The IEE

WIRING MATTERS

Autumn 2005 Issue 16

EARTHING:
Your questions answered

Electrical installations outdoors
Ongoing accuracy of test instruments
PAT testing of equipment

ELECTRICAL INSTALLATIONS OUTDOORS: A SUPPLY TO A DETACHED OUTBUILDING

By John Ware

In this article, we will consider the requirements when supplying a detached garage, or shed, from a dwelling

IN THIS EXAMPLE, the user has requested a small supply be provided to a detached garage to feed lighting and socket-outlets. The supply to the dwelling is PME.

Initially we will assume that the garage contains no extraneous-conductive-parts, such as a metallic water supply or other earthed metalwork.

Two methods of meeting the user's requirements will be discussed:

1. The preferred method, where the supply is taken from a spare way in the existing consumer unit
2. Where the supply to the garage will be spurred from an existing ring final circuit.

At the end of the article we will discuss:

- what to do if the garage has an extraneous-conductive-part such as a metal water pipe
- verifying the existing installation, including the assessment of the earthing and bonding arrangements
- protection of the cables, and
- inspection, testing and certification.

The electrical contractor making the addition to the installation must ensure all the applicable requirements placed by BS 7671 are met including the provision of protection against both direct and indirect contact, the correct selection of protective devices, the correct sizing and routing of cables and the earthing and bonding arrangements.

The requirements of all parts of the Building Regulations must be met and this work is notifiable.

1. Garage is to be supplied from a spare way in the consumer unit and a small two-way distribution board is to be provided in the garage (fig 1).

A suitably sized circuit-breaker should be fitted in the spare way in the dwelling's consumer unit and a cable run out to the small two-way consumer unit in the garage. The two-way consumer unit in the garage should be fitted with circuit-breakers for the two final circuits such as 6A for the lighting circuit and 16A for the socket-outlet circuit. The socket-outlet is very likely to be used to supply portable equipment outdoors and RCD protection must be provided by an RCD with a rated residual operating current not exceeding 30mA. RCD protection should be provided by means such as:

- An RCBO in the dwelling's consumer unit for the garage supply, or
- An RCCB in the dwelling's consumer unit, or
- Selecting a device that includes RCD protection as

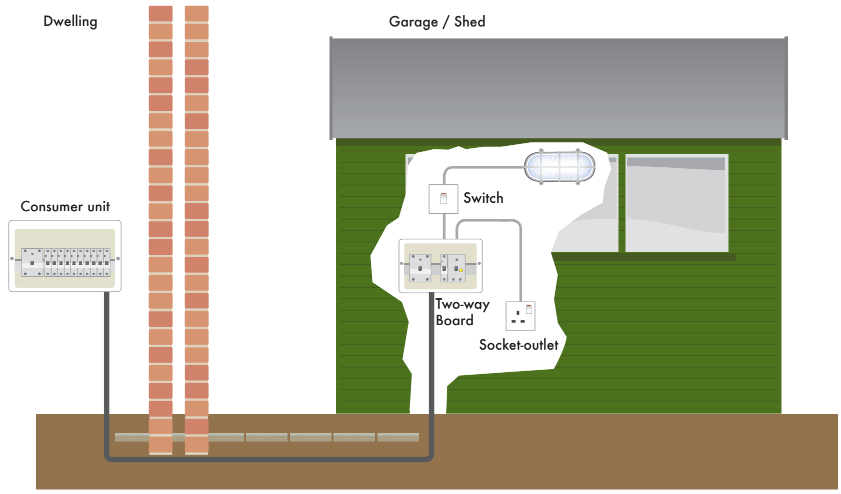

Fig 1: **Garage supply taken from a spare way in the consumer unit**

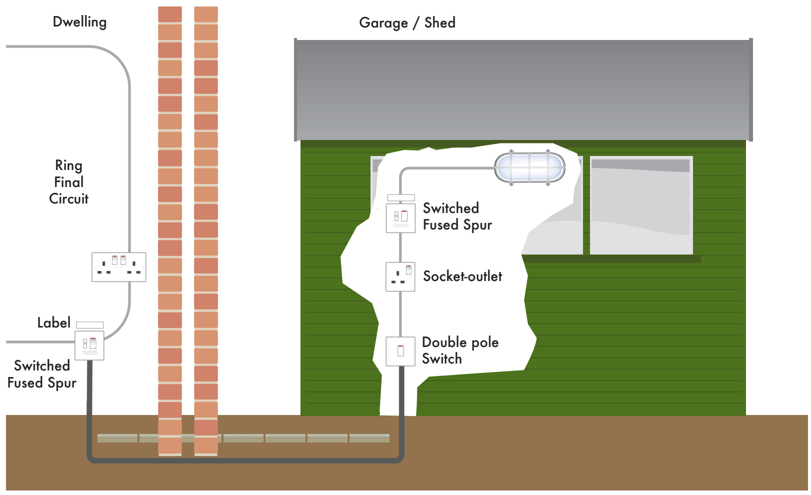

Fig 2: **Garage supply taken from a spur off the downstairs ring final circuit**

A Type B 6kA, 30mA, 1 module, 32A, RCBO

[Illustration courtesy of MK]

the main switch for the small two-way consumer unit in the garage, or

- Protecting the socket-outlet circuit in the garage with an RCBO, or
- Providing an SRCD (a socket-outlet incorporating RCD protection) for the socket-outlet in the garage.

2. Garage is to be supplied from a spur from the ground floor ring final circuit (fig 2).
If the ring final circuit is suitable for the additional load, the garage could be supplied from a fused spur inserted in the ring and a cable run out to the socket-outlet in the garage. In the garage a fused connection unit could be employed for the lighting circuit. Once again RCD protection should be provided for the socket-outlet, which is very likely to supply portable equipment outdoors.

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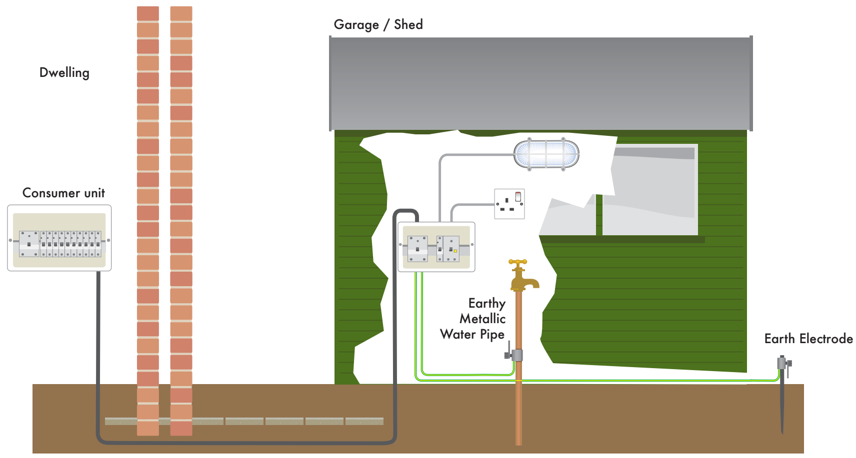

Fig 3: Garage installation made part of a TT system

Where the garage contains an extraneous-conductive-part such as a metal water pipe
Among the options open to the installation designer are to make the installation in the garage part of a TT system or to provide main equipotential bonding to the extraneous-conductive-part in the garage.

TT system

One possibility the electrical contractor may decide upon is to supply the garage from a spare way in the consumer unit and make the small installation in the garage part of a TT system (fig 3). A local earth electrode must be provided at the garage. The metal water pipe must not be used for this purpose (Regulation 542-02-04). To achieve protection against indirect contact for both circuits in the garage an RCD must be employed. Main equipotential bonding will need to be provided at the garage connecting the metal water pipe and any other extraneous-conductive-parts to the earthing terminal in the small distribution board (Regulation 413-02-02). An exposed-conductive-part connected to one means of earthing must not be simultaneously accessible with an exposed-conductive-part connected to another means of earthing (Regulation 413-02-03 refers). Where the installation in the garage is supplied by an armoured cable, the armour or any protective conductor in the cable must not be connected to and must not be simultaneously-accessible with any exposed-conductive-parts in the outbuilding.

