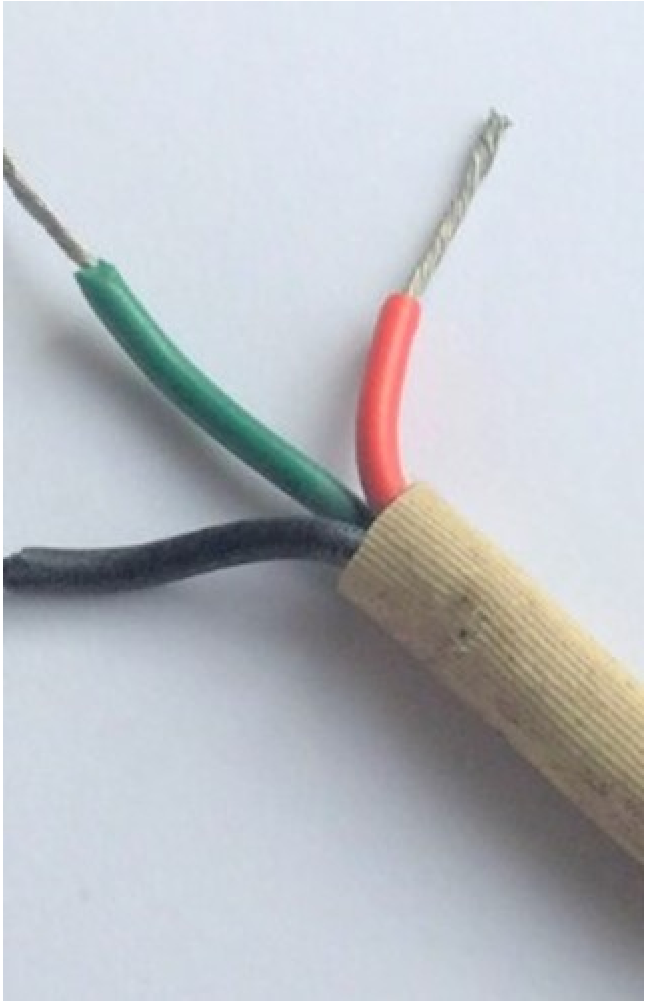
Wiring Matters

Issue 84

March 2021



Estimating the age of an electrical installation

By: Richard Giddings IEng MIET ACIBSE

It is often necessary as well as useful to be able to establish the approximate age of an electrical installation, whether needing this information for reporting purposes, work or just plain curiosity.

Electrical testing alone is insufficient to give an installation's exact age although, in some instances, it can assist. Instead, recognizing certain details will be a great skill which can be honed by experience.

Whilst appreciating that there is no substitute for time-served experience, the purpose of this article is to give some pointers to look out for in typical small/or medium-sized electrical installations.

It should of course be obvious that many installations will be comprised of components of differing ages – as installations often evolve and can be modified over time. Wiring accessories, switchgear, and light fittings, for example, are relatively easy to renew or replace (and often are). Wiring however, especially that concealed within the fabric of a building, is often left to serve successive updates to an installation.

Likewise, if a building is extended or partially modified and provided with an updated electrical installation in certain areas, often the remainder of the electrical installation may remain untouched. Many components within an electrical installation can deteriorate with age, giving rise to potential safety problems. ***Establishing the age of an installation and its components is therefore a crucial safety matter.***

All these aspects need careful evaluation before making any conclusion as to an installation's overall age. The older an installation is, the less common it becomes for it to remain totally in its original form.

Metrication of the construction industry

The British Standards Institution set a program for the metrication of the construction industry to take effect between 1969 and the end of 1972. Trade in British electric cables to metric standards began in January 1970.

To assist the industry in the transition, the logo shown in Figure 1 was often used between 1969 and 1975 on items that would contain incompatible differences between imperial and metric dimensions. This particularly applied to cables and items with screw threads. To this day, such legacy labels may still appear on things like trunking, conduits, and wiring accessory back boxes. Where spotted it is generally a very good indicator that the item was manufactured and probably first installed during the period 1969-1975.

Figure 1 - Metrication logo

Other distinguishing factors associated with the metrication process of electrical installations include:

Pre 1969/72:

- Round head imperial 2BA sized screws used on round conduit boxes.
- Raised head imperial 4BA screws with no lead-in chamfer used for wiring accessory front plates.

1969/72 onwards:

- Pan head metric M4 sized screws used on round conduit boxes.
- Raised head metric M3.5 screws, often with a lead-in chamfer used for wiring accessory front plates.

Figure 2 - Common fixings screws (Imperial version shown on top with its metric counterpart beneath)

Wiring and cabling

Due to its often concealed nature and relative difficulty and cost to replace, wiring may often form the oldest component of many installations.

Wiring type, conductor size, construction, sheath markings and identification colour of insulation are all factors that can prove revealing when scrutinized. Although the industry uses many different types of cable, focus will be made on the more common types.

Knowledge of cable manufacturers, that have come and gone, as well as trade names can reveal even more, although this topic is beyond the scope of this article.

Rubber insulated fixed wiring cable

This was in widespread use within the construction industry for general purpose installation work until the early 1950s. During that decade its usage sharply declined, in favour of thermoplastic insulation such as polythene (polyethylene) and, later, polyvinylchloride (PVC).

Whilst now it is increasingly rare to encounter rubber insulated cable still in service for general fixed wiring work, such cabling exhibits characteristics that make it easy to identify.

The two most common types were:

1. Rubber insulated & sheathed multicore cabling. These often have a dull black outer black sheath, usually now hardened and sometimes brittle. They were referred to as 'TRS' (tough rubber sheath) or sometimes 'CTS' (cab tyre sheathed) cabling.

2. Single core cables, often with a hemp type braided outer layer, usually coloured black or dull red. These are generally referred to as 'VRI' (vulcanized rubber insulated). They will often be found run within metal conduits, oval 'slip tubes', metal trunking or wooden capping. Occasionally they may be encountered unenclosed in building voids. Some cables of this type may also contain asbestos. Guidance for electricians dealing with asbestos can be found in Michael Peace's July 2020 article. Usage of the larger sizes of VRI cables continued into the 1960s for applications such as meter tails.

Thermoplastic insulated fixed wiring cable

The construction industry embraced this type of cable from the early 1950s onwards. During that decade it quickly began to supersede rubber insulated cabling for general applications.

The earliest variety used polythene insulation, characterized by its shiny appearance and slippery feel, these characteristics are still often evident decades on. Later cabling used PVC insulation and in recent years some cabling used may be low smoke halogen free (LSHF) which are usually much stiffer and more difficult to strip back.

Whilst the timespan of its usage and relative longevity can often make estimation of its age difficult, key factors that may help include:

1950s to 2004-06:

- Red and black line & neutral conductor identification for single phase installations.

1950s to late 1960s:

- Imperial sized conductors, usually of tinned copper stranded construction.
- 'BS 2004' sometimes marked on sheath.

1950s to early 1960s:

- Polythene cables produced by some manufacturers with characteristic shiny outer sheath and conductor insulation.

1950s – early 1970s:

- Insulated CPC sleeving on flat insulated & sheathed cables rarely used and many cables did not even incorporate an integral CPC.

Early 1960s onwards:

- Polythene insulation superseded in favour of PVC by most manufacturers.

1966 onwards:

- Wiring regulations from this point onwards required a CPC at all points in all circuits.

1950s to late 1960s:

- Metal 'buckle type' clips in common use with sheathed cables.

1967 – 1970:

- Many manufacturers gradually replaced tinned copper conductors in PVC cables with untinned copper.

Late 1960s onwards:

- Plastic clips introduced – often with the cable size marked on them.

1966 – 1977:

- Green coloured identification of protective conductors and if used, sleeving.

1968 – 1975:

- Certain PVC cables from this era with untinned conductors subsequently found to be susceptible to long term, slow chemical degradation with what became known as 'green goo' exuding at terminals. This was often encountered beneath vertical drops in warm indoor locations.

More information on this phenomenon can be found in this Wiring Matters article.

1969-72 onwards:

- Metric sizing replaced imperial, with untinned conductors and solid cores on sizes up to and including 2.5 mm^2.
- 'BS 6004' marking often on sheath (usually grey in colour or sometimes white).

1972-1976:

- Solid cored aluminum or copper-clad aluminum conductors made available due to world-wide copper supply crisis.

Late 1970s onwards:

- Where applicable, 'BASEC' marking appeared on outer sheath of cables, but only on those that had undergone the BASEC independent third-party certification.

1978 onwards:

- Sole use of green/yellow bi-coloured identification required for protective conductors.

1969-72 to 1981:

- 2.5 mm^2 flat PVC/PVC sheathed cables manufactured with 1.0 mm^2 CPC.

1981 onwards:

- 2.5 mm^2 flat PVC/PVC sheathed cables had CPC enlarged to 1.5 mm^2.

Mid 1990s onwards:

- Practice of showing production date and conductor size marking on outer cable sheaths was adopted by some manufacturers.

1995 onwards:

- CE marking introduced in the UK and may be evident on some cables.

2004-06 onwards:

- Brown and blue line and neutral conductor identification introduced for fixed wiring, replacing former red and black as part of harmonization process.
- Grey coloured sheath now almost exclusively used on PVC cables.

- White coloured sheath now used to signify LSHF type cables.

2015 onwards:

- Metal fixing clips became necessary in some installation conditions; to guard against cable collapse during a fire and associated entanglement hazards.

PVC insulated and sheathed flexible cables

Flexible PVC cables (often just referred to as 'flex' or previously 'cords') generally tracked many of the developments in fixed wiring cabling, but note the much earlier conductor insulation colour change transition:

Mid 1950s onwards:

- Commercial usage became popular, gradually replacing rubber insulated and sheathed or rubber and hemp braided cables.

1950s to late 1960s:

- Imperial sized conductors in use, often of tinned copper.

1969-72 onwards:

- Metric sized conductors introduced, often of untinned copper.

1950s to 1971:

- Conductor insulation was coloured red, black and green for general purpose three core flexes.

1971 onwards:

- Requirement for conductor insulation coloured brown, blue and green/yellow.

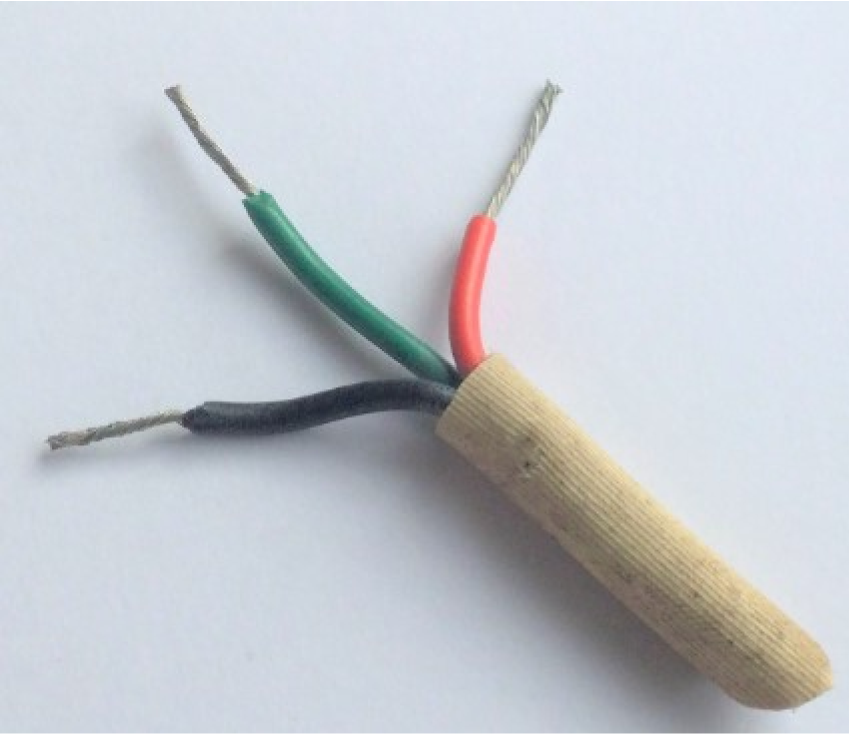
1950s – 1974:

- Unsheathed flexible cable permitted for applications such as pendant drops.

1974 onwards:

- Sheathed flexible cables required if operating at above extra-low voltage.

Figure 3 - Typical pre-1971 flex (note colours and tinned conductors)



Mineral insulated cabling

This cable became popular from the early 1950s onwards, although it had been in existence for many years prior. It offered very small outside diameter for a given current carrying capacity, good mechanical strength and of course, excellent fire resistance.

It enjoyed fairly extensive usage in the construction industry up until the late 1970s, particularly for external cabling, use in boiler rooms, churches and of course in fire alarm systems/safety system circuits. A single core special cable of this type was often used for electric underfloor heating.

Usage declined rapidly from the early 1980s with the introduction of pliable fire rated cables which offered faster installation time, a need for less skilled installation techniques and lower costs.

Typical signs to look for include:

Early 1950s onwards:

- Bare copper outer sheathed cables prevalent with occasionally black thermoplastic outer covering.

Mid 1960s to mid-1980s:

- Orange coloured outer covering in common use.

Mid 1980s onwards:

- Usage in steady decline, but where still used – predominantly on safety circuits, red outer covering became common.

1950s – 1969/72:

- Imperial gland size notation using a three digit number such as '234'.

1969/72 onwards:

- Metric gland size notation, using coding such as '2L 2.5'.

Wiring accessories

Although wiring accessories can be updated relatively easily, their age can mask older wiring behind. Caution should therefore be taken in this respect if using this factor alone to establish an installation's age. Changes to the relevant product standard to which wiring accessories are made and often marked, as well as manufacturing material and styling fashions, are all useful to assist in estimating their age.

In-depth knowledge of a particular manufacturer's production changes is also extremely useful – although this information is beyond the scope of this article.

Additionally, with the advent of manufacturers working under Quality Assurance regimes requiring traceability in the late 1980s onwards, wiring accessories often carry some sort of production date. Where found, either as characters printed on the item, moulded into its material, or sometimes a stick-on label, a date or code can be found – sometimes explicitly showing a date.

Other useful generic age-distinguishing factors for wiring accessories include:

1920s – mid 1960s

- Wooden mounting blocks for accessories such as light switches in common use.

1930s – mid 1960s

- Brown coloured thermosetting plastic 'Bakelite' used in many manufacturers' ranges.

Mid 1960s – early 1970s:

- Flush metal back boxes for light switches often had insulating plastic insert lugs for faceplate fixing screws - to overcome safety issues arising from lack of CPCs in some cables.

Late 1950s – 1972/3:

- Ivory coloured thermosetting plastic used by many manufacturers.

1972/1973 onwards:

- White coloured thermosetting plastic introduced and quickly adopted by the majority of wiring accessory manufacturers.

1975 onwards:

- Twin 13 A BS 1363 sockets using four front plate fixing screws discontinued production.

