AFSEC

TECHNICAL GUIDELINES FOR
LOW VOLTAGE ELECTRICAL INSTALLATIONS

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Foreword

The African Electrotechnical Standardization Commission (AFSEC) was established inter alia to improve the wellbeing of the African population, mainly by the promotion, development and application of harmonized standards on the entire continent in order to improve access to electricity. To achieve this objectives, AFSEC has the mission to:

- Identify existing standards and prioritize the needs of members of AFSEC with regard to standardization;
- Harmonize the existing standards, by adopting international standards, or in case of need, adapting them to the African conditions;
- Identify in case of need, the draft standards to be considered by the members of AFSEC for the purpose of adopting them;
- Make recommendations on the harmonized standards for their application by relevant Regulatory bodies.
- Recognizing the need for appropriate guide for electrical installation in Africa, AFSEC TC 64, which is a mirror committee of IEC TC 64, was tasked to develop Technical Guidelines for Low Voltage Electrical Installations. The committee decided to reference existing regulations and IEC standards to facilitate the project.

Introduction

The global energy consumption has increased recently with world population increase. This in effect, has also adversely affected African nations. There is a need to ensure a clean, reliable and sustainable supply of electricity in Africa as it is essential to the Socio-economic development of the continent. This must be without noticeable hazards to equipment, environment and all users whether the energy supply is grid, off-grid or alternative sources of supply.

This action calls for collaborated efforts within the regions as countries interconnect and engage in projects that will secure the future and improve the well-being of their people.

It is imperative to address compelling global issues such as rural-urban migration and climate change, which have impacted negatively on the energy needs of the people. Government should make access to clean, reliable and affordable electricity available to their respective rural domains. This can be possible through the provision of the off-grid alternative energy sources to serve both the served and unserved.

AFSEC guideline so provided is based on Electrical Installation Guide according to IEC Standards and IEC60364 series of standards structured to accommodate the regulations of countries; Nigeria (NESIS), Zambia (ZS 791), South Africa (SABS 0142), Cote d'Ivoire (NFC15-100), DRC (NFC15-100), DRC (NFC15-100) and Kenya (KS 662) where necessary. Otherwise, the contents of the main reference document stay.

Considering the buffering activities that will emanate from the provision of electricity to the population, the safety in implementing AFSEC (ATC64) guide through the deployment of electrical equipment will require the use of appropriate methods and means to forestall accidents and loss of lives and property.

In the fields of electrical installations, availability of standards and complying with their requirements are key necessities for Africans because, in the face of scarce energy, managing the little energy available through electrical installations requirement will also enhance energy efficiency, safety of lives and properties, economic emancipation of both individuals and nations and of course enjoying the wonderful beauties of modern engineering.

1 Scope

This Technical Guidelines for Low Voltage Electrical Installations is to provide electrical technicians, engineers and many others with a quick reference, immediate-use working tool. It is intended for electrical professionals in companies, design offices and inspection organizations.

This document guide covers techniques and standards related to low-voltage electrical installations.

The guide provides an overview of standards and regulations suitable for application in Low voltage electrical installations in Africa.

It is not a substitute for technical manuals or standards. This document shall be used in conjunction with IEC standards and AFSEC standards, national codes and regulations.

2 Normative References

This Guide is based on regulations of AFSEC members and the relevant IEC standards, in particular IEC 60364. IEC 60364 has been established by engineering experts of all countries in the world comparing their experience at an international level. Currently, the safety principles of IEC 60364 series, IEC 61140, 60479 series and IEC 61201 are the fundamentals of most electrical standards in the world and are so referenced (see table below and next page).

IEC 60364-1 Low-voltage electrical installations – Fundamental principles, assessment of general characteristics, definitions

IEC 60364-4-41 Low-voltage electrical installations – Protection for safety – Protection against electric shock

IEC 60364-4-42 Low-voltage electrical installations – Protection for safety – Protection against thermal effects

IEC 60364-4-43 Low-voltage electrical installations – Protection for safety – Protection against overcurrent

IEC 60364-4-44 Low-voltage electrical installations – Protection for safety – Protection against voltage disturbances and electromagnetic disturbances

IEC 60364-5-51 Low–voltage electrical installations – Selection and erection of electrical equipment – Common rules

IEC 60364-5-52 Low-voltage electrical installations – Selection and erection of electrical equipment – Wiring systems

IEC 60364-5-53 Low-voltage electrical installations – Selection and erection of electrical equipment – Isolation, switching and control

IEC 60364-5-54 Low-voltage electrical installations – Selection and erection of electrical equipment – Earthing arrangements and protective conductors

IEC 60364-5-55 Low-voltage electrical installations – Selection and erection of electrical equipment – Other equipment

IEC 60364-6 Low-voltage electrical installations – Verification

IEC 60364-7-701 Low-voltage electrical installations – Requirements for special installations or locations – Locations containing a bath or shower

IEC 60364-7-702 Low-voltage electrical installations – Requirements for special installations or locations – Swimming pools and fountains

IEC 60364-7-703 Low-voltage electrical installations – Requirements for special installations or locations – Rooms and cabins containing sauna heaters

IEC 60364-7-704 Low-voltage electrical installations – Requirements for special installations or locations – Construction and demolition site installations

IEC 60364-7-705 Low-voltage electrical installations – Requirements for special installations or locations – Agricultural and horticultural premises

IEC 60364-7-706 Low-voltage electrical installations – Requirements for special installations or locations – Conducting locations with restrictive movement

IEC 60364-7-708 Low-voltage electrical installations – Requirements for special installations or locations – Caravan parks, camping parks and similar locations

IEC 60364-7-709 Low-voltage electrical installations – Requirements for special installations or locations – Marinas and similar locations

IEC 60364-7-710 Low-voltage electrical installations – Requirements for special installations or locations – Medical locations

IEC 60364-7-711 Low-voltage electrical installations – Requirements for special installations or locations – Exhibitions, shows and stands

IEC 60364-7-712 Low-voltage electrical installations – Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

IEC 60364-7-713 Low-voltage electrical installations – Requirements for special installations or locations – Furniture

IEC 60364-7-714 Low-voltage electrical installations – Requirements for special installations or locations – External lighting installations

IEC 60364-7-715 Low-voltage electrical installations – Requirements for special installations or locations – Extra-low-voltage lighting installations

IEC 60364-7-717 Low-voltage electrical installations – Requirements for special installations or locations – Mobile or transportable units

IEC 60364-7-718 Low-voltage electrical installations – Requirements for special installations or locations – Communal facilities and workplaces

IEC 60364-7-721 Low-voltage electrical installations – Requirements for special installations or locations – Electrical installations in caravans and motor caravans

IEC 60364-7-729 Low-voltage electrical installations – Requirements for special installations or locations – Operating or maintenance gangways

IEC 60364-7-740 Low-voltage electrical installations – Requirements for special installations or locations – Temporary electrical installations for structures, amusement devices and booths at fairgrounds, amusement parks and circuses

IEC 60364-7-753 Low-voltage electrical installations – Requirements for special installations or locations – Heating cables and embedded heating systems

IEC 60364-8-1 Low-voltage electrical installations – Energy efficiency

IEC 60755 General requirements for residual current operated protective devices

IEC / TR 61439-0 Low-voltage switchgear and controlgear assemblies – Guidance to specifying assemblies

IEC 61439-1 Low-voltage switchgear and controlgear assemblies – General rules

IEC 61439-2 Low-voltage switchgear and controlgear assemblies – Power switchgear and controlgear assemblies

IEC 61439-3 Low-voltage switchgear and controlgear assemblies – Distribution boards intended to be operated by ordinary persons (DBO)

IEC 61439-4 Low-voltage switchgear and controlgear assemblies – Particular requirements for assemblies for construction sites (ACS)

IEC 61439-5 Low-voltage switchgear and controlgear assemblies – Assemblies for power distribution in public networks

IEC 61439-6 Low-voltage switchgear and controlgear assemblies – Busbar trunking systems (busways)

IEC 61557-1 Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – General requirements

IEC 61557-8 Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Insulation monitoring devices for IT systems

IEC 61557-9 Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Equipment for insulation fault location in IT systems

IEC 61557-12 Electrical safety in low voltage distribution systems up to 1000 V a.c. and 1500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Performance measuring and monitoring devices (PMD)

IEC 61558-2-6 Safety of transformers, reactors, power supply units and similar products for supply voltages up to 1100 V – Particular requirements and test for safety isolating transformers and power supply units incorporating isolating transformers

IEC 61643-11 Low-voltage surge protective devices – Surge protective devices connected to low-voltage power systems – Requirements and test methods

IEC 61643-12 Low-voltage surge protective devices – Surge protective devices connected to low-voltage power distribution systems – Selection and application principles

IEC 61643-21 Low voltage surge protective devices – Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods

IEC 61643-22 Low-voltage surge protective devices – Surge protective devices connected to telecommunications and signalling networks – Selection and application principles

IEC 61921 Power capacitors – Low-voltage power factor correction banks

IEC 61936-1 Power installations exceeding 1 kV a.c. – Part 1: Common rules

IEC 62271-1 High-voltage switchgear and controlgear – Common specifications

IEC 62271-100 High-voltage switchgear and controlgear – Alternating-current circuit breakers

IEC 62271-101 High-voltage switchgear and controlgear – Synthetic testing

IEC 62271-102 High-voltage switchgear and controlgear – Alternating current disconnectors and earthing switches

IEC 62271-103 High-voltage switchgear and controlgear – Switches for rated voltages above 1 kV up to and including 52 kV

IEC 62271-105 High-voltage switchgear and controlgear – Alternating current switch-fuse combinations for rated voltages above 1 kV up to and including 52 kV

IEC 62271-200 High-voltage switchgear and controlgear – Alternating current metal-enclosed switchgear and controlgear for rated voltages above 1 kVand up to and including 52 kV

IEC 62271-202 High-voltage switchgear and controlgear – High-voltage/low voltage prefabricated substations

IEC 62305-1 Protection against lightning – Part 1: General principles

IEC 62305-2 Protection against lightning – Part 2: Risk management

IEC 62305-3 Protection against lightning – Part 3: Physical damage to structures and life hazard

IEC 62305-4 Protection against lightning – Part 4: Electrical and electronic systems within structures

IEC 62586-2 Power quality measurement in power supply systems – Part 2: Functional tests and uncertainty requirements

IEC TS 62749 Assessment of power quality – Characteristics of electricity supplied by public networks

3 Terms and Definitions

Refer to IEC 60050 series – International Electrotechnical Vocabulary

4 General Rules and Regulations for Electrical Installations

This guide is intended to be applied to electrical installations generally but, in certain cases, it may need to be supplemented by the requirements or recommendations of individual member countries and applicable International Standards or by the requirements of the person ordering the work. The guide shall apply to items of electrical equipment only so far as selection and application of the equipment in the installation are concerned. It does not deal with requirements for the construction of assemblies of electrical equipment, which are required to comply with appropriate standards.

For installations in premises over which a licensing or other authority exercises a statutory control, the requirements of that authority shall be ascertained and complied within the design and execution of the installation.

This guide is based on relevant IEC standards but of particular importance is IEC 60364 series which addresses low voltage electrical installations and safety.

5 Design, Sizing and Protection of Conductors

Selection of cross-sectional-areas of cables or isolated conductors for line conductors is certainly one of the most important tasks of the design process of an electrical installation as this greatly influences the selection of overcurrent protective devices, the voltage drop along these conductors and the estimation of the prospective short-circuit currents: the maximum value relates to the overcurrent protection and the minimum value relates to the fault protection by automatic disconnection of supply. This has to be done for each circuit of the installation. Similar task is to be done for the neutral conductor and for the Protective Earth (PE) conductor.

5.1 Design of Installations

The electrical installation shall be designed to provide for:

i) the protection of persons, livestock and property in accordance with relevant national and international standards.

ii) the proper functioning of the electrical installation for the intended use.

5.2 Methodology

A preliminary analysis of the power requirements of the installation, a study of cabling and its electrical protection should be undertaken, starting at the origin of the installation, through the intermediate stages to the final circuits. The cabling and its protection at each level must satisfy several conditions at the same time, in order to ensure a safe and reliable installation e.g. it must:

- Carry the permanent full load current, and normal short-time overcurrent's
- Not cause voltage drops likely to result in an inferior performance of certain loads, for example: an excessively long acceleration period when starting a motor, etc.

6 Low Voltage (LV) Architecture Selection Guide for Buildings

Moreover, the protective devices (circuit breakers or fuses) must:

- Protect the cabling and busbars for all levels of overcurrent, up to and including short-circuit currents
- Ensure protection of persons against indirect contact hazards, particularly in TN- and IT-earthed systems, where the length of circuits may limit the magnitude of short-circuit currents, thereby delaying automatic disconnection (it may be remembered that TT-earthed installations are necessarily protected at the origin by a RCD, generally rated at 300 mA).