Main equipotential bonding

Another possibility is to include the garage within the installation in the main dwelling and provide main equipotential bonding, in accordance with Table 54H (PME conditions apply), in practice this would mean a $10mm^2$ main bonding conductor would be required to connect the water pipe in the garage with the Main Earthing Terminal in the dwelling.

Verify the existing installation

The electrical contractor must verify that the rating and condition of existing equipment, including that of the distributor, should be adequate for the additional load and that the existing earthing and bonding arrangements are also adequate (Regulation 130-07-01 refers). It is possible that the increased load placed by the garage would overload an existing ring final circuit if the second option (above) was adopted.

Protection of the cables

The cable run from the house to the garage must be suitably protected either by being run overhead (see Regulation 412-05-01) or buried in the ground (Regulation 522-06-03 refers). Where cables are installed in areas inhabited by rodents, such as might be found in a garage, the wiring system must be capable of resisting damage caused by gnawing (Regulation 522-10-01).

Inspection, testing and certification

Inspection and testing must be performed to confirm the adequacy of the relevant parts of the existing installation, which will support the changed requirements, the upgrading of the existing installation necessary to support the addition or alteration, and the addition or alteration itself. The requirements for initial verification are contained in Chapter 71 of BS 7671 and further information on the requirements for inspection and testing is given in the IEE Publication Guidance Note 3 Inspection and Testing. Compliance with BS 7671 must be verified for every addition or alteration (Regulation 721-01-02 refers). Requirements for certification and reporting in respect of electrical installations are given in Chapter 74. An Electrical Installation Certificate must be provided to the owner of the installation giving details of the extent of the installation covered by the certificate, with a record of the inspection and the results of the testing (Regulations 741-01-01 and 743-01-01). ■

ONGOING ACCURACY OF TEST INSTRUMENTS

By Mark Coles

When undertaking electrical testing on an installation, how accurate are the test results? The readings obtained from a test instrument when carrying out a measurement of earth-fault loop-impedance or the operating time of an RCD – is the reading shown on the instrument correct? How do I know?

This, the second article in the series of testing & inspection, looks at what can go wrong and how to keep track of an instrument's performance.

The requirements

Anyone can make a mistake, even the most experienced of electricians. For this reason, all electrical installations, alterations and additions should be tested, inspected and subsequently certified prior to handing over to the client for use. The certificate issued describes the current operating parameters and will provide the basis for any future alteration or addition to the installation. The results of testing, contained within the certificate, must be an accurate representation of the installation. The test instrument must, of course, be accurate and the obtained results must be consistent but what are the requirements?

The requirements of BS 7671

BS 7671 requires that every installation shall be inspected and tested to verify that the Regulations have been met before being put into service. The requirements are stated in the following Regulations:

- 133-02-01 On completion of an installation or an addition or alteration to an installation, appropriate inspection and testing shall be carried out to verify so far as is reasonably practicable that the requirements of this standard have been met.

- 711-01-01 Every installation shall, during erection and on completion before being put into service be inspected and tested to verify, so far as is reasonably practicable, that the requirements of the Regulations have been met.

  Precautions shall be taken to avoid danger to persons and to avoid damage to property and installed equipment during inspection and testing.

- 713-01-01 The tests of Regulations 713-02 to 713-13 where relevant shall be carried out and the results compared with relevant criteria.

  The tests of Regulations 713-02 to 713-09 where relevant shall be carried out in that order before the installation is energised.

  If any test indicates a failure to comply, that test and any preceding test, the results of which may have been influenced by the fault indicated, shall be repeated after the fault has been rectified.

Some methods of test are described in Guidance Note 3, Inspection & Testing, published by the Institution of Electrical Engineers. Other methods are not precluded provided they give valid results.

Electrotechnical Assessment Scheme (EAS)

Under the Electrotechnical Assessment Scheme (EAS), Annex 1, *Test Instruments – Calibration requirements*, it is a requirement that the *Enterprise* shall have a suitable system in place to ensure that the accuracy and consistency of all test instruments used for certification and reporting purposes is being maintained.

The Electrotechnical Assessment Scheme (EAS) specifies the minimum requirements against which an electrical installation enterprise, or electrical contractor, may be assessed in order to determine the technical competence of the enterprise. The ownership and management of the EAS was taken over by the IEE and is administered by the EAS Management Committee. An Electrotechnical Assessment Scheme was seen as necessary if the electrical industry and other interested parties were going to support the efforts of the then DETR in introducing electrical safety in to the Building Regulations.

Subsequently, the Office of the Deputy Prime Minister (successor body to the DETR) asked the EAS Management Committee to make recommendations for the technical competence of contractors to carry out electrical installation work in dwellings only without prior notification to building control.

The document 'Minimum Technical Competence of Enterprises that undertake Electrical Installation Work in Dwellings' (MTC) was prepared for this purpose and accepted by the Office of the Deputy Prime Minister. All authorised competent persons schemes are required to ensure that registered firms have the minimum technical competencies.

HSE guidance note GS 38

Electrical testing leads and accessories must be designed to provide adequate protection against danger. The HSE guidance note GS 38, *Electrical test equipment for use by electricians*, gives guidance to electrically competent people, along with advice on test probes, leads, voltage indicating devices and measuring equipment.

What can go wrong with test instruments?

Problems with test instruments are not always immediately obvious so it is important that any irregularities are discovered as early as possible. What can go wrong?

Damage to the instrument

Consider the scenario; a test instrument was calibrated by a calibration house six months ago and is still within the stated 12-month calibration period. It appears to be working well but, unbeknownst to the contractor, five months ago it had a collision with a conduit bender in the back of the firm's van and is now out of calibration. Many, many jobs have been tested with this instrument since the incident occurred and, hence, many certificates and forms have been issued. The certificates and forms, of course, are worthless as the test results contained within would not be representative of the installation. Therefore, it is extremely important that the instrument is regularly assessed.

Connecting leads and the importance of 'nulling'

Often, problems associated with test instruments can be traced to faulty leads. The leads suffer a great deal of punishment, constant flexing and pulling, uncoiling and recoiling, squashed into boxes, etc. As testing probes are repetitively changed and replaced with gripping 'crocodile' clips, over time, contact resistance at the point of connection can increase, which could throw doubt on the results obtained. The springs that maintain the gripping pressure of the crocodile clips can suffer fatigue with age or when not adequately maintained. Foreign bodies and particles, such as brick dust, can clog the connections and moving parts, again, increasing contact resistance. It is well documented that the leads should be 'nulled' prior to use and there is a correct way of nulling.

Fig 1 shows the correct method of connection when nulling test leads. Note that the current flow is directly from lead to lead.

Fig 2 shows the incorrect method of connection when nulling test leads. Note that the current flow is across two hinges. When the leads have been nulled with this method of connection, a value of resistance will be subtracted from the final test result.

Should the leads be re-connected in the correct manner and a measurement of resistance taken, the instrument may give an error message or show a value of 'negative' resistance.

Fig 3 shows that the leads have been nulled with the incorrect method of connection. The instrument shows the value of resistance as 0 Ω.

Fig 4 shows that when the leads are re-connected in the correct manner, a value of 'negative' resistance may be obtained.

The value of negative resistance is due to the

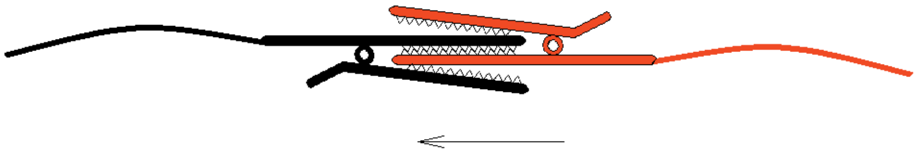

Fig 1: Correct method of connection

Fig 2: Incorrect method of connection

resistance of the hinges subtracted from the value of zero resistance. Hence, in this instance, the hinges would subtract a value of 0.08 Ω from the final result.

Often, 'hybrid' connecting leads are assembled in an ad hoc fashion from the remnants found in the bottom of a drawer. Obviously, these types of leads are extremely unreliable and the manufacturer's recommended leads should always be used. Adequate numbers of leads, along with a selection of the relevant spares should be retained.