Late 1980s onwards:

- Woodscrews used often for fixing accessory back boxes, changed from slotted to cross head design, due to rising popularity of powered screwdrivers.

Figure 4 - Date coding on a wiring accessory showing week 37 of 2005

Figure 5 - Date coding on a wiring accessory showing week 46 of 2007

Lighting and luminaires

As luminaires, like wiring accessories are easily replaced, they can mask an older installation.

Changes and development in lamp technology, compliance with lighting design guidance as well as styling cues can all assist in determining the age of a lighting installation however, information found relatively easily within such luminaires can often give more exact information. As with wiring accessories and switchgear, date codes can often be found inside luminaires.

Whilst in more recent years, production dating for traceability of manufacture will often be encountered in many luminaires, dating capacitors used in association with some lighting control gear is a practice that goes back to the 1940s.

The following gives some milestones in the development of lighting technology:

1940s – late 1970s:

- 38 mm (T12) lamps common for linear fluorescent lighting.

Early 1980s onwards:

- 25 mm (T8) linear fluorescent lamps introduced for all sizes except the 2,400 mm length.

Early 1980s onwards:

- Compact fluorescent lamps introduced.

Mid 1980s onwards:

- Metal louvred luminaires in extensive use for VDU and office lighting.

Mid 1980s onwards:

- Electronic control gear began to replace wire-wound components in fluorescent and discharge luminaires.

Mid 1990s onwards:

- 16 mm (T5) longer linear fluorescent lamps introduced.

Late 1990s onwards:

- VDU and office lighting designs incorporated more measures to illuminate ceilings and upper walls as VDU screen technology developed.

2010 onwards:

- LED lighting saw rapid development and take-up in the industry

Switchgear and distribution boards

As with wiring accessories and luminaires, switchgear such as distribution boards or consumer units are often an easy replacement and can mask an older installation.

Successive changes to the requirements set out in BS 7671 and earlier editions of the Wiring Regulations was generally the main driver behind distribution switchgear getting renewed, closely followed by the need for more circuits to be added to an existing installation.

As with wiring accessories, an in-depth knowledge of a particular manufacturer's production changes is also extremely useful; although again this information is beyond the scope of this article.

As with wiring accessories and switchgear, date codes can often be found on or within switchgear. In the case of larger industrial or commercial switchgear, a serial number and manufacturer's unique referencing can often lead to an exact date of manufacture.

Other useful generic age-distinguishing factors of note include:

1920s – mid 1980s:

- Re-wireable fuses frequently found many installations, particularly domestic dwellings.

1950s – early 1980s:

- Cartridge HRC (often to BS 88) fuses frequently found in commercial and industrial

  installations, and occasionally (to BS 1361) within consumer units in dwellings.

Mid 1960s onwards:

- Miniature circuit breakers (MCBs) became widespread in commercial installations.

  Uptake in domestic installations followed from the 1980s onwards.

1965 – 1988/89:

- MCBs manufactured to BS 3871.

1950s to 1981

- Voltage operated earth leakage circuit breakers in common use within TT-earthed

  installations.

1981 onwards:

- Current operated earth leakage circuit breakers (RCDs) usage began to supersede

  voltage operated types.

1988/89 onwards:

- Circuit breakers to BS EN 60898 introduced.

1990 onwards:

- Successive editions of BS 7671 recognized increasing use of RCDs for 'additional protection' requirements.

2015 onwards:

- Metal consumer units introduced by BS 7671 for use in dwellings.

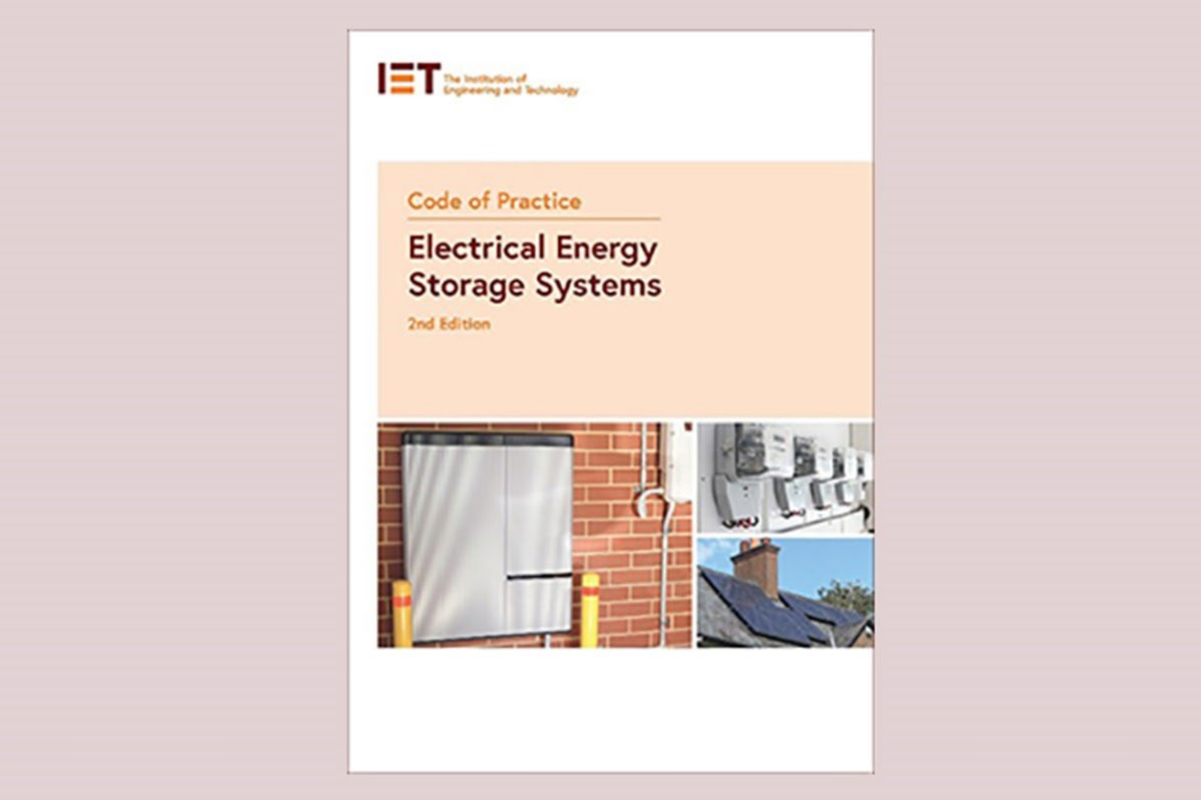
Figure 6 - Current operated earth leakage circuit breaker (RCD) of a style in widespread use during the 1980s

Figure 7 - BS 3871 plug-in miniature circuit breaker of a style produced from the late 1960s to 1985

Conclusions

Unless detailed, dated documentation exists, it will be difficult to establish an exact age for any installation. This dilemma may be compounded, particularly with larger and/or older installations incorporating sections and components of different ages. The possibility of equipment having been installed that was not new at the time should always be considered - particularly in domestic premises.

Notwithstanding this, by compiling findings from an installation inspection against some of the information highlighted, it is often found that different factors will 'fit' like jigsaw pieces and a reasonably accurate assessment of age can usually be made.



Island mode earthing arrangements: New Guidance in the Second Edition of the IET Code of Practice on Electrical Energy Storage Systems

By: EUR ING Graham Kenyon CEng MIET and Dr Andrew F Crossland CEng PhD

Introducing the concept of prosumer's electrical installations (PEIs), and operating modes for a electrical energy storage systems (EESS) and examining the earthing arrangements for island mode operation for PEIs with EESS.

Introduction

The second edition of the IET *Code of Practice for Electrical Energy Storage Systems* was published in December 2020.

It builds on the first edition to provide the most up-to-date guidance to help support the growth of the electrical energy storage market.

It has been updated to take account of developments in the industry, progress in standardisation and address emerging technical challenges such as arc flash risk assessments.

This article introduces the concept of prosumer's electrical installations (PEIs) and operating modes for an electrical energy storage systems (EESS).

It then examines the earthing arrangements for island mode operation for PEIs with EESS.

Prosumer's electrical installation (PEI)

Low-voltage electrical installation connected or not to a public distribution network able to operate:

- with local power supplies, and/or
- with local storage units,

and that monitors and controls the energy from the connected sources delivering it to:

- current-using equipment, and/or
- local storage units, and/or
- public distribution network

Source: *BS HD 60364-8-2*

EESS in PEIs

EESS mean that PEIs can continue to supply loads when the normal supply is interrupted.

EESS power conversion equipment (PCE) is typically connected either:

- on the DC side of the PCE for a local generation system, such as solar PV, as shown in Figure 1. This is termed DC coupling.
- in parallel with other loads, for example in the arrangement shown in Figure 2. This is termed AC coupling.

Unlike uninterruptible power supplies (UPS), EESS often operate in parallel with the grid supply, and power conditioning is not always guaranteed.

Figure 1: Example of DC coupled EESS

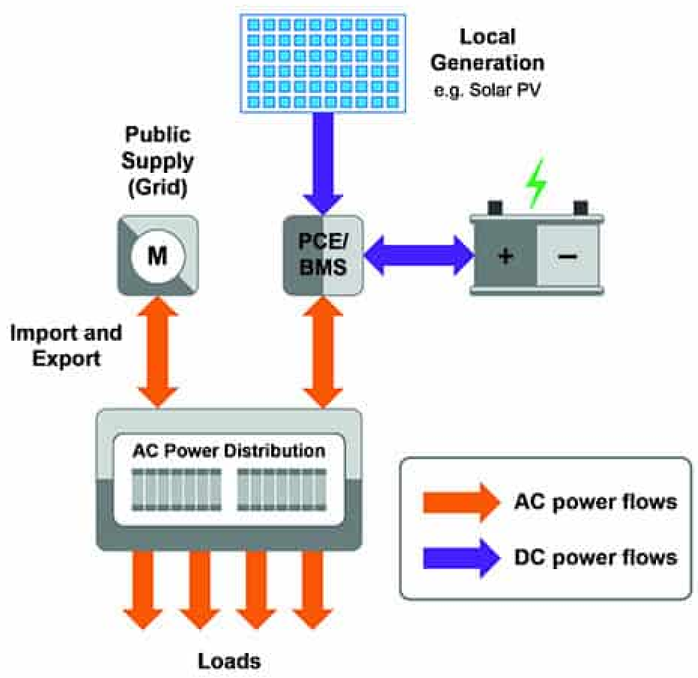
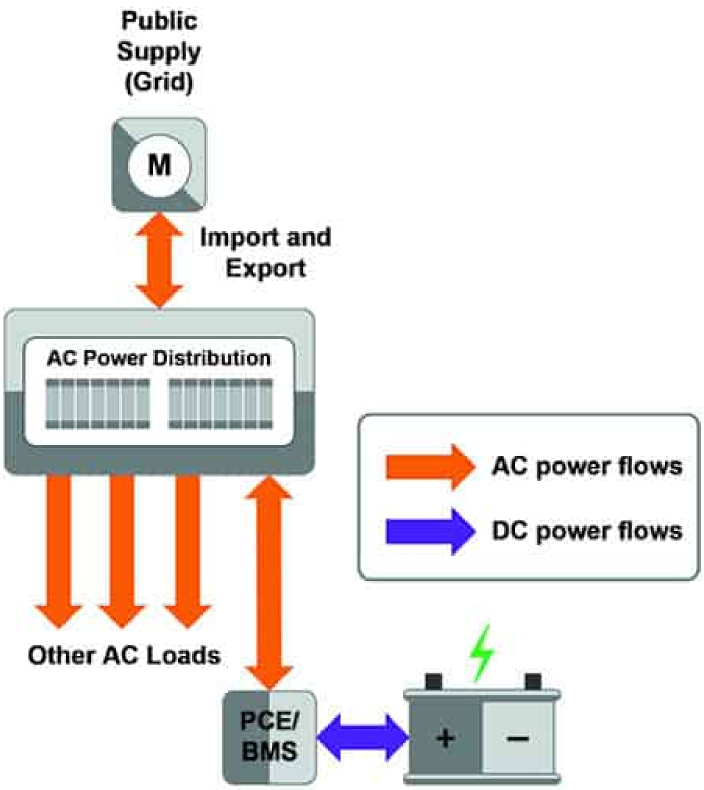


Figure 2: Example of AC coupled EESS



Modes of operation for EESS

Since EESS are effectively types of generator, Regulations 21 and 22 of the Electricity Safety, Quality and Continuity Regulations (ESQCR) guide the requirements for the basic modes of operation.

The modes of operation for EESS are:

- *Connected mode*, where the installation is connected to the grid.
  During *connected mode*, the installation may be *direct feeding* (importing power from the grid) or *reverse feeding* (exporting power to the grid).
- *Island mode*, where an electrical system normally connected to the grid is operating in a mode where some or all of the installation is isolated from the grid and is operating solely from an EESS. This is sometimes called "backup mode".

In *connected mode*, an installation with EESS must comply with Regulation 22 of the ESQCR. The PCE must meet appropriate standards set out in ENA Engineering Recommendations G98 or G99 to avoid disrupting the operation of the grid, and respond to voltage and frequency fluctuations present on the grid. When the grid supply is lost, the PCE must be disconnected from the grid.
In *island mode*, an installation with EESS must comply with Regulation 21 of the ESQCR, and the PCE operates as a switched alternative to the grid. All live

conductors, that is line(s) and neutral, that are to be powered in island mode must be disconnected from the grid. The installation may remain connected to the distributor's means of earthing (where this is provided).

Earthing arrangements for island mode operation

In *connected mode*, an installation with a TN earthing arrangement (TN-C-S or TN-S) may use the distributor's means of earthing. In a TT system, the consumer's earth electrode is used – but care needs to be taken to ensure that this provides an earth of sufficient quality. However, when the installation moves to *island mode*, it is important to make special earthing provisions.

Regulation 551.4.3.2.1 of BS 7671 states that, in TN systems, generators operating as a switched alternative to the public supply cannot continue to rely on the distributor's means of earthing.

> **551.4.3.2.1** Protection by automatic disconnection of supply shall not rely upon the connection to the earthed point of the system for distribution of electricity to the public when the generator is operating as a switched alternative to a TN system. A suitable means of earthing shall be provided.

In systems where a low voltage supply is provided to the installation, the neutral of the supply is earthed at the distributor's transformer.

Accordingly, in systems operating in *island mode*, the distributor's neutral-earth link cannot and must not be relied upon, as this is switched out when the live conductors are disconnected.

> ## Island mode isolator
>
> Device that disconnects the live conductors of the grid supply when the system switches to island mode.
>
> ## N-E bond relay
>
> Device that establishes a neutral in parts of the installation disconnected from the grid supply in island mode.
>
> **Source:** *IET Code of Practice for Electrical Energy Storage Systems, 2nd Edition*

An installation that operates in *island mode* therefore requires:

- a switching mechanism to disconnect live conductors of the installation that are to be powered in *island mode* from the grid. The IET *Code of Practice for Electrical Energy Storage Systems* calls this an *island mode isolator*
- a switching mechanism to provide a neutral for the *island mode* The IET *Code of Practice for Electrical Energy Storage Systems* calls this an *N-E bond relay,* and
- a consumer earth electrode. In TT systems, this may be the TT system consumer electrode, if it meets specific technical requirements.