Component parts of an electric circuit and its protection are determined such that all normal and abnormal operating conditions are satisfied.

The Electrical Distribution architecture of an installation involves the spatial configuration, the choice of power sources, the definition of different distribution levels, the single-line diagram and the choice of equipment. The choice of the best architecture is often expressed in terms of seeking a compromise between the various performance criteria that interest the customer who will use the installation at different phases in its lifecycle.

To be compatible with the "special" or "critical" work-site time, it is recommended to limit uncertainties by applying the following recommendations:

a. Use of proven solutions and equipment that has been validated and tested by manufacturers ("functional" switchboard or "manufacturer" switchboard according to the application criticality);

b. Prefer the implementation of equipment for which there is a reliable distribution network and for which it is possible to have local support (supplier well established);

c. Prefer the use of factory-built equipment (MV/LV substation, busway), allowing the volume of operations on site to be limited;

d. Limit the variety of equipment implemented for example, when possible harmonize transformers power;

e. Avoid mixing equipment from different manufacturers.

6.1 Inspection and Testing

Before a utility will connect an installation to its supply network, strict pre-commissioning electrical tests and visual inspections by the authority, or by its appointed agent, must be satisfied.

These tests are made according to local (governmental and/or institutional) regulations, which may differ slightly from one country to another. The principles of all such regulations however, are common, and are based on the observance of rigorous safety rules in the design and realization of the installation.

IEC 60364-6 and related standards included in this guide are based on an international consensus for such tests, intended to cover all the safety measures and approved installation practices normally required for residential, commercial and (the majority of) industrial buildings. Many industries however have additional regulations related to a particular product (petroleum, coal, natural gas, etc.). Such additional requirements are beyond the scope of this guide.

The pre-commissioning electrical tests and visual-inspection checks for installations in buildings include, typically, all of the following:

- Electrical continuity and conductivity tests of protective, equipotential and earth-bonding conductors
- Insulation resistance tests between live conductors and the protective conductors connected to the earthing arrangement
- Test of compliance of SELV (Safety Extra Low Voltage) and PELV (Protection by Extra Low Voltage) circuits or for electrical separation
- Insulation resistance/impedance of floors and walls
- Protection by automatic disconnection of the supply
- For TN, by measurement of the fault loop impedance, and by verification of the characteristics and/or the effectiveness of the associated protective devices (overcurrent protective device and RCD)
- For TT, by measurement of the resistance RA of the earth electrode of the exposed-conductive-parts, and by verification of the characteristics and/or the effectiveness of the associated protective devices (overcurrent protective device and RCD)
- For IT, by calculation or measurement of the current Id in case of a first fault at the line conductor or at the neutral, and with the test done for TN system where conditions are similar to TN system in case of a double insulation fault situation, with the test done for TT system where the conditions are similar to TT system in case of a double insulation fault situation.
- Additional protection by verifying the effectiveness of the protective measure
- Polarity test where the rules prohibit the installation of single pole switching devices in the neutral conductor.
- Check of phase sequence in case of multiphase circuit
- Functional test of switchgear and control gear by verifying their installation and adjustment
- Voltage drop by measuring the circuit impedance or by using diagrams

These tests and checks are basic (but not exhaustive) to the majority of installations, while numerous other tests and rules are included in the regulations to cover particular cases, for example: installations based on class 2 insulation, special locations, etc.

In many countries, all industrial and commercial-building installations, together with installations in buildings used for public gatherings, must be re-tested periodically by authorized agents.

The following tests should be performed

- Verification of RCD effectiveness and adjustments
- Appropriate measurements for providing safety of persons against effects of electric shock and protection against damage to property against fire and heat
- Confirmation that the installation is not damaged
- Identification of installation defects

7 Connection to the LV Utility Distribution Network

Where the connection is made at the Low Voltage level, the installation will be connected to the local power network and be metered according to LV tariffs and any other utility requirements.

The most-common LV supplies are within the range 120/208V single phase to 240/415V 3-phase 4-wires. Loads up to 250 kVA can be supplied at LV, but power-supply organizations generally propose a MV service at load levels for which their LV networks are marginally adequate. An international voltage standard for 3-phase 4-wire LV systems is recommended by the IEC 60038 to be 230/400 V.

The function of a LV "mains" distributor is to provide service connections (underground cable or overhead line) to a number of consumers along its route.

The current-rating requirements of distributors are estimated from the number of consumers to be connected and an average demand per consumer.

The two principal limiting parameters of a distribution network are:

a. The maximum current which it is capable of carrying indefinitely, and

b. The maximum length of cable which, when carrying its maximum current, will not exceed the statutory voltage-drop limit.

These constraints mean that the magnitude of loads which utilities are willing to connect to their LV distribution mains, is necessarily restricted.

Practices vary considerably from one power supply organization to another, and no "standardized" values can be given for maximum permitted loads connected to a LV distribution network. However, factors to be considered include:

a. The size of an existing distribution network to which the new load is to be connected;

b. The total load already connected to the distribution network;

c. The location along the distribution network of the proposed new load, i.e. close to the substation, or near the remote end of the distribution network, etc

7.1 Location of meters

For the convenience of both the meter reader and consumer, the location of meters is nowadays generally outside the premises, either:

a. In a free-standing pillar-type housing

b. In a space inside a building, but with cable termination and supply authority's fuses located in a flush-mounted weatherproof cabinet accessible from the public way,

c. For private residential consumers, the equipment can be installed in a weatherproof cabinet mounted vertically on a metal frame in the front garden, or flush-mounted in the boundary wall, and accessible to authorized personnel from the pavement.

d. Pole Mounted meters

The meter shall be located in a safe, secure, accessible and weatherproof location.

8 Residential and Other Special Locations

The IEC 60364 and IEC 61009 series of standards provide guidance for safety and reliability for electrical installations of residential premises.

8.1 Distribution boards components

The quality of electrical equipment used in residential premises shall be confirmed by the relevant "mark of conformity" on the item.

9 Circuits

Reference shall be to relevant national and international standards

10 Special Locations

In special locations containing a fixed bath (bath tub, birthing pool) or shower and to the surrounding zones a particular attention shall be paid to electrical installations and not electrical appliances. Bathrooms and shower rooms are areas of high risk, because of the very low resistance of the human body when wet or immersed in water. Guidance given in IEC 60364-7-701 should be taken into consideration.

11 LV Distribution

The function of a LV "mains" distributor is to provide service connections (underground cable or overhead line) to a number of consumers along its route (Residential and commercial consumers). The current-rating requirements of distributors are estimated from the number of consumers to be connected and an average demand per consumer. The two principal limiting parameters of a distributor are:

- The maximum current which it is capable of carrying indefinitely, and
- The maximum length of cable which, when carrying its maximum current, will not exceed the statutory voltage-drop limit

These constraints mean that the magnitude of loads which utilities are willing to connect to their LV distribution mains, is necessarily restricted.

Factors to be considered include:

- The size of an existing distribution network to which the new load is to be connected
- The total load already connected to the distribution network
- The location along the distribution network of the proposed new load, i.e. close to the substation, or near the remote end of the distribution network, etc. In short, each case must be examined individually.

The most-common LV supplies are within the range 120V single phase to 240/415V 3-phase 4-wires. Loads up to 250 kVA can be supplied at LV, but national power-supply organizations generally may propose a MV service at load levels for which their LV networks are marginally adequate. An international voltage standard for 3-phase 4-wire LV systems is recommended by the IEC 60038 to be 230/400V, however 240/415V 3 phase 4-wires may be the preference of other countries.

Where the connection is made at the Low Voltage level the installation will be connected to the local power network and will (necessarily) be metered according to LV tariffs.

11.1 Earthing connections

In a building, the connection of all metal parts of the building and all exposed conductive parts of electrical equipment to an earth electrode prevents the appearance of dangerously high voltages between any two simultaneously accessible metal parts.

12 Connections

12.1 The main equipotential bonding system

The bonding is carried out by protective conductors and the aim is to ensure that, in the event of an incoming extraneous conductor (such as a gas pipe, etc.) being raised to some potential due to a fault external to the building, no difference of potential can occur between extraneous-conductive-parts within the installation. The bonding must be effected as close as possible to the point(s) of entry into the building, and be connected to the main earthing terminal. However, connections to earth of metallic sheaths of communications cables require the authorization of the owners of the cables.

12.2 Supplementary equipotential connections

These connections are intended to connect all exposed-conductive-parts and all extraneous-conductive-parts simultaneously accessible, when correct conditions for protection have not been met, i.e. the original bonding conductors present an unacceptably high resistance.

12.3 Connection of exposed-conductive-parts to the earth electrode(s)

The connection is made by protective conductors with the object of providing a low-resistance path for fault currents flowing to earth.

12.4 Components

Effective connection of all accessible metal fixtures and all exposed-conductive-parts of electrical appliances and equipment is essential for effective protection against electric shocks.

12.5 Definition of standardized earthing schemes

The different earthing schemes (often referred to as the type of power system or system earthing arrangements) describes the method of earthing the installation downstream of the secondary winding of a MV/LV transformer and the means used for earthing the exposed conductive-parts of the LV installation supplied from it. The choice of these methods governs the measures necessary for protection against indirect-contact hazards. The earthing system qualifies three originally independent choices made by the designer of an electrical distribution system or installation:

- The type of connection of the electrical system (that is generally of the neutral conductor) and of the exposed parts to earth electrode(s)

- A separate protective conductor and neutral conductor being a single conductor

- The use of earth fault protection of overcurrent protective switchgear which clear only relatively high fault currents or the use of additional relays able to detect and clear small insulation fault currents to earth. In practice, these choices have been grouped and standardized as explained below. Each of these choices provides standardized earthing systems with three

12.6 Advantages and Drawbacks:

- Connection of the exposed conductive parts of the equipment and of the neutral conductor to the PE conductor results in equipotentiality and lower overvoltages but increases earth fault currents

- A separate protective conductor is costly even if it has a small cross-sectional area but it is much more unlikely to be polluted by voltage drops and harmonics, etc. than a neutral conductor is. Leakage currents are also avoided in extraneous conductive parts

- Installation of residual current protective relays or insulation monitoring device, are much more sensitive and permits in many circumstances to clear faults before heavy damage occurs (motors, fires, electrocution). The protection offered is in addition independent with respect to changes in an existing installation.

13 TT system (earthed neutral)

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

13.1 TN systems (exposed conductive parts connected to the neutral)

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

14 TN-C system

The neutral conductor is also used as a protective conductor and is referred to as a PEN (Protective Earth and Neutral) conductor. This system is not permitted for conductors of less than 10 mm^2 or for portable equipment. The TN-C system requires an effective equipotential environment within the installation with dispersed earth electrodes spaced as regularly as possible since the PEN conductor is both the neutral conductor and at the same time carries phase unbalance currents as well as 3rd order harmonic currents (and their multiples). The PEN conductor must therefore be connected to a number of earth electrodes in the installation.

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

15 TN-S system

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

16 TN-C-S system

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

17 IT system (isolated or impedance-earthed neutral)

17.1 IT system (isolated neutral)

No intentional connection is made between the neutral point of the supply source and earth (see Figure 1). Exposed- and extraneous-conductive-parts of the installation are connected to an earth electrode. In practice all circuits have a leakage impedance to earth, since no insulation is perfect. In parallel with this (distributed) resistive leakage path, there is the distributed capacitive current path, the two paths together constituting the normal leakage impedance to earth

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

17.2 IT system (impedance-earthed neutral)

An impedance Z_s (in the order of 1000 to 2000 Ω) is connected permanently between the neutral point of the transformer LV winding and earth. All exposed- and extraneous-conductive-parts are connected to an earth electrode. The reasons for this form of power-source earthing are to fix the potential of a small network with respect to earth Z_s is small compared to the leakage impedance) and to reduce the level of overvoltages, such as transmitted surges from the MV windings, static charges, etc. with respect to earth. It has, however, the effect of slightly increasing the first-fault current level.

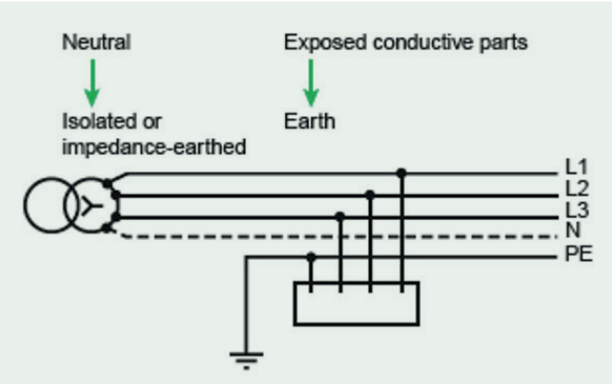


Figure 1: IT systems (Isolated neutral)

18 Characteristics of TT, TN and IT systems

Technique for the protection of persons: the exposed conductive parts are earthed and residual current devices (RCDs) are used.

