to unambiguous written procedures.

• The MPE program must incorporate effective provisions for analyzing, correcting, and controlling the recurrence of root causes of failures.

• Information systems must be in place to record and update maintenance history.

• The MPE program must be carried out only by qualified personnel.

• Management must continuously monitor and reassess the effectiveness of the MPE program.

Evaluation

1- How to protect an electrical panel from moisture?

2-What are the signs that an electrical panel is overloaded?

3- What safety precautions do you take when working with cables?

4- How do you troubleshoot a signal loss issue?

5- What are the main types of cables you work with?

6- How do you handle a damaged cable?

7- What is the role of cable armor?

8- What are the signs of cable wear?

9- What to check after a cable repair?

10- What is the objective of preventive maintenance?

11- What is the first step in an intervention?

12- What are the 5 safety rules (SNC)?

APPENDIX

Appendix A

Chapter 1

2. Why is electricity transmitted at high voltage?

Part of the transmitted electrical energy dissipates as heat due to the Joule effect in the line's resistance. Line losses are given by the equation: $P_J = RI^2$, where:

PJ is the power of the line losses (in Watts),

R is the line resistance (in ohms Ω), and

I is the line current (in amperes A).

The transmitted power is $P_T = UI$, where:

U is the voltage to be transmitted, and

I is the line current.

$I = P_T/U$, therefore $PJ = R(P_T/U)^2$.

For a given power transmitted, line losses are inversely proportional to the square of the voltage, which explains the advantage of high voltage. If the voltage is high, the power of the line losses, P_J, will be low.

3. Why has alternating current become so widespread in electrical networks?

Alternating current is present in 99% of electrical networks, at the expense of direct current. To understand the reasons for this choice, we have compiled two tables outlining the advantages and disadvantages of sinusoidal and direct current regimes.

Alternating Current:

Advantages	Disadvantages
Allows the use of transformers to raise and lower the voltage.	Difficulty in interconnecting multiple networks (they must have the same voltage, frequency, and phase).
Facilitates current interruption through natural zero crossings twice per cycle, i.e., 100 times per second.	This implies inductive and capacitive effects throughout the network, hence the existence of reactive power that is detrimental to the producer.
Direct generation by alternators	It also implies a skin effect, meaning the concentration of current in the periphery of the cables, hence the need for suitable, and therefore more expensive, cables and lines.

Direct Current:

Advantages	Disadvantages
No reactive power, therefore no negative reactive power for production.	Difficulty in interrupting direct currents, hence the need for more efficient and expensive switching devices.
Facilitates network interconnection; all that is needed is the same voltage everywhere.	
No skin effect; cables and lines are simpler and less expensive.	Very costly terminations.

Comparison of AC and DC Systems in Electrical Power Transmission

It therefore appears that each advantage of one corresponds to a disadvantage of the other, and vice versa. However, two main elements stand out as advantages of the AC system:

* The (extensive) use of transformers is only possible with AC systems; it is still the only way to increase the voltage to 400 kV (750 kV or even 1 MV).

The cost per kilometer of an AC network tends to increase with the distance, primarily due to the cost of conductors, which are more complex than in a DC network. Conversely, the cost per kilometer of a DC network tends to decrease with the distance, since only the termination points of this type of network are complex.

Ultimately, the critical distance above which a DC network becomes less expensive is approximately 800 km. Therefore, on average, it is more economical to design an AC network than a DC network, especially for small countries.

4. Why sinusoidal waves?

The justification for the sinusoidal nature of the voltages and currents used is also interesting. It is indeed legitimate to ask why the pure sinusoidal regime is the only one used and not square, triangular, etc., voltage regimes. To answer this question, one simply needs to understand that alternating but non-sinusoidal electrical quantities can be decomposed into a "fundamental" frequency to which is added a series of harmonics whose frequencies are multiples of the fundamental frequency. From there, the answer lies in two points:

* The active power consumed by a receiver consuming a non-sinusoidal current is, in most cases, only related to the fundamental component of this current. The set of harmonics then imposes a greater effective current than it would have been in sinusoidal regime, which amounts to considering a lower value power factor (in other words, the presence of distorting power harms the power factor).

* In alternating current, the skin effect is more pronounced as the frequency of the signals increases. Harmonic components, whose frequencies are multiples of the fundamental frequency, thus travel through smaller cross-sections compared to the main conductor cross-section. The apparent resistance of the lines and cables is therefore much greater for harmonics, and the corresponding line losses are also significantly higher.