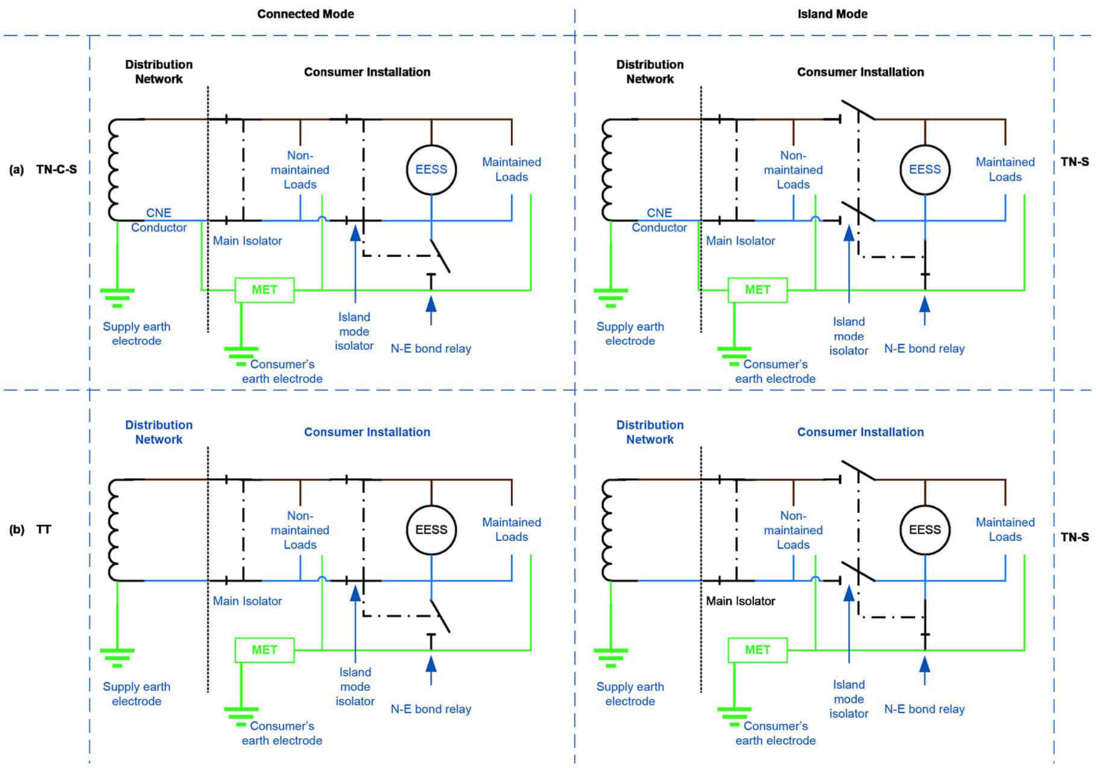
The earthing arrangement of most EESS in *island mode*, where the installation has a low voltage public supply connection, is therefore always TN-S.
Note: If the N-E bond relay were not present, and the EESS inverter has a permanent connection between neutral and earth, RCDs in the installation would operate, as this would effectively be a neutral to earth fault in the installation.
Note: In installations where PME conditions apply in *connected mode*, PME conditions continue to apply in *island mode*. This is because the distributor's means of earthing remains connected, even though it is not used.

Table 1: Connected and *island mode* earthing arrangements for installations with a low voltage public supply connection

Connected mode earthing arrangement	*Island mode* earthing arrangement
TN-C-S	TN-S
TN-S	TN-S
TT	TN-S

Figure 3 is a simplified illustration of earthing and switch-over arrangements for connected and *island mode*. It shows the state of *island mode* isolator and N-E bond relay.

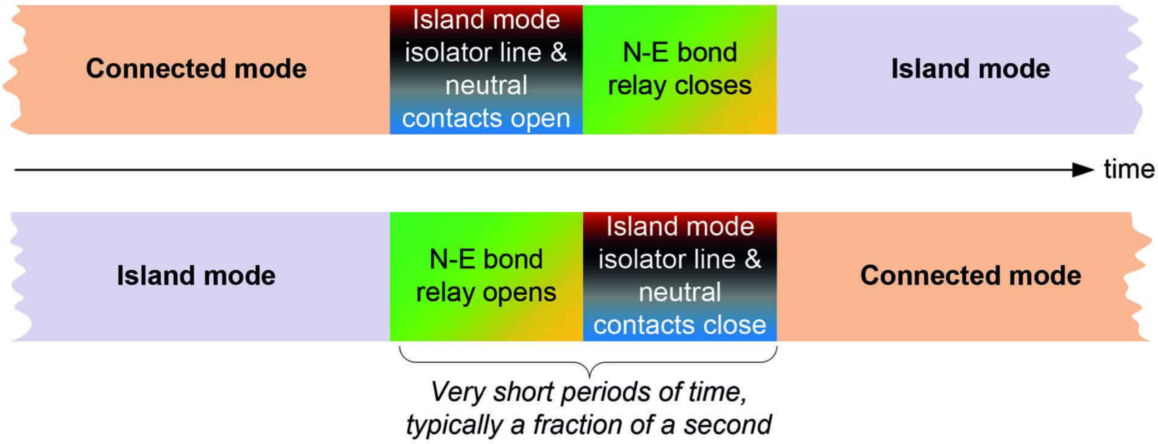
Figure 3: Simplified illustration of earthing and switch-over arrangements in *connected mode* and *island mode*



Timing of the operation of the *island mode* isolator and N-E bond relay should comply with Regulations 431.3 and 537.1.5 of BS 7671. This requires:

- The N-E bond relay to be interlocked, or mechanically linked, with the *island mode isolator*, as illustrated in Figure 4, so that:
    - When moving to *island mode*, the N-E bond contact is closed immediately after the live conductor contacts of the *island mode* isolator are opened
    - When moving to *connected mode*, the N-E bond contact should be opened immediately before the live conductor contacts of the *island mode* isolator are closed
- In polyphase systems, the neutral contact of the *island mode isolator* should not disconnect before those of the line conductors, and should not reconnect after those of the line conductors.

Figure 4: Timing requirements for *island mode* switching arrangements



The consumer earth electrode

A consumer earth electrode is required for *island mode* operation, because, as Regulation 551.4.3.2.1 of BS 7671 states, the distributor's earthing arrangement cannot be relied upon.

Existing consumer earth electrodes, such as those used in TT systems, may be used where they meet the design requirements for the EESS. The selected earth electrode system should meet the requirements of BS 7671, and as much as possible should be installed to reduce the risk of freezing or drying out.

The maximum acceptable earth electrode resistance for installations operating TN-S, or in TT systems where earth fault loop impedance is not restricted to a lower value, is 200 Ω. Above this value, the earth electrode system may not present a stable resistance. This is a major change in the 2nd Edition of the IET *Code of Practice for Electrical Energy Storage Systems*, which previously recommended a maximum of 200 Ω only for systems below 10 kVA.

In some cases, better earthing needs to be provided. Some consumers have parts of the installation with different earthing arrangements to the main installation. Examples include installations with a PME earthing arrangement for the grid connection, but separate TT earthing arrangements for outbuildings, or electric vehicle charging equipment. An example is shown in Figure 5.

In these systems, the designer should ensure the values of both the consumer earth electrode for the *island mode* earthing arrangement, and the TT earth electrodes, are low enough to ensure operation of protective devices in the event of a fault to earth in the TT part of the installation. Usually, this will involve the operation of RCDs, and the maximum earth fault loop impedance must meet Table 41.5 of BS 7671.

Figure 5: Example of an installation where circuits with separate earthing arrangements remain connected in *island mode*

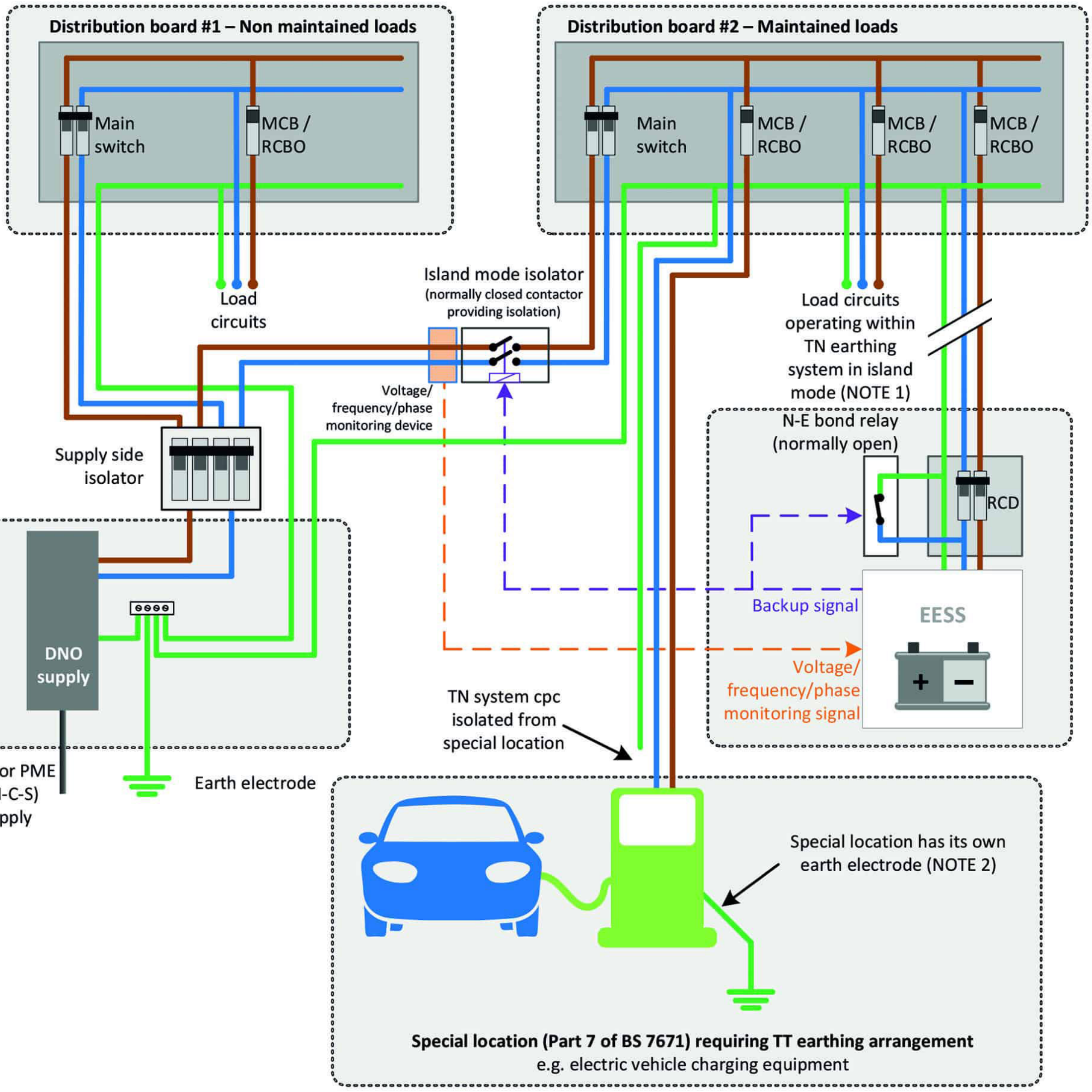
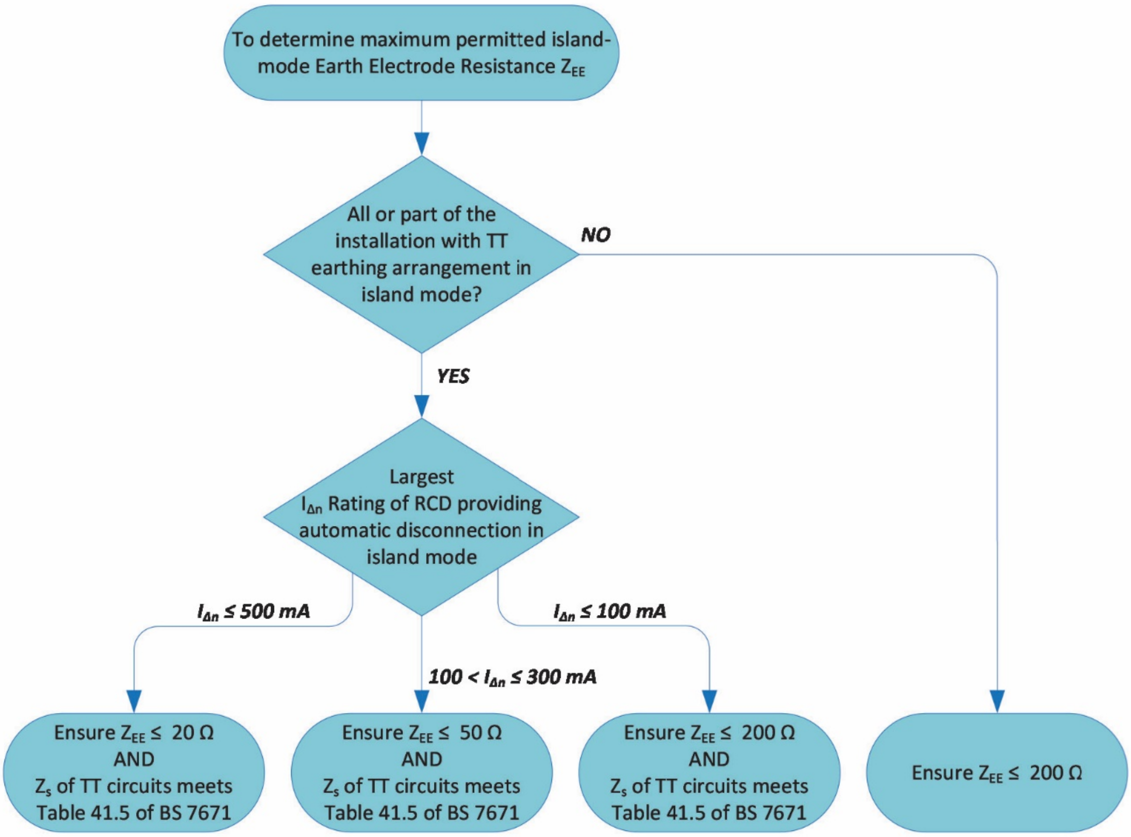


Figure 9.10 of the IET *Code of Practice for Electrical Energy Storage Systems*. Contains a flowchart to quickly enable the designer to determine the maximum *island mode* earth electrode resistance. See Figure 6.

Figure 6: Flowchart to determine maximum permitted *island mode* earth electrode resistance



Protection against electric shock in *island mode*

Ultimately, the earthing arrangement is essential to facilitate automatic disconnection of supply (ADS). Often, the prospective fault current available from PCE in an EESS will be far lower than that from the grid, and may be insufficient to operate overcurrent protective devices within the times stated in Chapter 41.