Fused connecting leads and internal fuses

The probes and gripping clips of some connecting leads are fitted with fuses. The fuses protect the user and the equipment from high currents that may be unexpectedly encountered. Suitably rated high-breaking capacity (HBC) or high-rupturing capacity (HRC) fuses should be used, usually not exceeding 500mA but the manufacturer's instructions should always be followed.

Test instruments are protected by internal fuses, commonly rated at 440V 10kA. The impedance of the test leads will limit the maximum current that could flow through the internal fuse. In the case of a fault, this current will be limited to 10 kA.

If the manufacturer states that sufficient protection is provided by the fuse within the instrument then fused connecting leads could be omitted.

Batteries

One final point on problems with items of test equipment is batteries. The test instrument may be in good working order but will be unreliable unless fitted with working batteries. Commonly, a low battery symbol will appear in the instrument's display panel, warning that the cells are nearly exhausted. Sufficient quantities of new batteries

Fig 3: Leads nulled in the incorrect manner

Fig 4: Leads reconnected in the correct manner

should be kept with the instrument as spares to be used for this purpose only.

Types of instruments and the associated standards

When deciding which test instruments to purchase, it is important to ensure that the instruments are fit for purpose and fulfil the testing requirements of BS 7671. The basic instrument standard is BS EN 61557: Electrical safety in low voltage distribution systems up to 1000V a.c. and 1500V d.c. Equipment for testing, measuring or monitoring of protective measures. This standard includes performance requirements and requires compliance with BS EN 61010. BS EN 61010: *Safety requirements for electrical equipment for measurement control and laboratory use* is the basic safety standard for electrical test instruments.

The following list shows the test instrument along with the associated harmonised standard:

- Low-resistance ohmmeters — BS EN 61557-4
- Insulation resistance ohmmeters — BS EN 61557-2
- Earth fault loop impedance testers — BS EN 61557-3
- Earth electrode resistance testers — BS EN 61557-5
- RCD testers — BS EN 61557-6
- Voltage indicators — Consult guidance note GS 38 – *Electrical test equipment for use by electricians*

Manufacturers will state which standard, or standards, the instrument conforms to. Other standards or directives that the instrument may conform to, such as emissions and immunity standards EN50081-1: 1992, EN50082-1: 1992 or EN61326-1: 1997 will be stated within the instruments documentation.

Calibration

Historically, many electrical contractors have had test instruments calibrated on an annual basis. The instrument would be sent away to a calibration house and it would arrive back, some time later, with a certificate stating the date of calibration, the time period for which the certificate would be valid along with the findings of the assessment in the form of a table of results. The certificate would state that the instrument was within calibration parameters at that time only; it certainly could not guarantee that the instrument would still be fit for purpose at any time after that.

Ongoing accuracy and maintaining records

Establishing an effective method of proving the accuracy of test instruments is of paramount importance. BS 7671 offers no guidance as to the method that should be employed to ensure consistency and accuracy other than requiring that the results of testing are compared with the relevant criteria.

One method of assessing the on-going accuracy of test instruments is to maintain records, over time, of measurements taken from designated circuits of reference. Before such a system is implemented, the accuracy of each test instrument must be confirmed; this could only be carried out by a formal calibration house. An important point to note is that test leads should be assessed at the time of calibration.

The following examples are methods in which the on-going accuracy of test instruments may be assessed.

In each instance, the designated circuit or socket-outlet must be used for every subsequent assessment.

Fig 5: Proprietary checkbox
[Image courtesy of Seaward Instruments. Model shown– Checkbox 16]

To avoid ambiguity, the relevant testing points should be labelled allowing other operatives, who may not usually be charged with the task of test instrument assessment, to follow the system. Should the results waver by ±5%, the instrument should be recalibrated. If the results remain within the ±5% limits then the instrument could feasibly go for a number of years without the need of calibration assessment by a calibration house. For some businesses, this could be a major cost saving.

It is worth noting that changes to the electrical supply network could affect the actual supply characteristics at the installation.

Many test instrument manufacturers produce proprietary 'checkboxes' (see fig 5) that incorporate many testing functions, such as high and low resistance, earth fault loop impedance and RCD testing.

Such instruments could be used in conjunction with the following systems.

Other equally effective methods of assessment could be utilised.

Resistance Ohmmeters

Once a month, take a measurement of each resistor and record the results in tabulated form. Over a period of time, the table will show how the instrument is performing.

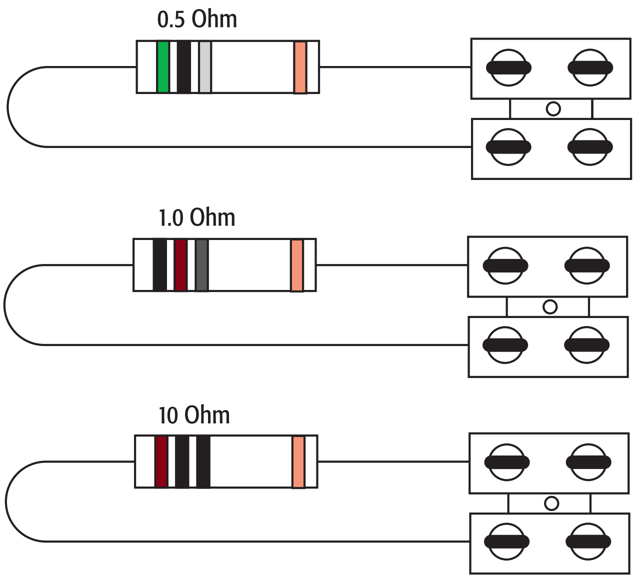

Fig 6: Set of low-value resisters

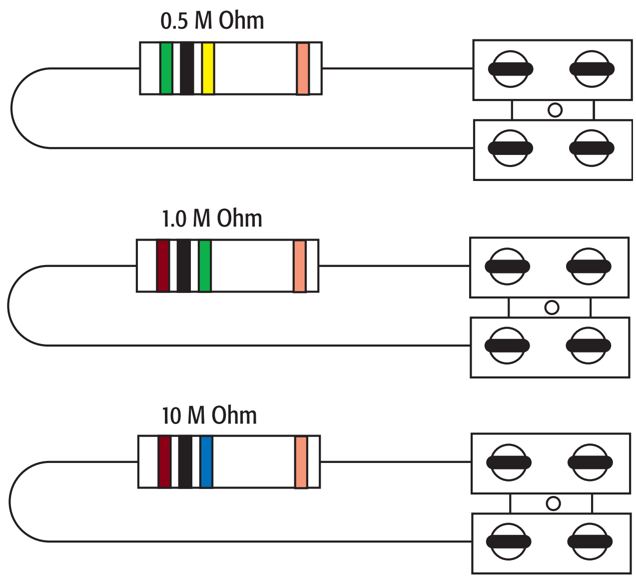

Fig 7: Set of high-value resisters

i.) Low-resistance ohmmeters (fig 6)
A set of suitable resistors could be used to assess the instrument; suitable values could be 0.5Ω, 1.0Ω and 10Ω.
i.) High-resistance (insulation resistance) ohmmeters (fig 7)
A set of suitable resistors could be used to assess the instrument; suitable values could be 0.5MΩ, 1.0MΩ and 10MΩ.

The resistor values chosen merely reflect common bands of resistance that are generally encountered when testing electrical installations. Other values of resistance, indeed, greater numbers of resistors, could be used to assess resistance ohmmeters across the spectrum of resistance.

Earth fault loop impedance test instruments

Earth fault loop impedance test instruments could be checked by carrying out tests on a designated socket-outlet, not RCD protected as unwanted tripping may occur. Once a month, take a measurement of earth fault loop impedance and record the result on a test-record sheet.

