Cahier technique no. 129

Uninterruptible static power supplies and the protection of persons

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Foreword

no. 129

Uninterruptible static power supplies and the protection of persons

Jean-Noël FIORINA

Joined Merlin Gerin in 1968 as a laboratory technician in the ACS (power supplies and static converters) department where he was involved with debugging static converters.
He then rejoined the ACS department in 1977 having graduated from ENSERG (Ecole Nationale Supérieure d'Electricité et de Radioélectricité de Grenoble, France).
Working initially as a design engineer and then project manager, he subsequently became Innovations Manager at MGE UPS Systems before taking up the post of Scientific Director. In some ways, he is the father of medium and high-power inverters.

ECT 129 first issue, September 2004

Uninterruptible static power supplies and the protection of persons

The primary function of uninterruptible power supplies is to ensure continuity of electrical power. Even when the line supply fails, they are able to provide the necessary power via their integrated batteries, a backup power source, or even an emergency standby source in the event of a fault.

Static transfer switches can be used to supply power to a load via two independent power sources. In the event of a fault, they automatically transfer the loads from one source to the other.

However, the number of power sources and the multiplicity of possible configurations, as well as the different types of earthing system increase the complexity of setting up these devices in accordance with the requirements of installation standards IEC 60364 and NF C 15-100.

This "Cahier Technique" summarizes these difficulties and offers explanations to assist with the selection of the most suitable solutions for the various case scenarios.

Contents

1 Reminders: Low-voltage neutral earthing systems
(standards IEC 60364-1 and NF C 15-100 Section 312)

1.1 Description

These standards define three types of earthing system for low-voltage installations:

- The **TT** system, known as directly earthed neutral
- The **TN** system, known as connected to neutral
- The **IT** system, known as unearthed or impedance-earthed neutral

They are identified by 2 letters:

- The first letter denotes the relationship of the neutral at machine zero to earth:

T = Neutral connected directly to earth

I = Either all live components isolated from earth or neutral connected to earth via an impedance

- The second letter denotes the relationship of the frames to earth:

T = Frames connected directly to earth

N = Frames connected to neutral

Two other letters are also used with TN systems:

- **TN-S** = When the protection function is provided by a separate conductor from the neutral or the live earthed conductor
- **TN-C** = When the neutral and protection functions are combined in a single conductor (PEN conductor).

The table in **Figure 1** next page summarizes the requirements of the standard governing the installation and operation of these systems.

1.2 In practice

- Although the TT system is the simplest in terms of design and operation, it does need to be protected by means of residual current devices (RCDs) on all circuits.
- The TN-S system is highly recommended for power supplies for data processing and other similar equipment due to the presence of numerous filtering capacities, which create a significant earth leakage current.
- The TN-C system is not recommended for communication equipment due to the inevitable differences in voltage between the various enclosures. Moreover, its use is prohibited in some cases (for example for electrical power supplies in hazardous areas where there is a risk of fire or explosion) due to the circulation of significant currents in the PEN conductor and in conductor components connected in parallel with the PEN (shielding, metal structures in buildings, etc.)
- Due to its ability to tolerate the first fault, the IT system may be required for safety equipment. It requires a permanent insulation monitor (PIM) to rectify the first fault before a second appears.

Note that a single installation may be designed with one of these earthing systems or with a number of earthing systems (see **Fig. 2**).

For more detailed information about earthing systems, see the following "Cahier Techniques":

- "Earthing systems in LV", no. 172
- "Earthing systems worldwide and evolutions", no. 173
- "The IT earthing system (unearthed neutral) in LV", no. 178.

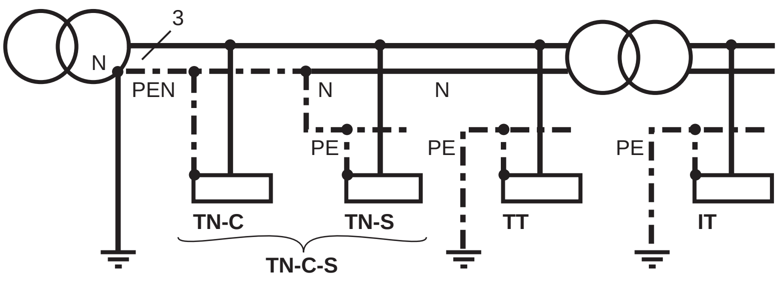
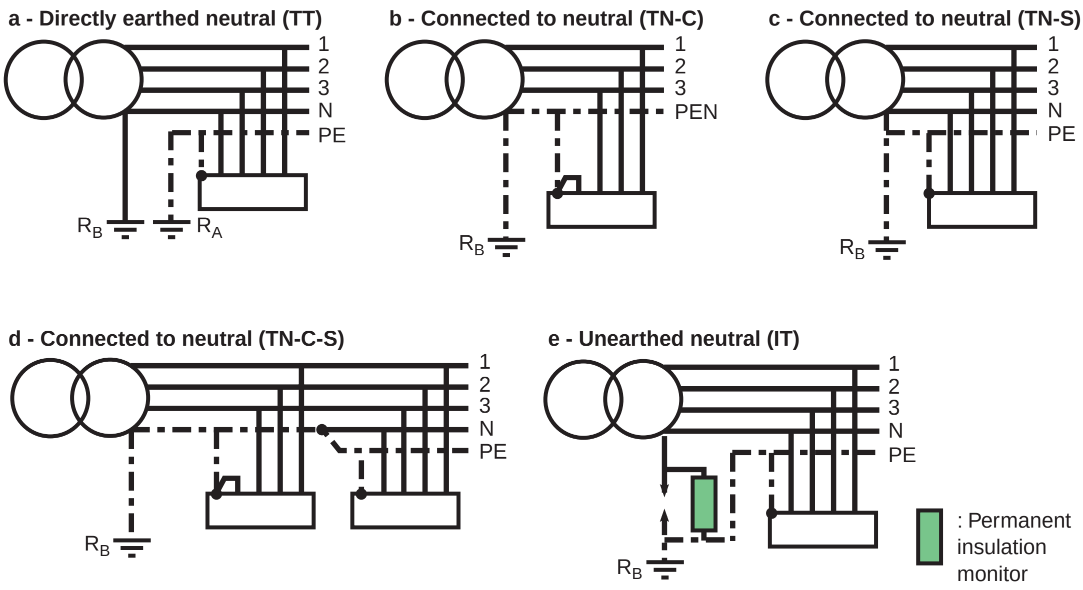


***Fig. 2** : Example of coexistence between the various earthing systems*



Neutral to earth -TT- (system a)

Operating principle:
Breaking on first insulation fault.

Principle for the protection of persons:
The use of residual current devices (RCDs) (at least one at the supply end of the installation) is necessarily associated with the earthing of frames.
This is the simplest solution in terms of design and installation. It does not require permanent insulation monitoring, although each fault will lead to the component affected being disconnected from the power supply.
Note: If, for specific operational reasons, the earth connection for the frames (applications) must be separated from the earth connection for the neutral (inverter) downstream of a UPS, only this neutral to earth (TT) system may be used.

Connected to neutral (TN)

In accordance with standards IEC 60364 and NF C 15-100, the TN system comprises a number of subsystems:

- TN-C (system **b**): If the neutral N and PE conductors are combined (PEN)
- TN-S (system **c**): If the neutral N and PE conductors are separate
- TN-C-S (system **d**): Use of a TN-S downstream of a TN-C (vice versa is not permitted)

Please note that the use of the TN-C system is not permitted on lines with conductors with cross-sectional areas of less than 10 mm^2.

Operating principle:
Breaking on first insulation fault.

Principle for the protection of persons:

- Frames and neutral MUST be interconnected and earthed
- Immediate breaking on first fault is achieved by tripping the overcurrent protection devices (circuit-breakers or fuses) or by means of a differential device.

Inexpensive in terms of installation, the TN scheme requires an installation study and skilled operating personnel. It results in the circulation of high fault currents, which may damage some sensitive equipment.

Isolated (IT) or high-impedance system

With this system **(e)**, the first insulation fault is not dangerous.

Operating principle:

- Signaling of first insulation fault
- Fault must be located and eliminated
- Breaking in the event of two simultaneous insulation faults

Principle for the protection of persons:

- Interconnection **(a)** and earthing of frames in accordance with the TT system if all frames are not interconnected, in accordance with the TN system otherwise
- Monitoring of first insulation fault by means of permanent insulation monitor
- Breaking on second fault is achieved by means of overcurrent protection devices (circuit-breakers or fuses) or a differential device

The IT system is the best solution for ensuring continuity of service. The signaling of the first fault enables protection to be provided against all risks of electrocution. It requires skilled maintenance personnel (first fault troubleshooting).

Public distribution

The most common earthing systems are TT and TN. Some countries, for example Norway, use the IT system.

Fig. 1 : Summary of the three earthing systems defined by IEC and NF standards (boxed text)

2 The main configurations or types of UPS

As its name suggests, the primary function of an uninterruptible power supply or UPS is continuity of service. However, a UPS can also perform other functions, in particular in terms of improving the quality of the voltage supplied to the load. This explains the various configurations used. The simplified systems below are designed to illustrate the main characteristics of these configurations. For more detailed information, see UPS standard IEC 62040-3.

2.1 Double conversion UPS (known as online UPS)

In normal operation, the load is supplied with power permanently via the inverter.
The DC voltage required by the inverter is supplied by the rectifier if the voltage of the main power supply lies within the tolerance limits permitted by the rectifier, or by the battery if it does not.

In this system (see **Fig. 3**), the battery is permanently represented on the DC section of the inverter and the rectifier also functions as a battery charger. In some configurations, the battery has a separate charger and is connected to the inverter directly via a switch when the main power supply fails. In other configurations, in particular in the event of low battery voltage, a DC/DC converter is inserted between the battery and the DC section of the inverter.
In this case, the battery may have a specific charger or the charger function may be provided by the DC/DC converter. A channel known as a bypass channel can be used to increase the availability of the power supply in the event of an overload or if the inverter shuts down following a fault or for maintenance purposes.

This configuration is the most popular, in particular for medium or high-power UPSs, as it optimizes the quality of the voltage supplied to the load. It is therefore suitable for all types of load, even the most sensitive.

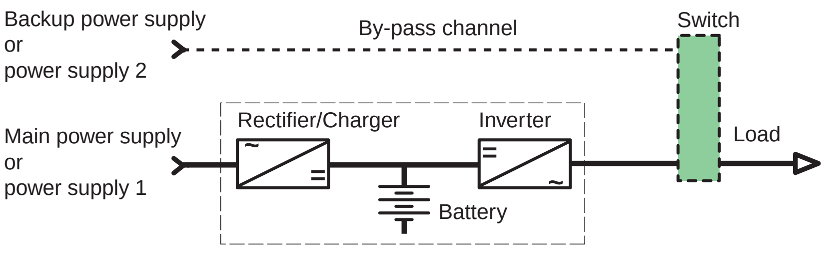


Fig. 3 : Schematic diagram of a double conversion or online UPS

2.2 UPS in line-interactive operation

This time, in normal operation, the power supply for the load is provided via the line by means of a power interface (see **Fig. 4**). This power interface, in conjunction with the inverter connected in parallel with the load, enables the quality of the voltage supplied to be improved on a configuration-specific basis by introducing voltage regulation, and also supports filtering of the harmonics generated by the load.
The battery is charged by the inverter, which operates in reversible mode.
If the main power supply voltage strays outside the tolerance limits permitted by the UPS, the inverter will continue to supply power to the load via its battery.

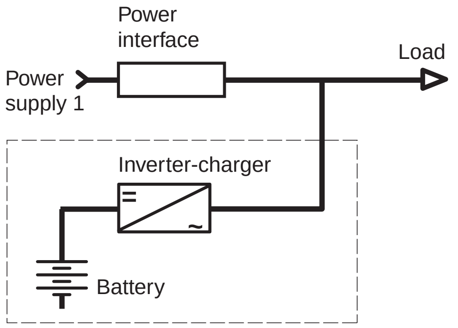


Fig. 4 : UPS in line-interactive operation

Note that in order to avoid load disturbance when the main voltage strays outside these limits, an ultra-fast breaking device must be installed on the power interface.

Moreover, the voltage supplied to the load has to be of the same frequency as that of the main power supply. If this frequency deviates or oscillates rapidly when the main power supply is replaced by a generating set, for example, you are left with a choice of transmitting this disturbance to the load or discharging the battery. It is for this reason that this configuration is less common than the double conversion UPS one and is only used in applications with average or low sensitivity.

Note that it is possible to add a bypass channel with a switch to this system in the same way as for a double conversion system.

2.3 UPS in passive stand-by operation

In normal operation, the load is supplied with power directly via the line (see **Fig. 5**). If the line voltage strays outside the permissible load tolerance limits, the switch can be activated in order to continue to supply the load with power via the inverter.

The switch is often a relay on which the breaking time is less than 10 ms on source transfer, as this system is usually reserved for low power ratings.

This configuration is designed for low-sensitivity loads such as personal computers, for which the voltage quality of the main power supply (line supply or possible replacement sources) is considered sufficient to ensure the correct operation of the devices.

The main function of this type of UPS is therefore to operate when there is no voltage or when the voltage strays outside the permissible tolerance limits.

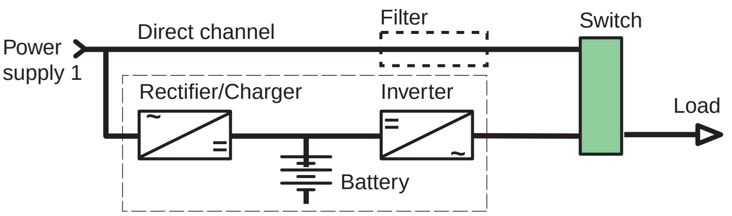


Fig. 5 *: UPS in passive stand-by operation or offline UPS*

2.4 UPS connection configurations

■ UPS connected in parallel

As a general rule, the power available can be increased by connecting the UPS in parallel. This configuration is obligatory when the power required by the load exceeds the maximum power available for a UPS.

However, in most cases, parallel connections are used to increase availability in order to be able to continue to supply the load with power in the event of a UPS fault.

In order to avoid parallel connections being associated systematically with increased availability, standard IEC 62040-3 reserves the term “paralleling” for increased power. Paralleling in order to increase availability is designated by “parallel redundant UPS”.

In this case, the total power of the UPSs connected in parallel will exceed the power required by the load by at least one UPS unit.

□ Paralleling with active redundancy with one bypass (see **Fig. 6**)

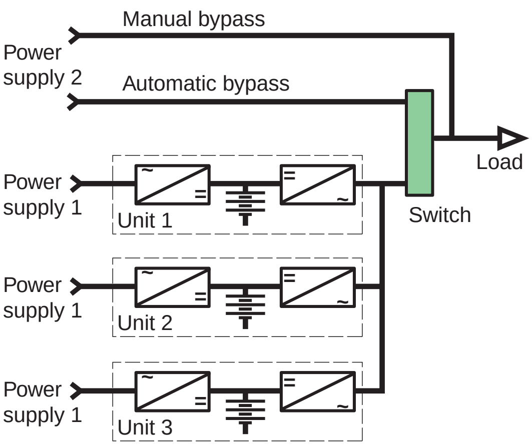


Fig. 6 *: Three UPSs connected in parallel with active redundancy and one automatic bypass. In this case, two UPS units are sufficient to provide the total power required by the load*

The single switch can be used to transfer the load to power supply 2 in the event of failure of all UPS units.

This single switch is usually installed in a specific cell, which also supports paralleling of the UPS units and connects the feeders to the load.

□ Paralleling with active redundancy with one bypass channel per UPS unit
This time, in order to supply the load with power via power supply 2, all switches, which in practice are static switches, must be controlled simultaneously (see **Fig. 7**).

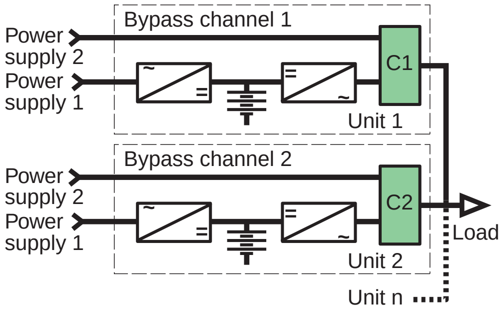


***Fig. 7** : Three UPSs connected in parallel with active redundancy and one automatic bypass channel per UPS unit. In this case, two UPS units are sufficient to provide the total power required by the load*

■ UPS with passive redundancy

If one of the UPS units fails during operation, the UPS in passive stand-by operation unit is started up in order to restore the power supply to the load.