To facilitate selectivity in *island mode*, RCDs can be used to achieve ADS. Section 9 of the IET *Code of Practice for Electrical Energy Storage Systems* provides comprehensive guidance on means of earthing and protection against electric shock in *island mode*, as well as guidance on protection against overcurrent in *connected mode*.

References

- IET *Code of Practice for Electrical Energy Storage Systems*, 2nd edition (ISBN-13: 978-1-83953-041-8)
- BS HD 60364-8-2:2011+A11:2019 *Low-voltage electrical installations. Part 8-2. Prosumer's low-voltage electrical installations*
- *The Electricity Safety, Quality and Continuity Regulations* 2002 (as amended)
- ENA Engineering Recommendation G98 Issue 1 Amendment 4 (June 2019) *Requirements for the connection of Fully Type Tested Micro-generators (up to and including 16 A per phase) in parallel with public Low Voltage Distribution Networks on or after 27 April 2019*

- ENA Engineering Recommendation G99 Issue 1 Amendment 6 (9 March 2020) *Requirements for the connection of equipment in parallel with public distribution networks on or after 27 April 2019*
- BS 7671:2018+A1:2020 *Requirements for electrical installations. IET Wiring Regulations 18th Edition.*

Biographies

Graham Kenyon

Managing Director of the consultancy G Kenyon Technology Ltd, Graham is an electrical and systems engineering consultant who established his reputation designing and implementing control and information management systems in the challenging environments presented by world-class construction programmes, chiefly in the airport and rail sectors.

His experience encompasses project management, systems and product assurance, electrical and systems engineering, and control room design.

He is currently Chair of the IET Wiring Regulations Policy Committee, and Chair of JPEL/64 Sub-Committee D, Special Locations and External Influences for BS 7671.

Graham has authored a number of IET publications and is co-author of the Code of Practice for Electrical Energy Storage Systems, now in its 2nd Edition.

Andrew Crossland

Andrew has a PhD in interdisciplinary modelling of energy systems.

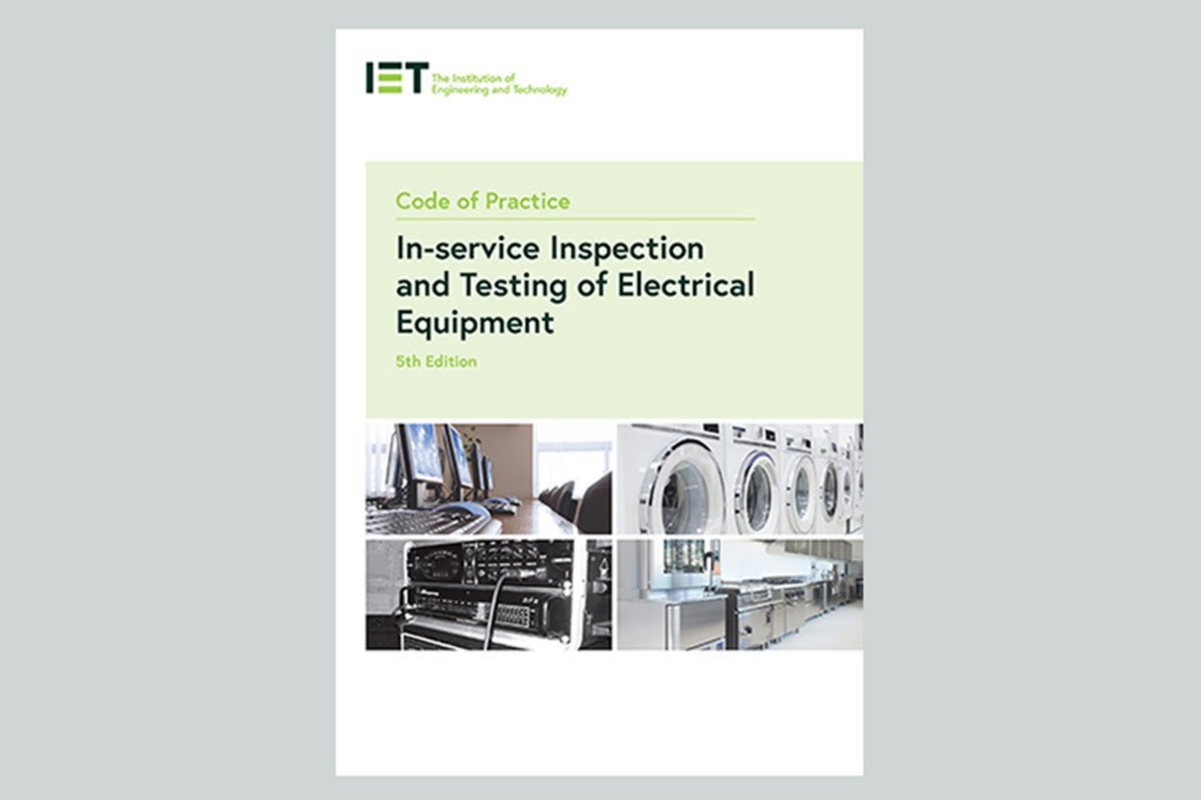
He has worked in the railway, electrical distribution, research, solar and energy storage industries developing new techniques and models for the rapidly changing, and increasingly low carbon energy mix.

He won the Energy UK "Rising Star" Award for his work in the sector in 2017 and was nominated for an Energy Leader award by Energy UK in 2020.

Andrew founded the energy tracking system MyGridGB.co.uk, charting the British electricity mix, carbon emissions and fossil fuel consumption in real-time. Through this, he works to provide an unbiased view of the potential and contribution of different energy sources.

As an Energy Storage Specialist for three years at SolarCentury, Andrew helped to develop residential, large battery and microgrid projects in the UK and Africa. Andrew was also Chair of the Behind the Meter Energy Storage Group at the Solar Trade Association at this time.

In 2018, Andrew joined Infratec working on energy projects across New Zealand and the Pacific where he develops and consults on solar/storage. He is also a director of Advance Further Energy Ltd which provides specialist energy storage consultancy services in the UK.



The all-new 5th edition of the IET Code of Practice for In-Service Inspection and Testing of Electrical Equipment

By: **James Eade**

In this article, James Eade, author of the 5th edition, continues his brief insight into the changes to this important Code, now available from the IET.

The last instalment of this article gave an insight into some of the changes that the 5th edition of the IET *Code of Practice for In-Service Inspection and Testing of Electrical Equipment* (commonly referred to by many using the easier-to-pronounce initials 'COPISITEE') has introduced.

As hinted at in the last article, a significant change (perhaps the most significant, depending on your view!) is a complete review of the frequency of testing, previously given in Table 7.1 of the 4th edition. This table has now disappeared in the 5th edition and has not been replaced. This will come as a shock to many, but if the rationale for its removal is understood, it becomes apparent that for many dutyholders, the existence of a table can be more of a hindrance than a help.

Equipment should be checked annually, shouldn't it?

As briefly noted in the previous article, the focus of the COPISITEE is to encourage electrical equipment used in the workplace to be checked for damage or deterioration that may lead to *danger*. The primary (but not the only) legislation that governs electrical safety in the workplace is the Electricity at Work Regulations 1989 (EWR). These require equipment that may be subject to deterioration, damage or other effects that could cause danger to be maintained. Danger in the context of the Regulations is broadly defined as the *risk of injury*, which could arise not only from electric shock but also from electrical arcing, explosions, burning or even smoke inhalation from an electrical fire for example.

Nearly all electrical equipment is subject to wear and tear in general use; thermal damage to insulation or components (electricity is usually dissipated as heat in equipment), accidental damage, damage caused by electrical faults, and even environmental damage, such as exposure to solar radiation are all examples of deterioration found in electrical equipment.

Because most electrical equipment is – to varying degrees – susceptible to damaging effects, it follows that it is necessary to maintain most electrical equipment. This is typically accomplished by inspecting it and, where appropriate, conducting electrical tests to ascertain if it is suitable for continued use and, importantly, not likely to give rise to danger. This approach is illustrated in the title for the Code of Practice: *In-Service <u>Inspection</u> and <u>Testing</u>*.

With the need for inspection and testing identified, the next question, of course, is "How often should I conduct the maintenance activity of inspection and testing?" To be blunt, the short answer is "We don't know." That statement, though, should not be seen as a dereliction by the guardians of electrical safety at the IET; but taken as a hint of the difficulty in specifying a definitive answer. It is a problem that has been discussed ad nauseam in electrical safety committees for decades and is best illustrated using an example of two offices, as follows.

In the first office, staff undergo basic electrical safety check awareness training as part of their induction. The company policy on electrical safety in the workplace is explained to the new employees and regular 'toolbox talks' are held. Consequently, employees are good at reporting electrical hazards on equipment when they use it and the issues are resolved promptly. It is a new office building and residual current device (RCD) protection has been installed on most final circuits, providing additional protection for users of the electrical equipment.

In the second office, staff are mostly field-sales operatives and technicians who are not regularly in the office itself, so opportunities for training and tool-box talks are fewer. It is an old building and doesn't have RCDs fitted on all socket-outlets, but the electrical installation itself is checked every five years. The staff manual doesn't (yet) mention electrical safety in the workplace.

Should the electrical equipment in both offices be checked at the same frequency? Evidently not: it can be seen that the risk of an electrical hazard going undetected is more likely in the second office than in the first, so the second office should conduct a formal inspection and/or testing activity more often.

The same approach can be applied to other industries. The risk profile of a factory using electrical equipment to make computer keyboards, for example, is different to that of a factory using electrical equipment to make steel bridge components; the profile of a business hotel in a city is different to that of a bed and breakfast hotel in the countryside; the profile of a construction site for a children's play area in the park is different to that of a construction site for a railway line; the profile of a company hiring office vending machines is different to that of a company hiring Christmas lighting once a year – and so on.

Cleary not all offices/factories/hotels/construction sites/hire companies have the same risk profile and the maintenance activities should differ accordingly. For this reason, it is near-impossible to state in a Code of Practice what a suitable interval is. Categorizing industries is not the correct approach: as exampled above, what is reasonable for one company might be quite unreasonable for the next, even if they are both in the same industry.

When one considers the breadth of workplaces to which the COPISITEE applies, from military bases to hospitals, hotels and holiday homes, the scale of the task of providing specific guidance for industry sectors becomes apparent. It also explains why dutyholders may struggle with prescribed published intervals which they feel are inappropriate for their business.

Assessing the risk

The key to good electrical safety management is understanding the nature of the electrical equipment in the workplace and how it is used. The best person to decide how to maintain it, and how often, is the person who knows the equipment and the environment it is in: i.e. the dutyholder.

The 5th edition of the COPISITEE provides advice for dutyholders on how to conduct a risk assessment for determining suitable intervals, based on the core factors of:

- **the environment:** equipment installed in a benign environment, such as an office, will suffer less damage than equipment in an arduous environment, such as a construction site.
- **the users:** if the users of equipment report damage as and when it becomes evident, hazards will be mitigated. Conversely, if equipment is likely to receive unreported abuse, or equipment damage be ignored, more frequent inspection and testing will be required.
- **the equipment construction:** the safety of Class I equipment is dependent upon a connection with the earth of the fixed electrical installation, whereas, for example, Class II doesn't rely on any protection fitted within the installation.
- **the equipment type:** equipment that is hand-held is more likely to be damaged than fixed equipment and the risk of electric shock in the event of a fault is likely to be greater.
- **the frequency of use:** this is important, particularly where mobile or hand-held equipment is concerned, because it may have implications for service life and exposure to possible damage.
- **the type of installation method:** installation methods should be taken into account, especially when assessing fixed equipment. For example, the isolator position and cable management can be an important factor when assessing for risk. The type of protective devices fitted in the distribution will also have a bearing.
- **previous records:** where available, previous records of inspection, testing and maintenance should be used to evaluate the required frequency of subsequent inspections and tests. These will provide a history of the environment and users and show how all this information affects the condition of the equipment within the environment.
- **the functional in-service life:** some equipment may have an intentionally short service life because of built-in components such as internal batteries, or software obsolescence in IT equipment, for example.

In summary, there is no right or wrong answer in determining a suitable interval, but it is *unlikely* to be annually in many cases, as has been the 'norm' in many workplaces. All of the factors described will need to be considered in a risk assessment and the responses to each will allow the dutyholder to make an informed decision as to an appropriate frequency of inspection and testing. Example risk assessments can be found in Appendix 9 of the 5th edition, which demonstrates how to look at a workplace and analyse the factors described above, and then decide on appropriate intervals.

The Code of Practice is now published and copies can be purchased online.

Broken PEN

By: Michael Peace CEng MIET

Don't panic, this article is not about broken ballpoint pens, it is concerning broken PEN conductors in PME earthing arrangements.

What is a PEN conductor?

A protective earthed neutral (PEN) conductor is a single conductor that has the combined function of providing the neutral and protective earth conductor in a TN-C-S earthing arrangement.

A PEN conductor is normally, but not exclusively, used with an LV PME supply service earthing system. The conductor can be either separate from the line conductors as with an overhead line service or combined in a multi-core cable in the form of a number of conductors wound around the line conductors to form the armouring, as in a concentric cable. The copper armouring of the concentric cable indicated in Figure 1 is the PEN conductor.

Figure 1: Concentric cable

If the supply cable has a separate protective conductor, is it TN-S?

Due to the nature of a PME earthing arrangement, distributors should not mix TN-C-S and TN-S earthing arrangements on the same network. However, when repairs or alterations are made to the distribution network, sometimes damaged 4-core cables can be replaced with 3-core.

It is sometimes assumed that if a supply cable has a separate protective conductor, the installation has a TN-S earthing arrangement. This is not necessarily correct; if it is supplied from a distribution network the installer should presume it is a TN-C-S, unless it is confirmed by the Distribution Network Operator (DNO) in writing to be a TN-S earthing arrangement.

What is a PME earthing arrangement?