RCD test instruments

RCD test instruments could be checked by carrying out a test on an RCD, ideally from a socket-outlet. Once a month, perform an RCD test and record the tripping time on a test-record sheet. The instrument could be set to test at the rated tripping current, IΔn, of the RCD. An example of a testing record sheet is shown (right). ■

Test Instrument Record

Company:	Phil Lament & Sons Electrical Contractors	**Tel:**	01234 56789
Address:	Unit 1, Industrial Estate, Workington, Cumbria	**Mob:**	079 1234 5678
		Fax:	01234 56788

Phil Lament & Sons
Electrical Contractors

Type: EFLI | **Model:** UFO Meters Ltd ELFI 1 | **Serial:** RI 01234 | **Last Calibration:** 9/01/05 | **Asset:** PL01

Month	1	2	3	4	5	6	7	8	9	10	11	12
Date of Test	9/01/04	10/02/04	10/03/04	9/04/04	10/05/04	10/06/04	9/07/04	10/08/04	10/09/04	09/10/04	10/11/04	10/12/04
Result (Ω)	1.01	1.03	1.02	1.04	1.01	1.03	1.02	1.0	1.03	1.02	1.04	1.02
Deviation ±%	N/A	2%	1%	3%	0	2%	1%	1%	2%	1%	3%	1%
Notes:	Designated test socket - labelled as "EFLI - Testing Point" above desk. Batteries replaced 10/03/04. New test leads purchased 10/08/04. (Pete Way - Storeman)											

Type: RCD | **Model:** UFO Meters Ltd RCD 1 | **Serial:** RCD01234 | **Last Calibration:** 9/01/05 | **Asset:** PL02

Month	1	2	3	4	5	6	7	8	9	10	11	12
Date of Test	9/01/04	10/02/04	10/03/04	9/04/04	10/05/04	10/06/04	9/07/04	10/08/04	10/09/04	09/10/04	10/11/04	10/12/04
Result (mS)	49	50	51	60	X	48	49	50	47	46	49	49
Deviation ±%	N/A	2%	4%	18%	X	N/A	2%	4%	2%	4%	2%	2%
Notes:	Designated test socket - labelled as "RCD - Testing Point" below main consumer unit. Instrument sent for repair and re-calibration 12/04/04, returned and put back in service 8/06/04. (Pete Way - Storeman)											

Test Instrument Record

Company:	Phil Lament & Sons Electrical Contractors	**Tel:**	01234 56789
Address:	Unit 1, Industrial Estate, Workington, Cumbria	**Mob:**	079 1234 5678
		Fax:	01234 56788

Phil Lament & Sons
Electrical Contractors

Type: Insulation Resistance | **Model:** UFO Meters IR1 | **Serial:** IR 01234 | **Last Calibration:** 9/01/04 | **Asset:** PL 01

Month	1	2	3	4	5	6	7	8	9	10	11	12
Date of Test	9/01/04	10/02/04	20/03/04	9/04/04	16/05/04	9/06/04	28/07/04	10/08/04	10/09/04	19/10/04	10/11/04	25/12/04
Low Resistance												
0.5Ω	0.5	0.51	0.51	0.52	0.5	0.49	0.5	0.52	0.52	0.52	0.5	0.51
Deviation ±%	N/A	2%	2%	4%	0	2%	0	4%	2%	2%	0	2%
1.0Ω	1.0	1.02	1.0	1.0	1.02	1.01	1.02	1.04	1.03	1.02	1.03	1.01
Deviation ±%	N/A	2%	1%	0	2%	1%	2%	4%	3%	2%	3%	1%
10Ω	10	10	10.05	10.2	10.05	10.09	9.99	9.85	10.01	10.01	10	10.23
Deviation ±%	N/A	0	1%	2%	1%	1%	1%	2%	1%	1%	0	3%
High Resistance												
0.5MΩ	0.5M	0.48M	0.49M	0.48M	0.5M	0.51M	0.52M	0.5M	0.5M	0.51M	0.51M	0.5M
Deviation ±%	N/A	4%	2%	4%	0	2%	4%	0	0	2%	2%	0
1.0MΩ	1.0M	1.0M	1.0M	0.99M	0.98M	1.01M	1.01M	1.04M	1.02M	1.04M	1.03M	1.04M
Deviation ±%	N/A	0	0	2%	2%	1%	1%	4%	2%	4%	3%	4%
10MΩ	10M	10.04M	10M	10M	10M	9.98M	9.99M	9.99M	9.98M	9.97M	9.96M	10M
Deviation ±%	N/A	4%	0	0	0	2%	1%	1%	2%	3%	4%	0
Notes:	Resistor test-board kept in test-meter cupboard. Key held by Phil Mogg, Qualified Supervisor.											

PAT TESTING OF EQUIPMENT HAVING HIGH PROTECTIVE CONDUCTIVE ('LEAKAGE') CURRENT

By Peter Still, Schneider Electric Ltd

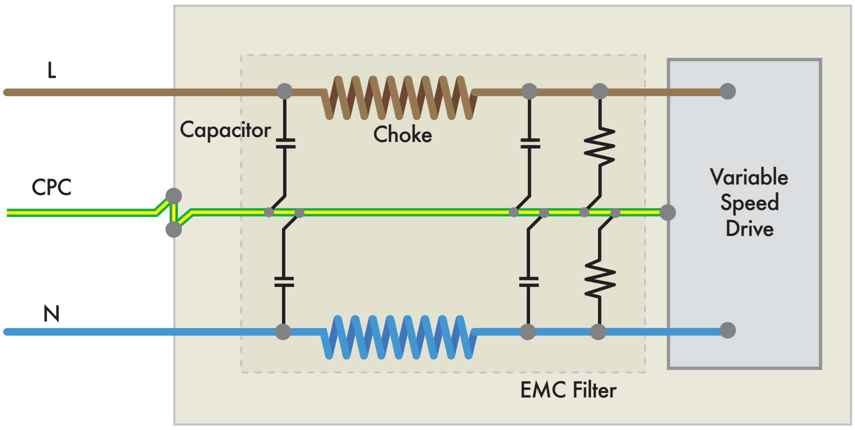

Fig 1: Protective conductor current due to EMC filter

ELECTRICAL EQUIPMENT employing small Variable Speed Drives (VSDs) is reducing in cost and size and is appearing more frequently in equipment for non-industrial use. Examples include fitness machines for use in gymnasiums and potters' wheels used in schools and colleges. The installation of such equipment often falls under the jurisdiction of Local Authorities, who, in many cases, have a standing policy that all items of electrical equipment are subject to Portable Appliance Testing (PAT) before being put into service and annually thereafter. VSDs are fitted with EMC filters, (see fig 1) and, often, there is a significant current flow (around 6 mA) through the filters to earth, under normal conditions. This can be indicated as a failure during an earth leakage current measurement performed as part of a portable appliance test, although it is a normal characteristic of the equipment. Regulation 4(2) of the Electricity at Work Regulations 1989 (EWR) requires that:

"As may be necessary to prevent danger, all systems shall be maintained so as to prevent, so far as is reasonably practicable, such danger."

There is no specific requirement in legislation detailing that in-service maintenance consisting of inspecting or testing equipment must be performed on an annual basis. However the IEE gives guidance in its publication the 'Code of Practice for In-service Inspection and Testing of Electrical Equipment' that a system of maintenance including performing such testing on a routine basis may achieve compliance with Regulation 4(2) of the EWR. The Code of Practice makes it clear that inspection and testing alone will not result in compliance with the law. The requirement is to maintain electrical equipment as necessary to prevent danger. This means that the requirements of the Electricity at Work Regulations are not met simply by carrying out tests on equipment – the aim is to ensure that equipment is maintained in a safe condition.

Paragraph 15.3 of the IEE's guidance is entitled 'In-service tests' and proposes that in-service testing should be preceded by a preliminary inspection, as described in paragraph 15.1 and summarised in table 1 (see p16).

Testing should then be performed and the Code recommends that three tests are made; Earth continuity, insulation resistance and functionality.