This configuration may or may not feature a bypass.

Figure 8 shows two identical double conversion UPSs. The emergency power supply for unit 1 is replaced by unit 2, which provides much greater availability than that of the line.

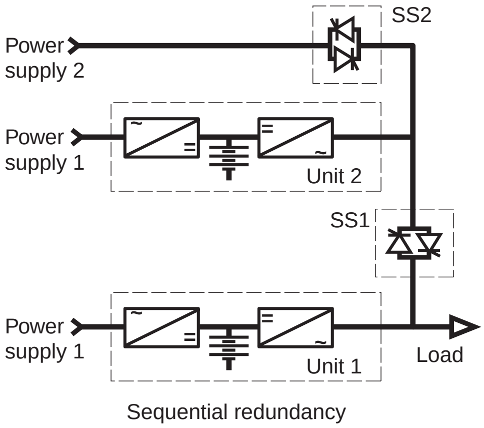


***Fig. 8** : Example of two identical UPSs with passive redundancy and bypass*

2.5 Specific features associated with different types of UPS

This overview of the different UPS configurations highlights the following essential points:

■ The UPS acts as a load for the power supply voltage source(s).

■ The UPS acts as a source from the point of view of the loads.

■ In principle, the UPS output voltage is available even in the absence of one or more of the power supply sources.

■ UPSs are an arrangement of AC and DC circuits.

■ In some operational sequences, the load may be supplied with power directly via one of the power supply sources.

Moreover, the protection of persons is based on neutral earthing systems, which require appropriate protection devices.

Depending on the installation, the earthing systems upstream and downstream of the UPS may be identical or different.

2.6 Specific restrictions

Presence of electrical isolation in a UPS

Depending on configuration, UPSs may feature transformers in various places, which electrically isolate certain circuits from the power supplies or loads, requiring the following cases to be considered:

■ With or without electrical isolation between upstream and downstream equipment, see Section 5

■ With or without electrical isolation between the battery and DC circuits on the one hand and the upstream and downstream equipment on the other, see Section 6

For instances of redundant double conversion UPS paralleling, **Figure 9** next page shows the various possible locations for transformers.

This representation is as complete as it can be due to the fact that some channels do not exist in other configurations.

The switches have been replaced by the static switches (SS) used as standard.

Requirement for continuity of service

In order to optimize power supply continuity for loads connected to the UPS, devices for providing protection against overcurrents must be discriminated in terms of whether these overcurrents are due to a fault between live conductors or an insulation fault.

Moreover, as the short-circuit current of an inverter is relatively low (between 2 and 3 times the nominal current), the protection devices must be defined with great care.

Also, the possible presence of EMC filters, in particular for the power supply for computer equipment type loads, must be taken into account when defining protection devices. Essentially, these filters include capacitors located between the live conductors and earth, which can interfere with the operation of residual current protection devices (see "Cahier Technique" no. 114, "Residual current devices in LV").

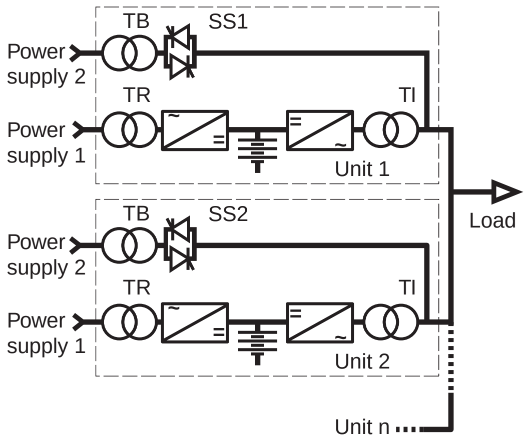


Fig. 9 : The various possible locations for transformers for instances of redundant double conversion UPS paralleling

3 Protection against direct contact

The following standards govern protection against electric shock:

■ For installation

□ IEC 60364-4-41

□ IEC 61140

□ EN 61140

□ NF C 15-100 Part 4-41

■ For type-tested and partially type-tested assemblies (referred to as equipment previously assembled in the factory)

□ IEC 60439-1

□ EN 60439-1

■ For UPSs

□ IEC 62040-1-1

□ EN 62040-1-1

□ EN 62040-1-2

Persons can be protected against direct contact with a component that is live under normal circumstances by installing UPSs (rectifier, inverter and possibly other devices such as static switch) inside enclosures (see **Fig. 10**). The degree of protection of these enclosures must be at least IP 2xx or IP xxB (in accordance with IEC and EN 60529).

As far as battery packs are concerned, observance of these standards and the associated operating restrictions produce three installation modes:

■ Integration of batteries with other static power supply components (rectifier, inverter, bypass, transfer switch, etc.) in a single cell (in this case, the batteries are compartmentalized)

■ Installation of batteries in separate enclosures

Fig. 10 : UPS for protecting persons against risks of direct contact with degree of protection IP 215 (Galaxy 3000 UPS, source MGE-UPS)

■ Grouping of batteries in specialized locations (delimited by partitions in buildings or enclosures inside a cabinet) reserved for the electrical power supply

Moreover, the risks inherent in battery packs (dissipation of explosive gases, corrosive substances) impose specific installation conditions.

4 Protection against indirect contact

In accordance with standards IEC 60364-4-41 and NF C 15-100 Part 4-41, indirect contact is understood to include contact by persons or animals with frames energized accidentally as a result of an insulation fault.

Usually, this type of protection is provided by:

- Interconnecting and earthing metal machine frames (equipotentiality)
- Eliminating a fault that may endanger persons (or property) by means of a protection device selected on the basis of neutral earthing systems (see Section 1.1)

Safety can also be achieved using other methods (class II, electrical isolation, etc.), which are not usually employed in UPS installations.

4.1 Selection of earthing systems upstream of the UPS

It ought to be possible to use all standardized earthing systems due to their equivalence in terms of the protection of persons.
However, it is important to understand their main operating characteristics in order to be able to make a definitive selection (see Fig. 1).

Moreover, depending on their relationship to the UPSs (upstream and downstream), earthing systems must be installed in accordance with other requirements, which are outlined in the following subsections.

4.2 TN-C earthing system upstream of the UPS

The PEN (protective earth and neutral conductor) must never be broken. The continuity of the neutral conductor is always assured.

The downstream system may therefore be TN-C, TN-S or TT, without the need for any specific configuration.

4.3 Different earthing systems downstream and upstream of the UPS

Any change in earthing system, with the exception of the transition from an upstream TN-C to a downstream TN-S or TT, requires total electrical isolation of the circuits concerned.
If a UPS is used, this isolation, which comprises one or a number of transformers with separate windings, can be achieved in various ways depending on the number of channels and the use of transformers in the UPS
(see **Fig. 11**).

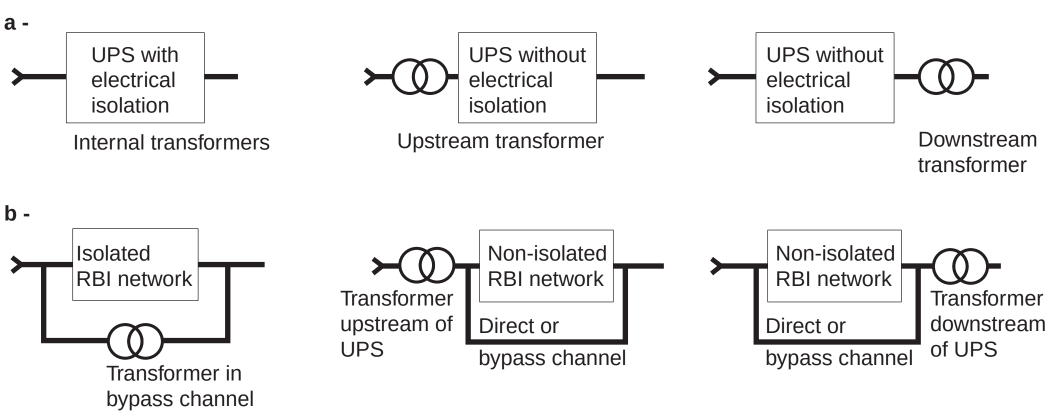


***Fig. 11** : The various ways to electrically isolate line supplies upstream and downstream of a UPS*
***[a]** UPS without bypass channel or without direct channel and reversible UPS (direct interaction with the line supply)*
***[b]** UPS with bypass channel or direct channel*

If isolated RBI (Rectifier - Battery - Inverter) network UPSs are used, there may be one or a number of transformers. Therefore, the DC circuits and the battery may be connected with upstream, downstream or total isolation. Of the numerous different systems, the systems outlined here demonstrate the principles used to set up earthing systems on an installation featuring UPSs. Knowledge of these principles is essential in order to be able to understand and analyze the offers available from the various manufacturers to meet a specific requirement.

4.4 Identical earthing systems upstream and downstream of the UPS

There are two possible scenarios:

- The upstream system is a TN-C system.
- The upstream and downstream systems are TN-S, TT or IT.

The upstream and downstream systems are TN-C systems

As for the general scenario in Section 4-2 with a TN-C system upstream, there are no specific configuration requirements.

The upstream and downstream systems are TN-S, TT or IT

In such cases, when a protection device is operating or maintenance is being carried out, the neutral conductor upstream of the UPS may be broken or isolated.

- During this interruption, if electrical isolation is not assured on all channels, the downstream system is an IT system, regardless of the type of upstream system.
Therefore, for TN-S and TT systems:

□ Equipment compatibility with the IT earthing system must be assured, in particular in terms of the withstand voltage of the capacitors designed to meet EMC (electromagnetic compatibility) requirements. Essentially, these capacitors, which accept the phase voltage in neutral earthing systems, run the risk of having to accept a phase-to-phase voltage in the event of a fault on the IT system. In the event of a phase-to-earth insulation fault, the potential of the other phases in relation to earth is the same as the phase-to-phase voltages.
However, for the purpose of maintenance operations, which are usually completed relatively quickly, the probability of a fault occurring is very low. It is for this reason that it is generally accepted that capacitors do not suffer this phase-to-phase voltage.

□ You must check that the conditions for protection against indirect contact have been satisfied, not only for the TN-S or TT system but also for the IT system. For this purpose, make sure, in the IT system, that in the event of a double fault, the current is sufficient to trip the protection devices (NFC 15-100, Part 4 Section 411-6-4 and IEC 60364, Part 4 Section 413-1-5-5).

□ You must make sure that the neutral conductor is protected by using an overcurrent detection device that will cut off the power supply to all live conductors, including the neutral (NFC 15-100 and IEC 60364, Part 4 Section 431-2).

□ During this operating period, insulation monitoring is not carried out, although the protection of persons remains assured.
However, this state does not usually last for long as the tripping of a protection device is the consequence of a fault, which can be rectified quickly. Moreover, if discrimination has been calculated correctly, the tripping of the protection device need only affect the faulty feeder and not the other feeders, which are operating correctly. It is for this reason that standards do not require PIMs on installations that usually operate as TN-S or TT systems with a UPS in accordance with this configuration.

For the IT system, operation remains with the same system, although insulation monitoring cannot be guaranteed during the period in which the neutral is broken upstream.

- If there is total electrical isolation upstream and downstream of the UPS, the various scenarios illustrated before with different earthing systems upstream and downstream apply:

The earthing system must be reconstructed upstream of the UPS:

□ As a TN-S or TT system by means of direct earthing upstream of this electrical isolation

□ As an IT system by means of the installation of a new permanent insulation monitor

Total electrical isolation is recommended for improved protection against disturbance present on upstream power supplies.

4.5 Detailed requirements regarding the extent of protection by means of automatic power supply disconnection (NFC 15-100 Part 4 Section 411 and IEC 60364 Part 4 Section 413-1)

When load circuits downstream of the UPS can be supplied with power directly via the main source or replacement source (UPS with bypass circuit or offline UPS), you must check the conditions for protection against indirect contact in accordance with the requirements of these standards, taking into account the main source (power supply 1) and, if applicable, the replacement source (power supply 2).

Moreover, in all cases, you must check the protection conditions when the circuits are supplied with power via the inverter, taking into account the operating characteristics of the latter provided by the manufacturer.

It is particularly important to be aware of the maximum current that can be supplied by the inverter for overloads that may lead to short-circuits and the period of time during which the inverter is able to provide this current.

Usually, the manufacturer will provide information about these devices along with their rated data in order to safeguard this type of protection.

Two practical recommendations

- In order to avoid load disturbance while protection devices are in operation, the use of high-speed current-limiting circuit-breakers or fast-acting fuses is recommended.
- In order for protection devices to operate, as the short-circuit current of an inverter is limited to values between 2 and 3 times its nominal current, maximum subdivision of the feeders is recommended in order to maximize the ratio between the fault current for a feeder and the trip current for the protection device.

Therefore, with 4 identical feeders and an inverter short-circuit current equal to 2.5 times its nominal current, when applied to a feeder, this current is equal to 10 times its rated current.

Special case of low-power UPSs connected to the main line supply via a power outlet

Low-power UPSs are power supplies with a rating of less than 3 kVA, which are connected via a single-phase power outlet with a maximum rated current of 16 A. They must not be used to supply power to a permanent installation.

When the cable is disconnected, the protective earth conductor PE is broken and the power supply to the load circuits is provided via the UPS battery pack.

The installation can be considered small-scale with floating potential. Protection is then provided by means of the equipotentiality between the various hardware components connected. This requires that the power outlets downstream of the UPSs have an earth contact.

4.6 Protection against input voltage feedback

UPS standards IEC and EN 62040-1-1 and 62040-1-2 require the provision of protection against input voltage feedback.

- For low-power UPSs connected via an outlet, this requirement is justified in particular by the fact that when the cable is disconnected, the presence of voltage at the male connectors could put persons or animals at risk.
- For permanent UPSs, this requirement is justified for maintenance reasons, when personnel have to intervene upstream of the UPS. This device can be integrated into the equipment or installed externally. In the latter case, the manufacturer must specify the type of insulation device to be used. A label reading "ISOLATE THE UNINTERRUPTIBLE POWER SUPPLY BEFORE WORKING ON THIS CIRCUIT" must also be affixed by the user to all insulation devices installed in a zone not in the immediate vicinity of the UPS.

5 Application

5.1 Application in relation to single UPSs

Different earthing systems upstream and downstream

■ UPS with electrical isolation: the UPS features a transformer on each of its channels.

In the systems described below, the transformer has been installed upstream of the RBI network and is marked TR (for rectifier transformer). This channel can also be electrically isolated by installing a transformer downstream of the inverter (TI).

□ TT system: The load neutral is earthed at the downstream UPS terminal (see **Fig. 12**).

Protection of persons is achieved using an RCD connected to a circuit-breaker either globally or individually on each feeder.

□ TN system: The load neutral is earthed via the UPS terminal.

Protection of persons is usually provided by overcurrent protection devices.

If the load earthing system is a TN-C system, the combined protective earth and neutral conductor (PEN) is distributed via this terminal (see **Fig. 13**).

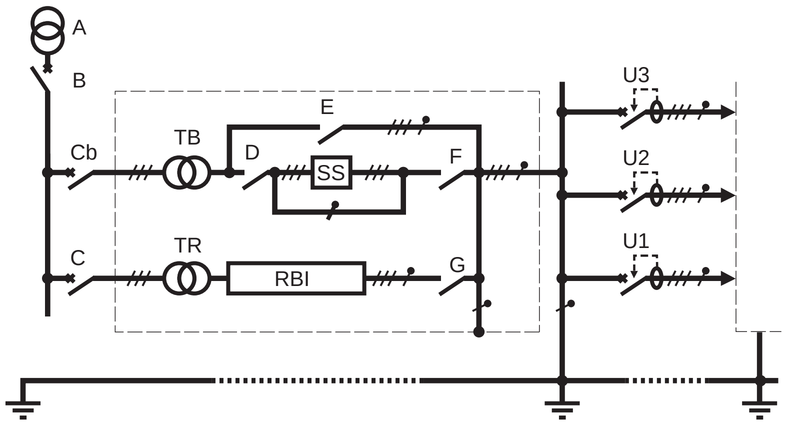


***Fig. 12** : TT earthing system downstream (any type of earthing system upstream - TT, TN or IT)*

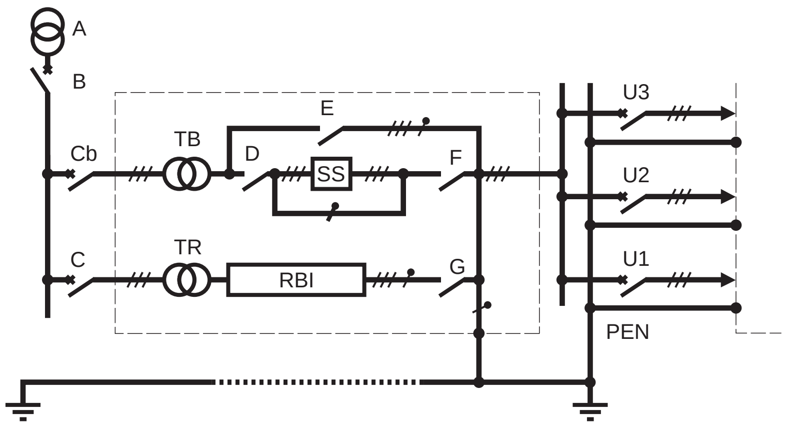


***Fig. 13** : TNC earthing system downstream (any type of earthing system upstream - TT, TN or IT)*

If, as is most common, the load earthing system is a TN-S system, the protective earth and neutral conductors are connected to the same earth connection on the UPS terminal (see **Fig. 14**). RCDs may then be installed, if necessary, on the feeders.