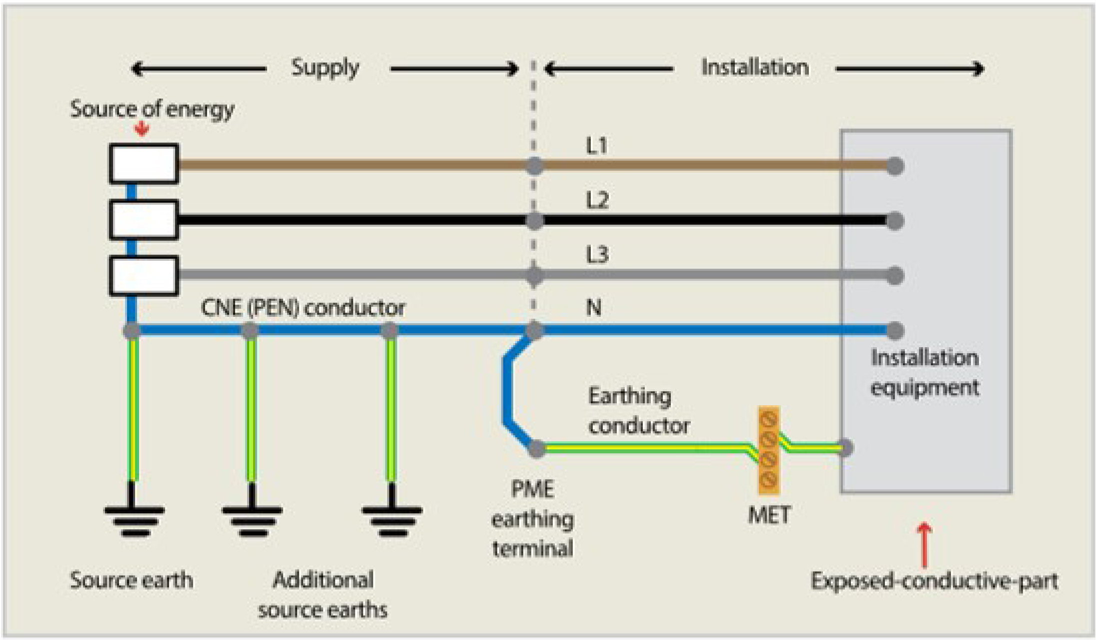
A protective multiple earthing (PME) arrangement is a form of TN-C-S, as seen in Figure 3. It refers to the earthing arrangement provided by the distributor where it terminates in the cut-out at the origin of the consumers TN-C-S installation.

'Multiple' in PME means there could be multiple earth electrodes installed along the cable route to ensure the resistance of the PEN conductor to Earth is within the values required by the DNO, ENA Engineering Recommendation G12/4 states 20 ohms.

The 'S' refers to separation of the neutral and earth on the installation side. The star point is earthed by the distributor, usually in the spill box of the transformer, as seen in Figure 2.

Figure 2: Transformer neutral to Earth connection inside transformer spill box

Figure 3: TN-C-S system with PME



What is a PNB earthing arrangement?

A protective neutral bonding (PNB) arrangement is also a form of TN-C-S and may be used depending on individual DNO requirements. The PEN or CNE conductor is connected to one point only, remote from the transformer, between the transformer and the supply terminals of the consumer.

ENA Engineering Recommendation G12/4 recommends that the distance between the connection to Earth and the consumers intake shall be 40 m or less, however in order to minimise the risk of voltage rise in the event of a broken neutral this connection should be made as close as practicable to the consumers supply terminals. This is usually located within the customers LV switchboard, along with the neutral earth link, see Figure 4. However, note that the neutral and Earth are separated on the consumers side of the installation.

Figure 4: Neutral – Earth link in customers LV switchboard

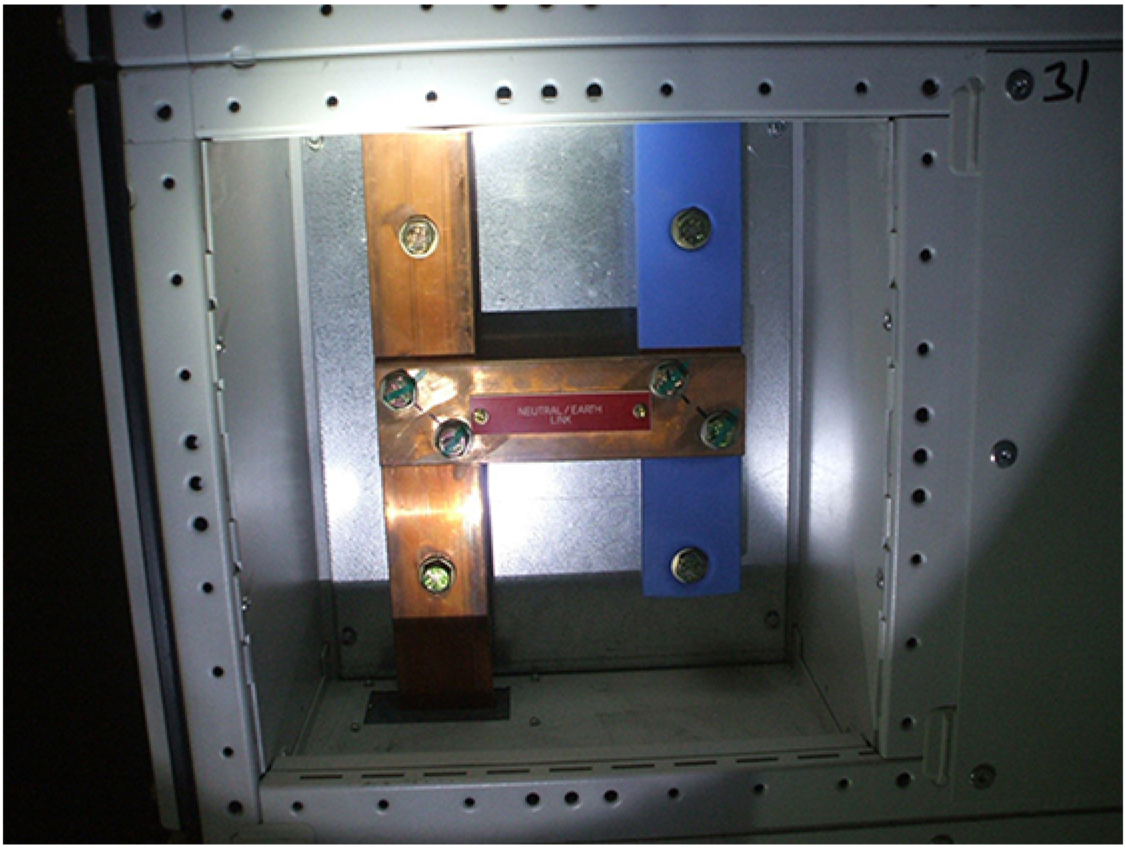
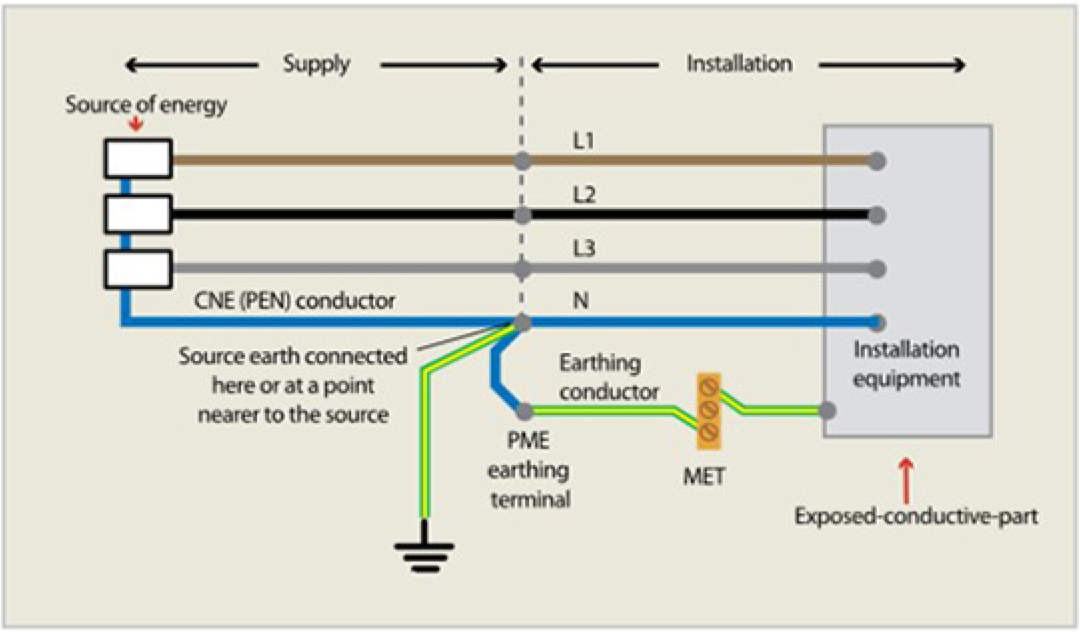


Figure 5: IET Guidance Note 8 TN-C-S system with PNB



What are the responsibilities of the distributor for PME?

Electrical distributions are governed by the Electrical Safety Quality and Continuity Regulations (ESQCR) 2002 (as amended), which is a statutory instrument. The Energy Networks Association (ENA) provides guidance to distributors in their Engineering

[Recommendation G12 issue 4, *Requirements for the application of protective multiple earthing to low voltage networks.*]

ESQCR prevents distributors from providing a PME earth terminal for certain installations, such as the metalwork in a caravan or boat and fuel filling stations. Although, if part of a larger site, PME facilities may be provided for the permanent buildings, provided the independent earthing arrangement is segregated from the PME.

What are the requirements of BS 7671:2018+A1:2020 for PME systems?

The requirements of ESQCR are repeated in BS 7671:2018+A1:2020, in the following Sections:

- Section 708 - Electrical installations in caravan/camping parks
- Section 709 - Marinas and similar locations
- Section 730 - Onshore units of electrical shore connections for inland navigation vessels
- Section 740 - Temporary electrical installations for structures, amusement devices and booths at fairgrounds, amusement parks and circuses.

Installations which may be allowed a PME earthing arrangement, but special precautions must be taken, include:

- Section 702 - Swimming pools and other basins
- Section 704 - Construction and demolition site installations
- Section 705 - Agricultural and horticultural premises
- Section 711 - Exhibitions, shows and stands
- Section 717 - Mobile or transportable units.

When the 14th Edition of the IEE Wiring Regulations was published in 1966, Appendix 5 acknowledged the introduction of PME earthing systems, as shown in Figure 6.

Figure 6: Appendix 5 of 14th Edition IEE Wiring Regulations

APPENDIX 5

NOTE—

The typical form of approval used in particular instances by the Minister of Technology or the Secretary of State for Scotland when authorising the use of Protective Multiple Earthing, which appeared in earlier printings of the Fourteenth Edition, is not included in this reprinting.

Approval of the use of the system known as Protective Multiple Earthing is granted by the Minister of Technology or the Secretary of State for Scotland to individual Area Electricity Boards and is subject to the conditions in the particular form of approval. Various forms of approval are in use at the time of this reprinting of the Regulations, and it is therefore thought no longer appropriate to reproduce any one form of approval as an appendix to these Regulations.

Where P.M.E. is permitted, the Area Electricity Board responsible for the distribution system should be consulted regarding particular requirements for consumers' installations to be connected to the system.

A note was added to Regulation 411.4.2 in BS 7671:2008+A3:2015 which states, '*The PE and PEN conductors may additionally be connected to Earth, such as at the point of entry into the building.*', as it is acceptable under *Electricity Safety, Quality and Continuity Regulations*

(ESQCR), but prior to this under the 'Supply Regulations 1988' it was not acceptable for the customer to Earth the DNO neutral.
Regulation 543.4 of BS 7671:2018+A1:2020 sets out the requirements for combined protective and neutral (PEN) conductors. A note states that '*Regulation 8(4) of the ESQCR prohibits the use of PEN conductors in consumers' installations.*'

Amendment 1 to BS 7671:2018 was published in February 2020, the Amendment applied only to Section 722, which is for electric vehicle charging. The main change in this Amendment is the inclusion of additional methods of protection against open-circuit PEN conductors for electric vehicle charging installations, using devices that detect under- or over-voltages on the distribution network.

The requirements for protective bonding of installations with a PME earthing arrangement are identified in Table 54.8 of BS 7671:2018+A1:2020. The requirements are more onerous than for TN-S systems, in order to withstand any diverted neutral currents which may exist, due to an open-circuit PEN conductor.

Interestingly, Regulation 114.1 of BS 7671:2018+A1:2020 states that for a supply provided in accordance with the Electricity Safety, Quality and Continuity Regulations (ESQCR), 'it shall be deemed that the connection with Earth of the neutral of the supply is permanent.'

Whilst an open-circuit PEN conductor occurs on the distribution network, the consequences can have serious effects on the consumers electrical installation. Each installation should be assessed individually, and if the risk of a person coming into contact with conductive parts connected to the PME earthing arrangement and Earth, is not acceptable, additional protective measures must be taken.

What are the issues with PME?

In the event of the distributor's PEN conductor becoming broken (open-circuit), diverted neutral currents and dangerous touch voltages can appear on any metalwork connected to the Main Earthing Terminal (MET) of the installation.

The risk of electric shock is increased for persons outdoors, as they are likely to be in contact with Earth, possibly even barefooted, which would lower the body resistance to Earth and increase the touch current.

Examples of areas of risk would include outside water taps and Class I electrical equipment connected to the MET. Fire can also be a risk due to the heating effect of extraneous-conductive-parts, such as water and gas pipes caused by the diverted neutral current.

Further information can be found in *IEC 60479-1:2018 Effects of current on human beings and livestock and IEC/TR 60479-5 Touch voltage threshold values for physiological effects.*

What voltages can appear on PME earthed metalwork under open-circuit PEN conditions?

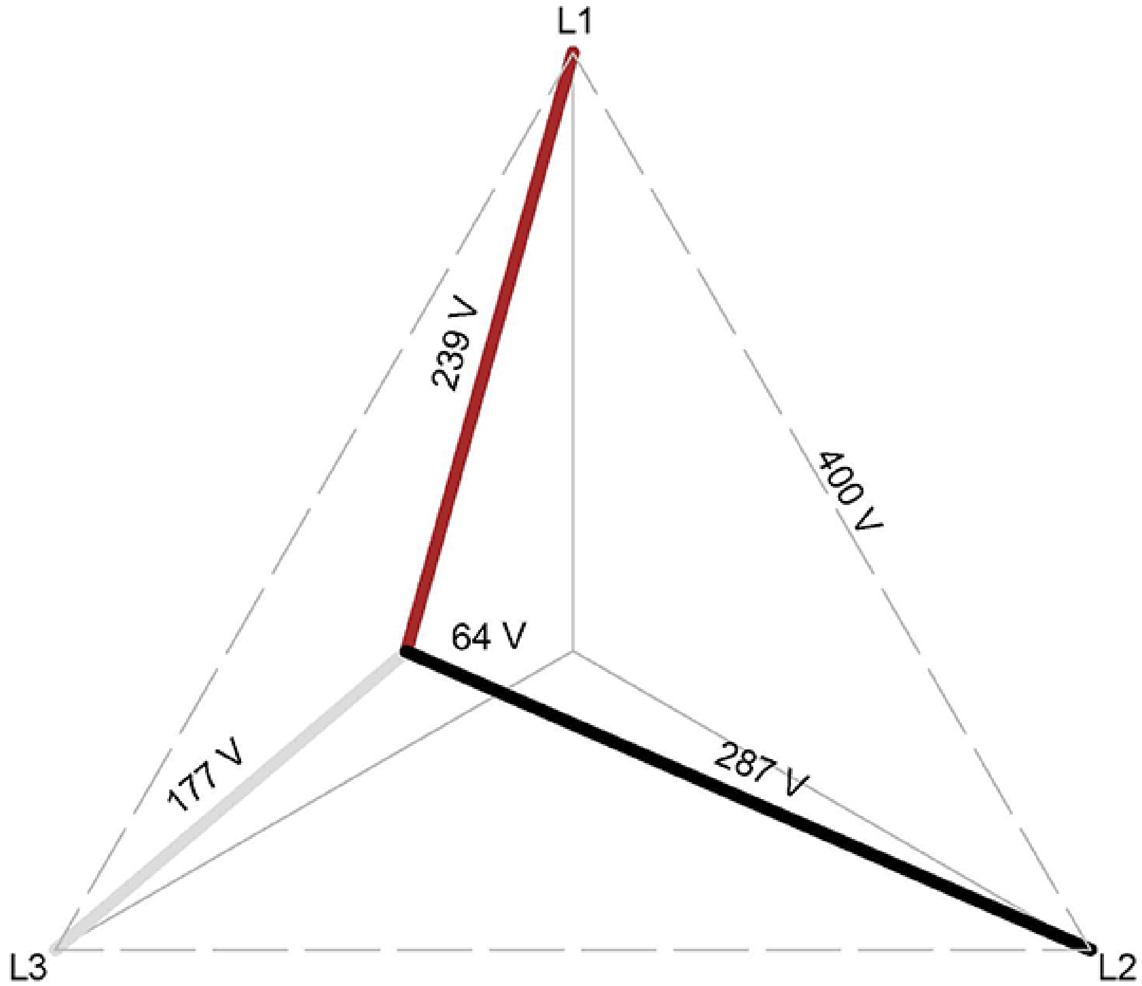
Under open-circuit PEN conditions, the voltage between the neutral and Earth will depend on the ratio of the balance of load on the distribution network. In some cases, this can be up to 230 V. This becomes more complex when power factor is taken into consideration. For the purposes of this article, power factor has not been considered.