Operating technique: interruption for the first insulation fault

NOTE:
If the exposed conductive parts are earthed at a number of points, an RCD must be installed for each set of circuits connected to a given earth electrode.

18.1 Main characteristics

1. Simplest solution to design and install.

2. Used in installations supplied directly by the public LV distribution network.

3. Does not require continuous monitoring during operation (a periodic check on the RCDs may be necessary).

4. Protection is ensured by special devices, the residual current devices (RCD), which also prevent the risk of fire when they are set to 500 mA.

5. Each insulation fault results in an interruption in the supply of power, however the outage is limited to the faulty circuit by installing the RCDs in series (selective RCDs) or in parallel (circuit selection).

6. Loads or parts of the installation which, during normal operation, cause high leakage currents, require special measures to avoid nuisance tripping, i.e. supply the loads with a separation transformer or use specific RCDs; as stated in the requirements of IEC 60364-4-41.

19 TN system

Technique for the protection of persons:

1. Interconnection and earthing of exposed conductive parts and the neutral are mandatory

2. Interruption for the first fault using overcurrent protection (circuit breakers or fuses)

Operating technique: interruption for the first insulation fault

19.1 Main characteristics

Generally speaking, the TN system:

1. requires the installation of earth electrodes at regular intervals throughout the installation

2. Requires that the initial check on effective tripping for the first insulation fault be carried out by calculations during the design stage, followed by mandatory measurements to confirm tripping during commissioning

3. Requires that any modification or extension be designed and carried out by a qualified electrician

4. May result, in the case of insulation faults, in greater damage to the windings of rotating machines

5. May, on premises with a risk of fire, represent a greater danger due to the higher fault currents

In addition, the TN-C system:

1. At first glance, would appear to be less expensive (elimination of a device pole and of a conductor)

2. Requires the use of fixed and rigid conductors

3. Is forbidden in certain cases:
   – Premises with a risk of fire
   – For computer equipment (presence of harmonic currents in the neutral)

In addition, the TN-S system:

1. May be used even with flexible conductors and small conduits

2. Due to the separation of the neutral and the protection conductor, provides a clean PE (computer systems and premises with special risks).

20 IT system

20.1 Protection technique:

1. Interconnection and earthing of exposed conductive parts
2. Indication of the first fault by an insulation monitoring device (IMD)
3. Interruption for the second fault using overcurrent protection (circuit breakers or fuses)

20.1.1 Operating technique:

1. Monitoring of the first insulation fault
2. Mandatory location and clearing of the fault
3. Interruption for two simultaneous insulation faults

20.1.2 Main characteristics

1. Solution offering the best continuity of service during operation
2. Indication of the first insulation fault, followed by mandatory location and clearing, ensures systematic prevention of supply outages
3. Generally used in installations supplied by a private MV/LV or LV/LV transformer
4. Requires maintenance personnel for monitoring and operation
5. Requires a high level of insulation in the network (implies breaking up the network if it is very large and the use of circuit-separation transformers to supply loads with high leakage currents)
6. The check on effective tripping for two simultaneous faults must be carried out by calculations during the design stage, followed by mandatory measurements during commissioning on each group of interconnected exposed conductive parts
7. Protection of the neutral conductor must be ensured

21 Selection criteria for the TT, TN and IT systems

Selection does not depend on safety criteria. The three systems are equivalent in terms of protection of persons if all installation and operating rules are correctly followed. The selection criteria for the best system(s) depend on the regulatory requirements, the required continuity of service, operating conditions and the types of network and loads.

In terms of the protection of persons, the three system earthing arrangements (SEA) are equivalent if all installation and operating rules are correctly followed.

Consequently, selection does not depend on safety criteria. It is by combining all requirements in terms of regulations, continuity of service, operating conditions and the types of network and loads that it is possible to determine the best system(s)

Selection is determined by the following factors:

1. Above all, the applicable regulations which in some cases impose certain types of SEA
2. Secondly, the decision of the owner if supply is via a private MV/LV transformer (MV subscription) or the owner has a private energy source (or a separate-winding transformer). If the owner effectively has a choice, the decision on the SEA is taken following discussions with the network designer (design office, contractor).

The discussions must cover:

First of all, the operating requirements (the required level of continuity of service) and the operating conditions (maintenance ensured by electrical personnel or not, in-house personnel or outsourced, etc.) and secondly, the particular characteristics of the network and the loads.

Choice of earthing method – implementation
After consulting applicable regulations, Table 1 can be used as an aid in deciding on divisions and possible galvanic isolation of appropriate sections of a proposed installation.

21.1 Division of source

This technique concerns the use of several transformers instead of employing one high-rated unit. In this way, a load that is a source of network disturbances (large motors, furnaces, etc.) can be supplied by its own transformer.

The quality and continuity of supply to the whole installation are thereby improved. The cost of switchgear is reduced (short-circuit current level is lower). The cost-effectiveness of separate transformers must be determined on a case by case basis.

21.2 Network islands

The creation of galvanically-separated "islands" by means of LV/LV transformers makes it possible to optimize the choice of earthing methods to meet specific requirements.

22 Distribution and installation methods

Distribution takes place via cableways that carry single insulated conductors or cables and include a fixing system and mechanical protection. To add further text summarizing this topic and include reference international Stds.

Conductor marking (in accordance with country regulation)

Conductor identification must always respect the following three rules:

1. The double colour green and yellow is strictly reserved for the PE and PEN protection conductors
2. When a circuit comprises a neutral conductor, it must be light blue or marked "1"for cables with more than five conductors. When a circuit does not have 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
3. Phase conductors may be any colour except:

   – Green and yellow

   – Green

   – Yellow

   – Light blue (see rule 2).

NOTE:
Conductors in a cable are identified either by their colour or by numbers on conductor marking.

23 Busbar trunking (busways)

A busbar trunking system comprises a set of conductors protected by an enclosure (see Figure 2) used for the transmission and distribution of electrical power, busbar trunking systems have all the necessary features for fitting: connectors, straights, angles, fixings, etc. The tap-off points placed at regular intervals make power available at every point in the installation.

23.1 Sizing of Busbar trunking Systems

The first step in the selection procedure for Busbar trunking systems is to assess the phase currents and 3rd harmonic current level.

NOTE:
The 3rd harmonic current level has an impact on the neutral current, and consequently on the rating of all components in the installation:

1. Switchboard,
2. Protection and dispatching switchgear,
3. Cables and Busbar trunking systems.

Depending on the estimated 3rd harmonic level, 3 cases are possible:

a. 3rd harmonic level below 15% (ih3 ≤15%): The neutral conductor is considered as not loaded. The size of the phase conductors is only dependent on the phase currents. The neutral conductor size may be smaller than the phase conductors', if the cross section area is higher than 16 mm^2 for copper, or 25 mm^2 for aluminum.

b. 3rd harmonic level between 15 and 33% (15 < ih3 ≤33%) The neutral conductor is considered as current-carrying conductor. The practical current shall be reduced by a factor equal to 84% (or inversely), select a Busbar with a practical current equal to the phase current divided by 0.84. The size of the neutral conductor shall be equal to that of the phases.

c. 3rd harmonic level higher than 33% (ih > 33%) The neutral conductor is considered as a current-carrying conductor. The recommended approach is to adopt circuit conductors with equal size for phase and neutral. The neutral current is predominant in the selection of the size of conductor. Generally, this leads to the selection of a Busbar trunking system which current rating is higher than the requested capacity (generally by a factor of two).

23.2 The Various Types of Busbar Trunking:

Busbar trunking systems are present at every level in electrical distribution: from the link between the transformer and the low voltage switchboard (MLVS) to the distribution of power sockets and lighting to offices, or power distribution to workshops. There are essentially three categories of busways.

1. Transformer to MLVS busbar trunking Installation of the busway may be considered as permanent and will most likely never be modified. There are no tap-off points. Frequently used for short runs, it is almost always used for ratings above 1600/2000 A, i.e. when the use of parallel cables makes installation impossible. Busways are also used between the MLVS and downstream distribution switchboards. The characteristics of main-distribution busways authorize operational currents from 1000 to 5000 A and short-circuit withstands up to 150 kA.

2. Sub-distribution busbar trunking with low or high tap-off densities. Downstream of main-distribution busbar trunking, two types of applications must be supplied:

3. Mid-sized premises (industrial workshops with injection presses and metalwork machines or large supermarkets with heavy loads). The short-circuit and current levels can be fairly high (respectively 20 to 70 kA and 100 to 1000 A)

4. Small sites (workshops with machine-tools, textile factories with small machines, supermarkets with small loads). The short-circuit and current levels are lower (respectively 10 to 40 kA and 40 to 400 A)

23.2.1 Sub-distribution using busbar trunking meets user needs in terms of:

1. Modifications and upgrades given the high number of tap-off points

2. Dependability and continuity of service because tap-off units can be connected under energized conditions in complete safety.

The sub-distribution concept is also valid for vertical distribution in the form of 100 to 5000 A risers in tall buildings.

1. Lighting distribution busbar trunking – Lighting circuits can be distributed using two types of busbar trunking according to whether the lighting fixtures are suspended from the busbar trunking or not.

2. Busbar trunking designed for the suspension of lighting fixtures – These busways supply and support light fixtures (industrial reflectors, discharge lamps, etc.). They are used in industrial buildings, supermarkets, department stores and warehouses. The busbar trunkings are very rigid and are designed for one or two 25 A or 40 A circuits. They have tap-off outlets every 0.5 to 1 m.

3. Busbar trunking not designed for the suspension of lighting fixtures – Similar to prefabricated cable systems, these busways are used to supply all types of lighting fixtures secured to the building structure. They are used in commercial buildings (offices, shops, restaurants, hotels, etc.), especially in false ceilings. The busbar trunking is flexible and designed for one 20 A circuit. It has tap-off outlets every 1.2 m to 3 m.

Busbar trunking systems are suited to the requirements of a large number of buildings.

1. Industrial buildings: garages, workshops, farm buildings, logistic centers, etc.

2. Commercial areas: stores, shopping malls, supermarkets, hotels, etc.

3. Tertiary buildings: offices, schools, hospitals, sports rooms, cruise liners, etc.

23.3 Standards

Busbar trunking systems must meet all rules stated in IEC 61439-6. This defines the manufacturing arrangements to be complied with in the design of busbar trunking systems (e.g.: temperature rise characteristics, short-circuit withstand, mechanical strength, etc.) as well as test methods to check them. IEC61439-6 also describes in particular the design verifications and routine verifications required to ensure compliance.

By assembling the system components on the site according to the assembly instructions, the contractor benefits from conformity with this standard.

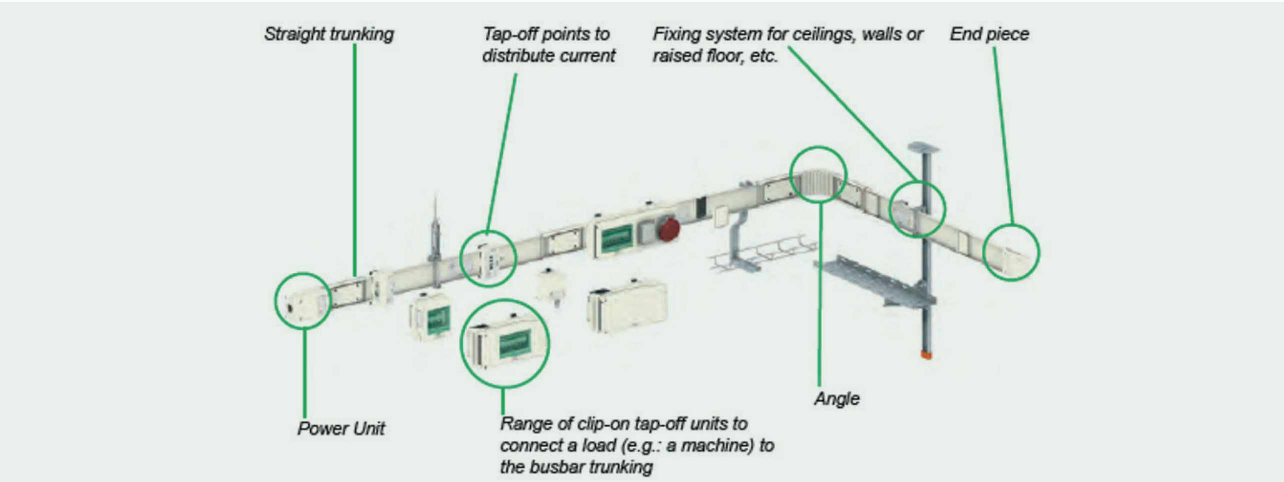


Figure 2: Busbar trunking system design for distribution of currents from 25 to 4000 A

24 Neutral Current and Load Factor in Three-Phase, Four-Wire Systems

The non-linear phase currents result in non-linear neutral current, in a three-phase, four-wire system supplying identical single phase loads. The neutral current only includes third or triple-n harmonics whose amplitudes are equal to three times the amplitude of the phase currents.

