MULTIPLE EARTH ELECTRODES IN A TT SYSTEM FOR A DWELLING

By Mark Coles

When installing an earth electrode it may not be easy to obtain an acceptably low value of earth electrode resistance, RA. This article looks at installations forming part of a TT system, the installation of the earth electrode and the use of multiple electrodes to achieve an acceptably low value of R_A.

What is a TT System?

A TT system is defined in BS 7671 as a system having one point of the source of energy directly earthed, the exposed conductive-parts of the installation being connected to earth electrodes electrically independent of the earth electrodes of the source, see figure 1.

An example of the layout of an installation forming part of a TT system in a dwelling is shown in figure 2.

Definitions of common earthing related terms

Figure 3, overleaf, is a list of terms used within this article.

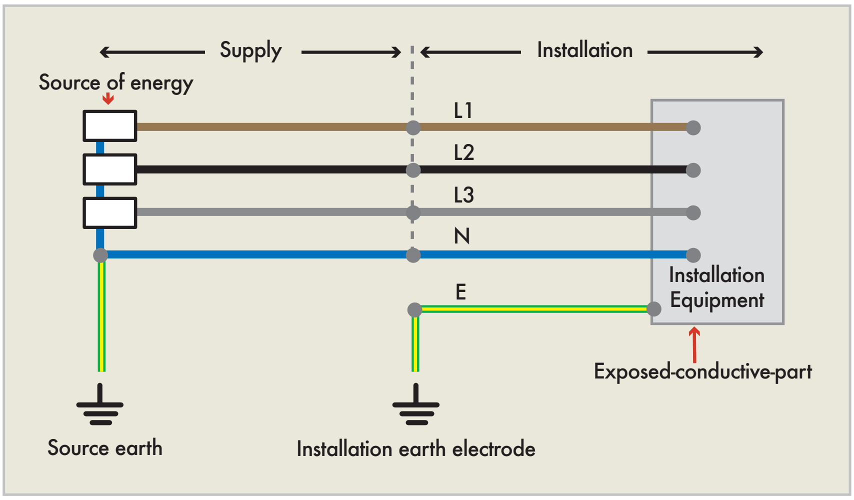
The need for a TT System

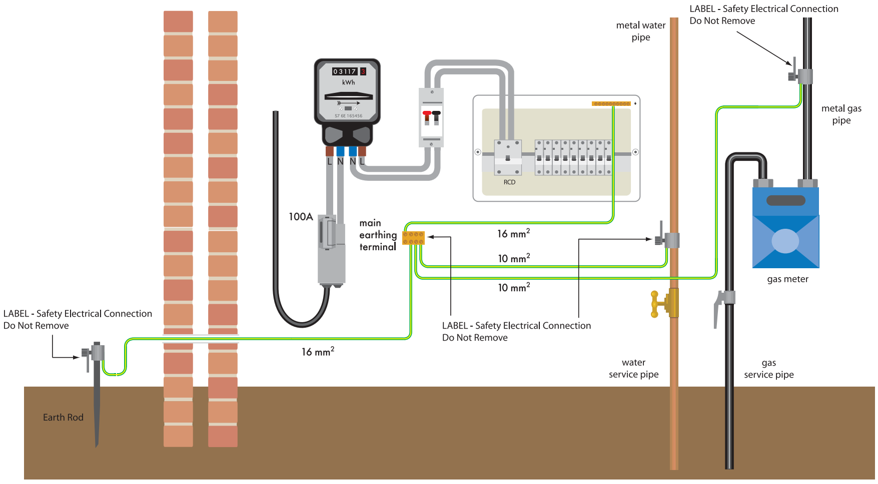
There are occasions when the electrical supplier will not provide a means of earthing with a new electrical supply to a building. This is quite acceptable, as regulation 24 (4) the Electricity, Safety, Quality and Continuity Regulations (ESQCR) states that if the supplier can reasonably conclude that it is appropriate, for reasons of safety, then a means of earthing could be refused for a new connection.

An example of this could be a house situated in the countryside which receives its electrical supply from an overhead line. The overhead supply consists simply of a phase and a neutral conductor. The supplier may state that, for safety reasons, a means of earthing for the consumer's installation will not be provided.