Table 1: Preliminary inspection		
1 Disconnection		Determine whether the equipment can be disconnected from the supply and disconnect if, and only if, permission is received. If permission is not received to disconnect the supply do not proceed with any tests and record that the equipment has not been inspected and label accordingly
2 Visual inspection	Appliance	Thoroughly inspect the equipment for signs of damage. Paragraph 14.5 of the Code of Practice gives full details
	Cable	Inspect the connecting cable for damage throughout its length. Look for cuts, nicks, and kinks. If damage has been repaired with insulating tape, the cable should be replaced. Ensure the cable is routed where it will not suffer damage in use
	Plug	Inspect the plug and check that the plug is suitable for the application. For 13 A applications, a resilient plug marked BS 1363A may be necessary if the plug is subjected to harsh treatment
	Socket-outlet or flex outlet	Inspect the socket-outlet or flex outlet of the fixed wiring system for any signs of damage such as cracks and overheating such as discoloration
3 Assessment	Assess if the equipment is suitable for the environment	

Table 2: Testing	
1 Earth continuity test	Earth continuity testing can only be applied to Class I equipment or cables. Paragraph 15.4 of the Code of Practice gives further details of the testing
2 Insulation resistance test	For many types of appliance, insulation resistance is generally checked by applying a test voltage and measuring the resistance. This test may not always be suitable and the protective conductor/touch current measurement of paragraph 15.6 of the Code of Practice may be a more appropriate alternative
3 Functional check	In its simplest form a functional check is a check to ensure that the appliance is working properly

Note that some electrical test devices apply tests that are inappropriate and may even damage equipment containing electronic circuits, such as VSDs, possibly causing degradation of safety. In particular, while the Code of Practice includes insulation resistance tests, equipment should not be subjected to dielectric strength testing (known as hi-pot testing or flash testing) because this may damage insulation and may also indirectly damage low voltage electronic circuits unless appropriate precautions are taken.

The limit stated in the Code of Practice for insulation resistance for Class I equipment when tested at 500V d.c. is 1 megohm. An item of equipment without input filters generally has an insulation resistance greater than 50 megohm and the use of the insulation test in preference to the leakage current measurement will therefore allow the equipment to be put into service safely.

Looking in detail at the insulation resistance test, for some types of equipment it may not be appropriate to perform an insulation test at 500 V d.c. because of the risk of damage to the electronic components in the equipment. The testing engineer may then decide to perform the protective conductor/touch current measurement, which is an alternative to the in-service insulation test for use if the insulation resistance test either cannot be carried out or gives suspect test results. The protective conductor current test consists of measuring the current flowing from live parts to earth for Class I equipment, or from live parts to accessible surfaces of Class II equipment.

For practical purposes the test voltage is the supply voltage and the current should be measured within five seconds after the application of the test voltage, the supply voltage, and should not exceed the

Table 3: Maximum permissible protective conductor current	
Appliance Class	Maximum Current note (1)
Portable or hand-held Class I Equipment	0.75 mA
Class I heating appliances	0.75 mA or 0.75 mA per kW, whichever is the greater, with a maximum of 5 mA
Other Class I equipment	3.5 mA
Class II equipment	0.25 mA
Class III equipment	0.5 mA

Notes to Table 3:

1. The values specified above are doubled:
   - if the applicance has no control device other than a thermal cut-out, a thermostat without an "off" position or an energy regulator without an 'off' postion.
   - if all control devices have an "off" position with a contact opening of at least 3 mm and disconnection in each pole.

2. Equipment with a protective conductor current designed to exceed 3.5 mA shall comply with the requirements of paragraph 15.12.

3. The nominal test voltage is:
   - 1.06 times rated voltage, or 1.06 times the upper limit of the rated voltage range, for applicanes for d.c. only, for single-phase applicances and for three-phase appliances which are also suitable for single-phase supply, if the rated voltage or the upper limit of the rated voltage range does not exceed 250V;
   - 1.06 times rated line voltage divided by 1.73, or 1.06 times the upper limit of the rated voltage range divided by 1.73 for other three-phase applicances.

Table 4: Additional requirements for equipment having higher leakage current		
Permanently wired or supplied by an industrial plug and socket-outlet	The equipment shall be permanently wired to the fixed installation, or be supplied by an industrial plug and socket to BS EN 60309-2 (BS 4343)	
Protective conductors	The equipment should have internal protective conductors of not less than 1.0 mm^2 cross-sectional area (based on clause 5.2.5 of BS EN 60950), and	
Label	The equipment should have a label bearing the following warning or similar wording fixed adjacent to the equipment primary power connection (based on clause 5.1.7 of BS EN 60950)	**WARNING** **HIGH LEAKAGE CURRENT** Earth connection essential before connecting the supply

values indicated in table 3.

However, equipment employing a VSD will, in most cases, have a leakage current greater then 3.5mA due to the filters at the input and hence will be unsuccessful when performing this test. Although this does not show the equipment to be unsafe if this test is performed, the value of current should be recorded since an increased current in any future tests can be due to deterioration of components within the equipment.

The engineer performing the tests will then have to decide if the equipment is still safe for service and will make his judgement based on whether the protective conductor current increased from the previously recorded value or from the manufacturer's advised maximum current. The engineer must then verify that such equipment with a protective conductor current designed to exceed 3.5mA complies with the requirements shown in table 4.

Further precautions need to be taken for equipment with a protective conductor current exceeding 10mA, see Section 607 of BS 7671.

When appliances have high protective conductor currents, substantial electric shocks can be received from exposed-conductive-parts and/or the earth terminal if the appliance is not earthed. It is most important that appliances with such high protective conductor currents are properly connected with earth before any supply is connected.

Connection to the mains supply via a portable cord set which does not meet EN 60309-2, such as a 13A plug and socket-outlet, is therefore not acceptable. The supply connection to the fixed installation will need to be made using a fused spur connection unit to BS 1363-4, or a plug and socket-outlet in accordance with BS EN 60309-2 and BS 7671. ■

EARTHING:
YOUR QUESTIONS ANSWERED

By Geoff Cronshaw

What are earthed and unearthed systems?
What are the requirements of BS 7671?
What are the advantages and disadvantages of the various types of earthing systems?

This article, which is based on IEE Guidance notes, is intended to provide information that it is hoped will prove helpful.

BS 7671 lists five types of earthing system:
TN-S, TN-C-S, TT, TN-C, and IT.
T = Earth (from the French word Terre)
N = Neutral
S = Separate
C = Combined
I = Isolated (The source of an IT system is either connected to earth through a deliberately introduced earthing impedance or is isolated from Earth. All exposed-conductive-parts of an installation are connected to an earth electrode.)

When designing an electrical installation, one of the first things to determine is the type of earthing system. The distributor will be able to provide this information.

The system will either be TN-S, TN-C-S (PME) or TT for a low voltage supply given in accordance with the Electricity Safety, Quality and Continuity Regulations 2002. This is because TN-C requires an exemption from the Electricity Safety, Quality and Continuity Regulations, and an IT system is not permitted for a low voltage public supply in the UK because the source is not directly earthed. Therefore TN-C and IT systems are both very uncommon in the UK.