□ IT system: A PIM, connected between one of the live conductors and earth, detects insulation faults upstream of the UPS (load) as well as on the UPS as far as the rectifier or inverter transformers (TR and TI respectively) (see **Fig. 15**). Protection of persons in the event of a second fault is usually provided by overcurrent protection devices.

■ UPS without electrical isolation (no transformers on any of the channels)

Without isolation, the only possible combinations are the TN-C earthing system upstream of the UPS with TN-S or TT earthing systems downstream (see **Fig. 16** next page). In effect, there is no need for an additional transformer, regardless of the number and position of any transformers that might be present in the UPS due to the continuity of the combined protective earth and neutral (PEN) conductor.

In this case, the combined PEN conductor splits into a separate neutral and protective earth at the UPS output terminal.

The neutral is distributed with the PE for the part of the installation supplied with power in TN-S configuration, but for the part supplied with power in TT configuration, only the neutral is distributed as the PE is distributed via a local earth.

If other earthing system combinations are required upstream and downstream, the previous scenario should be adopted with the addition of one or a number of transformers, possibly externally to the electronic equipment if the UPS does not feature built-in transformers on each of the channels.

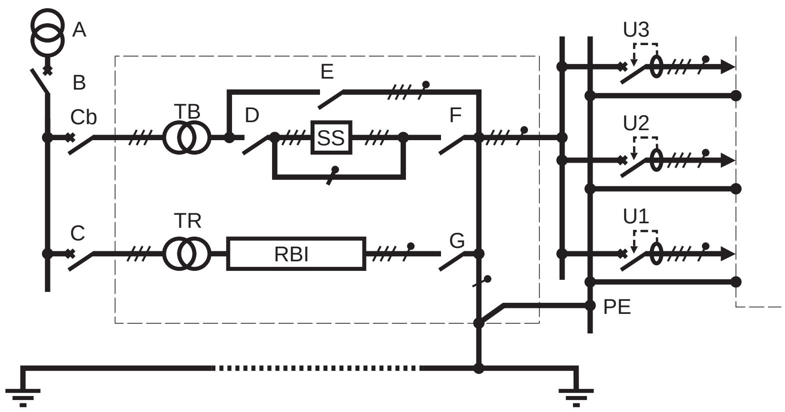


Fig. 14 *: TNS earthing system downstream (any type of earthing system upstream - TT, TN or IT)*

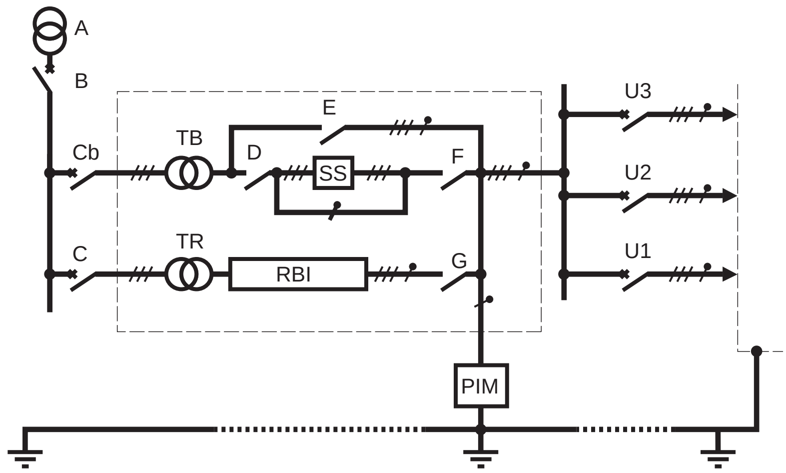


Fig. 15 *: IT earthing system downstream (any type of earthing system upstream - TT, TN or IT)*

■ Double conversion UPS with inverter transformer (TI)

This type of UPS with an inverter transformer and without isolation in the bypass channel is the most common for medium and high-power UPSs.

A bypass transformer (TB) must therefore be installed in the bypass channel.

□ Any type of system upstream, TT system downstream (see **Fig. 17**)

The load neutral is earthed at the UPS terminal. Protection of persons is achieved using an RCD connected to a circuit-breaker either globally or individually on each feeder.

□ Any type of system upstream, TN-S system downstream

In this case, which is the most frequent for TN systems, the protective earth conductor and the neutral are connected to the same earth connection on the UPS terminal (system identical to Fig. 15). Protection of persons is usually provided by overcurrent protection devices. RCDs can be installed on the various feeders if the fault current is not sufficient to reach the trip threshold for the overcurrent protection devices.

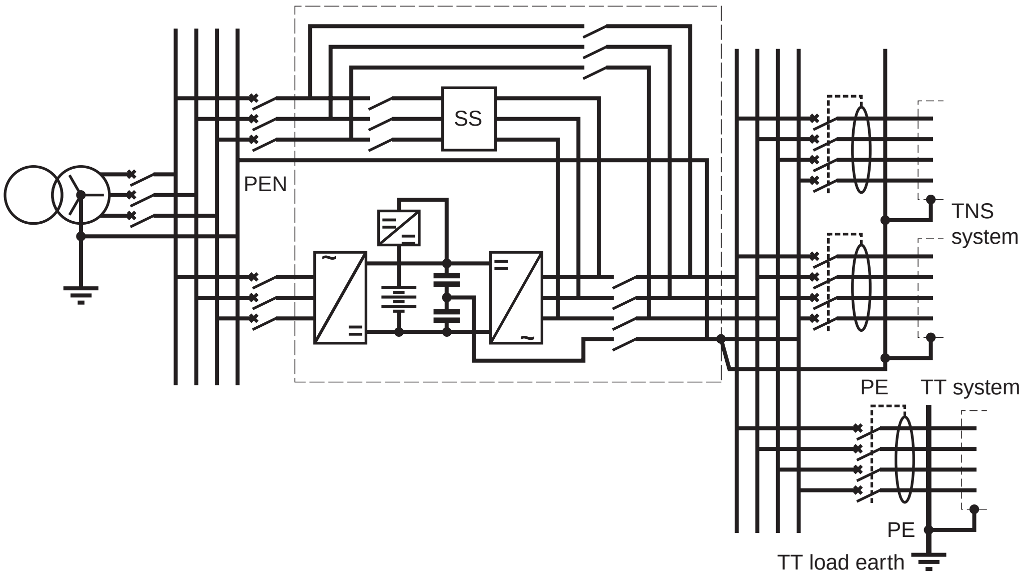


Fig. 16 *: Without electrical isolation, the possible combinations are the TN-C earthing system upstream and TN-S or TT earthing systems downstream*

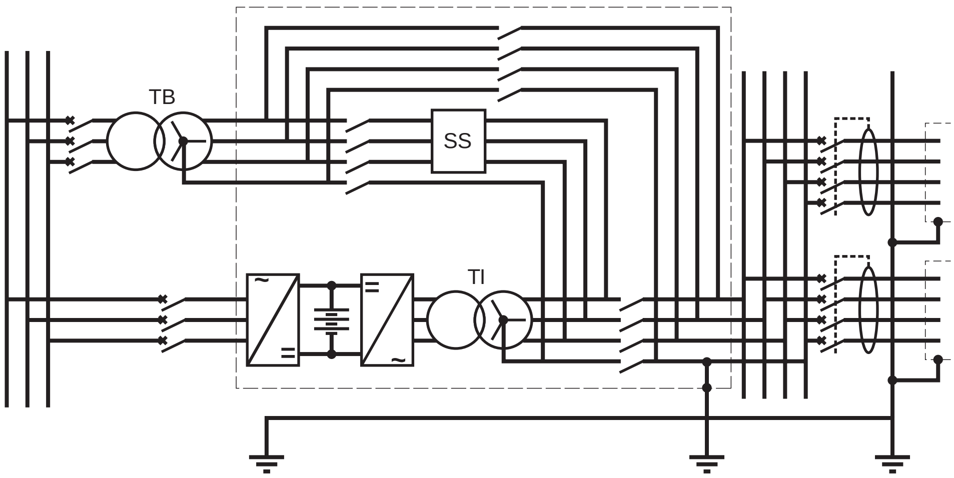


Fig. 17 *: Any type of system upstream, TT earthing system downstream*

□ Any type of system upstream, TN-C system downstream (see **Fig. 18**)

The load neutral is earthed at the UPS terminal. Protection of persons is usually provided by overcurrent protection devices.

The combined protective earth and neutral (PEN) conductor is distributed via this terminal.

□ Any type of system upstream, IT system downstream (see **Fig. 19**)

A PIM connected between one of the live conductors (the neutral in this case) and earth detects insulation faults on the load as well as on the UPS as far as the bypass and inverter transformers (TB and TI).

Protection of persons in the event of a second fault is usually provided by overcurrent protection devices.

■ Double conversion UPS without transformer

This system, which is usually reserved for low power ratings, is becoming increasingly popular in medium-power applications and is starting to be used in high-power applications.

In the very general case, where there is one main channel and one bypass channel, two transformers must be used in order to ensure upstream electrical isolation. The system required for the load is reconstructed upstream of the UPS as in previous scenarios.

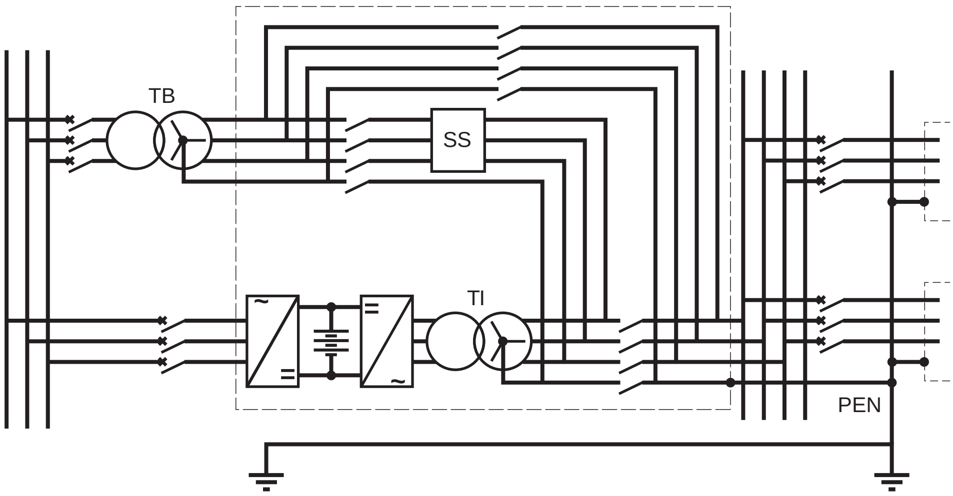


Fig. 18 *: Any type of earthing system upstream, TN-C earthing system downstream*

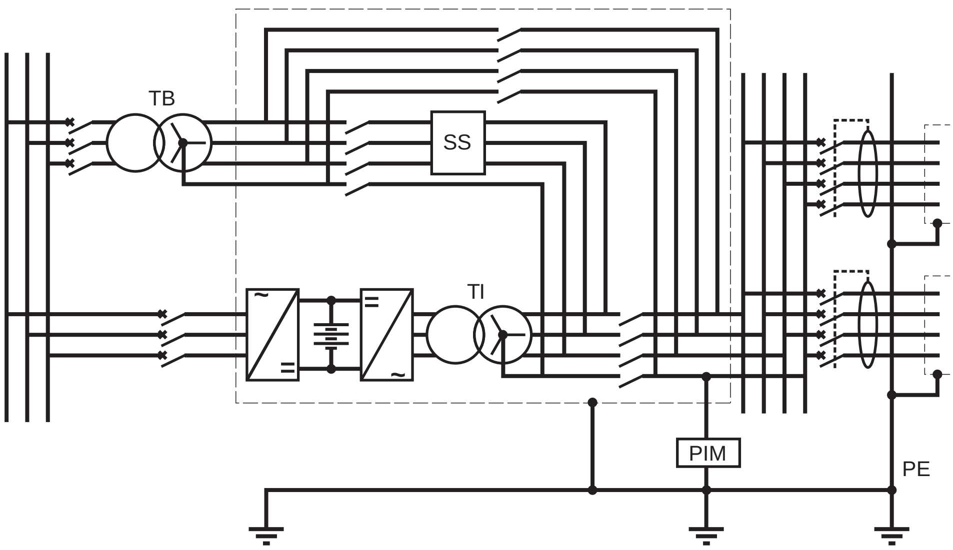


Fig. 19 *: Any type of earthing system upstream, IT earthing system downstream*

Internal inverter faults are protected by means of upstream circuit-breakers.

This two-transformer configuration is used for two main reasons:

- If the two AC voltage sources are not provided by the same busbar system
- In order to improve availability, because a fault on a transformer or input will not affect the other channel

Figure 20 illustrates an example of this with any type of system upstream and a TT system downstream.

It is also possible to use just one transformer if it is located at the output. In this case, the required earthing system can be reconstructed downstream of the output transformer (see **Fig. 21a**).

The neutral upstream of the UPS is only used if required for the UPS to operate. The transformer induces a voltage drop in relation to the UPS output, which may be harmful if the load current has an increased distortion rate and in particular with the third harmonic. In this case, a transformer with a zigzag-connection secondary may be used in order to reduce zero-sequence impedance.

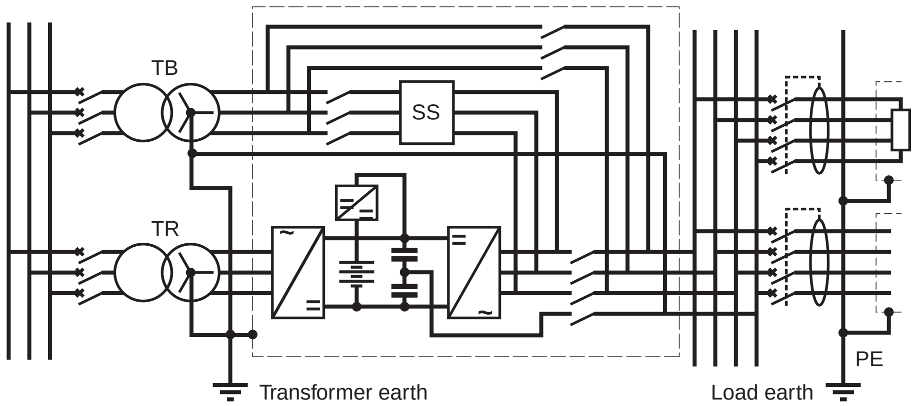


***Fig. 20** : If the two transformers (battery and rectifier) are located upstream (2 different sources), the upstream and downstream earthing systems do not have to be identical*

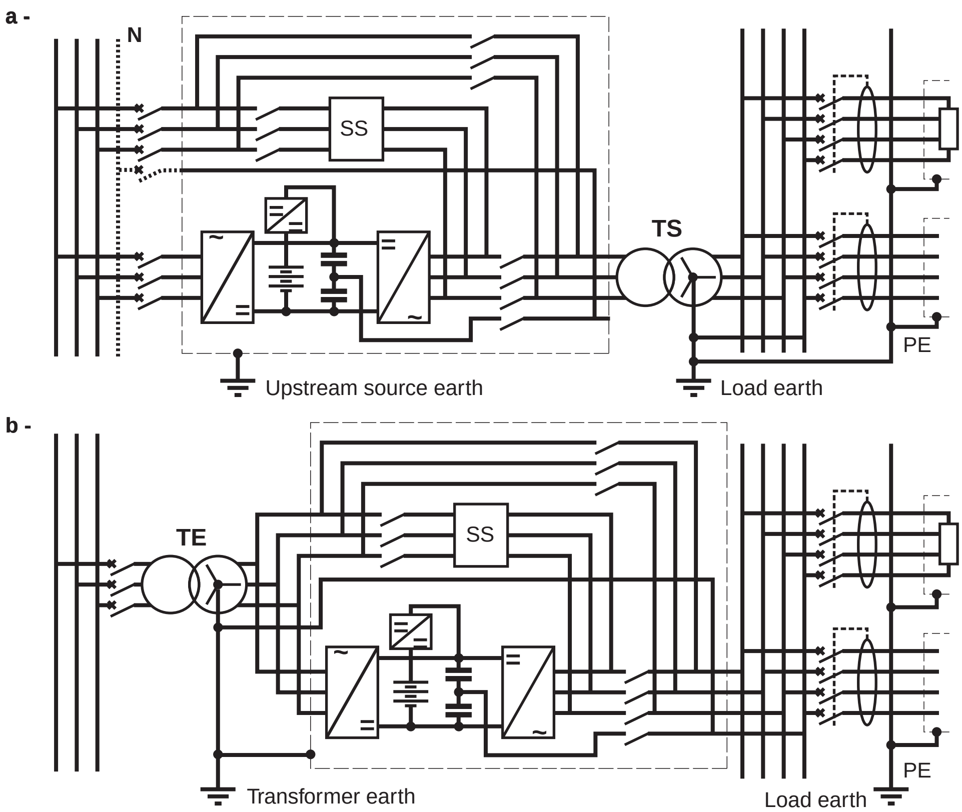


***Fig. 21** : With a single transformer TS **[a]** or TE **[b]**, different earthing systems can be used upstream and downstream*

Another possibility is to regulate the transformer secondary voltage, thereby matching its characteristics to those of the initial device.