Thus, the rms value of the neutral current is equal to 1.732 (√3) times the rms value of the line current.

When the loads include partially linear circuits (such as motors, heating devices, incandescent lamps), the rms value of the neutral current is strictly less than √3 times the rms value of the phase currents.

Simulations have been carried out to assess the influence of the 3rd harmonic level on the neutral conductor current.

The neutral current is then calculated and compared to the line current for different levels of third harmonic. The load factor of the neutral conductor (ratio of the neutral current to the line current) is represented in Figure 3.

In installations where there are a large number of single-phase electronic non-linear loads connected to the same neutral, a high load factor was found in that neutral.

In such installations the neutral current may exceed the phase current and a special attention must be given to sizing the neutral conductor. This prevents the installation of a reduced size neutral conductor, and the current in all four wires should be taken into account.

A common practice in these conditions is to use a 200% neutral conductor. This does not form part of the electrical/building regulations, but is encouraged by manufacturers as a good engineering practice.

Except in exceptional circumstances, the 3rd harmonic level in most installations does not exceed 33%, so the neutral current does not exceed the line currents. It is not therefore necessary to use an oversized neutral conductor.

24.1 Effects of harmonic currents on circuit conductors

The circulation of harmonic currents produces additional heating within the conductors for several reasons:

1. Heat is produced as a result of the additional high levels of triple-n harmonic currents, compared with the relatively minimal current flowing in the neutral for normal balanced linear loads.

2. Additional heating of all conductors by increase of the skin effect and eddy current losses due to the circulation of all harmonic orders.

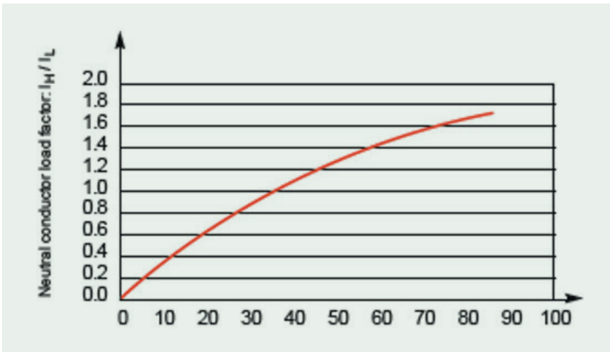


Figure 3: Neutral conductor load factor as a function of the 3rd harmonic level

25 Overvoltage Protection

Overvoltage occurs when supply voltage rises over the rated voltage of the equipment. This can be caused by Lightning, poor regulation of power supply, oversized transformers, varying circuit loading, wiring errors etc.

25.1 Lightning

Storms are accompanied by lightning strokes which represent a serious hazard for persons and equipment. Lightning flashes produce an extremely large quantity of pulsed electrical energy of several thousand amperes of high frequency (approximately 1 MHz), of short duration (from a microsecond to a millisecond). Lightning also causes a large number of fires, mostly in agricultural areas (destroying houses or making them unfit for use). High-rise buildings are especially prone to lightning strokes. Lightning damages electrical and electronic systems in particular: transformers, electricity meters and electrical appliances on both residential and industrial premises.

25.2 Principle of lightning protection

25.2.1 General rules

The system for protecting a building against the effects of lightning must include:

1. protection of structures against direct lightning strokes;

2. Protection of electrical installations against direct and indirect lightning strokes.

25.3 Procedure to prevent risks of lightning strike

The basic principle for protection of an installation against the risk of lightning strikes is to prevent the disturbing energy from reaching sensitive equipment. To achieve this, it is necessary to:

1. capture the lightning current and channel it to earth via the most direct path (avoiding the vicinity of sensitive equipment);

2. perform equipotential bonding of the installation;

This equipotential bonding is implemented by bonding conductors, supplemented by Surge Protection Devices (SPDs) or spark gaps (e.g., antenna mast spark gap).

Minimize induced and indirect effects by installing SPDs and/or filters.

Two protection systems are used to eliminate or limit overvoltages: they are known as the building protection system (for the outside of buildings) and the electrical installation protection system (for the inside of buildings).

25.4 Building protection system

The role of the building protection system is to protect it against direct lightning strokes.

The system consists of:

1. the capture device: the lightning protection system;

2. Down-conductors designed to convey the lightning current to earth;

3. “Crow’s foot” earth leads connected together;

4. Links between all metallic frames (equipotential bonding) and the earth leads.

25.5 The 3 types of lightning protection system

1. **The lightning rod (simple rod or with triggering system)** – The lightning rod is a metallic capture tip placed at the top of the building. It is earthed by one or more conductors (often copper strips)

2. **The lightning rod with taut wires** – These wires are stretched above the structure to be protected. They are used to protect special structures: rocket launching areas, military applications and protection of high-voltage overhead lines (see Figure 4).

3. **The lightning conductor with meshed cage (Faraday cage)** – This protection involves placing numerous down conductors/tapes symmetrically all around the building. (see Figure 5). This type of lightning protection system is used for highly exposed buildings housing very sensitive installations such as computer rooms. Consequently, the building protection system does not protect the electrical installation: it is therefore compulsory to provide for an electrical installation protection system.

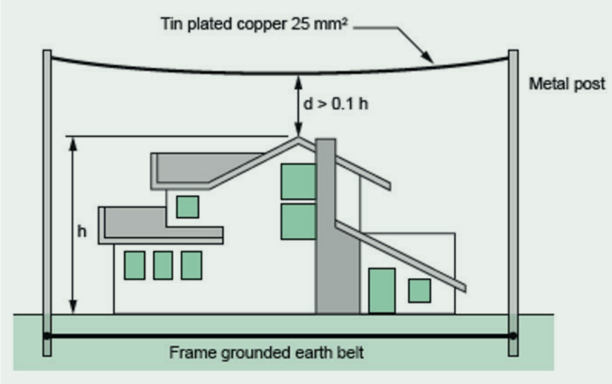


Figure 4: Taut wires

25.6 The Surge Protection Device (SPD)

Surge Protection Devices (SPD) are used for electric power supply networks, telephone networks, and communication and automatic control buses.

SPD is designed to limit transient overvoltages of atmospheric origin and divert current waves to earth, so as to limit the amplitude of this overvoltage to a value that is not hazardous for the electrical installation and electric switchgear and control gear.

SPD connected in parallel has a high impedance. Once the transient overvoltage appears in the system, the impedance of the device decreases so surge current is driven through the SPD, bypassing the sensitive equipment.

The Surge Protection Device (SPD) is a component of the electrical installation protection system.

This device is connected in parallel on the power supply circuit of the loads that it has to protect (see Figure 6). It can also be used at all levels of the power supply network. This is the most commonly used and most efficient type of overvoltage protection.

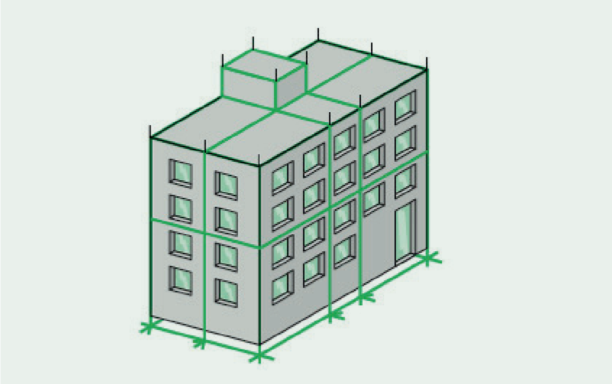


Figure 5: Meshed cage (Faraday cage)

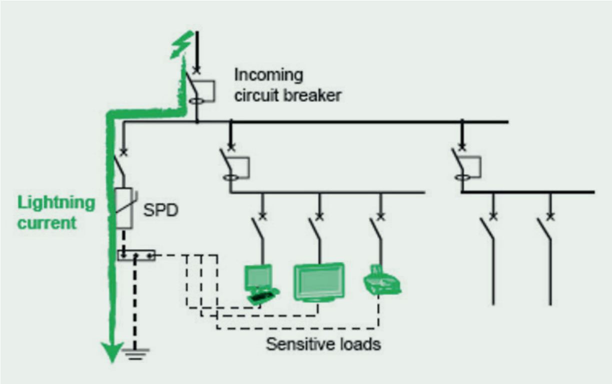


Figure 6: Principle of protection system in parallel

26 Energy Efficiency in Electrical LV Installations

The objective of energy efficiency is to provide the same level of service by consuming less energy. By implementing energy efficient electrical equipment and smart controllers, it is possible to save up to 30 % of energy. This is the most cost effective means for limiting CO_2 emissions, and saving energy and cost.

Energy Efficiency in Buildings can be the result of:

a. Regulatory measures, with the evolution of regulations, directives and standards, which can be issued at national, regional or international levels;

b. Voluntary approach by Promoters, building owners, occupiers etc deciding to have their building certified to help adopt sustainable solutions, and to obtain market recognition of their achievements.

To implement energy efficiency an energy audit becomes crucial as it highlights areas for possible savings.

26.1 Energy Audits

Energy audit is an inspection survey and an analysis of energy flows for energy conservation in a building. It may include a process or system to reduce the amount of energy input into the system without negatively affecting the output.

Once the energy audits have been completed, the energy saving measures have been implemented and the savings have been quantified, it is essential to have an energy monitoring system in place which can be used effectively and maintained to ensure performance is sustained over time. Performance tends to deteriorate if there is no continuous improvement cycle in place

26.2 Energy Efficiency standards

In undertaking energy efficiency measures, the following standards related to Energy Efficiency should be considered:

i) ISO 50001 – Energy Management Systems – Requirements with guidance for use

ii) ISO 50006 – Energy Baseline (EnBs) and Energy Performance Indicators (EnPIs)

iii) IEC 61557-12 – Power Metering and Monitoring devices

iv) IEC 60364-8-1 – Low voltage installations – Part 8-1: Energy Efficiency

27 Power Factor Correction

The Power Factor is an indicator of the quality of design and management of an electrical installation. It relies on two very basic notions: active and apparent power. The active power P (kW) is the real power transmitted to loads such as motors, lamps, heaters, and computers. The electrical active power is transformed into mechanical power, heat or light. The apparent power is the basis for electrical equipment rating. The power factor correction within electrical installations is carried out locally, globally or as a combination of both methods

The Power Factor λ, is the ratio of the active power P (kW) to the apparent power S (kVA):

λ = P(kW)/S(kVA)

27.1 Relevance of Power Factor Correction

Improvement of the power factor of an installation presents several technical and economic advantages, notably in the reduction of electricity bills and may also have an impact on the energy efficiency. Power factor improvement allows the use of smaller transformers, switchgear and cables, etc. as well as reducing power losses and voltage drop in an installation. The investment involved in Power factor correction can be recouped in less than a year. The most common method of improving the power factor of an installation requires a bank of capacitors which acts as a source of reactive energy. This arrangement is said to provide reactive energy compensation. The Capacitors can be either Fixed or Automatic but with the later proving more flexibility. Sizing and selection of capacitor banks should be in compliance with IEC 61921 (Power capacitors – Low-voltage power factor correction banks)

Other methods available for power factors correction are:

1. Synchronous Condenser: They are 3 phase synchronous motor with no load attached to its shaft.

2. Phase Advancer: This is an AC exciter mainly used to improve pf of induction motor.

28 Harmonic Management

28.1 Harmonic disturbances

Harmonics flowing in distribution networks represent disturbances in the flow of electricity. The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms. The quality of electrical power is deteriorated, and the efficiency of the system is decreased.

Harmonic currents are caused by non-linear loads connected to the distribution system. A load is said to be non-linear when the current it draws does not have the same waveform as the supply voltage. The flow of harmonic currents through system impedances in turn creates voltage harmonics, which distort the supply voltage.

28.2 Main risks associated with harmonics:

1. Overload of distribution networks due to the increase of r.m.s. currents,

2. Overload of neutral conductors, which current can exceed the phase currents,

3. Overload, vibration and premature ageing of generators, transformers and motors as well as increased transformer hum,

4. Overload and premature ageing of Power Factor Correction capacitors,

5. Distortion of the supply voltage that can disturb sensitive loads,

6. Disturbance in communication networks and telephone lines.

28.3 Economic impact of disturbances

1. Premature ageing of equipment means it must be replaced sooner, unless oversized right from the start,

2. Overload on the distribution network means higher equipment rating, increased subscribed power level for the industrial customer, and increased power losses,

3. Unexpected current distortion can lead to nuisance tripping and production halt.

28.4 A necessary concern for the design and management of electrical installations

Harmonics are the result of the always expanding number of power electronic devices. They have become abundant today because of their capabilities for precise process control and energy saving benefits. Typical examples are Variable Speed Drives in the Industry, and Compact Fluorescent Lamps in commercial and residential areas.