Kirchoff's Law states that the sum of currents flowing into a node is equal to the sum of currents flowing out of the node. In a three-phase distribution system the common neutral connection is the star point.

If the load is not balanced, a current will flow in the neutral conductor, this will be a phasor sum of the line currents. If the PEN conductor becomes open-circuit, the neutral current cannot flow. The voltages between line and neutral 'shift' until a balance point is reached eliminating the need for a neutral current. The star point is said to 'float' to a position that achieves balance.

This is illustrated on the phasor diagram in Figure 7. The distance from the centre point of the triangle to the displaced star point of the three-phases indicates the touch voltage to Earth; 64 V. The star point having moved towards the heaviest loaded phase, in this case, L3.

Figure 7: Phasor diagram



This condition will cause an overvoltage in some phases and undervoltage in others and is likely to cause equipment not designed to operate at either over- or under-voltage to malfunction or be damaged. It is a dynamic situation as equipment installed on the affected phase malfunctions will also affect the load demand and balance of the network and thus the voltage to Earth also changes.

Regulation 442.3 of BS 7671:2018+A1:2020 provides information regarding the power frequency stress voltage, in the event of loss of the neutral conductor in a TN or TT system.

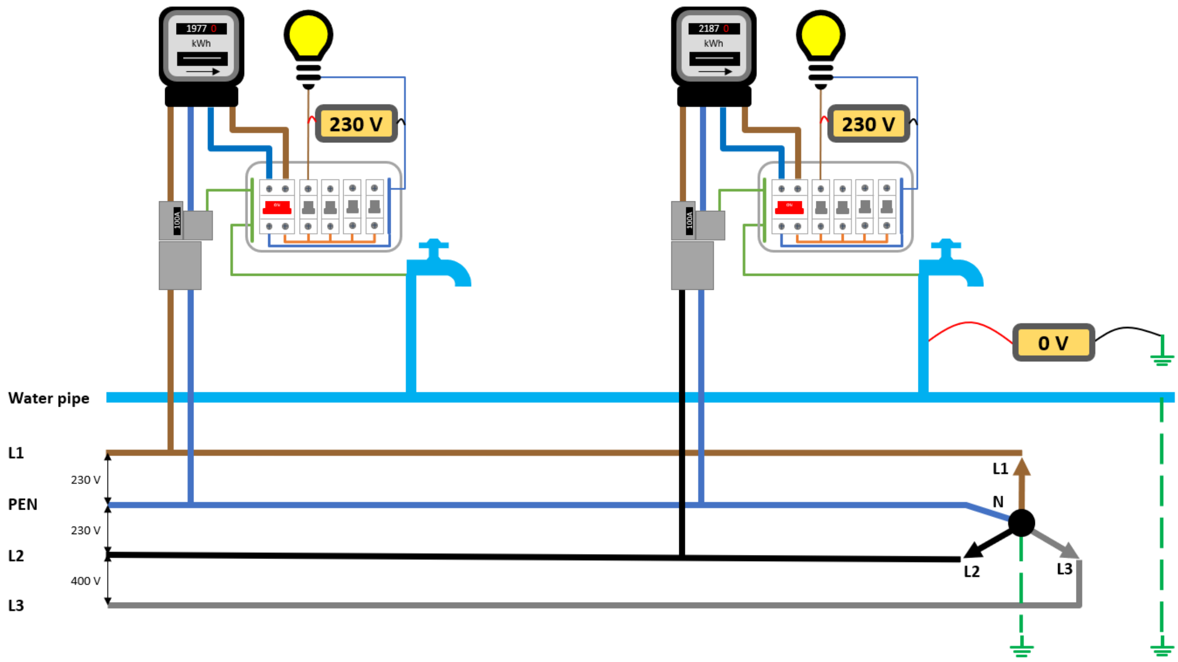
Three-phase balanced network

In a three-phase balanced network there is no neutral current, where there are no triple harmonics. However, it should be remembered that any electrical installation comprising several single-phase loads is unlikely to be or remain balanced for a period of time.

It should also be remembered that the voltage to Earth will depend on the ratio of balance on the distribution network and not just the consumers installation.

Scenario 1 Normal operating conditions

Figure 8: Normal operating conditions

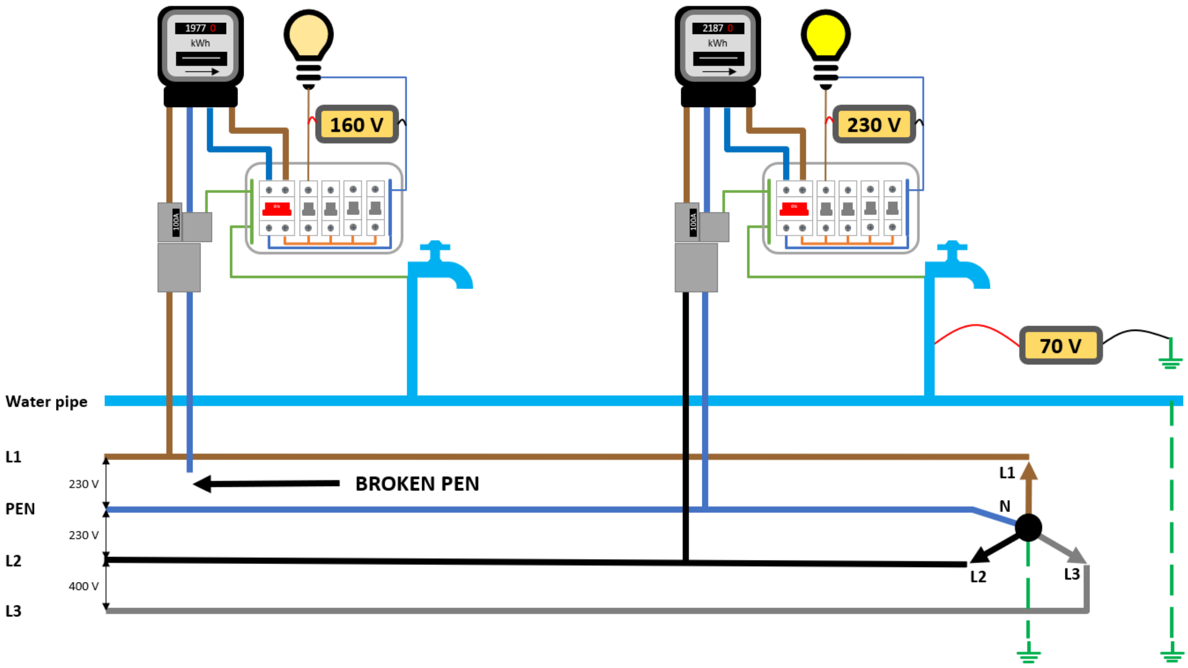


(Editors Note- This content appears as a video file on our online magazine page, thus the image does not represent what the author intended. Please refer to https://electrical.theiet.org/wiring-matters/years/2021/84-march-2021/broken-pen/)

Under normal operating conditions, the current path returns from each property via the PEN conductor to the distribution transformer, in such conditions there is no voltage between PME neutral and Earth.

Scenario 2 Open-circuit PEN conductor in single-phase section of cable

Figure 9: Open-circuit PEN conductor in single phase section of cable

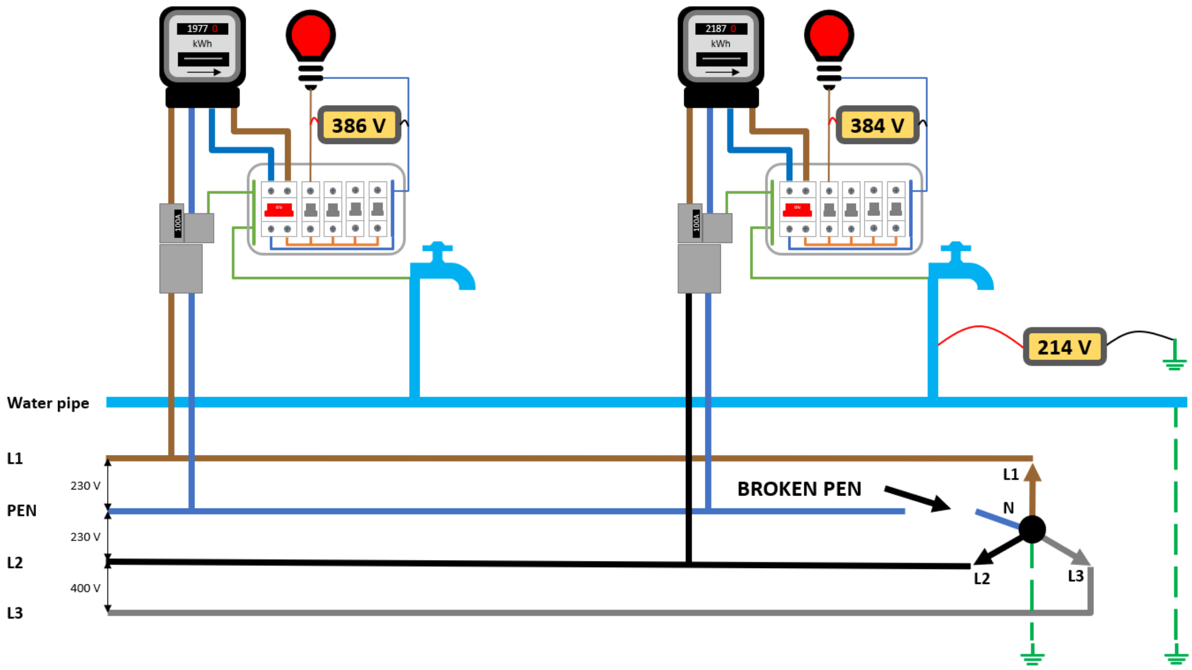


(Editors Note- This content appears as a video file on our online magazine page, thus the image does not represent what the author intended. Please refer to https://electrical.theiet.org/wiring-matters/years/2021/84-march-2021/broken-pen/)

In the event of an open-circuit PEN conductor on the single-phase section of cable, the return path is via the extraneous-conductive-part, such as a metallic water pipe shared with an adjacent installation. This will cause a touch voltage between any connected exposed- and extraneous-conductive-parts to Earth, the voltage will vary according to the resistance of the return path.

Scenario 3 Open-circuit PEN conductor in three-phase section of cable

Figure 10: Open-circuit PEN conductor in three-phase section of cable



(Editors Note- This content appears as a video file on our online magazine page, thus the image does not represent what the author intended. Please refer to https://electrical.theiet.org/wiring-matters/years/2021/84-march-2021/broken-pen/)

If the PEN conductor breaks in a section of three-phase cable, the return path will be via the adjacent installation, back to the L2 phase. This means that up to 400 V could exist within the single-phase installation. The voltage to Earth will be higher if the distribution network is unbalanced.

In the real world, the situation is likely to be much more complex with many variables affecting the level of touch voltage and diverted neutral current. It is possible that the combined neutral currents for several installations could return via one installation.

This situation, which can be difficult to detect, results in a voltage to Earth of up to 230 V and a voltage between live conductors up to 400 V present at any point in those installations that are affected by the break in the neutral conductor.

What precautions can be taken to limit the rise in voltage on the consumer's earth terminal in the event of an open-circuit PEN conductor?

If the consequences of an open-circuit PEN conductor pose an unacceptable risk, additional protective measures should be taken; but let's take a look at the practicalities.

Additional Earth electrode

A method of protection that can mitigate the effect of an open-circuit PEN conductor is the connection of an additional earth electrode with a suitably low resistance value to keep the touch voltage below a value deemed acceptable by the designer. The resistance value required can be calculated according to the load of the installation with the following equation:

$$R_A = R_L \, x \, \frac{Up}{(Us - Up)}$$

Table 14.1: IET Guidance Note 5 Protection against electric shock

U_S	is the nominal supply (source) voltage.
C_{max}	is the voltage factor of 1.1 for a supply derived in accordance with the ESQCR.
U_p	is the touch voltage.
R_e	is the external line supply resistance.
R_L	is the load resistance (U_S^2/ wattage). **Note:** No voltage factor is included for the calculation of R_L as this aligns with appliance ratings.
R_A	is the resistance of the additional earth electrode including any parallel earths (e.g. water and gas pipes).
R_B	is the resistance to Earth of the neutral point of the power supply.

▼ **Table 14.1** Additional electrode maximum resistance to Earth, R_A, necessary to reduce the touch voltage to 50 V and 100 V

Load (kW)	R_L (ohms)	R_A (ohms)	
		U_p = 50 V	U_p = 100 V
11	4.8	1.1	3.1
7	7.6	1.8	4.9
3	17.6	4.3	11.5
2	26.5	6.5	17.2
1	52.9	13.0	34.5

Table 14.1, extracted from The IET's Guidance Note 5 *Protection against electric shock*, provides typical values of resistance required to reduce touch voltages to 50 V and 100 V respectively. In practice and depending on load requirements, these resistance values can be difficult to achieve with an earth electrode and will likely require specialist earthing arrangements to be installed, such as earth mats. For example, for an electrical installation with a maximum demand of 7 kW, an earth electrode with a value of 2.1 ohms would be required to keep the touch voltage below 50 volts.