If, as is most common, two AC power supply sources are provided by a single busbar system, the system illustrated in **Figure 21b** preceding page, with a single transformer, is also possible.

This case is the same as UPSs with bypass and a single incoming line for the AC power supply, with the only difference that bridging between the two channels is implemented inside the UPS.

Identical earthing systems upstream and downstream and no electrical isolation

If electrical isolation is applied, the scenario is the same as before, with the same system upstream as downstream. It is for this reason that only the scenario in which electrical isolation is not applied is described below.

■ For the TN-C system

There are no particular requirements to be met due to the continuity of the neutral conductor. The downstream system can even be a TN-S or TT system without any particular configuration being required, as in the scenario described before.

The example in **Figure 22a** illustrates a scenario with a TN-C system both upstream and downstream for a UPS without a transformer.

■ For TN-S, TT or IT systems upstream and downstream

The isolation and disconnection of the neutral upstream of the UPS when specific events occur isolates this conductor from the earth downstream of the UPS. This configuration requires careful consideration in order to ensure the safety of personnel working on the backed-up section of the installation.

Figure 22b illustrates this scenario for the TN-S system.

The solution often advocated is to provide electrical isolation on all channels.

Under these conditions, the possible systems are those considered in the scenarios before and which support any type of upstream system.

However, the problem does need to be analyzed: During this period, the operating conditions for the load are those of the IT system.

□ For property or persons, this operating mode poses no risks, as long as the conditions for protecting persons against indirect contact have been met for the IT system.

□ Devices supplied with power by the UPS must be compatible for operation with this system. In particular, filter capacitors for EMC must be able to withstand the phase-to-phase voltage in the event of a fault on the IT system (see Section 4.2).

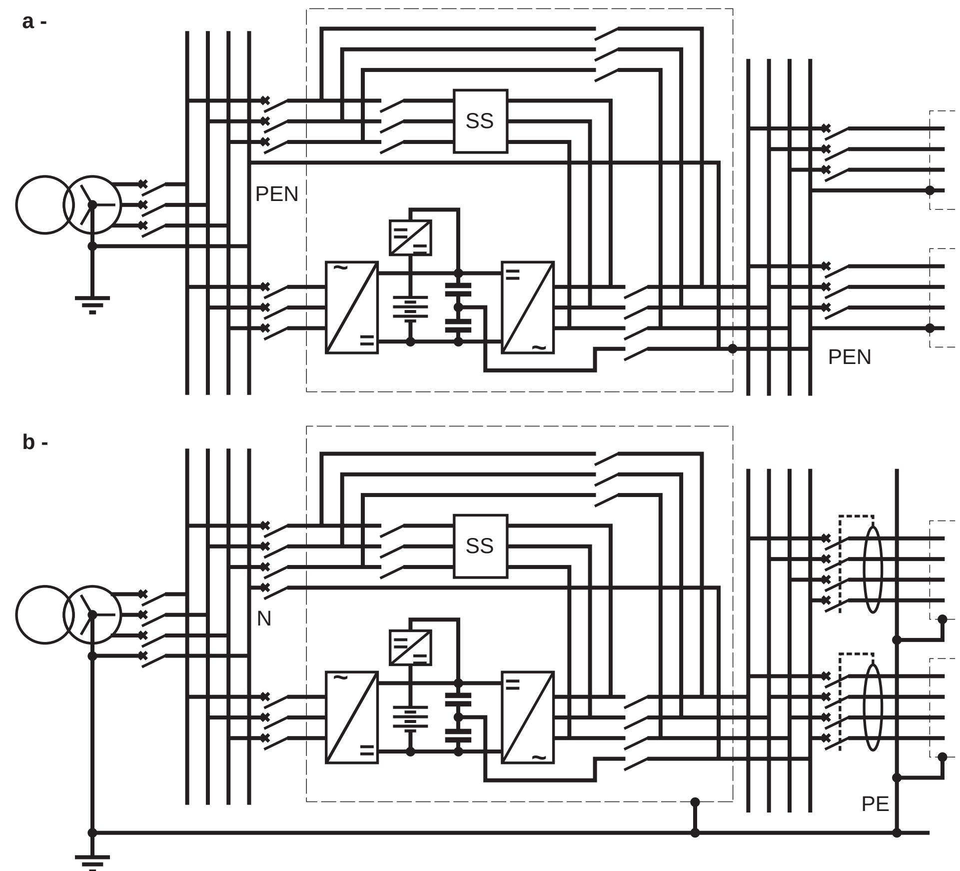


Fig. 22 : No electrical isolation, identical earthing systems upstream and downstream

□ In the absence of a PIM, although the operating conditions are the same as those of an IT system, the lack of a PIM will not affect operation. This device simply detects the first fault in order that it can be repaired before a second fault cuts off the power supply.

In order to optimize continuity of service in an IT system, a PIM can be installed downstream of the UPS and only put into operation when the upstream voltage is lost. **Figure 23** illustrates this option and therefore features PIM 1.

PIM 2 is put into operation via relay R2 only in the event of a loss of voltage upstream of the UPS.

In spite of the absence of voltage upstream of the UPS, it is possible, even very probable, that the neutral conductor will not be broken.
A circuit-breaker trips either in the event of a fault or for maintenance purposes.

If there is a risk that PIM 2 may be subject to disturbance from PIM 1, a relay R1 can be used to shut down the former when the transformer secondary voltage is zero.

Moreover, in the case of the TN-S system, depending on the country of application, it may not always be the case that the neutral is broken (see CT 173). If the neutral is not broken, there is no particular problem and the scenario will be as for the TN-C system.

The only difference is the presence of a neutral conductor and a PE instead of a PEN (see **Fig. 24**).

Low-power UPSs connected via a socket outlet

For these devices, there is only one incoming line, the main and bypass power supplies (if they exist) are combined.

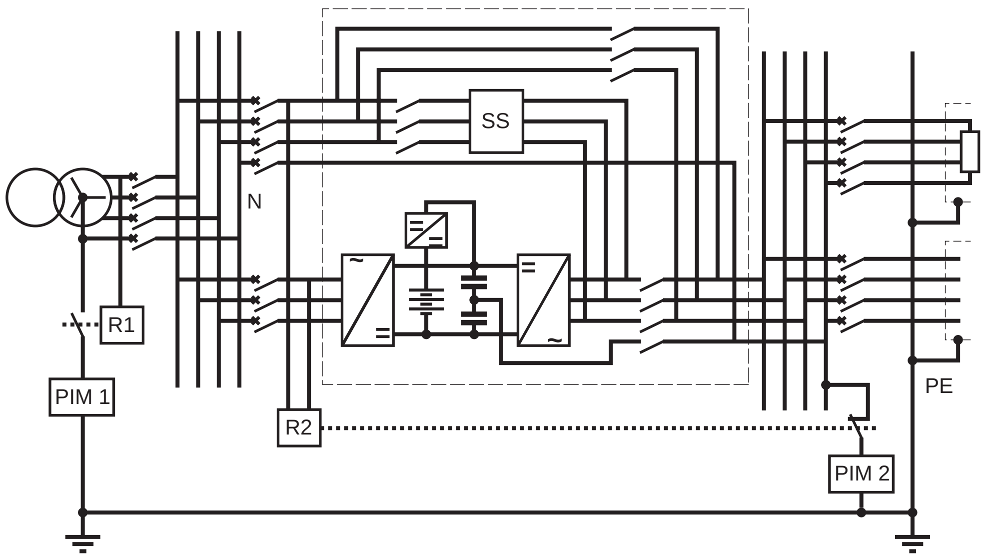


***Fig. 23** : IT earthing system upstream and downstream, PIM2 put into operation on loss of upstream voltage*

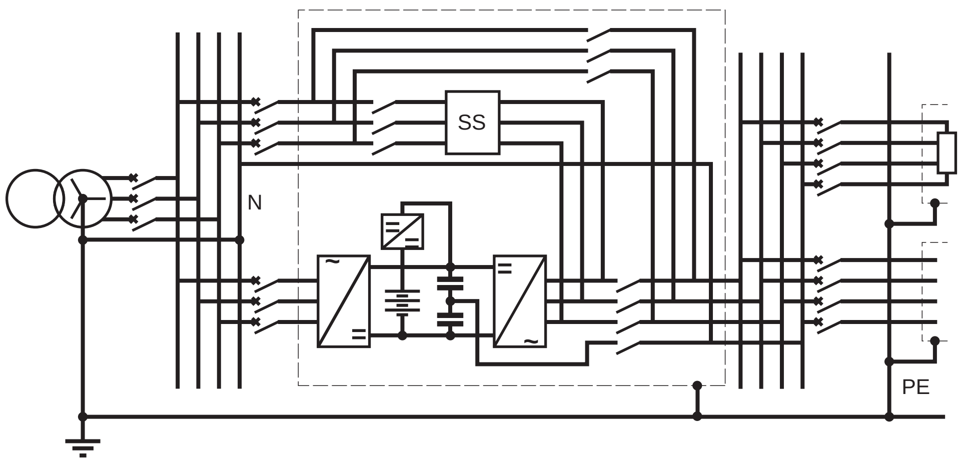


***Fig. 24** : TN-S earthing system upstream and downstream*

Moreover, the link to earth is made via the green/yellow cable conductor, which is always at risk of becoming broken or disconnected from the socket outlet.
Note that inserting an isolating transformer in order to create an earthing system downstream of the UPS, which is different to the earthing system upstream, will not alter this risk.

In the very general case, where the upstream and downstream systems are identical and without user knowledge of them, there are no specific requirements to be met. The safety of persons is ensured via the equipotentiality of the frames. It is therefore necessary that all sockets downstream of the UPS have an earth contact.

5.2 Application to UPSs connected in parallel

Different earthing systems upstream and downstream of UPSs

- UPS with electrical isolation

If the UPS has transformers on each channel (UPS with electrical isolation), it is sufficient to recreate the required system downstream, as in the case of single UPSs.

In the system illustrated in **Figure 25** , transformers have been installed upstream of the RBI networks and are marked TR (for rectifier transformers). This channel could also have been electrically isolated by installing a transformer in the inverter (TI).

- UPS without electrical isolation

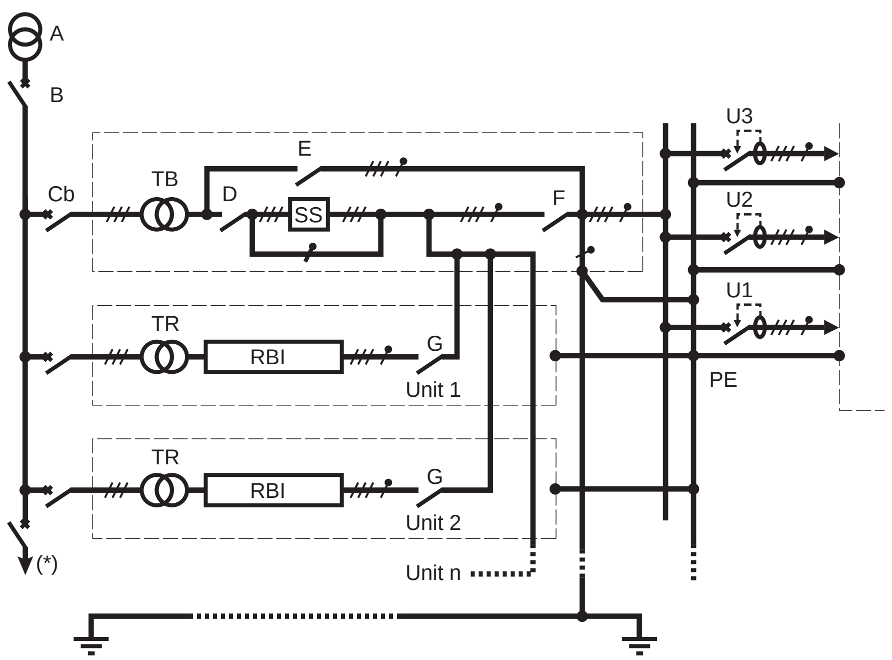
If the UPSs have not been totally electrically isolated, isolating transformers must be added to the channels that do not have them.
A single transformer can be used for all main power supplies and one for all secondary power supplies.

However, when parallel connections are used in order to improve reliability, it is not advisable to use a single transformer for all main power supplies, as the transformer is a reliability node.

For the secondary power supply, a single transformer is usually sufficient as it is more reliable than the line supply.

When there is only one standby system implemented by an NS static switch (the ideal solution for reliability), a single transformer is required for the secondary power supply.

Connecting both single devices and static switches in parallel allows a number of paths for the neutral and phase currents on the power supply circuits. There is therefore a risk of certain conductors becoming overloaded. As it is not easy to control current distribution in each of the conductors, this risk is usually eliminated by using a single cable as far as the vicinity of UPSs.



(*) Loads not needing to be put into operation

Fig. 25 : The electrical isolation achieved by installing upstream transformers permits different earthing systems to be used upstream and downstream of UPSs

□ Single static switch

- UPS with inverter transformer (TI)

Figure 26 illustrates the example of a downstream TN-S system and any type of system upstream. In this case, it is sufficient to add a transformer in the bypass channel (TB) to achieve total isolation. This configuration applies equally to increasing power and to active redundancy.

- UPS without transformer

In this case, a transformer must be added in each of the UPS units in addition to the transformer on the bypass channel (TB) (see **Fig. 27**). The transformers should be located upstream of the rectifiers (TR) rather than downstream of the inverters in order to preserve the quality of the inverter output voltage.

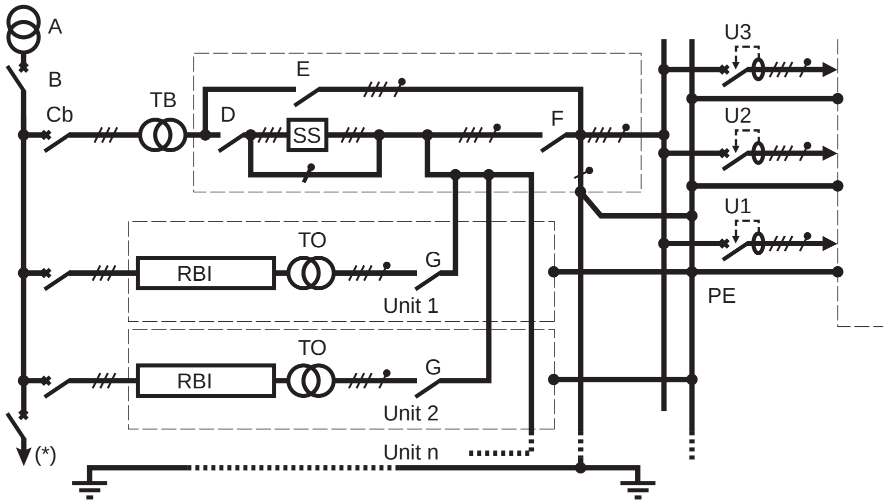
If paralleling is employed simply to increase power, a single rectifier transformer may be used upstream of the rectifiers.