International standards have been published in order to help the designers of equipment and installations. Harmonic emission limits have been set, so that no unexpected and negative impact of harmonics should be encountered. In parallel to a better understanding of effects, solutions have been developed by the Industry. Harmonic consideration is now a full part of the design of electrical installation

28.5 Main effects of harmonics in electrical installations

1. Resonance

2. Increased losses

3. Overload of equipment

4. Oversizing of equipment

5. Reduced service life of equipment

6. Nuisance tripping and installation shutdown

28.6 Standards applicable in harmonic management

Harmonic emissions are subject to various standards and regulations:

1. Compatibility standards for distribution networks

2. Emissions standards applying to the equipment causing harmonics

3. Recommendations issued by Utilities and applicable to installations

In view of rapidly attenuating the effects of harmonics, a triple system of standards and regulations is currently in force based on the documents listed below. Standards govern compatibility between distribution networks and products. These standards determine the necessary compatibility between distribution networks and products:

1. The harmonics caused by a device must not disturb the distribution network beyond certain limits

2. Each device must be capable of operating normally in the presence of disturbances up to specific levels

3. Standard IEC 61000-2-2 is applicable for public low-voltage power supply systems

4. Standard IEC 61000-2-4 is applicable for LV and MV industrial installations

Standards governing the quality of distribution networks

1. Standard EN 50160 stipulates the characteristics of electricity supplied by public distribution networks

2. Standard IEEE 519 presents a joint approach between Utilities and customers to limit the impact of non-linear loads. What is more, Utilities encourage preventive action in view of reducing the deterioration of power quality, temperature rise and the reduction of power factor. They will be increasingly inclined to charge customers for major sources of harmonics.

28.7 Standards governing equipment

1. Standard IEC 61000-3-2 EMC Limits for Harmonic current emissions (Equipment Input Current less or equal to 16A Per Phase)

2. Standard IEC 61000-3-12 EMC Limits for Harmonic currents produced by equipment connected to public low-voltage systems greater than 16 A and less than or equal to 75 A per phase

Maximum permissible harmonic levels
International studies have collected data resulting in an estimation of typical harmonic contents often encountered in electrical distribution networks.

28.8 Solutions to mitigate harmonics

There are three different types of solutions to attenuate harmonics:

a. Modifications in the installation

   1. Position the non-linear loads upstream in the system

   2. Group the non-linear loads

   3. Create separate sources for linear and non-linear loads

b. Special devices in the supply system

   1. Installation of harmonic suppression reactors

c. Harmonic filtering

In cases where the preventive action presented in (a) and (b) above is insufficient, it is necessary to equip the installation with filtering systems.

There are three types of filters:

1. Passive

2. Active

3. Hybrid

28.9 Harmonic Audit of MV and LV Networks

A harmonic audit is carried out by an engineer specialized in the disturbances affecting electrical distribution networks and equipped with powerful analysis and simulation equipment and software. By calling on an expert, you are guaranteed that the proposed solution will produce effective results (e.g. a guaranteed maximum THDu).

The entire audit process should be certified to the latest Quality Management Standard (ISO 9001:2015).

28.10 Characteristics of particular sources and loads

Protection of a LV generator set and the downstream circuits
Most industrial and large commercial electrical installations include certain important loads for which a power supply must be maintained, in the event that the utility electrical supply fails:

1. Either, because safety systems are involved (emergency lighting, automatic fire protection equipment, smoke dispersal fans, alarms and signalization, and so on…) or

2. Because it concerns priority circuits, such as certain equipment, the stoppage of which would entail a loss of production, or the destruction of a machine tool, etc. One of the current means of maintaining a supply to the so-called “priority” loads, in the event that other sources fail, is to install a diesel generator set connected, via a change-over switch, to an emergency-power standby switchboard, from which the priority services are fed.

29 Overload protection

The generator protection curve must be analyzed. Standards and requirements of applications can also stipulate specific overload conditions. For example:

1. Short-circuit current protection

2. Making the short-circuit current

3. The short-circuit current is the sum:

   – of an aperiodic current

   – of a damped sinusoidal current

The setting possibilities of the overload protection devices (or Long Time Delay) will closely follow these requirements. Note on overloads

1. For economic reasons, the thermal motor of a replacement set may be strictly sized for its nominal power. If there is an active power overload, the diesel motor will stall. The active power balance of the priority loads must take this into account

2. A production set must be able to withstand operating overloads:

   – One hour overload

   – One hour 10 % overload every 12 hours (Prime Power)

3. Sub-transient phase: When a short-circuit appears at the terminals of a generator, the current is first made at a relatively high value of around 6 to 12 In during the first cycle (0 to 20 ms). We determine the sub-transient short-circuit impedance of the generator:

4. Transient phase: The transient phase is placed 100 to 500 ms after the time of the fault. Starting from the value of the fault current of the sub-transient period, the current drops to 1.5 to 2 times the current I_n. The short-circuit impedance to be considered for this period is the transient reactance X_d expressed in % by the manufacturer. The typical value is 20 to 30 %.

5. Steady state phase: The steady state occurs after 500 ms. when the fault persists, the output voltage collapses and the exciter regulation seeks to raise this output voltage. The result is a stabilized sustained short-circuit current:

   – If generator excitation does not increase during a short-circuit (no field over excitation) but is maintained at the level preceding the fault, the current stabilizes at a value that is given by the synchronous reactance X_d of the generator. The typical value of X_d is greater than 200 %. Consequently, the final current will be less than the full-load current of the generator, normally around 0.5 In.

   – If the generator is equipped with maximum field excitation (field overriding) or with compound excitation, the excitation "surge" voltage will cause the fault current to increase for 10 seconds, normally to 2 to 3 times the full-load current of the generator

When the LV network is supplied by the Main source 1 of 2,000 kVA, the short-circuit current is 42 kA at the main LV board busbar. When the LV network is supplied by the Replacement Source 2 of 500 kVA with transient reactance of 30 %, the short circuit current is made at approx. 2.5 kA, i.e. at a value 16 times weaker than with the Main source.

29.1 Sub distribution boards

The ratings of the protection devices for the sub-distribution and final distribution circuits are always lower than the generator rated current. Consequently, except in special cases, conditions are the same as with transformer supply.

29.2 Main LV switchboard

1. The sizing of the main feeder protection devices is normally similar to that of the generator set. Setting of the STD must allow for the short-circuit characteristic of the generator set (see "Short-circuit current protection" before)

2. Discrimination of protection devices on the priority feeders must be provided in generator set operation (it can even be compulsory for safety feeders). It is necessary to check proper staggering of STD setting of the protection devices of the main feeders with that of the sub-distribution protection devices downstream (normally set for distribution circuits at 10 In).

NOTE:
When operating on the generator set, use of a low sensitivity Residual Current Device enables management of the insulation fault and ensures very simple discrimination.

29.3 Safety of people

In the IT (2nd fault) and TN grounding systems, protection of people against indirect contacts is provided by the STD protection of circuit-breakers. Their operation on a fault must be ensured, whether the installation is supplied by the main source (Transformer) or by the replacement source (generator set).

29.4 Calculating the insulation fault current

Zero-sequence reactance formulated as a % of U_o by the manufacturer X_o. The typical value is 8 %.

The insulation fault current in the TN system is slightly greater than the three phase fault current. For example, in event of an insulation fault on the system in the previous example, the insulation fault current is equal to 3 kA.

29.5 The monitoring functions

Due to the specific characteristics of the generator and its regulation, the proper operating parameters of the generator set must be monitored when special loads are implemented.

The behavior of the generator is different from that of the transformer:

- The active power it supplies is optimized for a power factor = 0.8

- At less than power factor 0.8, the generator may, by increased excitation, supply part of the reactive power Capacitor bank

An off-load generator connected to a capacitor bank may self-excite, consequently increasing its overvoltage.

The capacitor banks used for power factor regulation must therefore be disconnected. This operation can be performed by sending the stopping set point to the regulator (if it is connected to the system managing the source switching's or by opening the circuit-breaker supplying the capacitors.

If capacitors continue to be necessary, do not use regulation of the power factor relay in this case (incorrect and over-slow setting).

29.6 Motor restart and re-acceleration

A generator can supply at most in transient period a current of between 3 and 5 times its nominal current. A motor absorbs roughly 6 In for 2 to 20 s during start-up. If the sum of the motor power is high, simultaneous start-up of loads generates a high pick-up current that can be damaging. A large voltage drop, due to the high value of the generator transient and sub-transient reactances will occur (20 % to 30 %), with a risk of:

1. Non-starting of motors
2. Temperature rise linked to the prolonged starting time due to the voltage drop
3. Tripping of the thermal protection devices

Moreover, all the network and actuators are disturbed by the voltage drop.

29.7 Non-linear loads – Example of a UPS

These are mainly:

1. Saturated magnetic circuits
2. Discharge lamps, fluorescent lights
3. Electronic converters
4. Information Technology Equipment: PC, computers, etc.

These loads generate harmonic currents: supplied by a Generator Set, this can create high voltage distortion due to the low short-circuit power of the generator.

30 Uninterruptible Power Supply (UPS)

An uninterruptible power supply or uninterruptible power source (UPS) is an electrical apparatus that provides emergency power to a load when the input power source or mains power supply fails. A UPS differs from an auxiliary or emergency power system or standby generator in that it will provide near-instantaneous protection from input power interruptions, by supplying energy stored in batteries, super capacitors, or flywheels. The on-battery run-time of most uninterruptible power sources is relatively short (only a few minutes) but sufficient to start a standby power source or properly shut down the protected equipment. It is a type of continual power system.

A UPS is typically used to protect hardware such as computers, data centers, telecommunication equipment or other electrical equipment where an unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss. UPS units range in size from units designed to protect a single computer without a video monitor (around 200 volt-ampere rating) to large units powering entire data centers or buildings.

The primary role of any UPS is to provide short-term power when the input power source fails. However, most UPS units are also capable in varying degrees of correcting common utility power problems:

a. Voltage spike or sustained overvoltage
b. Momentary or sustained reduction in input voltage
c. Voltage sag
d. Noise, defined as a high frequency transient or oscillation, usually injected into the line by nearby equipment
e. Instability of the mains frequency
f. Harmonic distortion, defined as a departure from the ideal sinusoidal waveform expected on the line.

Some manufacturers of UPS units categorize their products in accordance with the number of power-related problems they address.

A number of technical solutions contribute to this goal, with varying degrees of effectiveness. These solutions may be compared on the basis of two criteria:

a. Availability of the power supplied

b. Quality of the power supplied

The availability of electrical power can be thought of as the time per year that power is present at the load terminals. Availability is mainly affected by power interruptions due to utility outages or electrical faults.

A number of solutions exist to limit the risk:

a. Division of the installation so as to use a number of different sources rather than just one

b. Subdivision of the installation into priority and non-priority circuits, where the supply of power to priority circuits can be picked up if necessary by another available source

c. Load shedding, as required, so that a reduced available power rating can be used to supply standby power

d. Selection of a system earthing arrangement suited to service-continuity goals, e.g. IT system

e. Discrimination of protection devices (selective tripping) to limit the consequences of a fault to a part of the installation

Note that the only way of ensuring availability of power with respect to utility outages is to provide, in addition to the above measures, an autonomous alternate source, at least for priority loads.

This source takes over from the utility in the event of a problem, but two factors must be taken into account:

i) The transfer time (time required to take over from the utility) which must be acceptable to the load

ii) The operating time during which it can supply the load

The quality of electrical power is determined by the elimination of the disturbances at the load terminals.

An alternate source is a means to ensure the availability of power at the load terminals, however, it does not guarantee, in many cases, the quality of the power supplied with respect to the above disturbances.

Today, many sensitive electronic applications require an electrical power supply which is virtually free of these disturbances, to say nothing of outages, with tolerances that are stricter than those of the utility.

This is the case, for example, for computer centers, telephone exchanges and many industrial-process control and monitoring systems.

These applications require solutions that ensure both the availability and quality of electrical power.

A UPS comprises the following main components:

i) Rectifier/charger, which produces DC power to charge a battery and supply an inverter.

ii) Inverter, which produces quality electrical power, i.e. Free of all utility-power disturbances, notably micro-outages within tolerances compatible with the requirements of sensitive electronic devices (e.g. for Galaxy, tolerances in amplitude ±0.5% and frequency ±1%, compared to ±10% and ±5% in utility power systems, which correspond to improvement factors of 20 and 5, respectively)

iii) Battery, which provides sufficient backup time (8 minutes to 1 hour or more) to ensure the safety of life and property by replacing the utility as required

iv) Static switch, a semi-conductor based device which transfers the load from the inverter to the utility and back, without any interruption in the supply of power

30.1 Types of static UPSs

Types of static UPSs are defined by standard IEC 62040.