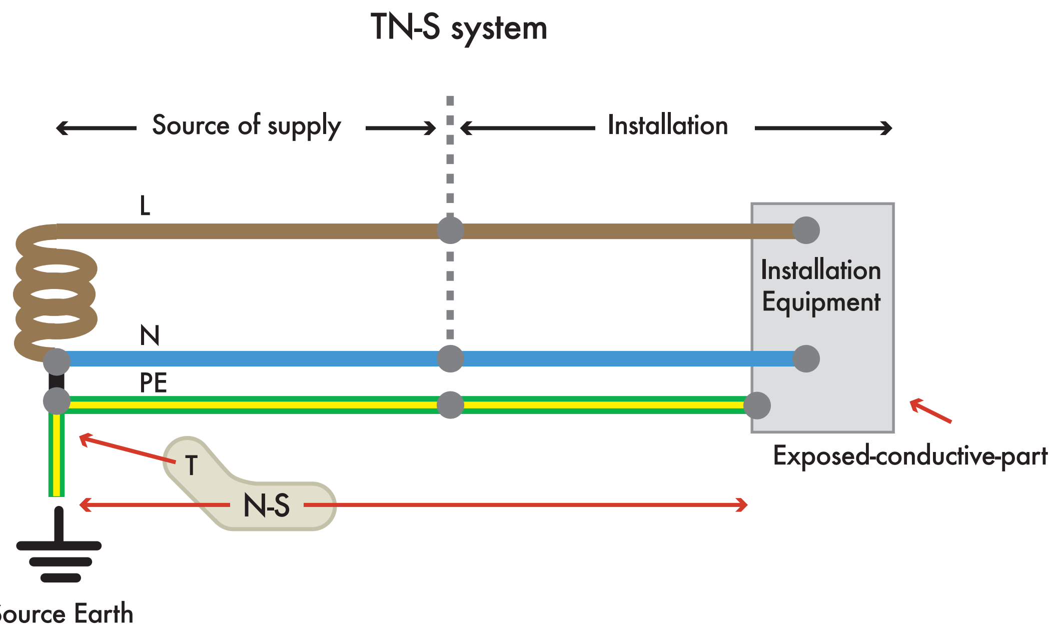

Fig 1: TN-S system

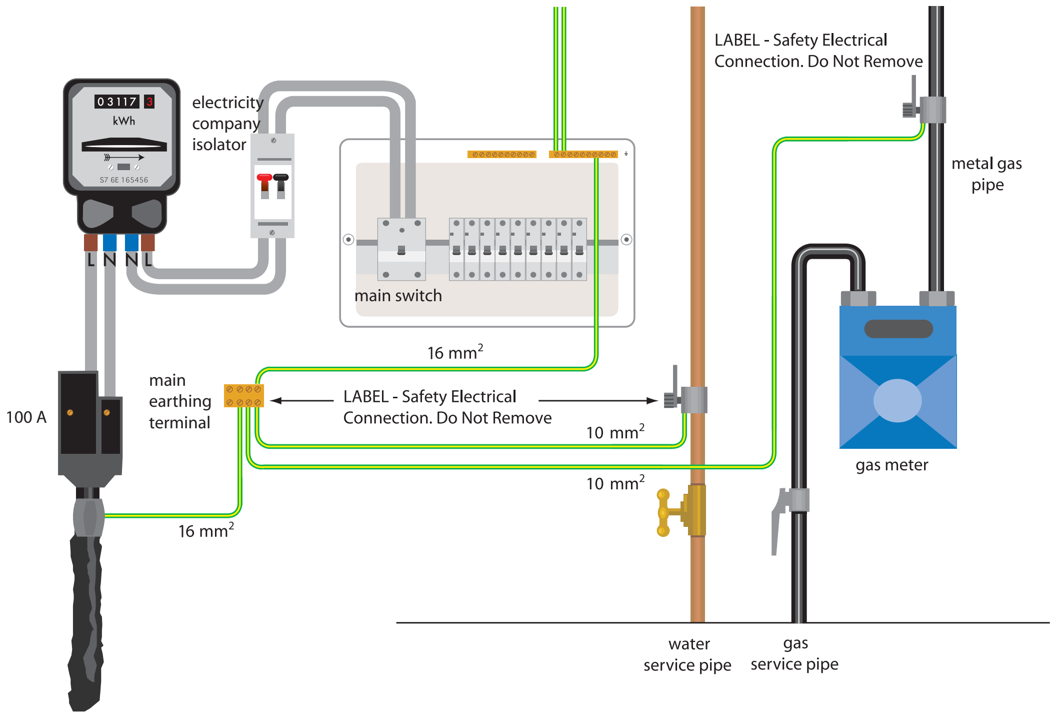

Fig 2: Cable sheath earth (TN-S system). Schematic of earthing and main equipotential bonding arrangements. Based on 25 mm^2 tails and selection from Table 54G.
Note: An isolator is not always installed by the electricity distributor.

1. Overview of earthing systems

1.1 TN-S system earthing

A TN-S system, shown in fig 1, has the neutral of the source of energy connected with earth at one point only, at or as near as is reasonably practicable to the source, and the consumer's earthing terminal is typically connected to the metallic sheath or armour of the distributor's service cable into the premises.

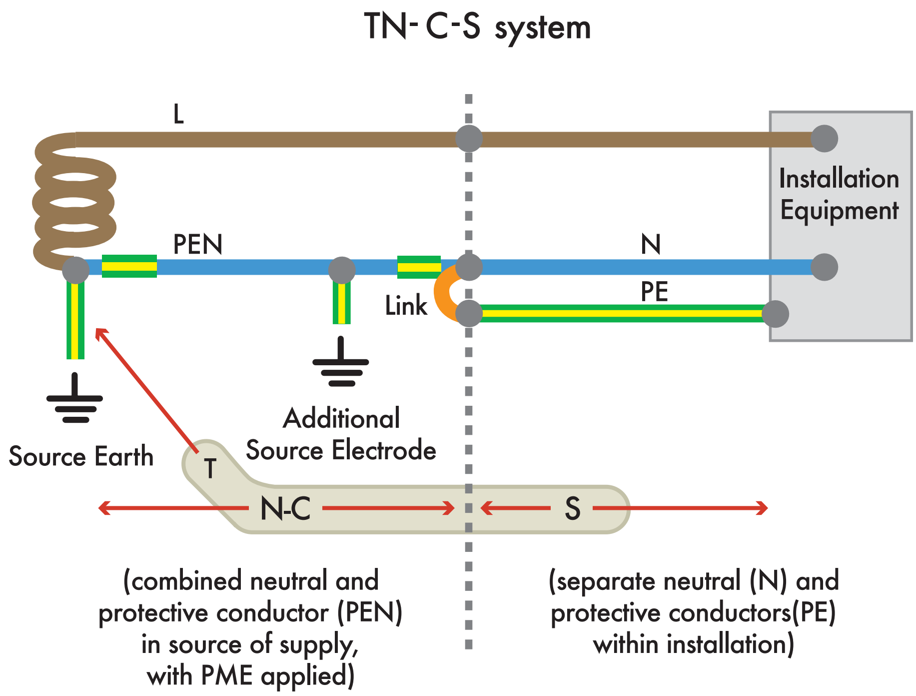

Fig 3: TN-C-S system

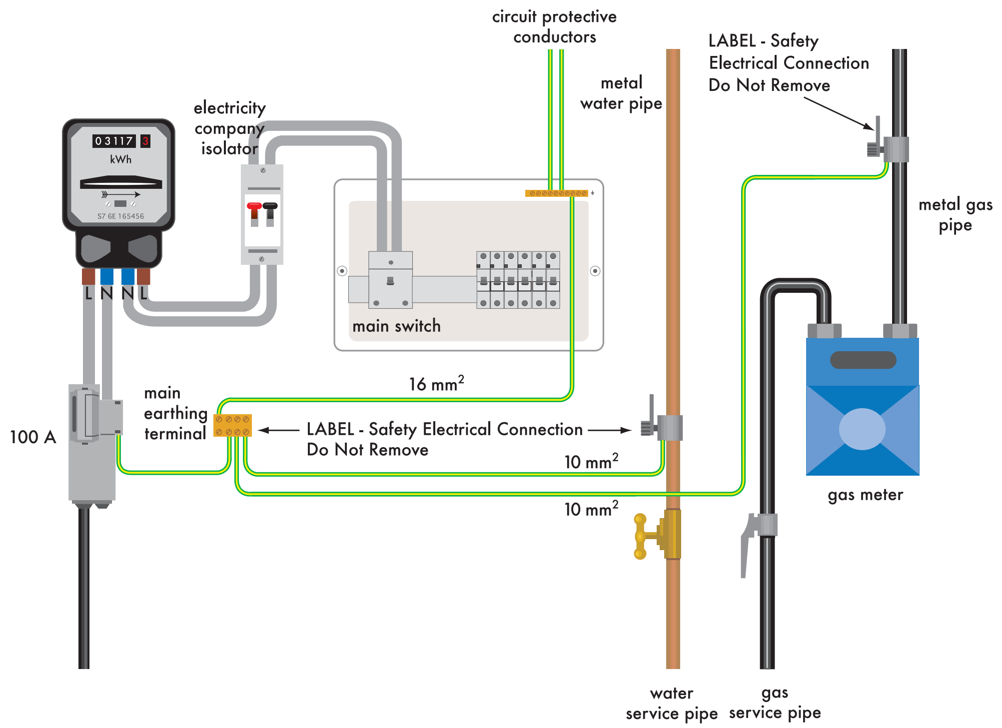

Fig 4: PME supply (TN-C-S system). Schematic of earthing and main equipotential bonding arrangements. Based on 25 mm^2 tails and selection from Table 54G. Note: An isolator is not always installed by the electricity distributor.

1.2 TN-C-S system earthing

A TN-C-S system, shown in fig 3, has the supply neutral conductor of a distribution main connected with earth at source and at intervals along its run. This is usually referred to as protective multiple earthing (PME). With this arrangement the distributor's neutral conductor is also used to return earth fault currents arising in the consumer's installation safely to the source. To achieve this, the distributor will provide a consumer's earthing terminal which is linked to the incoming neutral conductor.