□ Parallel connections with one bypass channel per UPS unit

Generally speaking, transformers must be installed on channels that do not already have them.

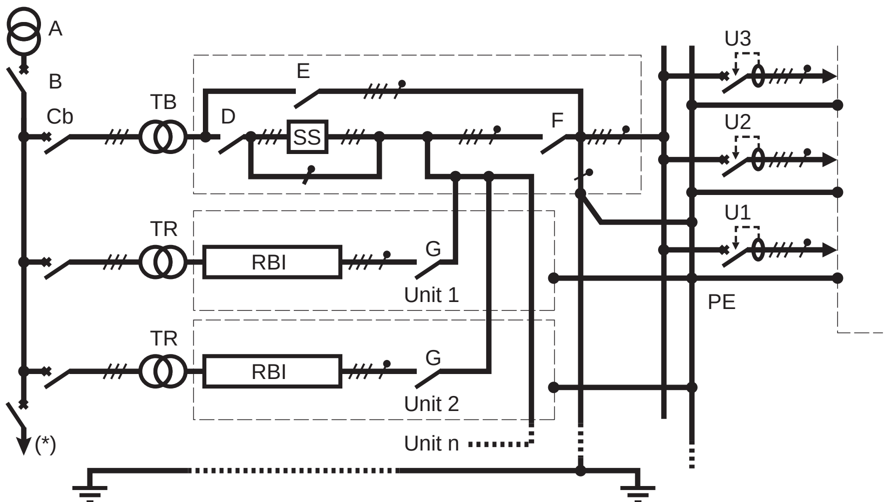
- UPS without isolating transformer

In this case and in the event of a redundant parallel connection, transformers must be installed on each channel.



(*) Loads not needing to be put into operation

Fig. 26 *: Installation of a transformer in the bypass channel (TB) will achieve total isolation of a UPS installation with inverter transformer (TI), permitting different earthing systems to be used upstream and downstream of UPSs*



(*) Loads not needing to be put into operation

Fig. 27 *: Installation of transformers upstream of rectifiers (TR) will achieve total isolation of a UPS installation without transformer, permitting different earthing systems to be used upstream and downstream of UPSs without affecting the quality of the output voltage*

As in the example before, transformers upstream of rectifiers (TR) should be used instead of transformers downstream of inverters (TI) in order to preserve the quality of the voltage supplied by the inverters (see **Fig. 28**).

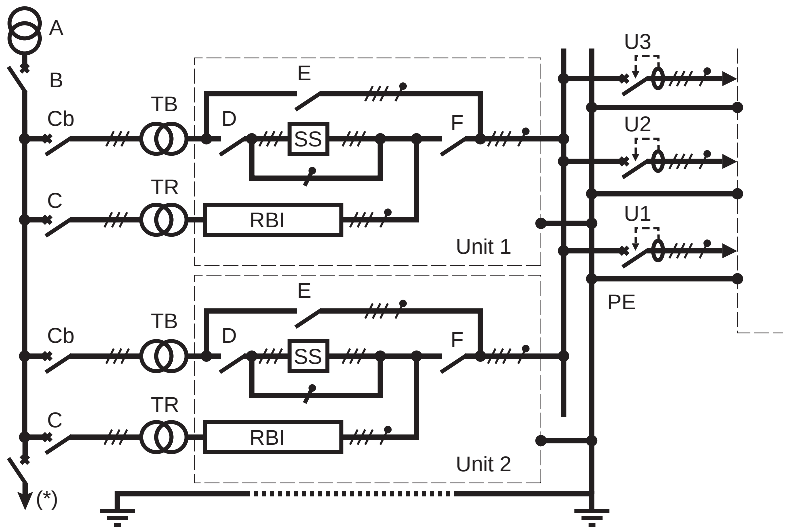
For increased power, one transformer may be used for the rectifiers and one for the bypass channels, or even a single transformer for both (see **Fig. 29**).

In this case, however, you must check that the current distribution in the various bypass channels is correct in the phase and neutral conductors.

If, for operational reasons, the neutral is required for rectifier operation, the problem becomes a little more delicate due to the presence of double the number of neutrals.

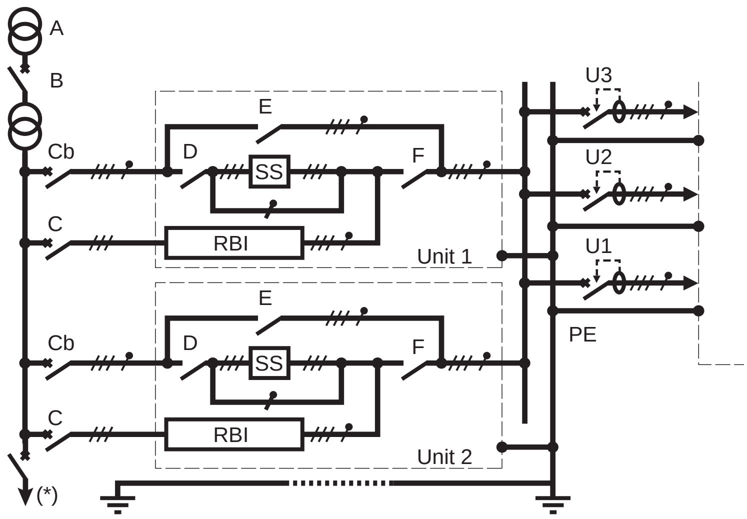
■ TN-C system upstream with TN-S or TT system downstream

As for single devices, no special requirements have to be met due to the continuity of the neutral (see **Fig. 30** next page).



(*) Loads not needing to be put into operation

Fig. 28 : Connection of a number of UPSs in parallel, each of which feeded by a transformer (TR) and each of which has a bypass channel with upstream transformer (TB), will achieve total electrical isolation of the installation, thus permitting the use of different earthing systems upstream and downstream of the UPSs without affecting the quality of the output voltage



(*) Loads not needing to be put into operation

Fig. 29 : Installation of an upstream transformer will achieve total electrical isolation of the installation, which is essential if different earthing systems are to be used upstream and downstream of the UPSs connected in parallel, each of which has a bypass channel

Identical earthing systems upstream and downstream and no electrical isolation

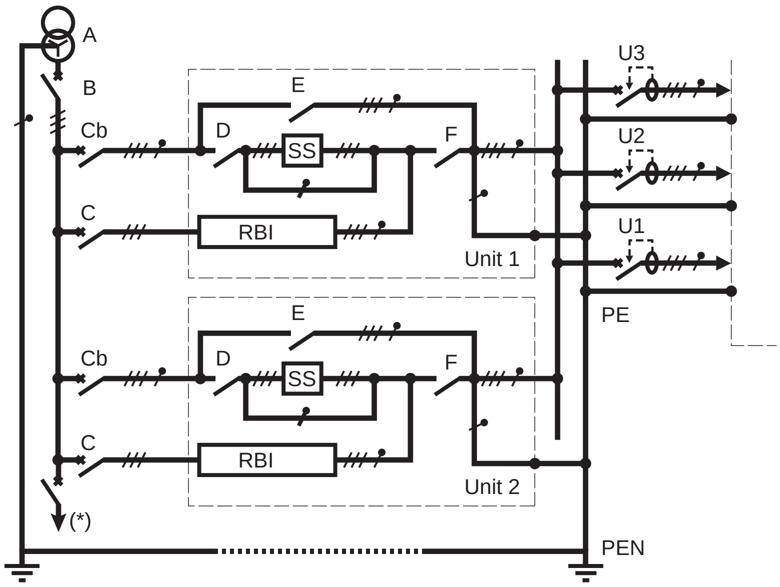
As for single UPSs, in the event of electrical isolation or if this electrical isolation is required in order to limit high-frequency disturbance transmitted via the power supplies or to avoid possible problems with the operation of the IT system while the neutral is broken, the situation is identical to the scenario before with identical systems upstream and downstream. It is for this reason that only the scenario without electrical isolation is described below.

■ For the TN-C earthing system

There are no specific requirements to be met due to the continuity of the neutral conductor.

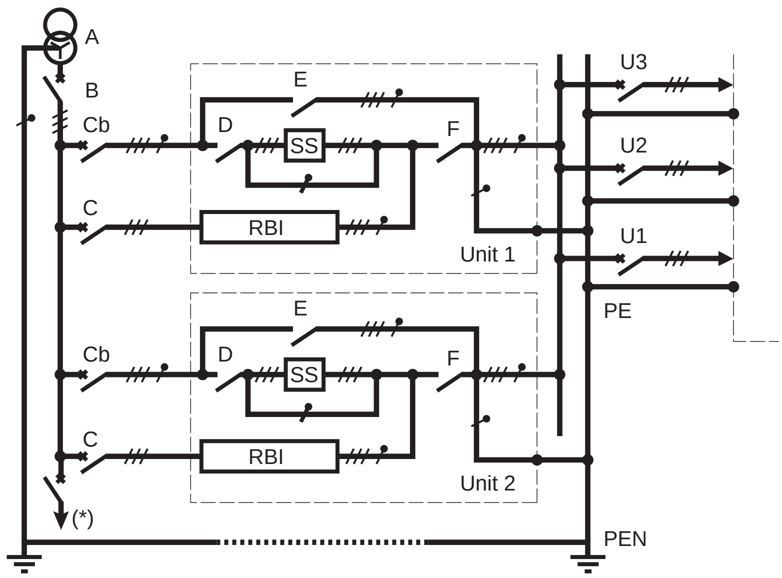
The downstream earthing system can even be a TN-S or TT system without the need for a special configuration, as described above (chapter 2).

Figure 31 illustrates a scenario with an upstream TN-C and a downstream TN-C for a redundant parallel UPS connection without a transformer.



(*) Loads not needing to be put into operation

Fig. 30 : TNC earthing system downstream and TNS earthing system upstream



(*) Loads not needing to be put into operation

Fig. 31 : TNC earthing system downstream and upstream

■ For TN-S, TT or IT earthing systems

As for single UPSs, the only difficulty is presented by the possible disconnection of the neutral conductor.
The comments made in previous Section remain valid and the same configurations are applicable.

□ Example of parallel connection of UPS units with inverter transformer (TI) and single static switch (NS)

Figure 32a illustrates this scenario with a TN-S system upstream and downstream.
In this case, if the neutral is broken (e.g. in the event of an upstream circuit-breaker B or Cb tripping), the downstream earthing system becomes an IT system, the protection of persons is assured and the PIM is not obligatory, as explained in Section 4.3.

In some cases, precautions must be taken, in particular in the case of the TT system, on which unintentional tripping of the RCD may occur when cables are connected in parallel.

□ Example of devices connected in parallel without isolation with one bypass channel per UPS unit

Figure 32b illustrates the scenario with a TT system upstream and downstream.
Because the two bypass channels are connected in parallel, the currents in the phase and neutral conductors on both channels are distributed on the basis of the impedances of the conductors and static switches. The sum of the currents for each of the channels is not zero, and this risks tripping the RCDs if they are located on these channels.

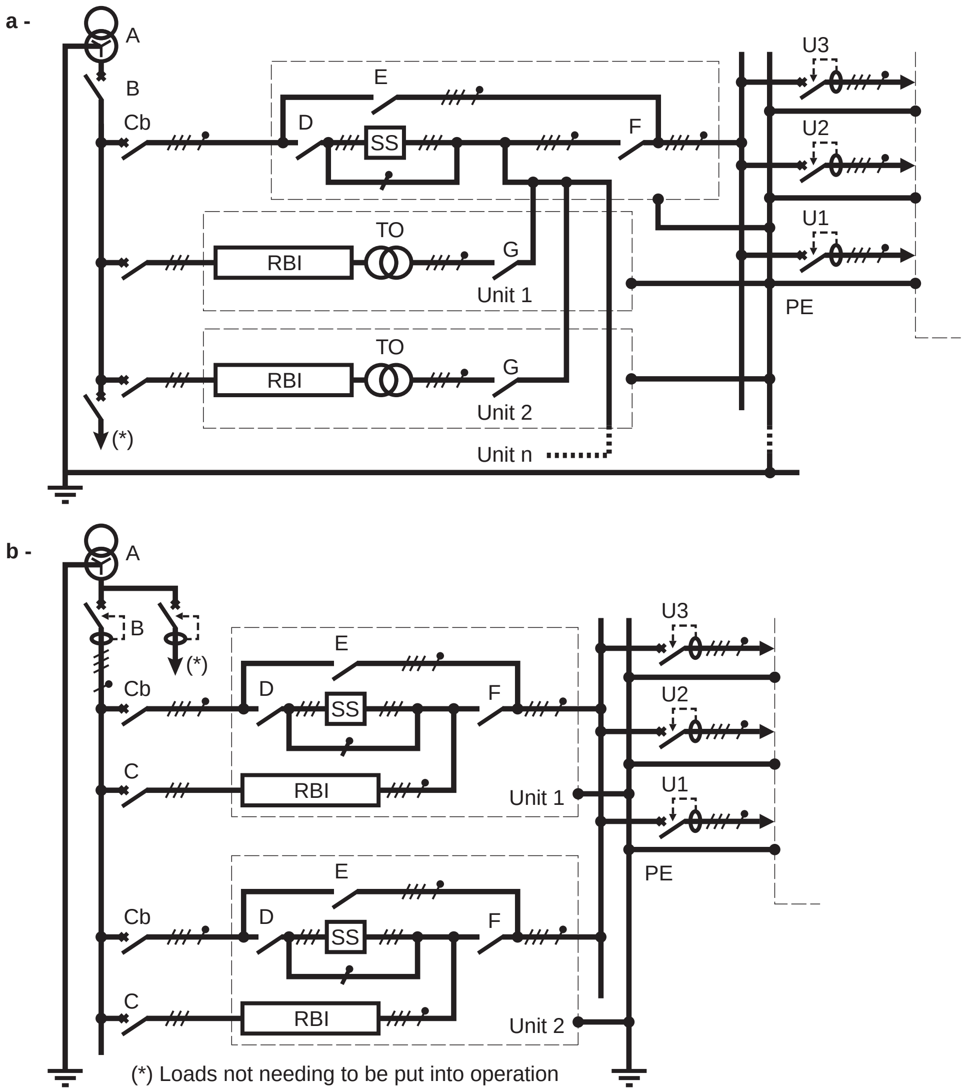


*Fig. 32 : Examples of several UPS units connected in parallel, **[a]** TN-S upstream and downstream with inverter transformer TI and a single static switch, **[b]** TT upstream and downstream without isolation with one bypass channel per UPS unit*

The solution is therefore to install a single common RCD at the supply end of the two channels, which will act upon the common circuit-breaker B. Note: If UPS units are connected in parallel with a single static switch, this problem does not occur.

However, as the number of possible configurations is high, it is advisable to ask manufacturers to specify the precautions to be taken as well as the associated equipment.

5.3 Application to STSs

Principle and difficulty

STSs - Static Transfer Switches - are devices for switching from one source to another (see **Fig. 33**).

They can be used to improve power availability for specific loads, which may obtain their power supply from 2 different sources.

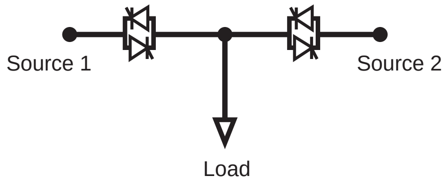


Fig. 33 : Using static switches to switch the power supply for a load between two separate sources

Initially, one of the sources is assigned to the load. If this source fails, the static switches transfer to the second source without interrupting the supply of power to the load.

The two sources, and the load, do not necessarily have identical neutral earthing systems.

If the systems for the two sources and the load are identical, the neutral conductors pose a problem. If they are interconnected, they risk being crossed by significant currents. If they are not, they must be switched in the event of source transfers.

This switching can be performed without overlap - i.e. with disconnection of the power supply - or with overlap in order to avoid this disconnection. However, a transient current may occur, causing, for example, the RCD (if there is one) to trip, or even the circuit-breakers if the exchange current is significant.

If the upstream and downstream earthing systems are not identical, the situation is less complicated, as one or a number of transformers must be used and the required system set up downstream of the device. Switching will therefore only affect the phase conductors.