The standard distinguishes three operating modes:

a. Passive standby (also called off-line)

b. Line interactive

c. Double conversion (also called on-line)

These definitions concern UPS operation with respect to the power source including the distribution system upstream of the UPS.

Standard IEC 62040 defines the following terms:

a. Primary power: power normally continuously available which is usually supplied by an electrical utility company, but sometimes by the user's own generation

b. Standby power: power intended to replace the primary power in the event of primary power failure

c. Bypass power: power supplied via the bypass.

Practically speaking, a UPS is equipped with two AC inputs, which are called the normal AC input and bypass AC input in this guide. The normal AC input, noted as mains input 1, is supplied by the primary power, i.e. by a cable connected to a feeder on the upstream utility or private distribution system.

The bypass AC input, noted as mains input 2, is generally supplied by standby power, i.e. by a cable connected to an upstream feeder other than the one supplying the normal AC input, backed up by an alternate source (e.g. by an engine-generator set or another UPS, etc.)

When standby power is not available, the bypass AC input is supplied with primary power (second cable parallel to the one connected to the normal AC input).

The bypass AC input is used to supply the bypass line(s) of the UPS, if they exist. Consequently, the bypass line(s) is supplied with primary or standby power, depending on the availability of a standby-power source.

30.2 UPS Operating in Passive-Standby (Off-Line) Mode

Operating Principle
The inverter is connected in parallel with the AC input in a standby:

a. Normal Mode

The load is supplied by utility power via a filter which eliminates certain disturbances and provides some degree of voltage regulation (the standard speaks of "additional device to provide power conditioning"). The inverter operates in passive standby mode.

b. Battery Backup Mode

When the AC input voltage is outside specified tolerances for the UPS or the utility power fails, the inverter and the battery step in to ensure a continuous supply of power to the load following a very short (<10 ms) transfer time.

The UPS continues to operate on battery power until the end of battery backup time or the utility power returns to normal, which provokes transfer of the load back to the AC input (normal mode).

30.3 Usage

This configuration is in fact a compromise between an acceptable level of protection against disturbances and cost. It can be used only with low power ratings (< 2 kVA).

It operates without a real static switch, so a certain time is required to transfer the load to the inverter. This time is acceptable for certain individual applications, but incompatible with the performance required by more sophisticated, sensitive systems (large computer centers, telephone exchanges, etc.).

What is more, the frequency is not regulated and there is no bypass.

> NOTE:
> In normal mode, the power supplying the load does not flow through the inverter, which explains why this type of UPS is sometimes called "Off-line". This term is misleading, however, because it also suggests "not supplied by utility power", when in fact the load is supplied by the utility via the AC input during normal operation.

That is why standard IEC 62040 recommends the term "passive standby".

30.4 UPS Operating in Line-Interactive Mode

Operating Principle
The inverter is connected in parallel with the AC input in a standby configuration, but also charges the battery. It thus interacts (reversible operation) with the AC input source.

a. Normal Mode

The load is supplied with conditioned power via a parallel connection of the AC input and the inverter. The inverter operates to provide output-voltage conditioning and/or charge the battery. The output frequency depends on the AC-input frequency.

b. Battery Backup Mode

When the AC input voltage is outside specified tolerances for the UPS or the utility power fails, the inverter and the battery step in to ensure a continuous supply of power to the load following a transfer without interruption using a static switch which also disconnects the AC input to prevent power from the inverter from flowing upstream.

The UPS continues to operate on battery power until the end of battery backup time or the utility power returns to normal, which provokes transfer of the load back to the AC input (normal mode).

c. Bypass Mode

This type of UPS may be equipped with a bypass. If one of the UPS functions fails, the load can be transferred to the bypass AC input (supplied with utility or standby power, depending on the installation).

30.4.1 Usage

This configuration is not well suited to regulation of sensitive loads in the medium to high-power range because frequency regulation is not possible.

For this reason, it is rarely used other than for low power ratings.

UPS Operating in Double-Conversion (On-Line) Mode

Operating Principle
The inverter is connected in series between the AC input and the application.

i) Normal Mode

During normal operation, all the power supplied to the load passes through the rectifier/charger and inverter which together perform a double conversion (AC-DCAC), hence the name.

ii) Battery Backup Mode

When the AC input voltage is outside specified tolerances for the UPS or the utility power fails, the inverter and the battery step in to ensure a continuous supply of power to the load following a transfer without interruption using a static switch.

The UPS continues to operate on battery power until the end of battery backup time or utility power returns to normal, which provokes transfer of the load back to the AC input (normal mode).

iii) Bypass Mode

This type of UPS is generally equipped with a static bypass, sometimes referred to as a static switch.

The load can be transferred without interruption to the bypass AC input (supplied with utility or standby power, depending on the installation), in the event of the following:

- UPS failure
- Load-current transients (inrush or fault currents)
- Load peaks

However, the presence of a bypass assumes that the input and output frequencies are identical and if the voltage levels are not the same, a bypass transformer is required.

For certain loads, the UPS must be synchronized with the bypass power to ensure load-supply continuity. What is more, when the UPS is in bypass mode, a disturbance on the AC input source may be transmitted directly to the load because the inverter no longer steps in.

NOTE:
Another bypass line, often called the maintenance bypass, is available for maintenance purposes. It is closed by a manual switch.

30.4.2 Usage

In this configuration, the time required to transfer the load to the inverter is negligible due to the static switch. Also, the output voltage and frequency do not depend on the input voltage and frequency conditions. This means that the UPS, when designed for this purpose, can operate as a frequency converter.

Practically speaking, this is the main configuration used for medium and high power ratings (from 10 kVA upwards). The rest of this chapter will consider only this configuration.

NOTE:
This type of UPS is often called "on-line", meaning that the load is continuously supplied by the inverter, regardless of the conditions on the AC input source. This term is misleading, however, because it also suggests "supplied by utility power", when in fact the load is supplied by power that has been reconstituted by the double conversion system.

That is why standard IEC 62040 recommends the term "double conversion".

30.5 Batteries

30.6 Selection of Battery Type

A battery is made up of interconnected cells which may be vented or of the recombination type.

There are two main families of batteries:

- Nickel-cadmium batteries
- Lead-acid batteries
- Vented cells (lead-antimony): They are equipped with ports to release to the atmosphere the oxygen and hydrogen produced during the different chemical reactions. Top off the electrolyte by adding distilled or demineralized water
- Recombination cells (lead, pure lead, lead-tin batteries): The gas recombination rate is at least 95% and they therefore do not require water to be added during service life. By extension, reference will be made to vented or recombination batteries (recombination batteries are also often called "sealed" batteries).

The main types of batteries used in conjunction with UPSs are:

- Sealed lead-acid batteries, used 95 % of the time because they are easy to maintain and do not require a special room
- Vented lead-acid batteries
- Vented nickel-cadmium batteries

The above three types of batteries may be proposed, depending on economic factors and the operating requirements of the installation, with all the available service-life durations. Capacity levels and backup times may be adapted to suit the user's needs. The proposed batteries are also perfectly suited to UPS applications in that they are the result of collaboration with leading battery manufacturers.

30.7 Selection of Back Up Time

Selection depends on:

- The average duration of power-system failures
- Any available long-lasting standby power (engine-generator set, etc.)
- The type of application

The typical range generally proposed is:

- Standard backup times of 10, 15 or 30 minutes
- Custom backup times

The following general rules apply:

1. Computer applications: Battery backup time must be sufficient to cover file-saving and system-shutdown procedures required to ensure a controlled shutdown of the computer system. Generally speaking, the computer department determines the necessary backup time, depending on its specific requirements.
2. Industrial processes: The backup time calculation should take into account the economic cost incurred by an interruption in the process and the time required to restart.

Increasingly, recombination batteries would seem to be the market choice for the following reasons:

- No maintenance
- Easy implementation
- Installation in all types of rooms (computer rooms, technical rooms not specifically intended for batteries, etc.) In certain cases, however, vented batteries are preferred, notably for:
- Long service life
- Long backup times

30.8 High power ratings

Vented batteries must be installed in special rooms complying with precise regulations and require appropriate maintenance

30.9 Installation methods

Depending on the UPS range, the battery capacity and backup time, the battery is:

- Sealed type and housed in the UPS cabinet
- Sealed type and housed in one to three cabinets
- Vented or sealed type and rack-mounted.

In this case the installation method may be:

- On shelves: This installation method is possible for sealed batteries or maintenance-free vented batteries which do not require topping up of their electrolyte.
- Tier mounting: This installation method is suitable for all types of batteries and for vented batteries in particular, as level checking and filling are made easy.

- In cabinets: This installation method is suitable for sealed batteries. It is easy to implement and offers maximum safety.

30.10 System Earthing Arrangements for Installations Comprising Ups's

Application of Protection Systems, stipulated by the standards, in installations comprising a UPS, requires a number of precautions for the following reasons:

a. The UPS plays two roles

b. A load for the upstream system

c. A power source for downstream system

d. When the battery is not installed in a cabinet, an insulation fault on the DC system can lead to the flow of a residual DC component. This component can disturb the operation of certain protection devices, notably RCDs used for the protection of persons.

30.11 Protection against direct contact (see Table 3)

All installations satisfy the applicable requirements because the equipment is housed in cabinets providing a degree of protection IP 20. This is true even for the battery when it is housed in a cabinet.

When batteries are not installed in a cabinet, i.e. generally in a special room, the measures presented at the end of this chapter should be implemented.

NOTE:
The TN system (version TN-S or TN-C) is the most commonly recommended system for the supply of computer systems.

30.12 Essential points to be checked for UPSs

Figure 7 shows all the essential points that must be interconnected as well as the devices to be installed (transformers, RCDs, etc.) to ensure installation conformity with safety standards

30.13 Choice of protection schemes

The circuit-breakers have a major role in an installation but their importance often appears at the time of accidental events which are not frequent. The best sizing of UPS and the best choice of configuration can be compromised by a wrong choice of only one circuit-breaker.

30.14 Circuit-breaker selection

The Choice of protection schemes by deploying circuit-breakers have a major role in an installation but their importance often appears at the time of accidental events which are not frequent. The best sizing of UPS and the best choice of configuration can be compromised by a wrong choice of only one circuit-breaker.

Circuit-breaker selection:

- Rating – The selected rating (rated current) for the circuit-breaker must be the one just above the rated current of the protected downstream cable.

- Breaking capacity – The breaking capacity must be selected just above the short-circuit current that can occur at the point of installation.

Figure 8 shows how to select the circuit-breakers.

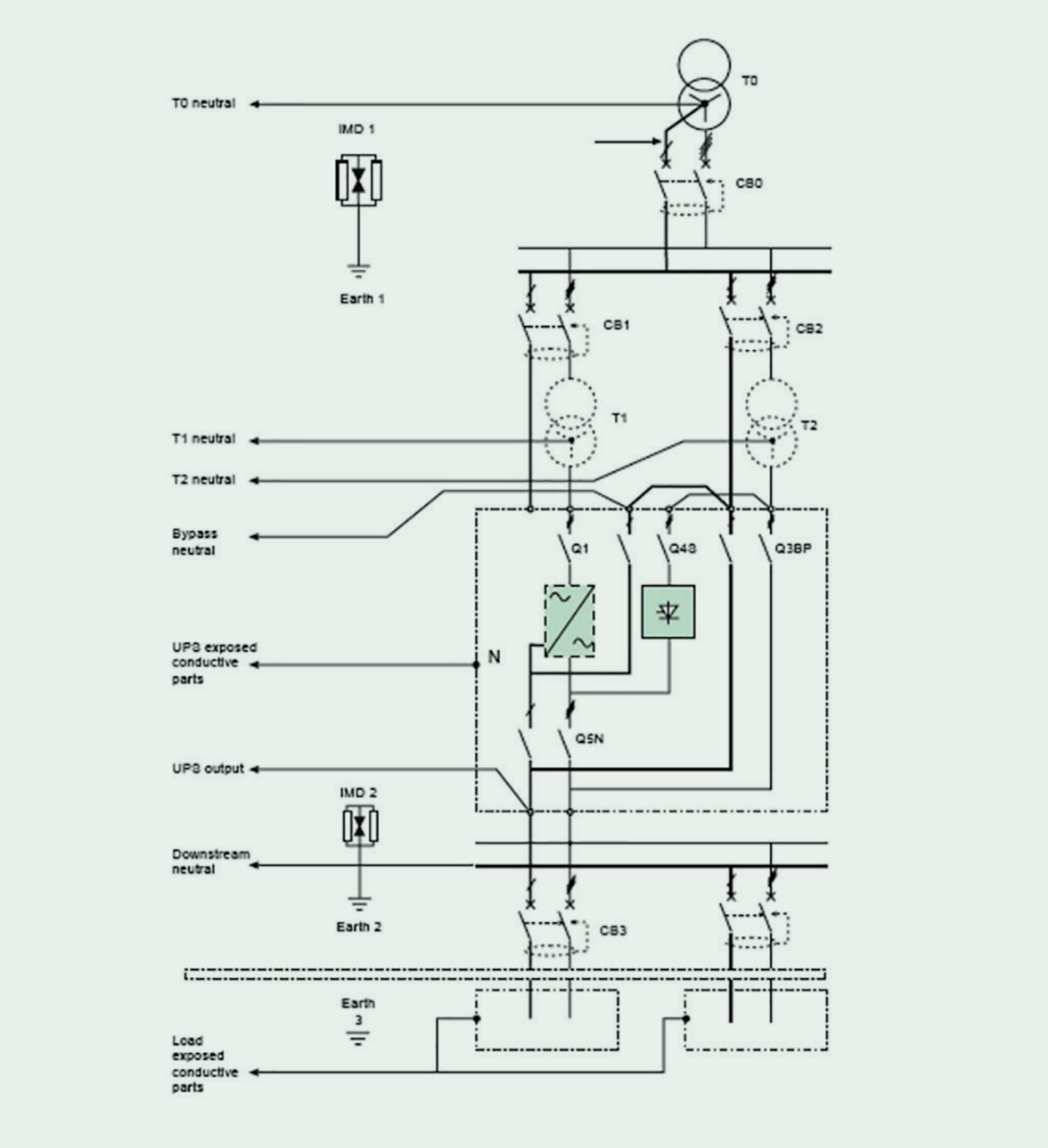


Figure 7: The essential points that must be connected in system earthing arrangements