In the Highway's sector when installing street furniture, such as street lighting, traffic lights and road signs connected to a PME earthing arrangement, it is common practice to install an additional earth electrode usually at the feeder pillar and the final column on the circuit.

Further information on calculating the resistance of additional earth electrodes can be found in *IET Guidance Note 5, protection against electric shock*.

TT Earthing arrangement

If the risk of an open-circuit PEN conductor is not acceptable, TT Earthing arrangements are a reliable and effective method. An earth electrode can be installed to create a TT earthing arrangement, either for part of or for the whole installation. BS 7671:2018+A1:2020 generally requires a resistance value of less than 200 ohms, with RCDs installed to provide fault protection. However, installing a TT earthing arrangement does not come without risk, care should be taken to avoid striking buried underground services, such as cables and pipes. Service location drawings will be required to determine the location of existing underground services.

It is also important to ensure requirements are adhered to with respect to minimum separation distance from other earthing systems or buried conductive parts connected to other earthing systems. This is to prevent voltages appearing on the TT earthing arrangement in the event of an open-circuit PEN conductor fault. DNOs have their own requirements, so it is important to check.

Further information can be found in *BS 7430:2011+A1:2015 Code of practice for protective earthing of electrical installations*.

How do I know if an installation I am working on has an open-circuit PEN conductor?

Precautions should be taken before working on any installation to determine if any hazardous touch voltages exist on conductive parts before starting work, this is especially important when working outdoors and in contact with Earth.

It is especially important before disconnecting any earthing or protective bonding conductors to check there is not any diverted neutral current flowing. This can still happen even if the installation is isolated.

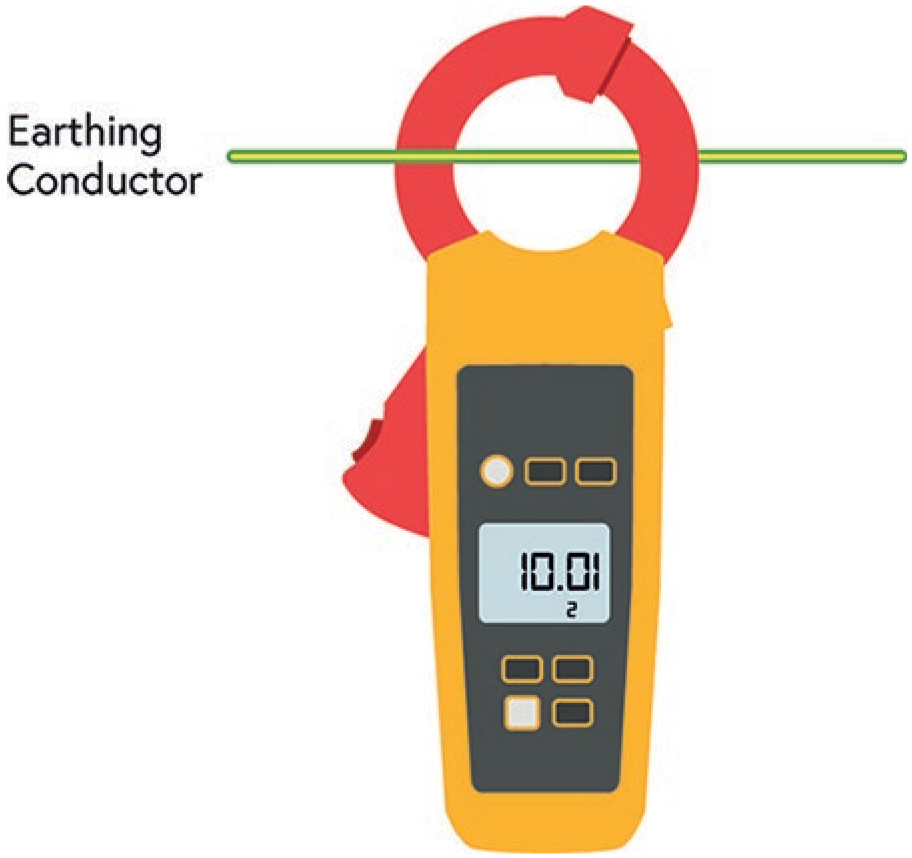
There is not one simple test to indicate if there is an open-circuit PEN conductor or not. There are many variables which will have an influence on the readings, such as the location of the break in the PEN conductor, the ratio of load of the network and if extraneous-conductive-parts are shared with other installations. However, the test methods below may give an indication if there is a problem.

As part of safe isolation procedure, a test to indicate the presence of voltage must be carried out between conductors in the usual manner. A simple non-contact voltage indicating device, more commonly known as a 'volt stick', can also be used to detect voltage and without the need for a reference to Earth. It should be noted that a 'standard' non-contact voltage indicating device, used by most electricians, has an operating threshold in excess of 200 volts AC. Therefore, a touch voltage of 70 volts or more could go undetected and could cause injury. Single-pole voltage indicating devices are available in a variety of different voltages, some can detect voltages of 50 volts or less.

However, it is important to understand that using voltage detection only may not detect the presence of an open-circuit PEN conductor, if the diverted neutral current is returning through an alternate path. It is not until the earth conductor is disconnected, that the circuit is broken and the voltage can be detected and the pipework becomes live. This could be an extremely dangerous situation as there could be several amps flowing depending on the distribution network arrangement.

An indication of diverted neutral currents can be identified with a standard clamp ammeter by testing for a current flowing in the earthing conductor, when the installation is supplying a connected load, as seen in Figure 11. It could also be placed around the pipework within the installation to detect the presence of diverted neutral current.

Figure 11: Clamp ammeter



There may be some leakage current in the installation. Depending on the equipment installed, it is likely to be in the region of a few milliamps. Several amps flowing indicates an open-circuit PEN conductor problem.

The location of the break in the neutral conductor will determine if the diverted neutral current is being 'imported' or 'exported' from the installation. If the current increases with the load of the installation, it indicates a broken PEN conductor on the installation as the neutral current is being 'exported', as seen in Figure 12. Whereas, if diverted neutral current can still be detected in the earthing conductor with the installation isolated, this would indicate diverted neutral current being 'imported' from other installation(s) on the distribution network, as seen in Figure 13.

Figure 12: Exported diverted neutral current

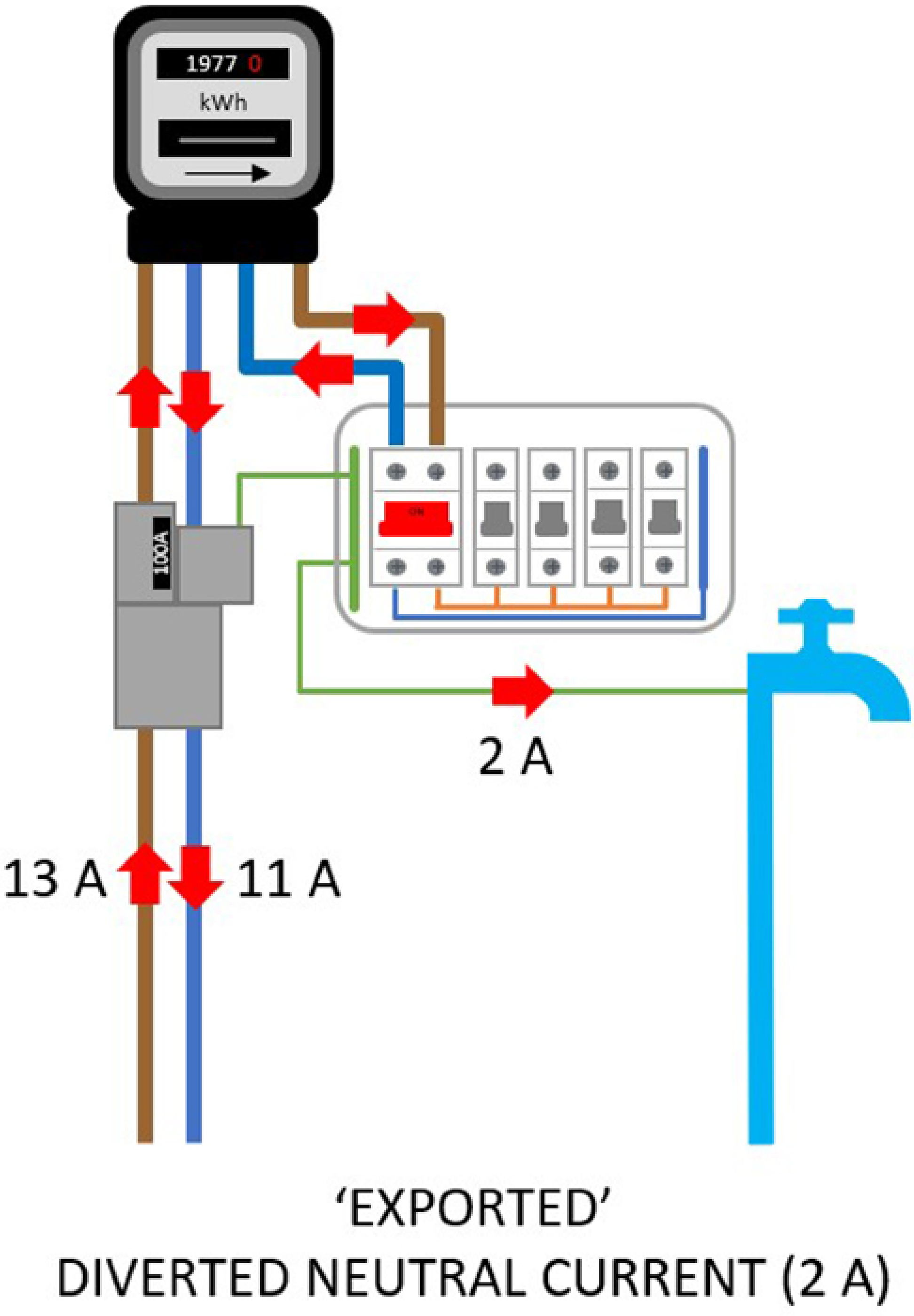
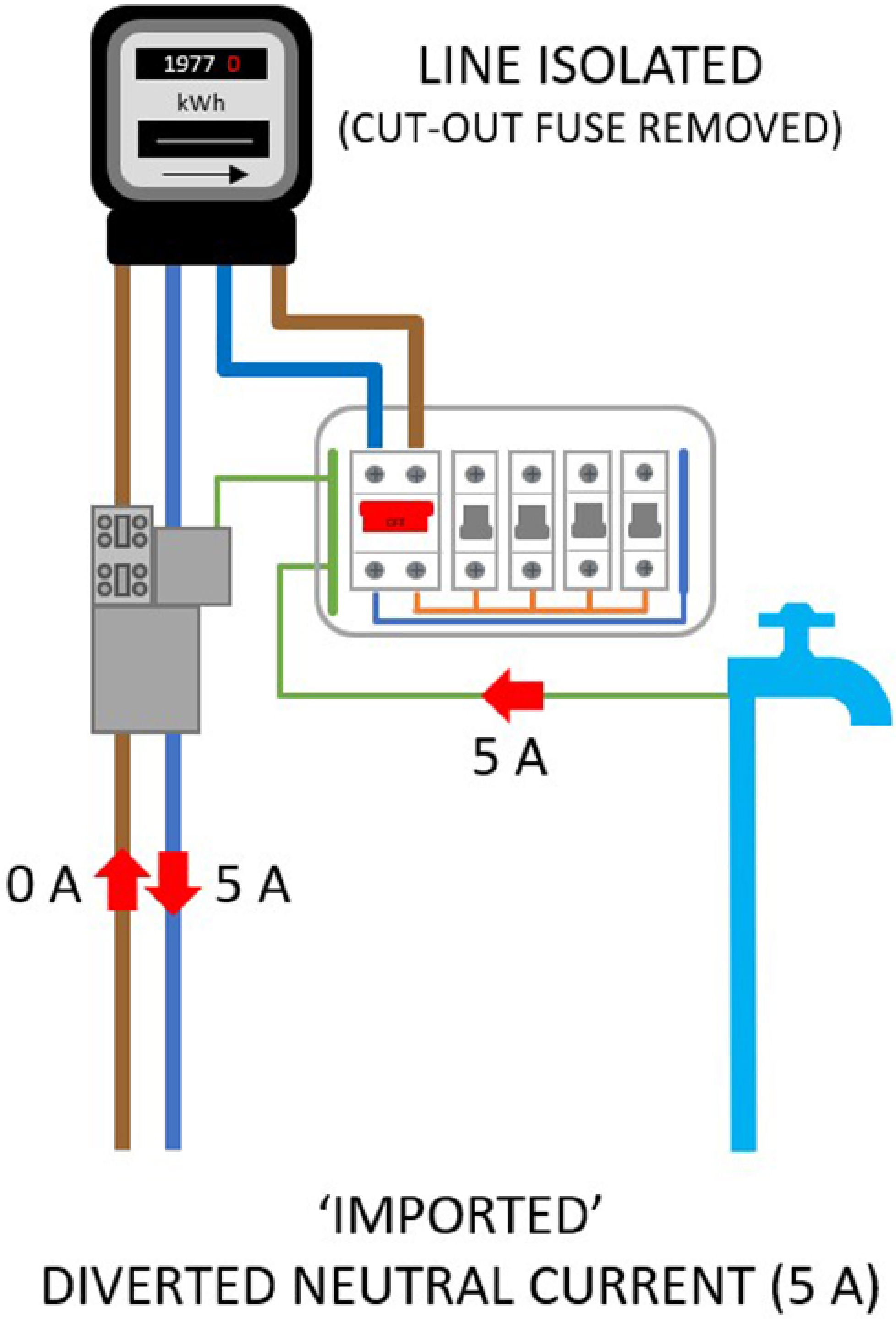


Figure 13: Imported neutral current



What do I do if I suspect an open-circuit PEN conductor?

Diverted neutral currents can cause fires and/or electric shock. When working on an installation, if an open-circuit PEN conductor is suspected, it must be reported to the electrical distributor immediately by telephone, using the emergency number 105. The call will be automatically directed to the local DNO's emergency number for the area.

Summary

Whilst the issue of an open-circuit PEN conductor is the distributor's responsibility, it could have serious consequences to the consumer's electrical installation. Depending on the arrangements of the installation and the potential consequences, additional protective measures should be installed.

PME is suitable for many applications, but caution should be taken where contact with true Earth and PME earthed metalwork is possible.

In order to determine if additional protective measures are required, the designer will need to assess the risk.

Prior to commencing work, carry out testing to determine if conductive parts are live.

If an open-circuit PEN conductor is suspected, call 105 immediately to report an emergency to the local electrical distributor without delay.

The IET SPEN Diverted Neutral Current Demonstration is now live, and readers may find it interesting.