Different systems upstream and downstream

In the very general case in which the two sources and the load have different earthing systems, the solution is to use two isolating transformers. The figures below illustrate scenarios for the various possible downstream earthing systems in cases where any type of upstream system can be used.

■ TT system downstream (see **Fig. 34a** on the opposite page)

The neutral conductors on the two transformers are interconnected and connected to a local earth.

This common neutral is the neutral for the load, and the sources are transferred using three-phase static switches (the neutral is not switched). The protective earth conductor PE for the load is connected to the load local earth.

■ TN-S system downstream (see **Fig. 34b** on the opposite page)

The neutral conductors on the two transformers are connected to the load earth.

This common neutral is the neutral for the load, and the sources are transferred using three-phase static switches (the neutral is not switched, as in the case of the TT system).

The PE conductor is connected to this earth.

■ TN-C system downstream (see **Fig. 34c** on the opposite page)

The neutral conductors on the two transformers are connected to the load earth.

The combined protective earth and neutral conductor is distributed via this earth connection. The sources are transferred using three-phase static switches (the neutral is not switched, specially in this case, where it is prohibited to disconnect it as it also serves as the protective earth).

■ IT system downstream (see **Fig. 34d** on the opposite page)

The neutral conductors on the two transformers are interconnected but isolated from earth.

The PE conductor is drawn from the local earth. A PIM is connected between the combined neutral and earth to monitor the installation's insulation.

If the sources have the same earthing system but the load does not, it is obviously possible to use the previous configuration, although it is also possible to use just a single transformer. However, the neutral conductors on the two sources must be connected to the same earth. If the IT system is used, the neutral conductors will obviously be isolated from earth. They must be interconnected if a single PIM is monitoring the installation.

Although offering fewer advantages in terms of availability (as the transformer is an availability node), this configuration is more cost-effective. In this case, the downstream system is implemented on the transformer secondary. The source is also transferred in three-phase mode (the neutral is not used).

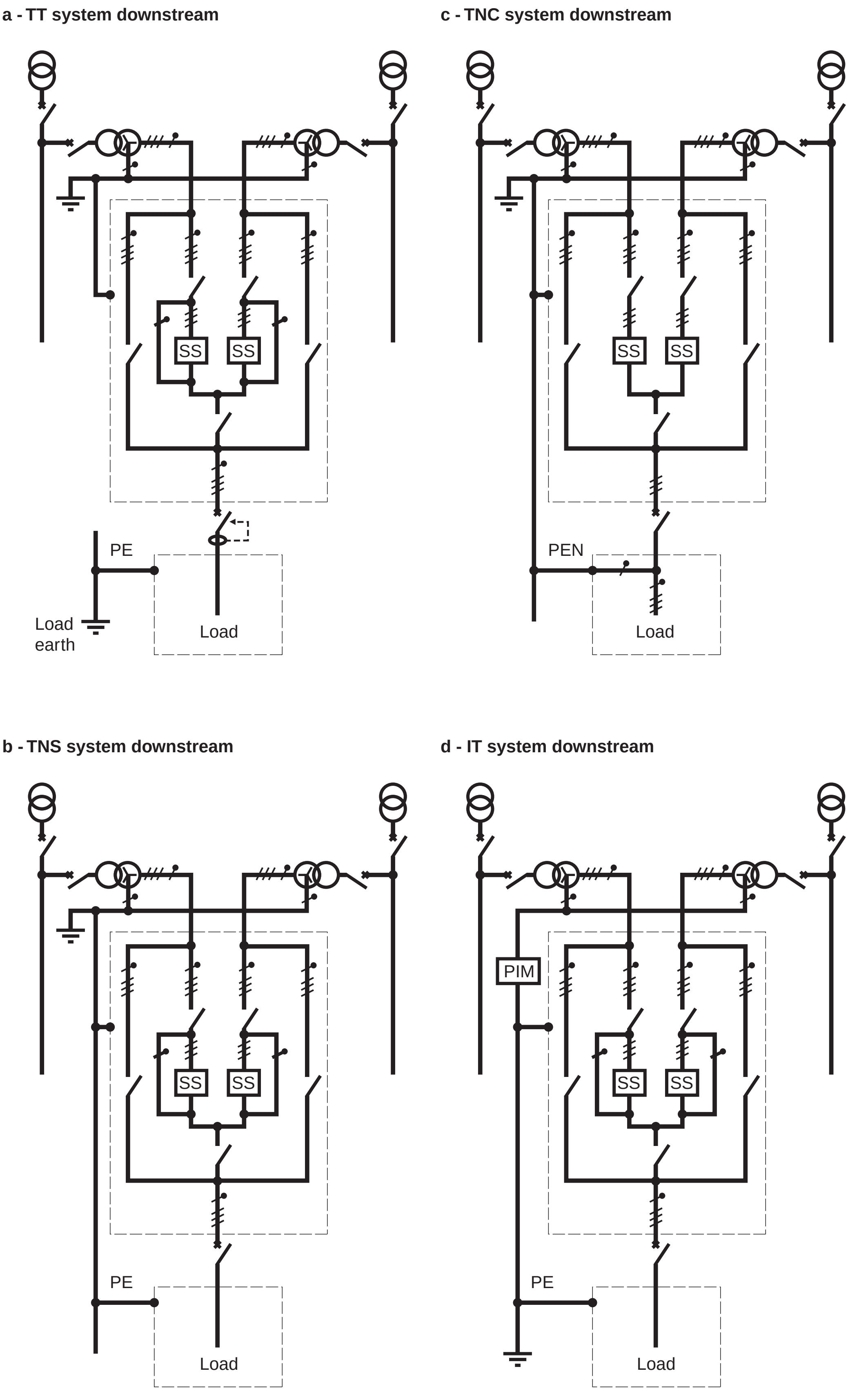


*Fig. 34 : Any type of earthing system upstream, downstream earthing system **[a]** TT, **[b]** TN-S, **[c]** TN-C, **[d]** IT*

Figure 35 shows how connections are made in a configuration with an upstream TT system and a downstream TN-S system.

Figure 36 shows how connections are made in a configuration with an upstream IT system and a downstream TN-S system.

Here, the two PIMs check insulation in relation to the same earth to which the protective earth PE is connected.

■ Special case of TN-C system upstream and TN-S downstream (see **Fig. 37** next page)

This time, the transformer is not required due to the continuity of the neutral.

The PEN conductor is separated into N and PE at the STS output terminal.

Identical systems upstream and downstream

Although using transformers as described above is not problematic, it is possible to do without them by taking the following precautions.

■ For all earthing systems, with the exception of the IT system, the neutral conductors on the transformers must be connected to the same earth connection in order that the earthing system and the load share the same protective earth (PE) as the sources.

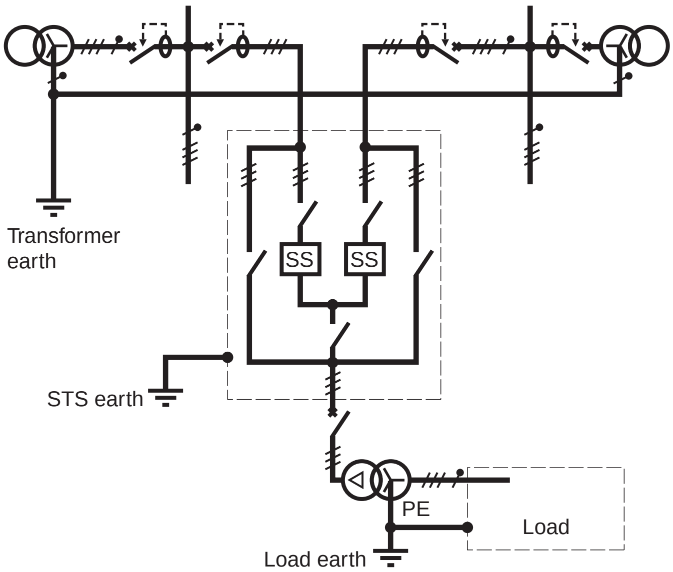


Fig. 35 : TT earthing system upstream and TN-S system downstream

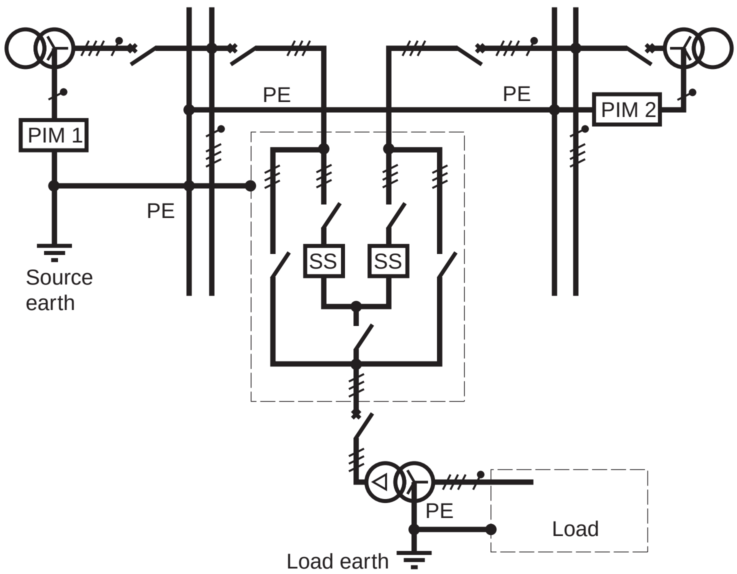


Fig. 36 : IT earthing system upstream and TN-S system downstream

If this connection is not made, the PE used for the STS and its load will only be associated with one of the sources, rendering it impossible to ensure the correct operation of the protection devices in the event of an insulation fault.
If this configuration is not possible, the earths on the two sources must at least be interconnected on the upstream LV switchboards.

- For the same reason, on the IT system, the two sources must share the same earth connection. Moreover, the neutral conductors on the transformers should be interconnected if possible in order to avoid sudden variations in the potential of the load's live conductors in the event of source transfers. This implies that the entire installation is monitored by a single PIM.

- If the neutral conductor is not distributed downstream, three-phase transfers can be made for the previous scenarios.

If the neutral conductor is distributed downstream, this conductor should also be switched, except on the TN-C system, on which the neutral conductor and protective earth are combined. This configuration is illustrated in **Figure 38** .

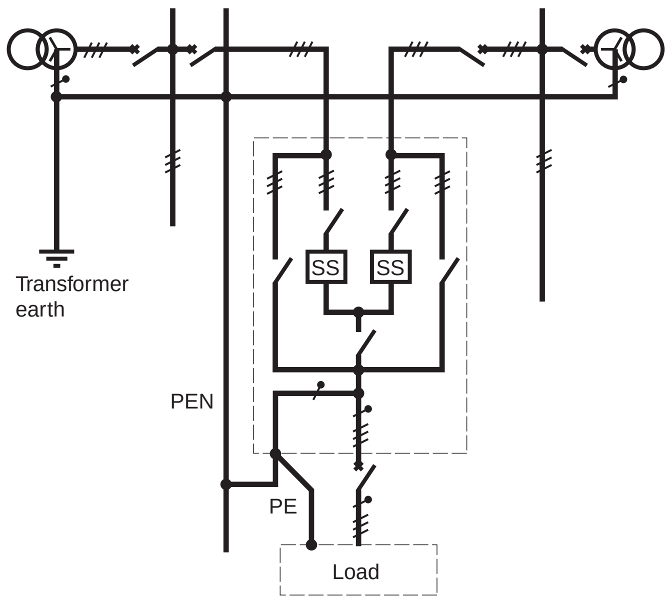


Fig. 37 : TN-C earthing system upstream and TN-S system downstream

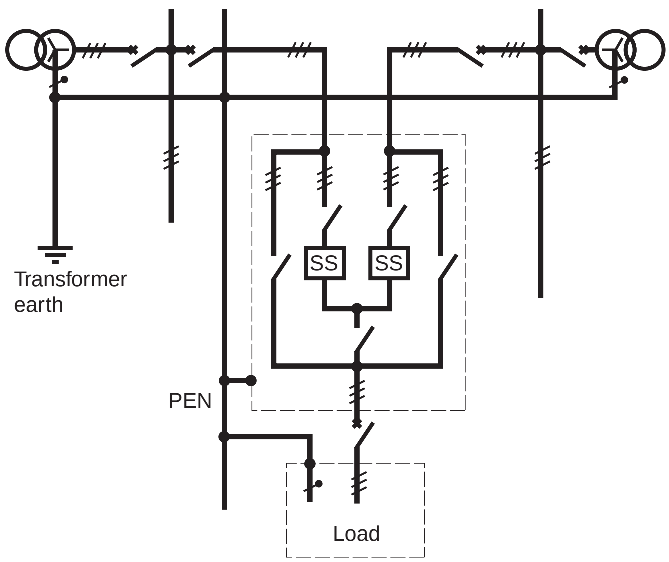


Fig. 38 : With the TN-C earthing system, the neutral does not have to be switched even if it is distributed downstream

For other scenarios, the switching of the neutral is justified by the significant circulating currents, which may exist in this conductor if it is permanently connected to the two sources (see **Fig. 39**). The neutral conductors must therefore be switched. There are two possible ways in which this can be achieved:

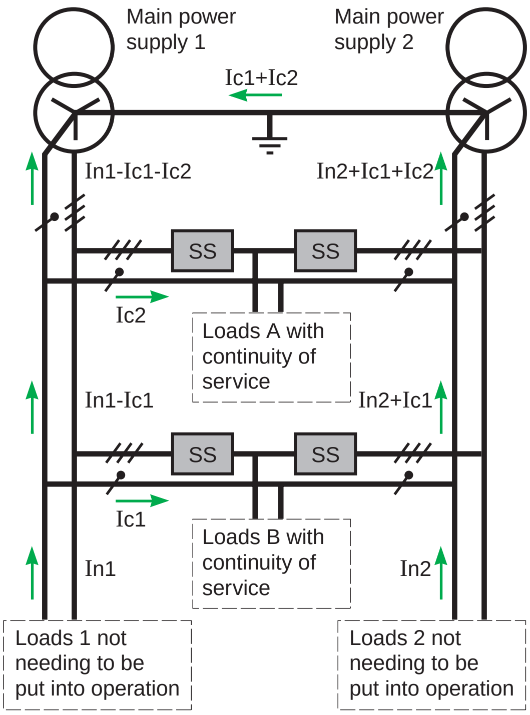
1- Switching without overlap

These conductors are not connected in parallel, even briefly, although the transfer time may exceed 10 ms. Moreover, there is a brief instant during which the potential of the STS load neutral concerned is unclear, posing a possible risk to the balance of the phase voltages. It must therefore be ensured that all devices to which power is being supplied can withstand this type of disturbance.

2- Switching with overlap

The transfer is faster (a few ms) and the potential of the load neutral remains fixed during switching. In order to ensure overlapping of the neutrals, one possible solution is to connect a switch, which will ensure continuity, in parallel with the thyristors on each SS. In effect, if the current is cut off in one of the neutral SS thyristors, the thyristor will only be capable of inverse conduction once the voltage at its terminals reaches a sufficient value, indicating that the potential of the neutral is different to that of the source.

Moreover, a transient exchange current appears, and it must be ensured that this will not pose a problem for the installation, in particular on TT systems with RCDs that “see” this current. In order to avoid unintentional tripping, these RCDs must have an appropriate threshold or a time delay (see **Fig. 40**).



On the above system, loads 1 and 2, which do not need to be put into operation, cause currents In1 and In2 to flow in the neutral conductor.

If the neutral conductors are permanently connected, there will be circulating currents between these two conductors due to the two possible backfeed paths to the sources.

If currents In1 and In2 are very different, the values of the circulating currents may be significant and, in certain cases, even exceed the ratings of the STSs.

If the common system is a TN-S or IT system, protection against overloads will be effective, but to the detriment of continuity of service.

In a TT system, it is the RCDs which “see” a permanent zero-sequence current, even on circuit-breakers at the supply end of the sources.

Fig. 39 *: With the exception of TN-C earthing systems, the switching of the neutral is justified due to the significant circulating currents, which may flow through this conductor*

Fig. 40 *: siE super-immune RCD (from Merlin Gerin)*

6 Protection against indirect contact for DC circuits and the battery

The mandatory emergency supply backup battery for a static UPS must be isolated from earth, as this operating mode supports continuity of service. In the absence of a transformer, and due to the use of semiconductors in static UPSs, there is electrical continuity between the upstream installation, the UPS and the downstream installation. Therefore:

■ An insulation fault on the DC circuits can be detected by the upstream and downstream installation protection devices.