Consequently, when the transmission and distribution of electrical energy are carried out using alternating current, it is essential that this regime be specifically sinusoidal alternating current.

5. Use of Three-Phase Systems

Three-phase systems are still used for the production, transmission, or distribution of high electrical power, often at the expense of single-phase systems. Yet, it is legitimate to ask why, given that their heavier and more complex appearance would suggest otherwise. The justification for this is based on the following points:

* At constant active power, a three-phase "three-wire" system requires half the volume of electrical conductors compared to a single-phase system. Consequently, a three-phase system allows for a "factor 2" reduction in overall weight, cost, tower dimensions, etc., related to the lines and cables that comprise it. * The power density of three-phase machines (particularly alternators) is greater than the power density of their single-phase equivalents.

* For optimization purposes, alternators should ideally be three-phase and balanced. Using a three-phase network and loads is directly suited to this objective.

* In a balanced three-phase system, fluctuating power is zero. Consequently, the electrical energy supplied by such a system is perfectly continuous. This characteristic, in the operation of all three-phase electrical actuators, prevents vibrations and the "unbalance" phenomenon caused by the presence of "vibrational" torques related to fluctuating power.

Chapter 2

List out the components of station output system.

Main generator, Generator transformer, PT, CT, CVT, lightning arrestor, wave trap, main 220 kV bus, transfer bus, SF6 circuit breakers and isolators, line protection scheme, GT and Generator protection scheme, bus bar protection scheme etc

5. What are the protections provided for 220 kV lines and bus bars?

a. Bus bar differential protection.

b. Distance protection.

c. Over current protection.

d. Earth fault protection.

6. What are the main sources of power supply to 6.6 kV buses?

a. Unit transformer which steps down the generated voltage to 6.6 kV from the generator.

b. Start up transformer, which steps down the grid voltage to 6.6 kV

7. List some important loads to 6.6 kV buses.

a. Auxiliary transformers.

b. PHT motors.

c. BFP motors.

d. CEP motors.

e. CCW motors.

f. Chiller motors.

g. Pressuring pump motors.

For how long 220 V DC batteries can supply power UPS?

220 V DC batteries can supply Power UPS for 30 minutes. Within this time class III power supply should be restored by DG's

1. Mention the commissioning tests on breaker and bus bars.

Breaker9

a. Milli volt drops test between the interrupting contacts and between the isolator contacts.

b. Closing and opening timing of the breaker for 5 times.

c. Checking whether the breaker trips or closes when the logics are fulfilled.

Bus bars

a. Milli volts drop test for the contact resistance value.

b. Tightness of the joints.

c. IR values between phase to phase and phase to ground.

Should I choose a single-phase or three-phase electrical panel for my home?

The choice between a single-phase and three-phase panel depends on the load capacity and electrical distribution of your home. Single-phase is sufficient for most residential homes, while three-phase is recommended for homes with high energy consumption or industrial equipment.

How do I know if I need a sub-panel?

If your electrical installation extends over several zones or floors and the main panel cannot efficiently handle the distribution, a sub-panel may be necessary to better distribute the load and improve energy management.

What is the difference between a main distribution board and a sub-distribution board?

The main distribution board is the primary point of electrical distribution in an installation, containing the main protective devices. A sub-distribution board distributes electricity from the main distribution board to different areas, allowing for more precise energy management.

How do I maintain my electrical panel?

Maintaining an electrical panel involves regular inspections to check the condition of connections and protective devices, cleaning to prevent dust accumulation, and periodic testing of its functionality to ensure it is working properly.

What type of electrical panel do you recommend for an industrial installation?

For an industrial installation, a three-phase electrical panel is often recommended due to its ability to handle higher loads and power industrial equipment requiring three-phase power. A modular panel could also offer the necessary flexibility to adapt to the specific needs of the installation.

How do I add an extra circuit to my electrical panel?

To add an extra circuit, you must first ensure there is enough space in your panel for a new circuit breaker. Then, install the circuit breaker following the manufacturer's instructions, and connect the wires of the new circuit according to safety standards. It is crucial to turn off the power before starting any work.

Is it necessary to hire a professional to change the type of electrical panel?