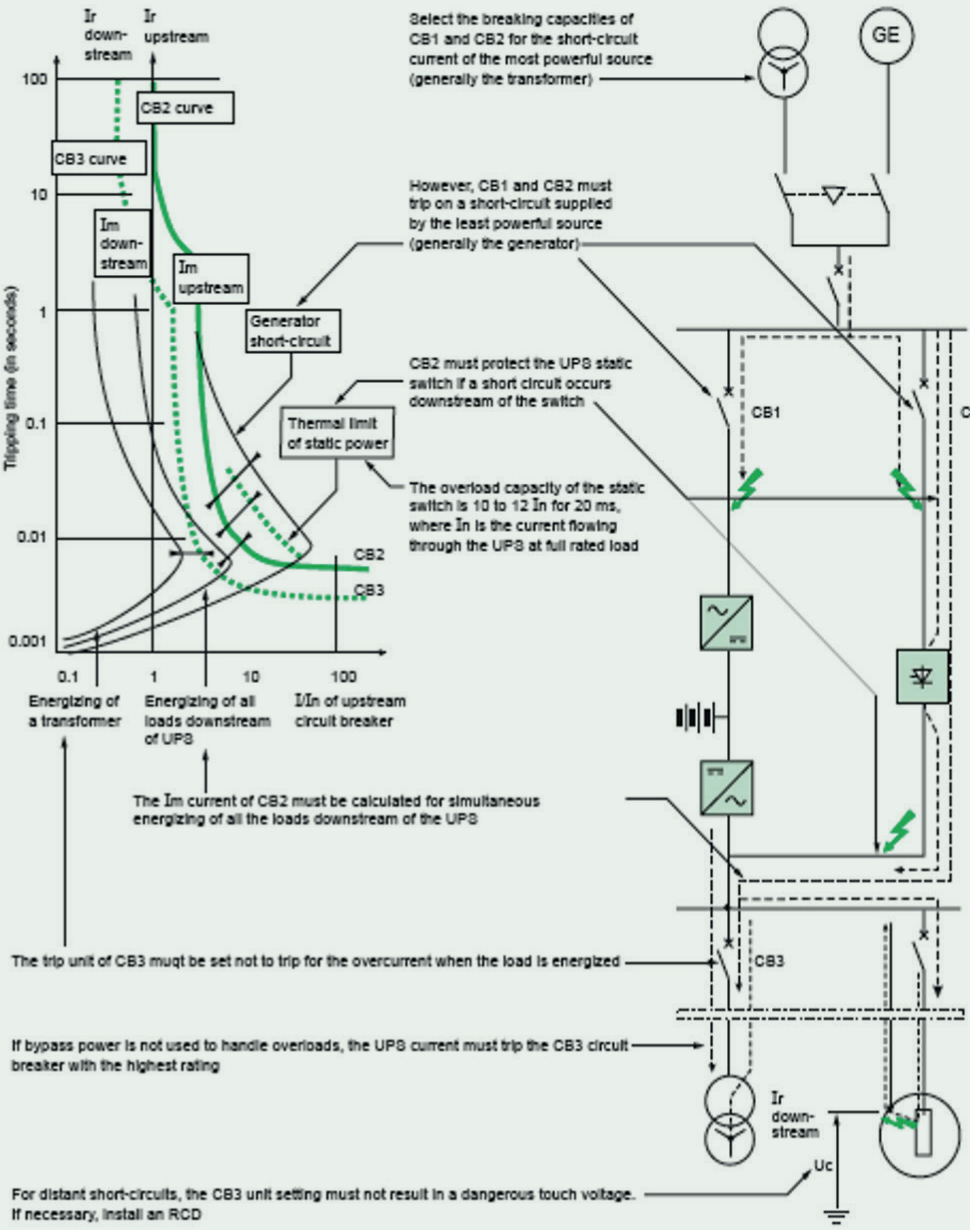


Fig. N25 : Circuit-breakers are submitted to a variety of situations

Figure 8

31 Alternative Supplies

Alternative supplies include but are not limited to low-voltage generating sets and Photovoltaic (PV) installations.

31.1 General

An installation that incorporates alternative supplies is designed to supply, either continuously or occasionally, all or part of the installation with the following supply arrangements:

a. Supply to an installation or part of an installation which is not connected to the main supply of a supplier;

b. Supply to an installation or part of an installation as an alternative to the main supply of a supplier; and

c. Appropriate combinations of the above.

> NOTE:
> Requirements of the supplier should be ascertained before a generating set is installed in an installation connected to the main supply of a supplier.

> NOTE:
> This part of the guide does not cover the supply to an installation that functions in parallel with the main supply (co-generation).

31.2 Requirements for alternative sources of supply

Where any form of alternative supply (emergency supply, UPS, etc.), is connected to an electrical installation, a notice to this effect shall be displayed at the main switch of the installation, and where such supply;

a. supplies power only to certain circuits in a distribution board, a power-on indicator (visible or audible) shall be provided on each such distribution board as well as a notice indicating that the standby power main switch shall also be switched off in an emergency.

b. only supplies a part of the electrical installation, the notice shall also be displayed on each distribution board in that part of the installation.

The means of excitation and commutation shall be appropriate for the intended use of the generating set and the safety and proper functioning of other sources of supply shall not be impaired by the generating plant.

The prospective short-circuit current and prospective earth fault current shall be assessed for each source of supply or combination of sources, which can operate independently of other sources or combinations.

The short-circuit rating of protective devices within the installation and, where appropriate, connected to the main supply, shall not be exceeded for any of the intended methods of operation of the sources.

Where the alternative supply is intended to provide a supply to an installation that is not connected to the main supply, or to provide a supply as a switched alternative to the main supply, the capacity and operating characteristics of the alternative supply shall be such that danger or damage to equipment does not arise after the connection or disconnection of any intended load as a result of the deviation of the voltage or frequency from the standard range.

Means shall be provided to automatically disconnect such parts of the installation, as may be necessary if the capacity of the alternative supply is exceeded.

Where an alternative supply is provided to an installation or part of an installation as a switched alternative to the main supply, the change-over switching device shall disconnect the main supply before the alternative supply is switched in. The change-over switching device shall be interlocked in such a way that the main supply and the alternative supply cannot be connected to the installation or part of the installation at the same time.

Except where otherwise permitted in the respective country regulations, where a socket-outlet is installed in a circuit on standby power, such circuit shall be protected by an earth leakage protection device with a rated earth leakage tripping current (rated residual current) $I\Delta_n$ not exceeding 30 mA.

A 230 V generator with a V-O-V earth connection (center tap on winding which is earthed), shall not be connected to a fixed electrical installation.

NOTE:
Such a generator may be used as a free-standing unit to provide power to specific appliances.

32 Measurement

This chapter is an introduction to the different applications of measurements, and to the main standards relevant for these different applications. There are different types of applications that require measurements. Basically, applications can be split between 5 categories, Power availability and reliability (see Figure 9).

So as to properly operate an electrical installation, it is recommended that measurements of the main characteristics of the supply such as voltage, current, frequency, and / or active power are provided as a minimum. Some electrical phenomena can have an impact on both installation assets and operations within a plant (e.g. unbalance can reduce the life time of motors, dips can stop a process, etc.)

Table 2 describes the main problems that can occur in a network:

32.1 Grid power quality

Some regulations or specific contracts require energy providers to keep voltage characteristics at any supply terminal within specified limits. These specifications cover limits or values related to voltage, frequency, rapid voltage changes, harmonics, inter harmonics, unbalance, dips, swells, interruptions, and flicker.

Measurements are typically made on the energy provider side (to check delivered energy complies to the contract) and on the consumer side (to check received energy complies with the contract) with Power Quality Instruments class A according to IEC 61000-4-30.

32.2 Billing

Billing is the process that allows energy suppliers or their representatives to invoice their customers according to a defined contract, for measured usages or services. These applications are covered by international, regional or local standards in addition to utility specifications. These applications are intended to protect the energy consumers and energy providers against incorrect or fraudulent metering. In most cases the meter used by the energy provider is installed at the consumer location, this is why attention is focused on avoiding frauds. This intent is achieved through setting out requirements:

- on meter performance (accuracy of active electrical energy meters, construction of meters where a third party assessment may be requested)

- on securing meters against tampering (sealing of the meter housing, securing the metrological relevant software, securing the meter configuration parameters and interfaces)

- on marking of meters, including marking of manufacturing year in order to allow accuracy verification with a time interval defined by national codes. Devices for billing applications are devices with specific legal metrology requirements, and are then subject to specific requirements such as periodic verification (usually every 6 to 10 years) according to local regulations.

32.3 Cost Allocation, Bill Checking and Sub-Billing

Sub-billing is the process that allows a landlord, property management firm, condominium association, homeowner association or other multi-tenant property to spread out an invoice over tenants, for measured usages or services. This fee is usually combined with other fees within a tenant's facility fee. Since the meter used for sub billing is typically installed in electrical room not accessible by the tenant, the risk of fraud is very limited. This is why devices complying with IEC 61557-12 as well as devices used for billing applications can be used for sub-billing applications. Attention should be put on environmental aspects where the device used for sub-billing needs to fit EMC, temperature and mechanical environment. In any case, measuring devices used in for sub-billing in switchboards and panels need to comply with IEC 61557-12.

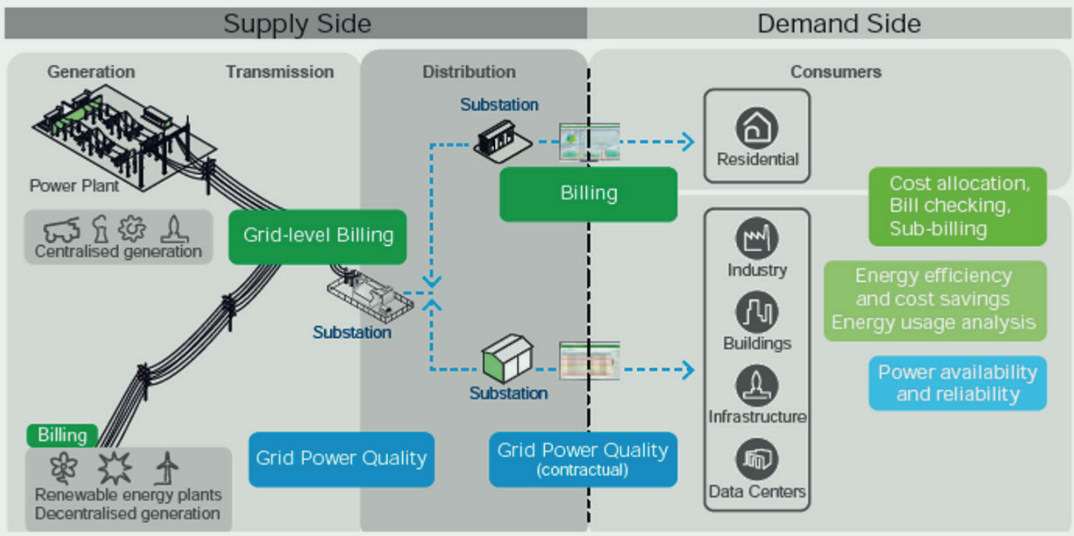


Fig. S1: The five main measurement applications in relationship to the supply side and the demand side

Figure 9

Cost allocation is the process that allows a facility manager to allocate energy costs to internal cost centers that consume energy (e.g. plants, workshop).