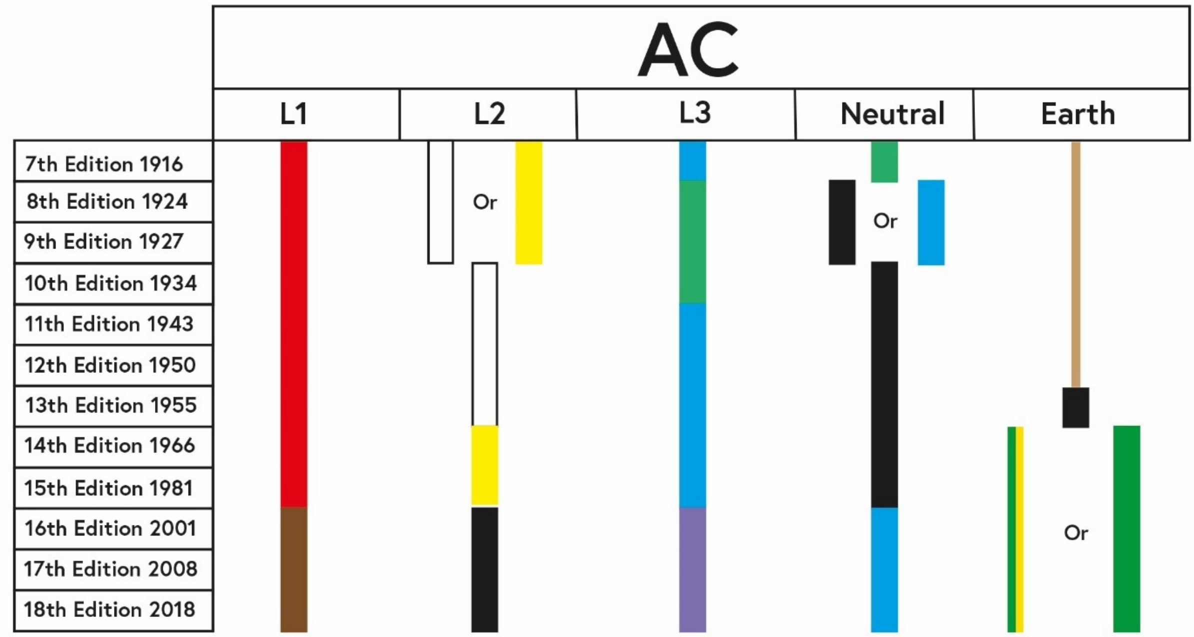
BACK TO THE FORUM

The history of colour identification of conductors

By: Michael Peace CEng MIET

We consider identification of conductors by colour as the norm today, but it wasn't always the case, as prior to 1916 conductors were not typically identified by colour.

Table 1: Colour identification history



This article looks at the changes over the years, and for simplicity looks at the requirements for AC conductors only. Note that DC was previously referred to as 'continuous current', as shown in Figure 1.

Figure 1: Regulation 51 from IEE Wiring Rules 7th Edition 1916

Colours for Conductors.

51. Where colours are used to distinguish the conductors, the following are recommended :—

Continuous current :		
	+	Red
	—	Black
	Neutral	Yellow or white
Alternating current :		
	(a) Phase	Red
	(b) Phase	Yellow or white
	(c) Phase	Blue
	Neutral	Green

Colour identification of conductors was first introduced in 1916 in the 7th Edition of the IEE Wiring Rules and Regulation 51 made recommendations for identifying conductors by colour, as identified in Figure 1.

Back then, the phases were referred to by the letters (a), (b), and (c), and the colours recommended were red, white (or yellow) and blue respectively. It may be a surprise for some to see that green was used to identify the neutral conductor.

The 8th Edition of the IEE Wiring Regulations was entitled 'Regulations for the Electrical Equipment of Buildings' and was issued in 1924. The 'recommendation' for identifying cables by colour became a requirement, Regulation 85 stated '*where colours are used to distinguish the conductors the following shall be employed*'. A note stated that the colours adopted for switchboard connections were different from those specified in Regulation 85 for cables and Regulation 63 N referred to British Standard Specification No. 158, which is 'Marking and arrangement of switchgear busbars, main connections and small wiring'.
Can you imagine how controversial the arguably major changes implemented in the 8th Edition would have been?

Only eight years after the recommendation to identify cables by colour was introduced it became a requirement, but the use of green for neutral is swapped with the L3 phase conductor and blue is used to identify the neutral (it is also worth nothing that black was also an option to identify the neutral conductor).

Figure 2: Table 7 from Regulations for the Electrical Equipment of Buildings 13th Edition 1955

Identification of conductors.

TABLE 7

Identification of bare conductors and cable cores by colour.

	Colour identification of core of rubber-, p.v.c.-, or polythene-insulated cable, or of sleeve or disc to be applied to conductor or cable core	Colour of core of flexible cable other than flexible cord, rubber-insulated
Earth	black	green, or in a 3-core flexible cable, white with green sleeve
A.C. single-phase line or non-earthed	red (or white or blue)*	red
A.C. single- or three-phase, earthed neutral	black	black, or in a 3-core flexible cable, blue
Phase R of 3-phase a.c. circuit	red	red
Phase Y of 3-phase a.c. circuit	white	white
Phase B of 3-phase a.c. circuit	blue	blue
D.C. 2-wire positive	red	red
D.C. 2-wire negative	black	black, or in a 3-core flexible cable, blue
Outer (positive or negative) of d.c. 2-wire derived from 3-wire system	red	red
Middle wire of 3-wire d.c. circuit	black, or in a 3-core cable, blue	black, or in a 3-core flexible cable, blue
Negative of 3-wire d.c. circuit	white	white

* As alternatives to the use of red, if desired, in large installations, up to the final distribution board.

101

The 10th Edition of the IEE Wiring Regulations in 1934 saw the removal of yellow or white as options, with white being the preferred choice for L2. The choice of blue for neutral was also removed. The phase conductors were identified by red, white and green respectively, with black used for the neutral conductor.

The option to use green was removed for a phase conductor in the 11th Edition of the IEE Wiring Regulations in 1943. With the phase colours changing to red, yellow, and blue for phases with black used to identify the neutral.
The 13th Edition of the IEE Wiring Regulations published in 1955, saw the first use of a table for colour identification. 'Table 7, Identification of bare conductors and cable cores by colour' specified the requirements for AC and DC conductors is shown in Figure 2. Funnily enough, the phases are referred to as phase R, Y and B for the first time, but the colours specified were red, white, and blue respectively. Also, the colour for earth was specified for the first time, black was used for fixed wiring although green was used in flexible cords.
The 14th Edition of the IEE Wiring Regulations was published in 1966, (not just a good year for football) some would argue that this edition was 'correct' in terms of colours. These were the days of using good old red, yellow, and blue for phases with black used to identify the neutral conductor.
The Electrical Appliances (Colour Code) Regulations 1969 came into effect on 1 July 1969 and set the scene. Regulation 4 provided the requirements for the colours for 'mains leads' for appliances, brown for live, blue for neutral and green and yellow for earth. Note the requirements for the colour of the 'earth-continuity conductor', *'The covering of the earth-continuity conductor' shall be coloured green and yellow, and in such a way that the covering (on any length of the conductor measuring 15 mm or more) has not more than 70 per cent. (nor less than 30 per cent.) of its surface coloured one of those colours, and has the remainder of its surface coloured the other.'*

Figure 3: Table B.4 from 14th Edition of IEE Wiring Regulation (1966 incorporating Amendments 1970)

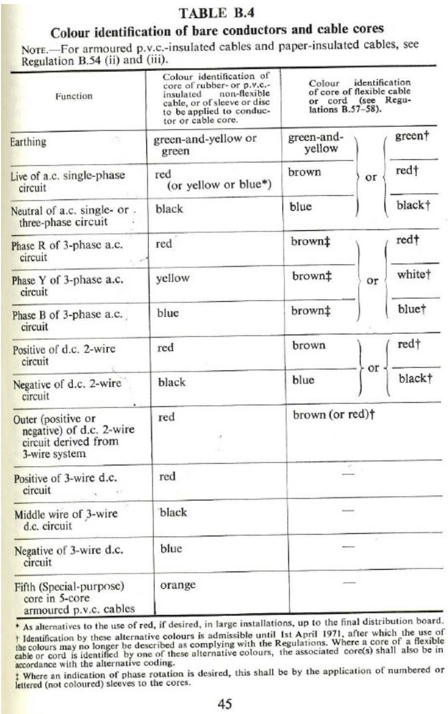


TABLE B.4

Colour identification of bare conductors and cable cores

NOTE.—For armoured p.v.c.-insulated cables and paper-insulated cables, see Regulation B.54 (ii) and (iii).

Function	Colour identification of core of rubber- or p.v.c.-insulated non-flexible cable, or of sleeve or disc to be applied to conductor or cable core.	Colour identification of core of flexible cable or cord (see Regulations B.57–58).		
Earthing	green-and-yellow or green	green-and-yellow	or	green†
Live of a.c. single-phase circuit	red (or yellow or blue*)	brown		red†
Neutral of a.c. single- or three-phase circuit	black	blue		black†
Phase R of 3-phase a.c. circuit	red	brown‡	or	red†
Phase Y of 3-phase a.c. circuit	yellow	brown‡		white†
Phase B of 3-phase a.c. circuit	blue	brown‡		blue†
Positive of d.c. 2-wire circuit	red	brown	or	red†
Negative of d.c. 2-wire circuit	black	blue		black†
Outer (positive or negative) of d.c. 2-wire circuit derived from 3-wire system	red	brown (or red)†		
Positive of 3-wire d.c. circuit	red	—		
Middle wire of 3-wire d.c. circuit	black	—		
Negative of 3-wire d.c. circuit	blue	—		
Fifth (Special-purpose) core in 5-core armoured p.v.c. cables	orange	—		

* As alternatives to the use of red, if desired, in large installations, up to the final distribution board.
† Identification by these alternative colours is admissible until 1st April 1971, after which the use of the colours may no longer be described as complying with the Regulations. Where a core of a flexible cable or cord is identified by one of these alternative colours, the associated core(s) shall also be in accordance with the alternative coding.
‡ Where an indication of phase rotation is desired, this shall be by the application of numbered or lettered (not coloured) sleeves to the cores.

45

The first use of a bi-colour combination was introduced in the 14th Edition of the IEE Wiring Regulations. There was an option to use green and yellow or green to identify 'Earthing' conductors. Note the use of the typographical dagger symbol to signify a note, this symbol was used where the '*' had already been used and it stated that use of these colours were admissible until 1 April 1971.

The use of brown, blue and green/yellow in flexible cables was to align with international standards to facilitate trade. It's important to remember that in those days, appliances in the UK were sold without a plug attached, so standardized colours for flexible cables would have been a very good idea.

The 15th Edition in 1981 saw the title change to 'Regulations for Electrical Installations'. The use of green for protective conductors was not included in the 15th Edition, with green and yellow being the only option. In addition to Table 52A, Regulation 524-1 stated that the colour combination of green and yellow was reserved exclusively for identification of protective conductors.
The 15th Edition required one of the colours in the combination to cover at least 30 % and at most 70 % of the surface being coloured, while the other colour covers the remainder of the surface. In reality, the split of colours is much more likely to be 50/50, this is to prevent rejects in product sampling from being too near the limits. The objective, from a manufacturing point of view, is to ensure both colours are visible when looking at the conductor from any angle.

It is more common to see conductors coloured completely yellow with a green stripe on the surface as identified in Figure 4. This is due to the cost of producing the masterbatch colour, which is a factor when determining the ratio of yellow and green with yellow being more cost effective to produce.

Figure 4: Solid yellow coloured insulation with green stripe

Amendment 2 to the 16th Edition of the IEE Wiring Regulations was published in 2004, and introduced some major changes with regards to identification of conductors. The IET Wiring Matters article, harmonised colours and alphanumeric marking, from Spring 2004 looks at the impact of BS 7671.

The process of international alignment was a long process and it took many hours of discussions to reach agreements for the colours we have today. The story of "the blue neutral" goes as far back as 1973, and who better to tell the story than David Latimer, Chair from 1990 to 2002 of IEC TC 64 International Committee and CENELEC TC 64 European committee for Wiring Regulations.

The use of blue as a neutral was originally adopted from IEC 446 published in 1973, what is now IEC 60446 Basic and safety principles for the man-machine interface, marking and identification, which specified blue shall be used for the neutral with black numerically identified phase conductors. At the time of developing this Standard, the Wiring Regulations Committee were not consulted, possibly because it was a BSI committee which was considering the international proposals and they therefore felt that they had no need to consider the Wiring Regulations which were, at that time, not a standard. It is also possible that the BSI committee thought that it applied only to machine wiring.

At that time the Wiring Regulations Committee and IEE representatives on BSI committees both reported to the Public Affairs Board but there was no liaison between them.

In the light of events it is quite clear that, led by Germany, the continental countries had got together and decided that IEC 446 applied to installations, with, in addition, the appliance manufacturers asking for standardization of flex colours to make things easier for them. So it was that, in Berlin in 1974, the UK were told without warning that flexes were to have a blue neutral and the phase conductor would be blue or brown and which did we want? We clearly could not accept black as a phase conductor (Ireland already used blue and black flexes but used black as the neutral and blue as the phase conductor); I went to an ad-hoc working group to discuss the matter, in French, and there was, of course, no alternative to accepting blue for the neutral and so I opted for brown, on condition that the colours of the fixed installation wiring should also be harmonized and they accepted that.

I went back to the Technical Sub-committee and reported what I had done and told them that we needed to harmonize the phase colours and that the other countries were prepared to accept, within reason, what we proposed and that the only available colours were brown, black and white.

There are 11 colours available, red was used as a protective conductor in Germany and Austria, yellow was used as a protective conductor in Italy and green was used in the UK. Orange is not available because it is either too near yellow or too near red, purple is not available because it is too near red or blue and turquoise is not available because it is too near blue. Pink is not available because it is too near red.

That leaves black, brown, grey, and white.

The technical committee, under the influence of David Bryce and later others, did not have harmonization of cable colours on the agenda until I became the chairman of CENELEC TC 64. In the mid-1990s I prepared a chart which showed all the changes which other European countries had made to their colour coding, all adopting blue as the neutral and most black, brown and white. The chart also showed that the UK uniquely had not made any changes. This galvanized JPEL 64 into discussing the matter and over something like 15 years they argued about it and eventually came up with, guess what, brown, black and white. The cable makers then asked for it to be grey rather than white because it was easier to manufacture and this was put to CENELEC TC 64 (I had by then finished my time as chairman) and it was accepted.

David Latimer

I would like to extend my sincerest thanks and appreciation to David Latimer, for the extraordinary insight behind the discussions of 'the blue neutral', and his contribution to producing this article, not to mention the opportunity of working with him.

Your Electrical Installation Guide awaits!

The aim of the present guide is to provide a clear, practical and step by-step explanation for the complete study of an electrical installation, according to IEC 60364 series and other relevant IEC Standards.

The Electrical Installation Guide is written for professionals who must design, install, inspect, and maintain low-voltage electrical installations in compliance with the standards published by the International Electrotechnical Commission (IEC).

Download your copy now!