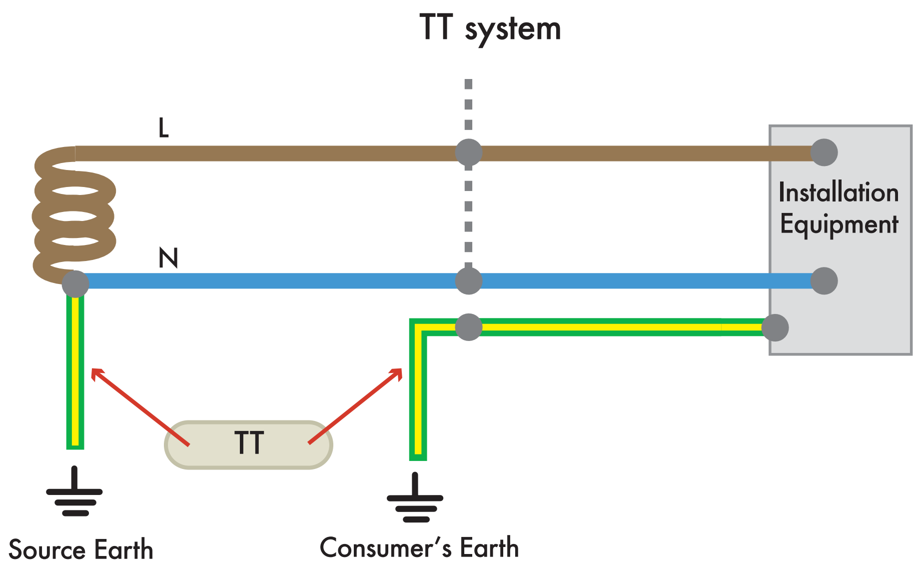

Figure 5: TT system

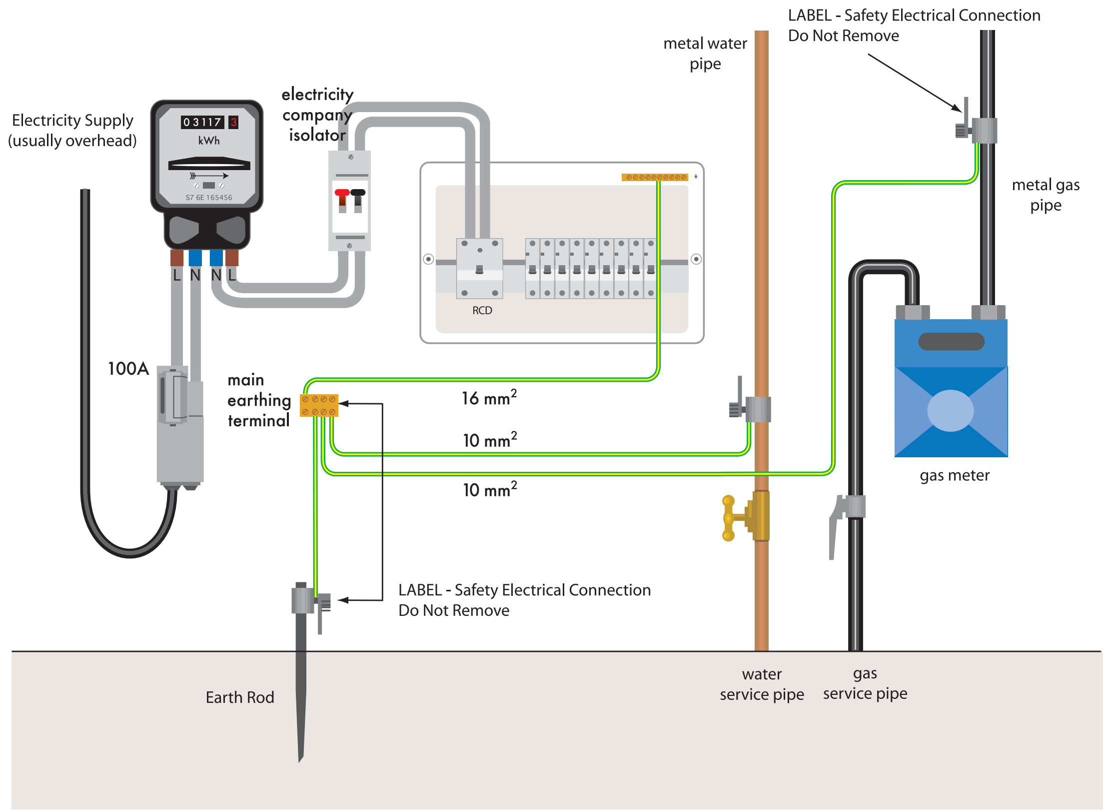

Figure 6: No earth provided (TT system). Based on 25 mm² tails and selection from Table 54G. Note: An isolator is not always installed by the electricity distributor. Manufacturers recommendations should be sought with regards to connections to earth electrodes.

1.3 TT system earthing

A TT system, shown above, has the neutral of the source of energy connected as for TN-S, but no facility is provided by the distributor for the consumer's earthing. With TT, the consumer must provide their own connection to earth, i.e. by installing a suitable earth electrode local to the installation.

2. Requirements of BS 7671

Earth electrodes

BS 7671 recognises a wide variety of types of earth electrode. Regulation 542-02-01 lists the types recognised which include earth rods, earth plates and underground structural metal work.

The soil resistivity of the ground is probably the single most important factor in the determination of the type of earth electrode. Rods can only be as effective as the contact they make with the surrounding material. Thus, they should be driven into virgin ground, not disturbed (backfilled) ground. Where it is necessary to drive two or more rods and connect them together to achieve a satisfactory result, the separation between rods should be at least equal to their combined driven depth to obtain maximum advantage from each rod. In some locations low soil resistivity is found to be concentrated in the topsoil layer, beneath which there may be rock or other impervious strata which prevents the deep driving of rods, or a deep layer of high resistivity. Only a test or known information about the ground can reveal this kind of information. In such circumstances, the installation of copper earth tapes, or pipes or plates, would be most likely to provide a satisfactory earth electrode resistance value.

Whatever form an earth electrode takes, the possibility of soil drying and freezing, and of corrosion, must be taken into account. Preferably, testing of an earth electrode should be carried out under the least favourable conditions, i.e. after prolonged dry weather. Further information on earthing principles and practice can be found in BS 7430 : 1998 *'Code of Practice for Earthing'*.

Earthing conductors

Earthing conductors which are defined in BS 7671 as a protective conductor connecting the main earthing terminal of an installation to an earth electrode or other means of earthing must be adequately sized particularly where buried partly in the ground, and be of suitable material and adequately protected against corrosion and mechanical damage.

The size of an earthing conductor is arrived at in basically the same way as for a circuit protective conductor, except that Table 54A of BS 7671 must be applied to any buried earthing conductor. For a TN-C-S (PME) supply, it should be no smaller than the main bonding conductors.

Sizing of circuit protective conductors

There are several factors which may influence or determine the size required for a circuit protective conductor. A minimum cross-sectional area of 2.5 mm^2 copper is required for any separate circuit protective conductor, i.e. one which is not part of a cable or formed by a wiring enclosure or contained in such an enclosure.

An example would be a bare or insulated copper conductor clipped to a surface, run on a cable tray or fixed to the outside of a wiring enclosure. Such a circuit protective conductor must also be suitably protected if it is liable to suffer mechanical damage or chemical deterioration or be damaged by electro-dynamic effects produced by passing earth fault current through it. If mechanical protection is not provided the minimum size is 4 mm^2 copper or equivalent.

BS 7671 provides two methods for sizing protective conductors including earthing conductors (see also Table 54A). The easier method is to determine the protective conductor size from Table 54G but this may produce a larger size than is strictly necessary, since it employs a simple relationship to the cross-sectional area of the phase conductor(s).

The second method involves a formula calculation. The formula is commonly referred to as the 'adiabatic equation' and is the same as that used for short-circuit current calculations (see Regulation 434-03-03). It assumes that no heat is dissipated from the protective conductor during an earth fault and therefore errs on the safe side. Even so, application of the formula will in many instances result in a protective conductor having a smaller csa than that of the live conductors of the associated circuit. This is quite acceptable.