Changing the type of electrical panel can involve complex modifications to your electrical installation. To ensure safety and compliance with electrical standards, it is strongly recommended that you hire a qualified professional, especially if you do not have extensive electrical expertise.

Chapter 3

1. What are the major impacts of environmental conditions on electrical equipment?

These include corrosion (marine environment), insulation defects (humidity/condensation), overheating (high temperature), and operational disturbances (electromagnetic fields).

2. How to choose the right equipment for a corrosive environment?

You must use corrosion-resistant materials such as stainless steel, treated aluminum, or fiberglass-reinforced polyester casings.

3. What is the impact of temperature on electrical cables?

High ambient temperatures reduce the current-carrying capacity (amperage) of the cable, requiring an oversized cross-section to prevent overheating.

4- What are the main types of disturbances?

• Transient overvoltages: Brief voltage spikes (lightning, load switching).

• Permanent overvoltages: Sustained increase in voltage (network fault).

• Voltage dips: Brief drop in voltage, often related to the starting of large motors.

• Micro-interruptions: Very short-duration interruptions.

• Harmonics: Distortion of the sinusoidal wave due to electronic devices.

5. What are the impacts of these disturbances on the installations?

Malfunctions and damage: Production stoppages, data loss on computers, and destruction of electronic components.

Overheating: Phase imbalances and harmonics cause overheating in transformers and cables.

Safety risks: Short circuits, fires due to faulty insulation.

6. What are the problems in station operation due to grid under voltage?

a) All the HT motors overloaded.

b) VAR load increases on generator leads to heating up of rotor

c) Stator current increases for same power export leads to stator overheating.

7. What are the problems in station operation due to grid under frequency?

a) Turbine having under frequency limitation, house load happen if < 48 Hz

b) Due to under frequency PHT flow reduces, therefore reactor power reduces, generator power reduces

c) If frequency is less than 48 Hz DG cannot be synchronized to grid, therefore DG kept on isolation running

d) GT overfluxing.

8. What causes harmonics in an electrical system?

Current harmonics are caused by nonlinear loads. When a nonlinear load, such as a rectifier, is connected to the system, it draws a non-sinusoidal current.

9. What are the effects of electrical harmonics?

In addition to the aforementioned effects on the current waveform, current harmonics also cause voltage waveform distortion due to voltage drops that occur as these currents flow through the impedance of lines and transformers.

They cause overheating due to increased Joule heating losses (skin effect) and eddy current losses, reducing their lifespan, particularly for transformers, by up to 30-50%.

10. What is a non-linear load?

It is equipment that does not draw a sinusoidal current, even when powered by a sinusoidal voltage (e.g., switched-mode power supplies, variable frequency drives, inverters, fluorescent lighting).

11. What are the visible symptoms of high harmonic pollution?

Bad tripping of circuit breakers, dielectric breakdowns, malfunctions of sensitive equipment (communication, medical devices), and whistling noises in motors or transformers.

12. How is harmonic pollution measured?

The total harmonic distortion (THD), often measured up to the 50th harmonic, indicates the extent of the distortion. A voltage THD > 8% requires analysis.

13- How to mitigate harmonics in an installation?

Use active or passive filters, transformers with specific couplings (e.g., Dyn11), line inductors, or group polluting loads.

Main effects:

• Overheating: Transformers, motors, cables.

• Resonance: Capacitors, cables.

• Disturbances: Electronic devices, sensors.

Overload: Neutral conductor.

14- How to protect installations against disturbances?

Surge arresters: To limit transient overvoltages due to lightning.

Uninterruptible power supplies (UPS): To compensate for micro-interruptions and voltage dips on sensitive equipment.

Harmonic filters: To reduce harmonic distortion.

Voltage regulators: To stabilize the voltage.

Basic solutions for mitigating harmonics

1. Position polluting loads upstream of the network.

2. Group together polluting loads.

3. Separate the sources.
4. Use transformers with specific couplings.
5. Place inductors in the installation.
6. Choose a suitable earthing system.

15. What to do in case of a disturbance?

- Inspect the grounding quality.
- Distribute the load evenly across the three phases to avoid imbalances.
- Install appropriate protection devices based on the sensitivity of the equipment.

Chapter 4

1. Why is grounding mandatory?

It is essential for personal safety (against electric shock/electrocution) and for protecting appliances in case of insulation faults.