■ These protection devices can be subject to disturbance due to the presence of an insulation fault on the DC circuits.

However, in some operational sequences, the battery and the DC circuits can be totally isolated from the upstream and downstream installations.

According to IEC 60364 and NFC 15-100, these circuits do not have to be monitored specifically if:

■ There is equipotentiality between the conductor components in the building and the frames, which is the case when the battery and the DC circuits are in the same location, in electrical cabinets or in the same cabinet as other UPS components (local equipotentiality of the UPS)

■ The installation meets the requirements of Section 413-2 of IEC 60364-4-41 or Section 412 of NFC 15-100 (e.g. additional isolation by means of a class II link if the battery is located away from the rest of the power supply)

Moreover, in other cases, the conditions to be met by the installation (IEC 60364-5-55 and NF C 15-100 Section 554-2) of the battery and its connection as far as the "battery" circuit-breaker render the risk of faults highly improbable, and this is considered sufficient for protecting persons against indirect contact on this section of the installation.

However, the measures to be taken in order to ensure personal protection on the DC section of the installation must be examined (this section is delimited by the rectifier, the inverter and the "battery" circuit breaker).

6.1 Devices for monitoring DC circuits

As indicated before, the poles on a battery pack for a UPS are isolated. Therefore, permanent insulation monitors (PIMs) are the devices most frequently used to monitor DC circuits, although depending on the neutral earthing systems on AC installations, RCDs may also be used.

Permanent insulation monitors

■ Permanent insulation monitor with low-frequency current injection (2, 5 or 10 Hz) (see **Fig. 41**)

How it works: The PIM applies a low-frequency AC voltage source between one of the poles on the DC circuits and earth. An insulation fault on the DC circuits will generate a current, which is detected by the measurement circuits (see **Fig. 42**).

These monitors, which are also able to monitor AC, mixed and DC line supplies, also support troubleshooting for insulation faults. They are therefore recommended if:

□ The line supply is a DC-only supply (several loads), which is not the case with UPSs

□ There is no electrical isolation between the battery and the equipment downstream of the UPS

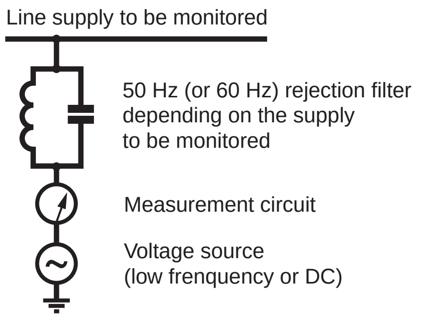


***Fig. 41** : Schematic diagram of a permanent insulation monitor (PIM) with current injection*

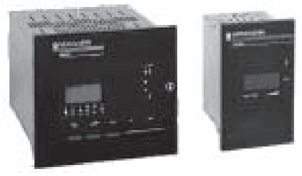


***Fig. 42** : Vigilohm XM200, a PIM with low-frequency current injection and Vigilohm TR22A, a PIM with DC injection (from Merlin Gerin)*

■ Permanent insulation monitor with DC injection

The principle is the same as that used by the PIMs cited before although its source supplies a direct current. This type of PIM, designed specifically for monitoring AC line supplies, is not suitable for DC circuits, as the DC voltage appearing in the event of an insulation fault alters the sensitivity of the monitor's threshold device. It is generally not recommended on mixed (AC and DC) line supplies. However, some DC injection PIMs are capable of indicating the presence of a fault on the "DC" section of a line supply (see Fig. 42).

■ Voltmetric-balance permanent insulation monitor (see **Fig. 43**)

This is a passive permanent insulation monitor.

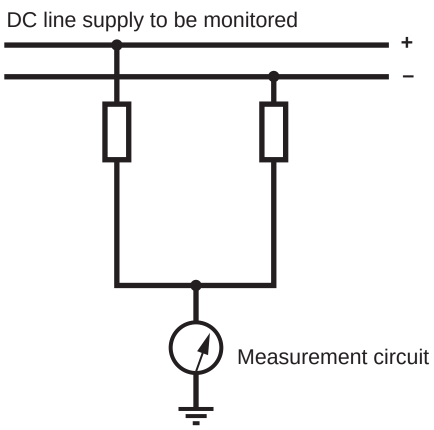


Fig. 43 : Schematic diagram of a voltmetric-balance permanent insulation monitor (PIM)

It comprises a resistive divider, which creates a mid-point for the DC voltage. The fault detection circuit is located between this mid-point and earth. An insulation fault on the (+) or (-) will generate a current to earth via one of the resistors and the detection circuit, which, connected to a threshold device, will activate an alarm or a trip (see **Fig. 44**).

Fig. 44 : Vigilohm TR5, a voltmetric-balance PIM (from Merlin Gerin)

Residual current devices (RCDs)

RCDs are designed to detect any abnormal earth fault currents.
However, precautions must be taken when selecting RCDs if the installation has one AC section and one DC section without electrical isolation (mixed line supply).

Standard IEC 60755 defines 3 types of RCD:

■ Class AC RCDs: Will only operate with AC-only line supplies

■ Class B RCDs: Will operate with all fault current shapes, including DC only

■ Class A RCDs: Can operate with non-alternating currents in accordance with the diagrams in **Figure 45**

With single-phase rectifiers, the waveforms of fault currents on the DC circuit are most often compatible with type A RCDs. However, with some systems, the fault current can be DC, requiring type B RCDs.

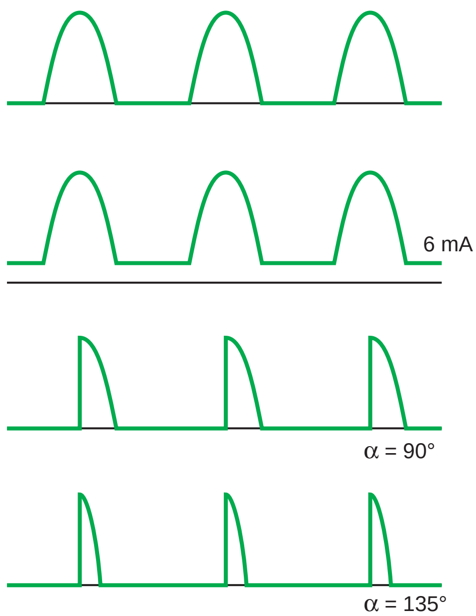


Fig. 45 : Different non-alternating fault current shapes applicable for class A RCDs

Finally, in most cases, DC fault currents for three-phase rectifiers are DC. They therefore require the use of type B RCDs (see **Fig. 46** on opposite page).

You must therefore contact the manufacturer to find out which type of RCD can be connected to the converter if this information has not been provided in the installation manual.

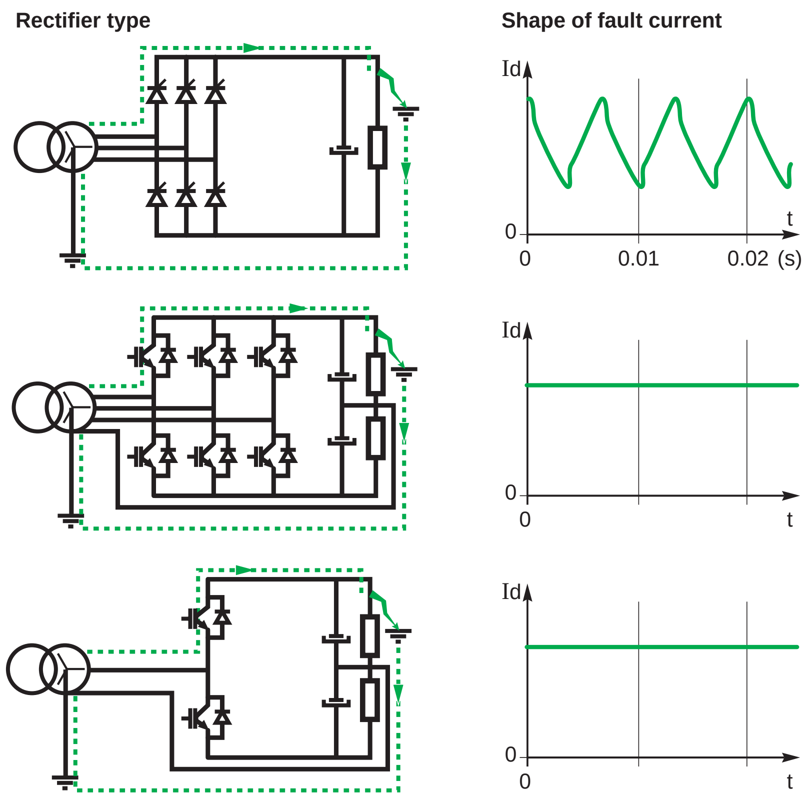


Fig. 46 : *Different fault current shapes requiring class B RCDs*

Disturbance due to filters

EMC filters based on capacitors connected to earth are frequently used upstream of computers and UPSs. They can cause disturbance on protection devices (undesirable alarms and/or trips), in particular:

■ They often cause RCDs to trip unintentionally:

□ During operation (earth leakage current due to capacitor unbalance between phases and earth), the RCD threshold must therefore be increased

□ On power-up (capacitor load), although an RCD time delay should rectify this

■ When used with PIMs, filters can sometimes generate:

□ A transient fault signal on power-up for DC injection PIMs (current flowing through the capacitors)

□ Or a permanent signal with AC-injection PIMs

One possible way to avoid these phenomena is to make sure that the total capacity of these filters does not exceed:

□ 30 µF for a 2 or 5 Hz injection PIM

□ 6 µF for a 10 Hz injection PIM

Disturbance due to high-frequency (HF) leakage currents

Although the high-frequency currents emitted by UPSs are considered weak in accordance with standard IEC 62040-2, they may be harmful to some residual devices and cause them to trip unintentionally. Moreover, HF currents from loads connected downstream of the UPS or even the sum of the UPS and load currents may cross the residual devices during some operating sequences.

The use of RCDs immune to this type of disturbance is recommended in order to avoid these difficulties.

Note: These leakage currents do not affect low-frequency current injection insulation monitors.

Interaction between monitoring devices on DC circuits and those on upstream and downstream equipment

■ This interaction is directly connected with the UPS system and depends in particular on:

□ The presence or absence of a static switch

□ The number of UPSs, one or more with active or passive redundancy

□ The presence or absence of TR or TI electrical isolation transformers

■ This interaction is directly dependent on the protection device selected and the earthing systems on the “upstream” and “downstream” equipment. Note:

□ For the most common system (independent UPS without transformer on bypass), it is essential that the downstream neutral earthing system is the same as the one upstream of the UPS (not excluding transition from TNC to TN-S or TN to TT).

□ For continuity of service, a downstream (and upstream) IT system is the best solution.

■ This interaction can be:

□ Positive, e.g. the upstream protection device also monitors the DC circuits

□ Negative:

- Between two PIMs

As on AC circuits, two devices of the same type connected on two sections of an installation without electrical isolation will cause mutual disturbance. A relay such as R1 on the system illustrated in Figure 22 should be used to avoid this eventuality.

- Between an injection PIM and a voltmetric-balance PIM

A DC injection or low-frequency PIM will measure the internal resistance (R/2) of a voltmetric-balance device (several tens of kW). Located either side of a power converter (rectifier or inverter) without electrical isolation, the extent to which each causes disturbance on the other will be directly dependent on the conduction rate of the converter semiconductors.

□ Or zero:

- If there is electrical isolation between the battery and the upstream and downstream equipment (AC)

- Between PIM and RCD or circuit-breaker

6.2 Main applications

The solutions advocated in this section supplement the measures to be taken for the protection of persons on equipment upstream of the UPS already described in Section 4. Without exception, they must be employed on each UPS link.

If a UPS includes DC circuits, which have not been isolated from the upstream and/or downstream equipment, and if the protection of persons requires the use of RCDs, these RCDs must be type A or B devices (see previous sections).

In general, when DC circuits are isolated from upstream and downstream equipments, one PIM must be used: the PIM 3.

If the DC circuits are not isolated, protection for persons should be considered on the basis of the electrical links between these circuits and the upstream and downstream equipment, resulting in the various scenarios outlined below.

DC circuits isolated from upstream and downstream equipment (inclusion of rectifier and inverter transformers - see **Fig. 47**)

There is no interaction with the monitoring devices. The PIM 3 designed for monitoring insulation on the DC circuits may be a voltmetric-balance or low-frequency current injection monitor.

Protection in the event of a second fault is then ensured:

■ By means of circuit-breaker H if the UPS is standalone

■ By means of circuit-breaker H and the upstream (or internal) protection on the rectifier if the UPS is connected to the line supply

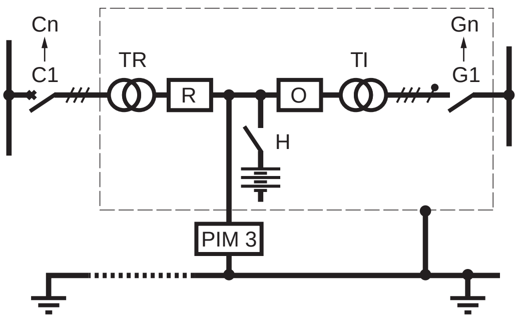


Fig. 47 : Insulation monitoring on a UPS link with battery pack isolated from the upstream and downstream equipment

DC circuits not isolated from the upstream equipment (Inclusion of an inverter transformer (TI), but no rectifier transformer)

For the following scenarios, as a general rule, if the power supply voltage is present, protection is provided by the upstream devices.

If this voltage is lost, the DC circuits are isolated from upstream (rectifier blocked) and downstream (via the inverter transformer). These circuits then temporarily form part of an IT system.

As illustrated in the previous section, this operating mode does not put safety at risk as it is able to withstand a first fault.

In the event of a second fault, the battery circuit-breaker and/or internal inverter protection devices will provide protection.

However, if monitoring for these circuits and in particular for the battery is required, in the event of prolonged independent operation or if the battery is located away from the UPS, loss of voltage results in the rectifier being blocked and the DC circuits being isolated. A PIM can be installed to indicate the first insulation fault on these DC circuits. PIM 3 features in the following figures and is connected automatically via a voltage relay (R3).

■ Upstream equipment operating as a TT system (see **Fig. 48**)

If there is voltage upstream of the rectifier, the RCD installed on the UPS power supply will provide protection by tripping circuit-breaker C. Note: Put into operation by the R3 relay, PIM 3 controls the insulation of DC circuits when they are isolated.

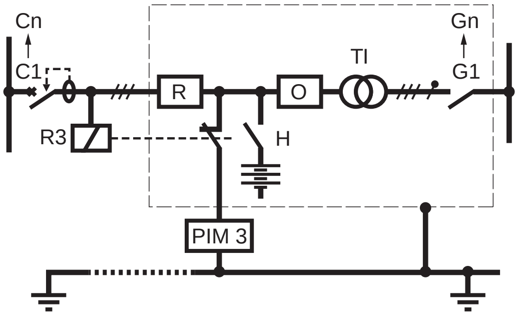


***Fig. 48** : Insulation monitoring on a UPS link with battery pack not isolated from the upstream equipment operating as a TT system and isolated from the downstream equipment*

■ Upstream equipment operating as a TN system (see **Fig. 49**)

If there is voltage upstream of the rectifier, the protection of persons can be ensured by:

□ The circuit-breaker C installed on the UPS, if the impedance calculation for the fault loop has permitted confirmation of the selection

□ An RCD or additional interconnection if not, with the TN-S system

Note: Put into operation by the R3 relay, PIM 3 controls the insulation of DC circuits when they are isolated.

■ Upstream equipment operating as an IT system (see **Fig. 49**)

If there is voltage upstream of the rectifier, PIM 1 on the upstream equipment monitors the insulation of the DC circuit (positive interaction).

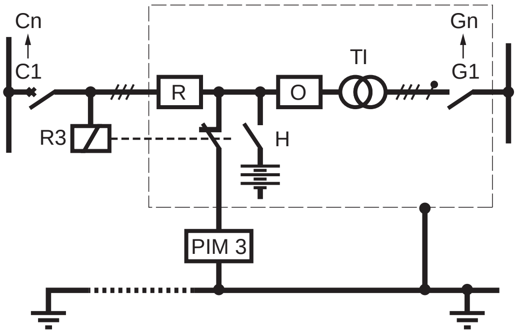


***Fig. 49** : Insulation monitoring on a UPS link with battery pack not isolated from the upstream equipment operating as a TN or IT system and isolated from the downstream equipment*

Note: Put into operation by the R3 relay, PIM 3 controls the insulation of DC circuits when they are isolated.