Regulation 543-01-03 states:
The cross-sectional area, where calculated, shall be not less than the value determined by the following formula or shall be obtained by reference to BS 7454.

$$\mathbf{S} = \frac{\sqrt{\mathbf{I^2 t}}}{\mathbf{k}}$$

where:

S is the nominal cross-sectional area of the conductor in mm^2.

I is the value in amperes (rms. for a.c.) of fault current for a fault of negligible impedance, which can flow through the associated protective device, due account being taken of the current limiting effect of the circuit impedances and the limiting capability (I^2 t) of that protective device.

Account shall be taken of the effect, on the resistance of circuit conductors, of their temperature rise as a result of overcurrent - see Regulation 413-02-05.

t is the operating time of the disconnecting device in

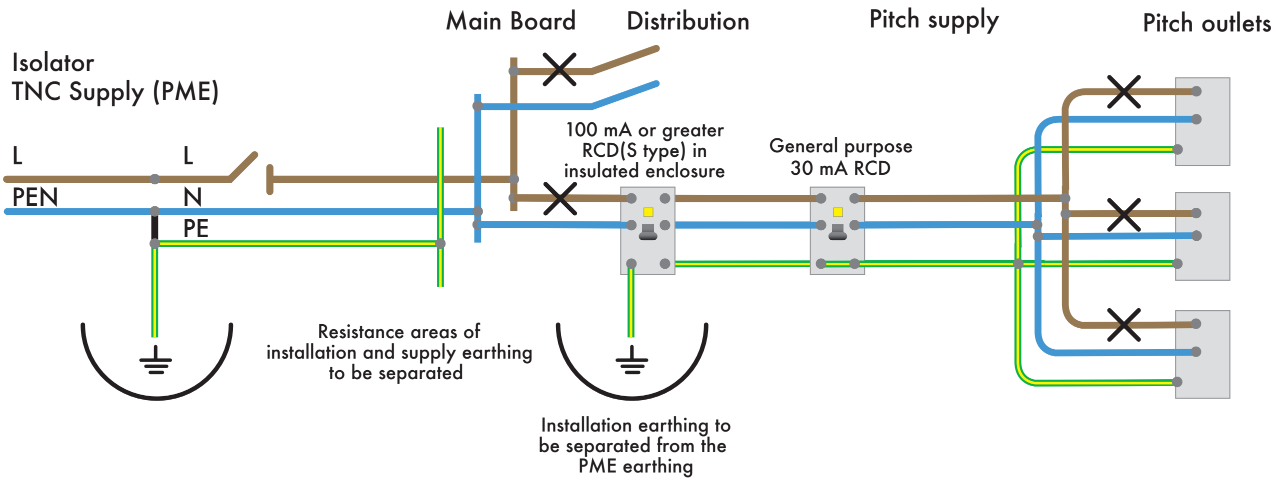

Figure 7: Typical site distribution for a PME supply, separation from PME earth at main distribution board

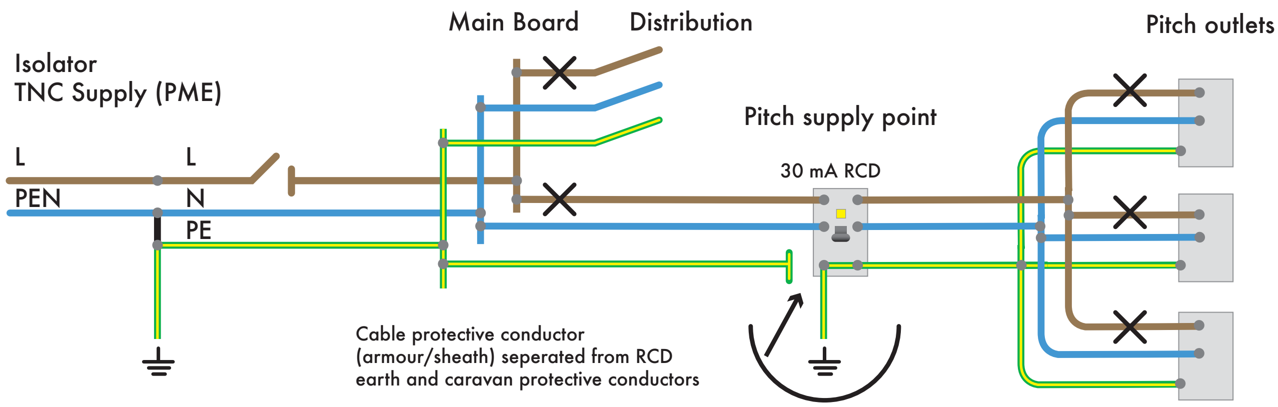

Figure 8: Typical site distribution for a PME supply, separation from PME earth at pitch supply point

seconds corresponding to the fault current I amperes. **k** is a factor taking account of the resistivity, temperature coefficient and heat capacity of the conductor material, and the appropriate initial and final temperatures.

3.0 Type of earthing systems, advantages and disadvantages

3.1 Protective multiple earthing (PME).

Such a supply system is described in BS 7671 as TN-C-S. The advantage of this system is that it provides an effective and reliable method of providing customers with an earth connection. For example the maximum Ze specified by a distributor is 0.35 Ω for TN-C-S supplies compared to 0.8 Ω for TN-S supplies.

However, under certain supply system fault conditions (PEN conductor of the supply becoming open circuit external to the installation) a potential can develop between the conductive parts connected to the PME earth terminal and the general mass of earth. However, since there are multiple earthing points on the supply network and bonding is provided within the building complying with BS 7671, the risk is considered to be small.

Special Locations

The Electricity Association publications provides guidance on PME systems. Whilst PME systems provide an effective and reliable earth connection precautions need to be taken when dealing with special locations. For example Regulation 9(4) of the Electricity Safety, Quality and Continuity Regulations does not allow the combined neutral and protective conductor to be connected electrically to any metalwork in a caravan or boat. This prevents PME terminals being used for caravans or boat mooring supplies, although they may be used for fixed premises on the sites, such as the site owner's living premises and any bars or shops, etc.

Petrol filling stations are another area where precautions need to be taken. The reference publication is "Guidance for the design, construction, modification and maintenance of petrol filling stations", published by the Association for Petroleum and Explosives Administration (APEA) and the Institute of Petroleum, which recommends a TT supply for hazardous areas.

A separate earth electrode and RCD or other alternative arrangement is required to ensure the segregation of petrol filling area earthing and that of the PME earth of the distribution network. A PME earth may be used for permanent buildings such as shops and restaurants.

Also, mines and quarries are another area. A supply taken to an underground shaft, or for use in the production side of a quarry, must have an earthing system which is segregated from any system bonded to the PME terminal.

Finally, because of the practical difficulties in bonding all accessible extraneous-conductive-parts electricity distribution companies might not provide a PME earth to agricultural and horticultural installations and construction sites.

3.2 TT system

With TT, the consumer must provide their own connection to earth, i.e. by installing a suitable earth electrode local to the installation. The circumstances in which a distributor will not provide a means of earthing for the consumer are usually where the distributor cannot guarantee the earth connection back to the source, e.g. a low voltage overhead supply, where there is the likelihood of the earth wire either becoming somehow disconnected or even stolen.

A distributor also might not provide means of earthing for certain outdoor installations, e.g. a construction site temporary installation, leaving it to the consumer to make suitable and safe arrangements for which they are fully responsible. The electricity distributor is required to make available his supply neutral or protective conductor for connection to the consumer's earth terminal, unless inappropriate for reasons of safety (Reg 24 of ESQCR). Construction site, farm or swimming pool installations might be inappropriate unless additional precautions are taken, such as an additional earth electrode.

3.3 TN-S system

A TN-S system has the neutral of the source of energy connected with earth at one point only, at or as near as is reasonably practicable to the source and the consumer's earthing terminal is typically connected to the metallic sheath or armour of the distributor's service cable into the premises or to a separate protective conductor of, for instance, an overhead supply.

Large consumers may have one or more HV/LV transformers dedicated to their installation and installed adjacent to or within their premises. In such situations the usual form of system earthing is TN-S.

More information on earthing and bonding is available in IEE Guidance Note 5. Also more information on special locations is available in IEE Guidance Note 7. ■