2. What causes poor grounding?

One of the most common, yet most basic, grounding errors is failing to properly connect electrical appliances to the grounding system. Another is forgetting to reconnect system components after moving them. Incorrect connections between appliances and ground rods or wires can occur when appliances are improperly wired.

3. What are the consequences of improper grounding?

The consequences of improper grounding are serious, as users can be electrocuted if they come into contact with a live metal part. Overloading and the formation of electrical arcs are other consequences of a poorly executed ground connection.

4. What do the letters in TT, TN, and IT mean?

The first letter indicates the transformer neutral (T=Earth, I=Insulated). The second letter indicates the exposed conductive parts of the installation (T=Earth, N=Neutral).

5. What is the main use of the TT system?

It is the standard system for low-voltage distribution in residential buildings (public grid).

6 - What protection device is mandatory in a TT system?

The residual current device (RCD) is mandatory to cut off the current in the event of a first fault.

7 - What happens in the event of an insulation fault?

The fault current returns to the source via earth. It is detected by the RCD, which cuts off the circuit.

8 - What is the difference between TN-C and TN-S?

In TN-C, the neutral and earth conductors are combined (PEN). In TN-S, they are separate (PE and N). TN-S is mandatory for small cross-sections in residential buildings.

9 - What is the advantage of the TN system?

It is economical (no RCD is required upstream) and allows for high fault currents, simplifying detection by circuit breakers.

10- What is the main advantage of the IT system?

It offers the best continuity of service. The first fault does not cause a power outage, preventing the shutdown of critical processes (hospitals, industry).

11- How do you choose the neutral system?

The choice depends on the need for continuity of service (IT), ease of installation (TT), or cost savings in cabling (TN).

12- What is the most common neutral system?

The most common neutral system is the TT system.

13- Where does the neutral current go?

The neutral wire is blue. It ensures the return of current to the grid. Without it, there would be no current flow, and therefore, nothing would work. Safety devices, such as thermal-magnetic circuit breakers, use the neutral wire to take measurements and detect faults.

Chapter 6

1-How to protect an electrical panel from moisture?

To protect an electrical panel from moisture, it is essential to install it in a dry and well-ventilated location. Using waterproof enclosures specifically designed for humid environments can also prevent water infiltration. Moisture absorbers or dehumidification systems near the panel can help maintain a dry environment.

2-What are the signs that an electrical panel is overloaded?

Signs of an overloaded electrical panel include circuit breakers that trip frequently, blown fuses, a hot feeling when touching the panel, or even a burning smell coming from the wiring or protective devices. Flickering lights or malfunctioning appliances can also indicate an overload.

3-What safety precautions do you take when working with cables?

Always turn off power before work, use insulated tools, wear personal protective equipment (PPE) like gloves and glasses, and adhere to safety regulations to prevent injuries.

4-How do you troubleshoot a signal loss issue?

o Check all connections for security, then use a cable tester, multimeter, or signal meter to test continuity and signal strength along the route to identify breaks.

6-What are the main types of cables you work with?

Coaxial, twisted pair (Ethernet), fiber optic, and electrical wiring.

7-How do you handle a damaged cable?

Assess the damage level. If minor, repair it (e.g., splicing); if severe, replace the cable run to ensure performance.

8-What is the role of cable armor?

It protects the cable against mechanical injury.

9-What are the signs of cable wear?

Damaged or corroded sheath, loose connections, or abnormal overheating.

10- What to check after a cable repair?

The phase at both ends must be checked and the phase symbol updated to avoid confusion

11-What is the objective of preventive maintenance?

To reduce the risk of breakdowns and increase the lifespan of the equipment.

12- What is the first step in an intervention?

Disconnect the power supply, perform a voltage absence test (VAT), and lock out the installation.

13-What are the 5 safety rules (SNC)?

1. Disconnection
2. Lockout/Tagout (prevent reconnection),
3. Voltage Absence Test (VAT)
4. Grounding and Short-Circuiting
5. Marking/Protection.

Appendix B

Exam 1

Questions :

1- Explain the meaning of each of the following grounding diagrams.:

TT :

IT :

TN :

2- What are the main rules that an earth connection must comply with??

3 – List and explain the three topological structures of electrical networks.

4- a- What can be done to maintain a constant power supply to a consumer?

b- Provide the necessary details about the device used.

5- Explain the difference between an overvoltage and an overload.