Bill checking is the process that allows customers to check that invoice(s) sent by energy suppliers or their representatives is correct.

32.4 Power Metering and Monitoring Device (PMD)

Increasingly, digital equipment is replacing analog equipment in electrical installations. It supports more accurate measurement of new values and is able to make these available to users at both local and remote locations. Devices intended to perform monitoring have various characteristics which require a shared reference system. This system must allow users to make easier choices in terms of performance levels, dependability and to interpret different measured parameters.

All these various measuring devices (referred to as "PMD" for "Power Metering and Monitoring Device") have to meet the requirements of International Standard IEC 61557-12: "Electrical safety in low voltage distribution systems up to 1000V a.c. and 1500V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 12: Power Metering and monitoring devices (PMD)". The standard gives a list of the main requirements applicable to PMD with guidance about sensors to use (in case sensors are requested).

32.5 PMD Functions

All the possible electrical parameters to be measured are listed. For each parameter, a list of requirements is specified, such as the rated range of operation, the range of influence quantities, the measurement techniques, etc.

The considered electrical parameters are given here:

1. Active energy (classes are equivalent to the classes defined in IEC 62053-21 and IEC 62053-22),
2. Reactive energy (classes are equivalent to the classes defined in IEC 62053-23)
3. Apparent energy,
4. Active, reactive and apparent power,
5. Frequency,
6. r.m.s. phase and neutral current,
7. r.m.s. voltage,
8. Power factor,
9. Voltage dip and swell,
10. Voltage interruption,
11. Voltage unbalance,
12. Harmonic voltage and distortion,
13. Harmonic current and distortion,
14. Maximum, minimum, peak, average, demand and values.

33 Marking

According to International Standard IEC 61557-12, devices have a code denoting their installation options, operating temperature range and accuracy class. As a result, it has become significantly easier to select and identify these devices.

33.1 Uncertainty over a measuring range

The notion of performance classes (e.g. class 1 for active energy measurement) specified by IEC 61557-12 is much more than a requirement related to uncertainty at nominal current.

- **Intrinsic uncertainty:** compliance covers performance under two sets of reference conditions
- **Operating uncertainty:** compliance covers performance under 12 environmental and electromagnetic influence quantities which typically affect PMD operation
- **Overall system uncertainty:** some information is provided about how to estimate uncertainty of a PMD operating with external sensors.

33.2 Intrinsic uncertainty

Intrinsic uncertainty is the uncertainty of a measuring instrument when used under reference conditions (e.g. at 23 °C) for different Power Factor values. In this standard, it is a percentage of the measured value (readings).

Intrinsic uncertainty limits for class 1 and class 0,2 active energy measurement at Power Factor = 1, is according to Table 8 of IEC 61557-12.

33.3 Operating uncertainty

Operating uncertainty is the uncertainty under the rated operating conditions (including drifts related to temperature, frequency, EMC, and others).

Table 9 of IEC61557-12 specifies tests and uncertainty maximum variation of uncertainty due to various influence quantities such as ambient T°, frequency, unbalance, harmonics and EMC.

33.4 Overall system uncertainty

Overall system uncertainty is the uncertainty including the instrumental uncertainty of several separated instruments (sensors, wires, measuring instrument, etc.) under the rated operating conditions. In case sensors are embedded in the power meter, overall system uncertainty and operating uncertainty are the same. In case sensors are external, it is recommended to use sensors with the same performance class as the power meter.

Appendix A: Tables

	TT	TN-S	TN-C	IT1[(a)]	IT2[(b)]	Comments
Electrical characteristics						
Fault current	–	––	––	+	–	Only the IT system offers virtually negligible first-fault currents
Fault voltage	–	–	–	+	–	In the IT system, the touch voltage is very low for the first fault, but is considerable for the second
Touch voltage	+/––	–	–	+	–	In the TT system, the touch voltage is very low if system is equipotential, otherwise it is high
Protection						
Protection of persons against indirect contact	+	+	+	+	+	All SEAs (system earthing arrangement) are equivalent, if the rules are followed
Protection of persons with emergency generating sets	+	–	–	+	–	Systems where protection is ensured by RCDs are not sensitive to a change In the internal impedance of the source
Protection against fire (with an RCD)	+	+	Not allowed	+	+	All SEAs in which RCDs can be used are equivalent. The TN-C system is forbidden on premises where there is a risk of fire
Overvoltages						
Continuous overvoltage	+	+	+	–	+	A phase-to-earth overvoltage is continuous in the IT system if there is a first insulation fault
Transient overvoltage	+	–	–	+	–	Systems with high fault currents may cause transient overvoltages
Overvoltage if transformer breakdown (primary/secondary)	–	+	+	+	+	In the TT systems, there is a voltage imbalance between the different earth electrodes. The other systems are interconnected to a single earth electrode
Electromagnetic compatibility						
Immunity to nearby lighting strikes	–	+	+	+	+	In the TT system, there may be voltage imbalances between the earth electrodes. In the TT system, there is a significant current loop between the two separate earth electrodes.
Immunity to lighting strikes on MV lines	–	–	–	–	–	All SEAs are equivalent when a MV line takes a direct lighting strike
Continuous emission of an electromagnetic field	+	+	–	+	+	Connection of the PEN to the metal structures of the building is conducive to the continuous generation of electromagnetic fields
Transient non-equipotentiality of the PE	+	–	–	+	–	The PE is no longer equipotential if there is a high fault current

	TT	TN-S	TN-C	IT1[(a)]	IT2[(b)]	Comments
Continuity of service						
Interruption for first fault	–	–	–	+	+	Only the IT system avoids tripping for the first insulation fault
Voltage dip during insulation fault	+	–	–	+	–	The TN-S, TNC and IT (2nd fault) systems generate high fault currents which may cause phase voltage dips
Installation						
Special devices	–	+	+	–	–	The TT system requires the use of RCDs. The IT system requires the use of IMDS
Number of earth electrodes	–	+	+	–/+	–/+	The TT system requires two distinct earth electrodes. The IT system offers a choice between one or two earth electrodes
Number of cables	–	–	+	–	–	Only the TN-C system offers, in certain cases, a reduction in the number of cables
Maintenance						
Cost of repairs	–	––	––	–	––	The cost of repairs depends on the damage caused by amplitude of the fault currents
Installation damage	+	–	–	++	–	Systems causing high fault currents require a check on the installation after clearing the fault

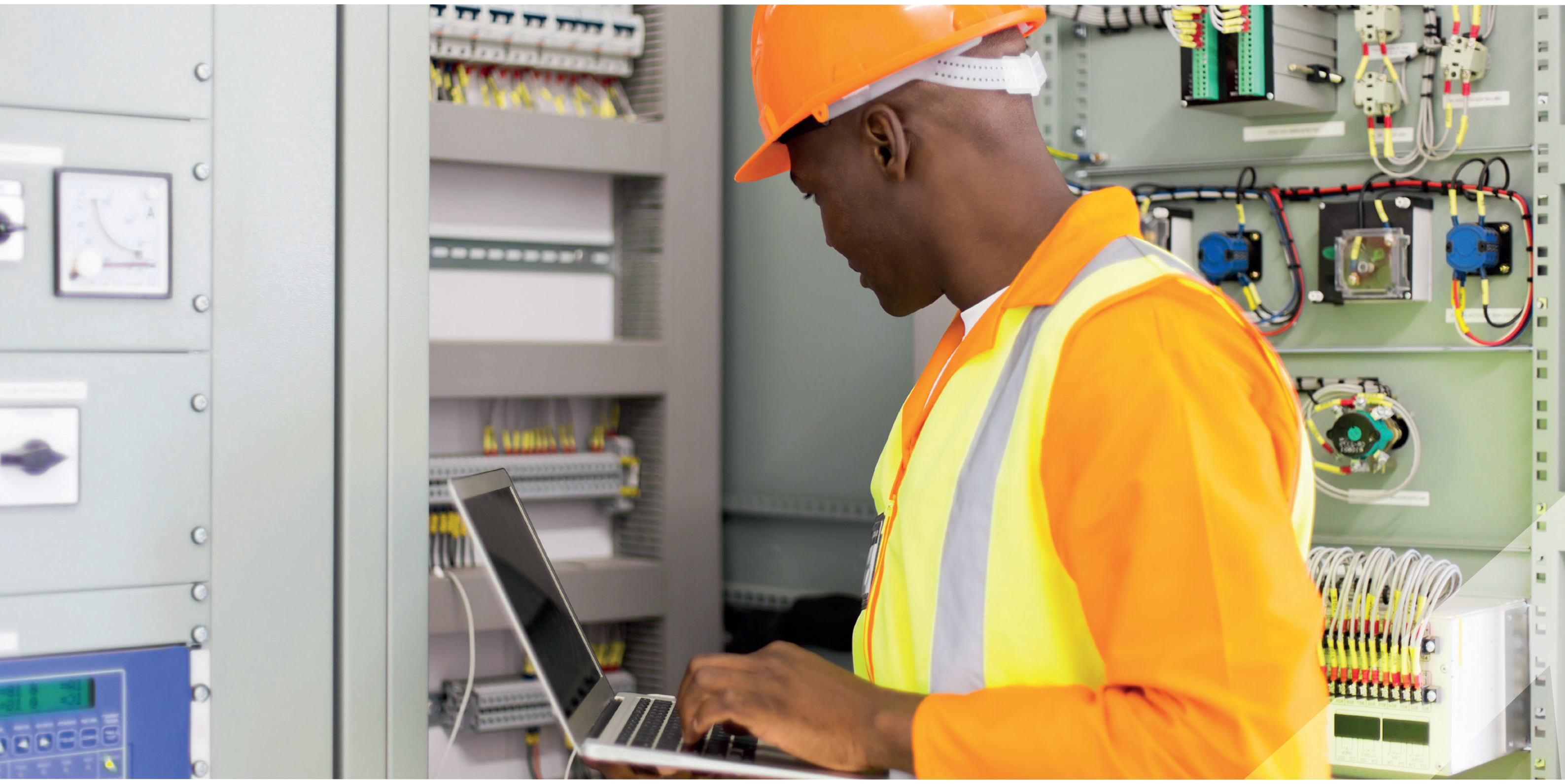
Table 1: Comparison of system Earthing arrangements.

Parameter	Measure-ment	Influence on installation energy efficiency	Comments
Power Factor (PF or cos phi)	PF	Low PF generates additional losses in the installation. Energy provider is charging penalties to the customer	Cables heating (cables need to be oversized)
Voltage and current har-monics	THDu	Low PF generates additional losses in the installation. Energy provider is charging penalties to the customer	Early failure of some devices, mainly motors
Permanent or frequent evia-tions of voltage	U	Negative sequence harmonics (u2) are slowing motors down. Harmonics generates extra losses in the installation	Early failure of some devices, mainly motors
Voltage unbalance	Uimb	Devices may work outside their specified range, and they may over consume, mainly motors	Early failure of some devices, mainly motors
Dips and interruptions	Udip Uint	Voltage unbalance generates extra losses in motors	Process interruption with financial impacts
Frequency	f	–	Rotating machines may change their speed according to frequency
Flicker or RVC	Pst RVC	–	These phenomena can generate disturbing phenomena on lighting

Table 2: Main problems that can occur in an electrical network and their potential consequences.

Type of arrangement	IT system	TT system	TN system
Operations	• Signaling of first insulation fault • Locating and eliminating of first fault • Disconnection for second insulation fault	• Disconnection for first insulation fault	• Disconnection for first insulation fault
Techniques for protection of persons	• Interconnection and earthling of conductive parts • Surveillance of first fault using an insulation monitoring device (IMD) • Second fault results in circuit interruption (circuit-breaker or fuse)	• Earthling of conductive parts combined with use of RCDs • First insulation fault results in interruption by detecting leakage currents	• Interconnection and earthling of conductive parts and neutral imperative • First insulation fault results in interruption by detecting overcurrent (circuit-breaker or fuse)
Advantages and disadvantages	• Solution offering the best continuity of service (first fault is signaled) • Required competent surveillance personnel (location of first fault)	• Easiest solution in terms of designs and insulation • No insulation monitoring device (IMD) required • However, each fault results in interruption of the concerned circuit.	• Low-cost solution in terms of insulation • Difficult design (Calculation of loop impedances) • Qualified operating personnel required • Flow of high fault currents

Table 3: Main characteristics of system Earthing arrangements.



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