The owner of the installation must then provide their own means of earthing. In this instance, an earth electrode, or electrodes, could be installed to provide the means of earthing and, hence, the installation becomes part of a TT system.

TT system



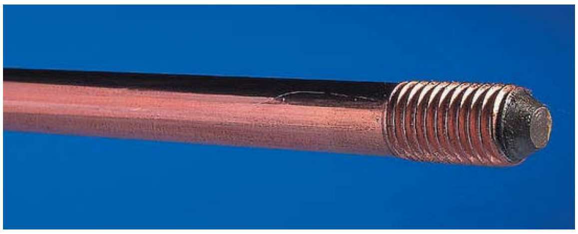


Top, Fig 1: TT system
Above, Fig. 2: Example of a TT system in a dwelling

The legal requirements

The Electricity at Work Regulations 1989 require that

Adiabatic equation	The definition of an adiabatic process is one for which no heat is gained or lost, the term "adiabatic" literally means an absence of heat transfer. Regulation 543-01-03 refers to an adiabatic equation which may be used to determine the cross-sectional area required for a protective conductor. The equation is shown here: $S = \frac{\sqrt{I^2 t}}{k}$ where:
	S nominal cross-sectional area of the conductor in mm^2
	I 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 operating time of the disconnecting device in seconds corresponding to the fault current I amperes.
	k factor taking account of the resistivity, temperature coefficient and heat capacity of the conductor material, and the appropriate initial and final temperatures.
Earth	The conductive mass of the Earth, whose electric potential at any point is conventionally taken as zero.
Earthing	Connection of the exposed-conductive-parts of an installation to the main earthing terminal of that installation.
Earthing conductor	A protective conductor connecting the main earthing terminal of an installation to an earth electrode or to other means of earthing
Earth electrode	A conductor or group of conductors in intimate contact with, and providing an electrical connection to, Earth
Earth electrode resistance	The resistance of an earth electrode to Earth
R_A (Ω)	The sum of the resistances of the earth electrode and the protective conductor connecting it to the exposed-conductive-parts
Ia (A)	The current causing the automatic operation of the protective device within 5 s
$I\Delta n$ (A)	Rated residual operating current of the protective device in amperes



Above, Fig 3: Definitions of common earthing related terms

Left, Fig 4: Threaded rods can be used

Below Left, Fig 5: Couplers are used to join earth rods

earthing, or other suitable precautions are taken, to prevent danger arising when any conductor (other than a circuit conductor) which may reasonably foreseeably become charged as a result of either the use of a system, or a fault in a system, becomes so charged.

The reference to "other suitable precautions" means that some installations, or parts of installations, may operate without a connection to Earth and use another method as a means of protection against electric shock. However, in a dwelling, it is unlikely that any other method of protection would be used throughout the installation, therefore, to meet the requirements of the law, an electrical installation in a dwelling must be provided with a means of earthing.

Considerations

There are many different types of earth electrode, as recognised in Regulation 542-02-01, for the purpose of this article we will just consider earth rods.

Choosing the site

Regulation 542-01-07 of BS 7671 requires that the value of impedance from the consumer's main earthing terminal to Earth for TT systems is in accordance with the protective and functional requirements of the installation and considered to be continuously effective.

In reality this means that the drying of the ground, in summer, or freezing of the ground, in winter, should not adversely affect the value of earth fault loop impedance for the installation. In itself, soil temperature has little bearing on the value of R_A; it is only important just above or just below freezing point. To reflect this, BS 7430, ***The code of practice for earthing***, states that any part of an earth electrode system within one metre of the soil surface should be regarded as ineffective under frost conditions. Therefore, if the ground in which the electrodes are installed is subject to freezing, the electrodes should penetrate to depth greater than one metre.

The type of soil has a bearing on the overall efficiency of the earth electrode and BS 7430 lists the following soil types in order of preference:

1. Wet marshy ground, not naturally well drained. Avoid sites kept moist by moving or flowing water as beneficial salts, which aid the conduction of electric current, may be washed away.
2. Clay, loamy soil, arable land, clayey soil, clayey soil or loam mixed with small quantities of sand;
3. Clay and loam mixed with varying proportions of sand, gravel, and stones;
4. Damp and wet sand, peat.