6- What are the likely causes of each of the following faults:

a- A short circuit

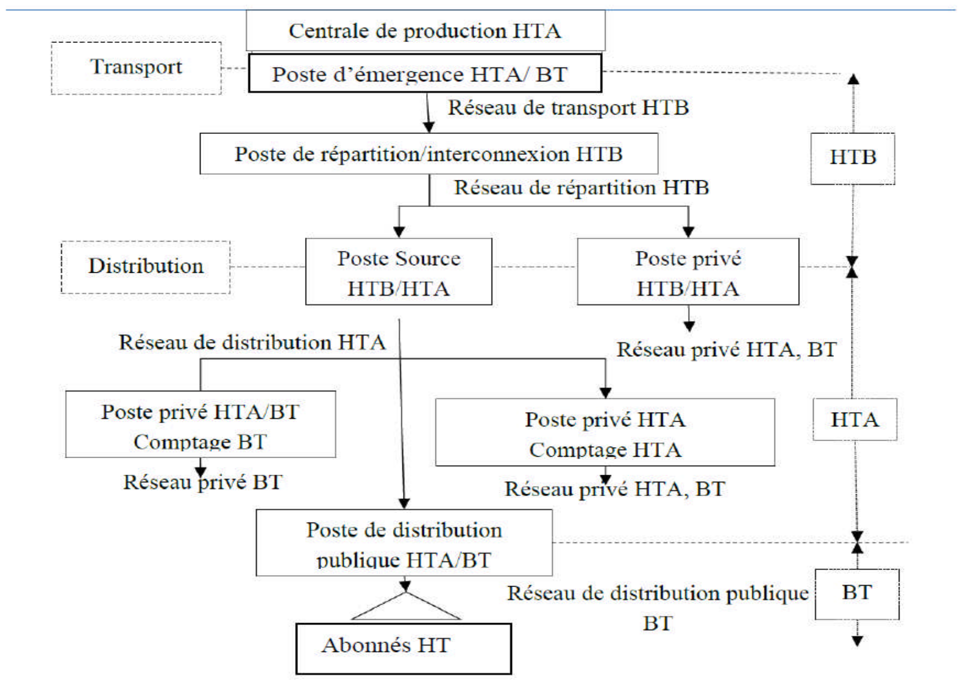
b- An overvoltage

7- Draw a diagram of a radial half-wave high-voltage network.

Exam 2

Questions :

1. Draw a block diagram illustrating the overall configuration of an electrical network (4 points)
2. Why is electricity transported as alternating current? (3 points)
3. List and briefly explain the different power supply systems of a medium-voltage (MV) network (3 points)
4. What is the role of the ground wire in an electrical network? (2 points)
5. What are the different disturbances that can affect the voltage amplitude? List them with brief explanations (6 points)
6. The following figure represents the organization of a network, but it contains two errors that you must identify and correct. (2 points)



Exam 3

Questions :

1- Complete the following table:

Abbreviations	BT		
Names			medium voltage
Values		1KV < U ≤35KV	

2. When is a three-phase electrical system considered unbalanced?

3. List and briefly explain the different power supply diagrams for a medium-voltage (MV) network.

4. What are the main rules to follow when installing grounding systems?

5. List and explain the four topological structures of electrical networks.

Exam 4

Questions :

1. When is a three-phase electrical system considered unbalanced?

2. What is the role of the grounding cable?

3. What are the different functions of an electrical substation?

4. What are the different types of electrical substations?

5. List and briefly explain the different power supply diagrams for a medium-voltage network.

Exam 5

Questions *(16pts)*

1- Draw a block diagram illustrating the overall configuration of an electrical network (2 points)

2- Why is electricity transported as alternating current? (2 points)

3- List and briefly explain the different topological structures of networks (3 points)

4- What is the role of the grounding wire in an electrical network? (2 points)

5- What are the different disturbances that can affect the voltage amplitude?

List them with brief explanations (4 points)

6- What are the main rules that must be followed when installing (3 points)

grounding connections?