Protection in the event of a second fault is then ensured:

□ If the UPS power supply is supplied with power via the circuit-breaker (C) installed on the UPS power supply, if the impedance calculation for the fault loop has permitted confirmation of the selection, or via an RCD if not

□ During independent operation, via the battery circuit-breaker

Special cases of UPSs supplied with power via an intermediate power outlet, with a maximum rated current equal to 32 A.

These power outlets must be protected by a high-sensitivity RCD, $I\Delta n$ < 30 mA (NF C 15-100 § 532). Also, if these UPSs do not feature a rectifier transformer and specific measures (class II, double isolation) have not been taken, this protection must be provided by a high-sensitivity type A RCD.

DC circuits not isolated from the downstream equipment

(Inclusion of a rectifier transformer (TR) but no inverter transformer)

In this case, if the neutral systems upstream and downstream of the UPS are not identical, an isolating transformer (TB) must be installed.

■ Downstream equipment operating as a TT system

□ Without bypass transformer

If there is voltage upstream of the rectifier, the RCD installed on the bypass will provide protection in the event of a fault on the DC circuits by tripping the battery circuit-breaker H and the circuit-breakers C and Cb installed on the UPS power supply (see **Fig. 50**).

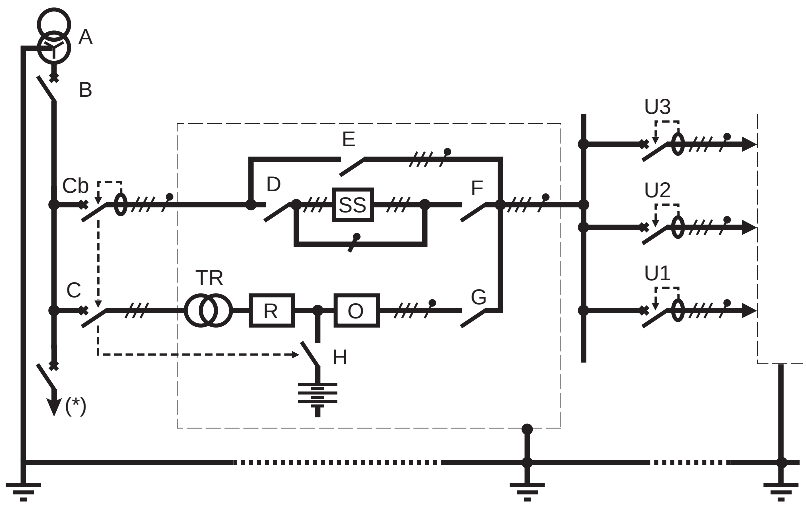
If this voltage is lost, the DC circuits and the upstream equipment will continue to be protected by the same RCD if the neutral conductor remains connected. This requires that the auxiliary power supply for this RCD is connected downstream of the UPS.

If the neutral conductor is broken, the DC circuits and the downstream equipment will switch to IT system operating conditions.

□ With bypass transformer (TB)

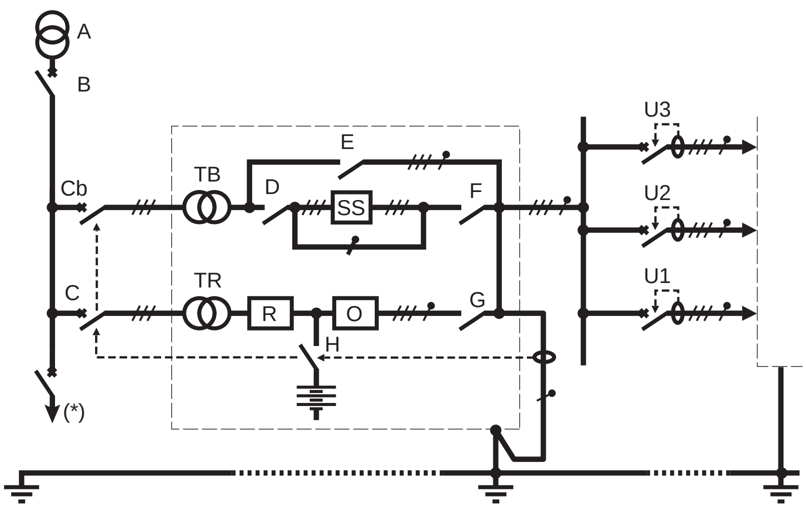
This same protection is provided permanently by an RCD installed on the neutral earth connection at the UPS output (see **Fig. 51**).

With or without a bypass transformer, these configurations do however present a problem as they totally disconnect the power supply to all loads. Also, if continuity of service is essential



(*) Loads not needing to be put into operation

Fig. 50 : Devices for protecting persons on a UPS link for DC circuits isolated from the upstream equipment but not from the downstream equipment functioning as a TT system, without a bypass transformer



(*) Loads not needing to be put into operation

Fig. 51 : Devices for protecting persons on a UPS link for DC circuits isolated from the upstream equipment but not from the downstream equipment functioning as a TT system, with a bypass transformer (TB)

and in particular in the case of redundant UPSs, the following measures can be taken. They consist in isolating the fault link from the rest of the installation. For this purpose:

- Every output in the link is permanently monitored by an RCD, which will provide protection by tripping the circuit-breakers C and H and the switch or circuit-breaker J on the faulty link (see **Fig. 52**).

- In the absence of a bypass transformer, the discrimination must be checked between the upstream RCD and the downstream RCDs. If the tripping of output switch G can be controlled, device J does not have to be included as the RCD can act directly upon it.

■ Downstream equipment operating as a TN system

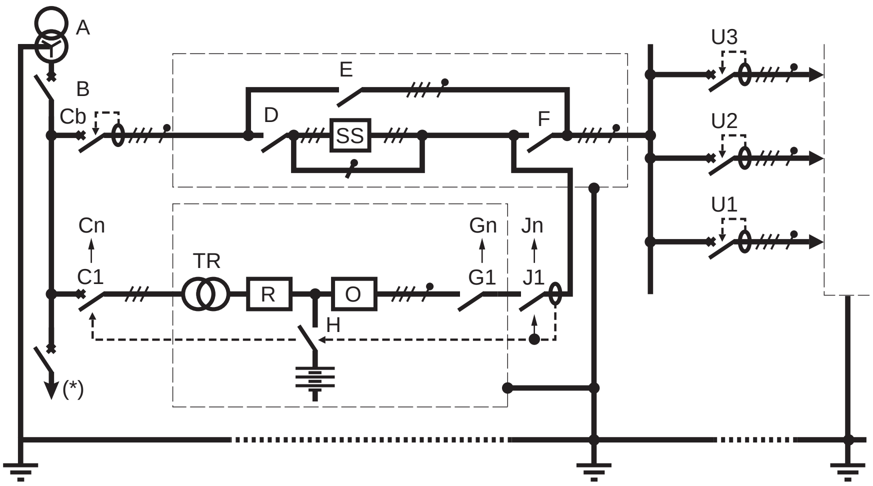
To protect persons, usually, as soon as an insulation fault occurs, circuit-breakers C and H trip. If the conditions required for correct operation are not met, in particular for the TNS system, the measures described in the previous section (for the TT system) must be taken.

■ Downstream equipment operating as an IT system

The DC circuits are monitored by:

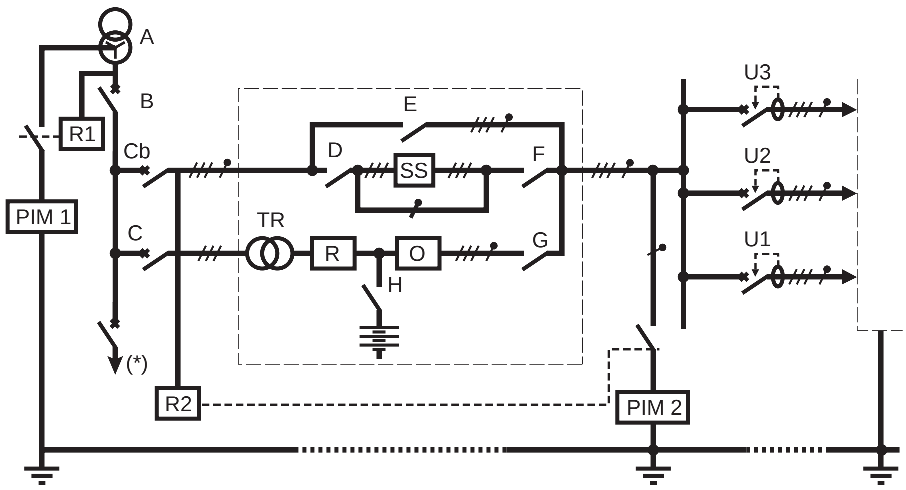
□ PIM 1, if the bypass maintains electrical continuity

□ PIM 2, if the UPS is providing an autonomous power supply to the loads (see **Fig. 53**).



(*) Loads not needing to be put into operation

***Fig. 52** : Measures to be taken to isolate a UPS link in the event of an insulation fault, for UPSs isolated from the upstream equipment but not from the downstream equipment operating as a TT system*



(*) Loads not needing to be put into operation

***Fig. 53** : Devices for protecting persons on a UPS link for DC circuits isolated from the upstream equipment but not from the downstream equipment functioning as an IT system, without a bypass transformer*

PIM 2 is started up via relay R2 only in the event of the loss of the voltage upstream of the bypass.

Despite the absence of the upstream voltage, it is possible, even very probable, that the neutral conductor will remain connected. A circuit-breaker will trip either in the event of a fault or for maintenance purposes.

If PIM 2 is at risk from disturbance from PIM1, it can be shut down by relay R1 if the transformer secondary voltage is zero.

Protection in the event of a second fault is then ensured:

□ In a TN system if the frames are connected

□ In a TT system if the frames are not connected

DC circuits not isolated from upstream and downstream equipment

In this case, the neutral systems upstream and downstream of the UPS must be identical.

■ Equipment operating as a TT system (see Fig. 54)

If there is voltage upstream of the rectifier and bypass, the RCD installed on the common power supply will provide protection by tripping circuit-breakers C and Cb and the battery circuit-breaker H.

If the power supply upstream of the UPS is lost and if the neutral conductor remains connected, this RCD will continue to provide protection, as long as its power supply is connected to the UPS output.

If the neutral conductor is broken, operation will switch to an IT system.

This configuration does however present a problem as it totally disconnects the power supply to all loads.

If continuity of service is essential and in particular in the case of redundant UPSs, use the configurations in Figure 55 .

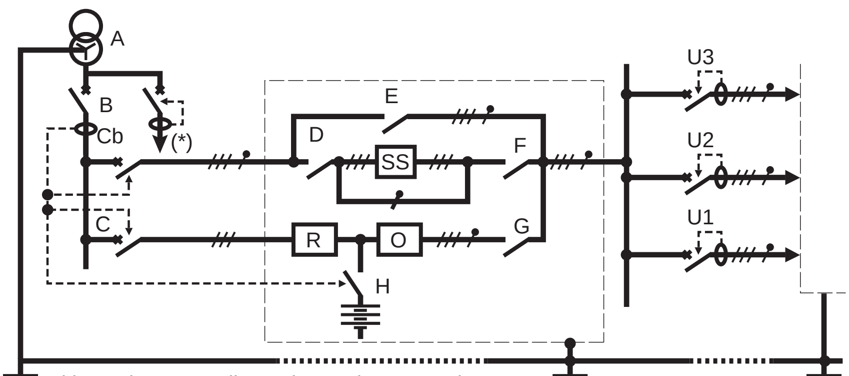


Fig. 54 : Protection of persons for DC circuits in a UPS link not isolated from the upstream and downstream equipment operating as a TT system -Basic implementation-

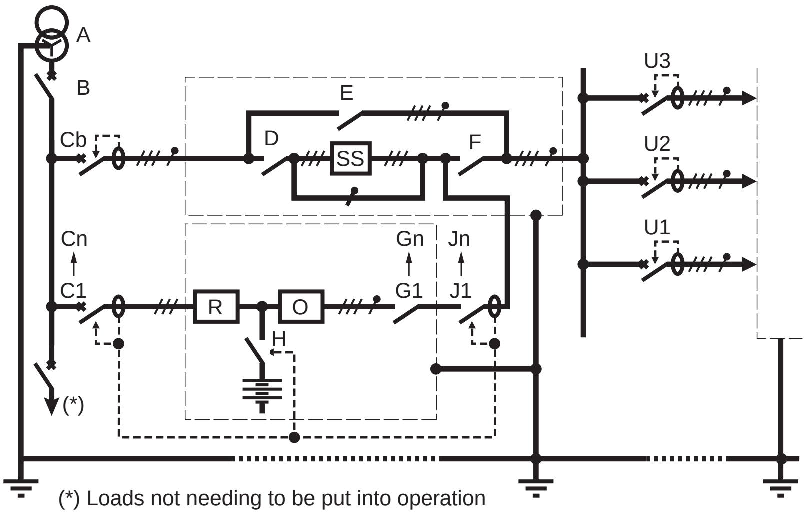


Fig. 55 : Protection of persons for DC circuits in a UPS link not isolated from the upstream and downstream equipment operating as a TT system -Implementation for optimizing continuity of service-

The RCDs installed upstream of the rectifier and downstream of the inverter on each link will trip circuit-breakers C and J on each of the links. Discrimination between these RCDs and the RCD upstream of the bypass channel must be checked in order to ensure the availability of this channel.

■ Equipment operating as a TN system

To protect persons, usually, as soon as an insulation fault occurs, circuit-breakers C and H trip. If the conditions required for correct operation are not met, for example for the TNS system, the configurations described in the previous section (for the TT system) must be used.

■ Downstream equipment operating as an IT system

The DC circuits are monitored by:

□ PIM 1, if there is voltage upstream of the UPS

□ PIM 2, if the UPS is providing an autonomous power supply to the loads (see **Fig. 56**).
PIM 2 is started up via relay R2 only in the event of the loss of the upstream voltage.

Despite the absence of the upstream voltage, it is possible, even very probable, that the neutral conductor will remain connected. A circuit-breaker will trip either in the event of a fault or for maintenance purposes.

If PIM 2 is at risk from disturbance from PIM 1, it will be shut down by relay R1 if the transformer secondary voltage is zero.

Protection in the event of a second fault is then ensured:

□ In a TN system if the frames are connected

□ In a TT system if the frames are not connected

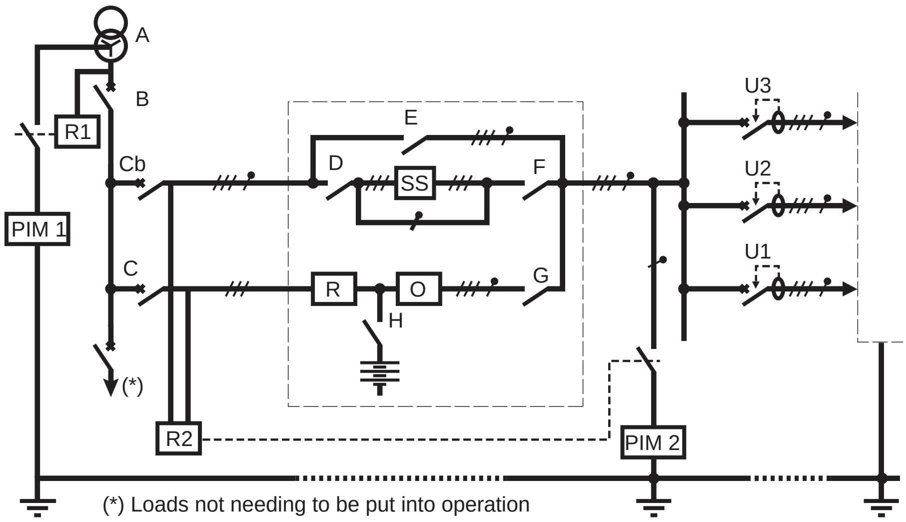


***Fig. 56** : Protection of persons for DC circuits in a UPS link not isolated from the upstream and downstream equipment operating as an IT system*

7 Conclusion

This document demonstrates that setting up equipment to protect persons against indirect contact on line supplies with DC circuits is actually more complex than it first seems.

Particular attention must therefore be paid to the various configurations that can be installed or may occur during operation, for example in the event of a fault.

This is why it is often advisable to use equipment supported by thorough documentation and assistance from specialists or professional system builders to obtain a complete and reliable solution for a specific requirement in a given configuration.

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Transl: Lloyd International - Tarporley - Cheshire - GB
DTP: AXESS - Valence (26)
Editor: Schneider Electric

- 20 € -

09-04