Dry sand, gravel, chalk, limestone, whinstone, granite and any very stony ground should be avoided if possible, also all locations where virgin rock is very close to the surface. If the ground has been subject to backfill or disturbed from building operations, the electrodes should be driven down until stable ground is reached. Earth rods can be extended to make longer lengths using purpose made materials; figure 4 shows an earth rod which is threaded at one end, figure 5 shows a coupler used to join two earth rods together.

In situations where the ground is impenetrable or it is found that the best conductive area of the soil is found at relatively shallow depths, rods can be driven in at an angle of approximately 30˚ to the horizontal. As stated earlier, due to the possibility of freezing, earth rods penetrating to a depth of less than one metre should not be installed in ground susceptible to freezing.

A final point to note is to be aware of what could be hidden beneath the surface of the ground. The ESQCR states that electricity distributors have a duty to make and, so far as is reasonably practicable, keep up to date a map or series of maps indicating the position of underground and overhead networks. Regulation 15.-(3) (c) states that such maps will be made available for inspection by any person who can show reasonable cause; it would be sensible to check the map prior to driving rods.

Multiple earth electrodes

Some ground conditions may warrant a number of earth rods connected in parallel in order to achieve an acceptable value of RA. The benefit of multiple earth electrodes is that the overall resistance is then virtually proportional to the reciprocal of the number of earth rods installed provided that each is located outside the resistance area, also known as the sphere of influence, of any other.

Generally, the resistance area is deemed to be fulfilled by a separation distance equal to the driven depth of the rod. A separation distance in excess of twice the driven depth offers little benefit. Figure 6 shows two electrodes and the required separation distance.

Multiple electrodes may be connected in different arrangements; an example is shown in figure 7 of three earth rods installed in a triangular arrangement.

The earthing conductor

The earthing conductor can be sized in two ways. Firstly, the cross-sectional area may be calculated in accordance with Regulation 543-01-01, which is an adiabatic equation, or secondly, in accordance with Regulation 543-01-04, selected from a table.

Table 54A, from Regulation 542-03-01, states the minimum cross-sectional areas of a buried earthing conductor. Further, Table 10C of the IEE publication, The On-Site Guide, provides a handy guide to the selection of the earthing conductor; table 10C is reproduced in figure 8.

The connection of the earthing conductor to the earth electrode should be by way of a purpose-made clamp, see figure 9. Further, the connection should be housed in a suitable earth-pit to protect the connection from damage, see figure 10.