Exercise *(04pts)*

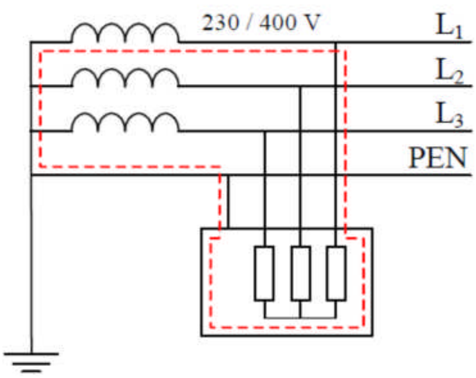
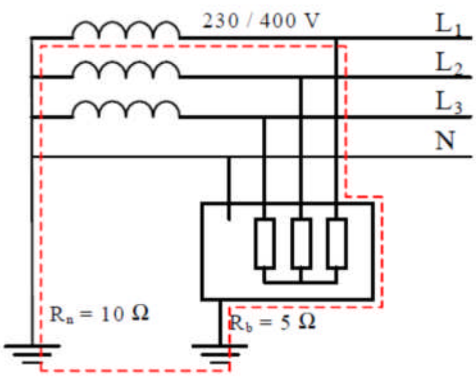


Diagram A



DiagramB

1. State the type of each of the earthing systems.
2. For both systems, a solid fault occurs between the frame and phase 1 (the fault current path is shown as a dashed line).
Deduce the value of the fault current (system A) and calculate the value of the fault current (system B).
3. Calculate the value of the fault voltage.

Exam 6

Questions **(13pts)**

1- Draw a block diagram illustrating the overall configuration of an electrical network (2 points)

2- Clearly explain the role of the grounding wire in the electrical network. (1.5 points)

3- What is an emergency power supply? (2 points)

4- List and explain the different disturbances that can affect the voltage amplitude. (4 points)

5- What are the main rules to follow for grounding? (1.5 points)

6- What is the neutral system represented by each of Figures 1 and 2? (2 points)

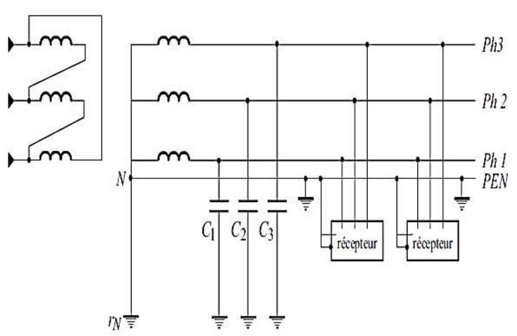


Fig. 1

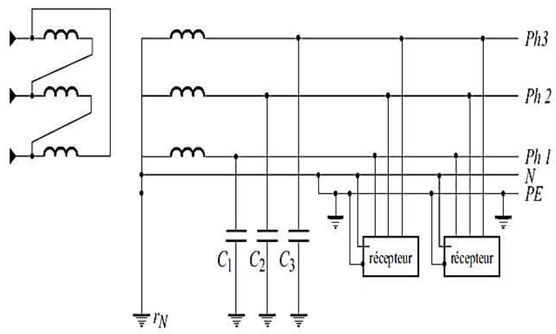


Fig. 2

Exercise ***(7pts)***

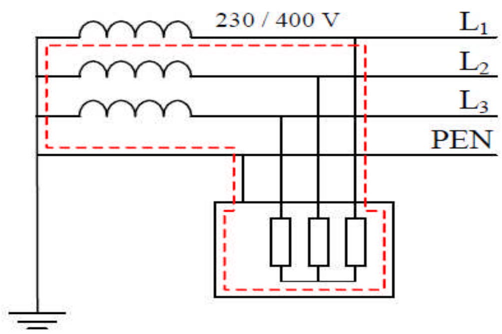


Diagram A

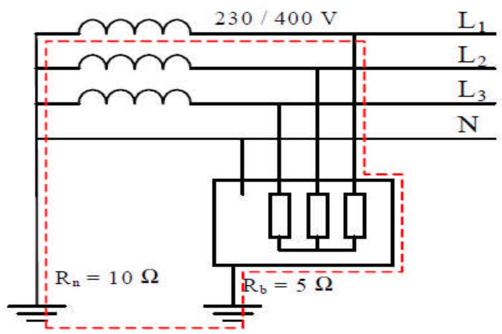


Diagram B

1. State the type of each of the earthing systems.

2. For both systems, a solid fault occurs between the frame and phase 1 (the fault current path is shown in dashed lines).

Deduce the value of the fault current (system A) and calculate the value of the fault current (system B).

3. Calculate the value of the fault voltage (system B).

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