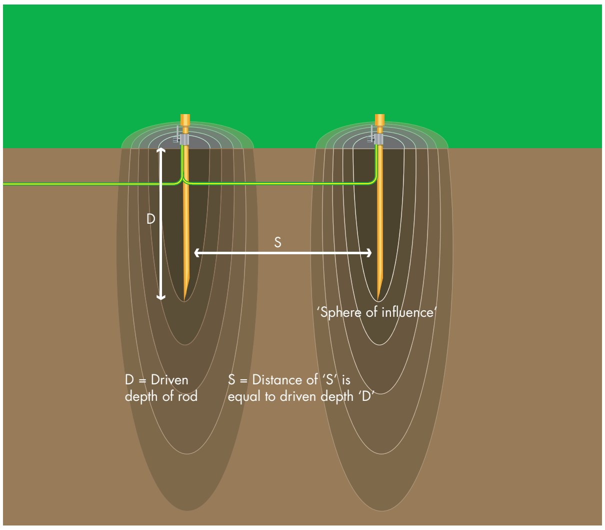


Fig 6: **Image showing the separation distance of earth electrodes**

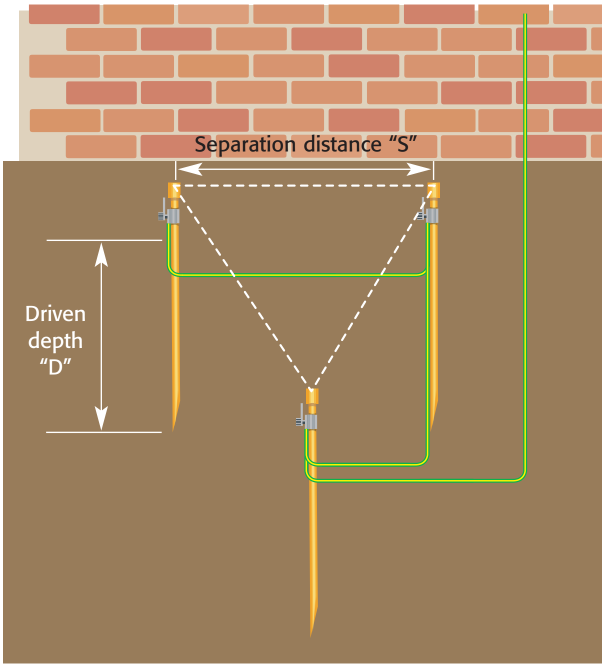


Fig 7: **An example of three earth rods installed in a triangular arrangement**

Earthing conductor buried		
Unprotected	Protected against corrosion	Protected against corrosion and mechanical damage
25 mm²	16 mm²	2.5 mm²

Earthing conductor not buried		
Unprotected	Protected against corrosion	Protected against corrosion and mechanical damage
4 mm²	4 mm²	2.5 mm²

NOTES
1. Protected against corrosion by a sheath.
2. For impedances less than 1 Ω determine as per Regulation 543-01-02.

Fig 8: Table 10C from the IEE publication, *The On-Site Guide*, Copper earthing conductor cross-sectional area for TT supplies for earth fault loop impedances not less than 1Ω

Testing & verification

1. New installation

Regulation 713-10-01 requires that where the earthing system incorporates an earth electrode as part of the installation, the electrode resistance to earth shall be measured. This test is carried out prior to energisation of the electrical installation. Ideally, the test should be undertaken when the ground conditions are least favourable, such as during dry weather. The test requires the use of two temporary test electrodes, or spikes and is carried out in the following manner.

Connection to the earth electrode is made using terminals C1 and P1 of a four-terminal earth tester. To exclude the resistance of the test leads from the resistance reading, individual leads should be taken from these terminals and connected separately to the electrode. If the test lead resistance is insignificant, the two terminals may be short circuited at the tester and connection made with a single test lead, the same being true if using a three-terminal tester. Connection to the temporary spikes is made as shown in figure 11.

The distance between the test spikes is important. If they are too close together, their resistance areas will overlap. In general, reliable results may be expected if the distance between the electrode under test and the current spike is at least ten times the maximum dimension of the electrode system, e.g. 30 m for a 3 m long rod electrode.

Three readings are taken: with the potential spike initially midway between the electrode and current spike, secondly at a position 10% of the electrode-to-current spike distance back towards the electrode, and finally at a position 10% of the distance towards the current spike. By comparing the three readings, a percentage deviation can be determined. This is calculated by taking the average of the three readings, finding the maximum deviation of the readings from this average in ohms and expressing this as a percentage of the average.

The accuracy of the measurement using this technique is typically 1.2 times the percentage deviation of the readings. It is difficult to achieve a measurement accuracy better than 2% and inadvisable to accept readings that differ by more than 5%. To improve the accuracy of the measurement to acceptable levels, the test should be repeated with a larger separation between the electrode and the current spike.

The instrument's test current may be a.c. or reversed d.c.; reversed d.c. is used to overcome

Fig 9: Earth rod clamp

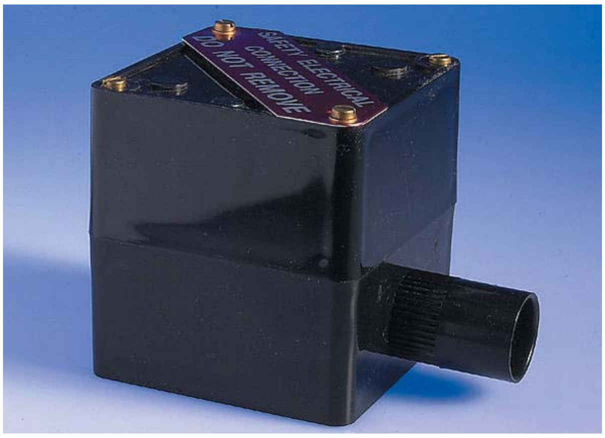


Fig 10: Earth pit

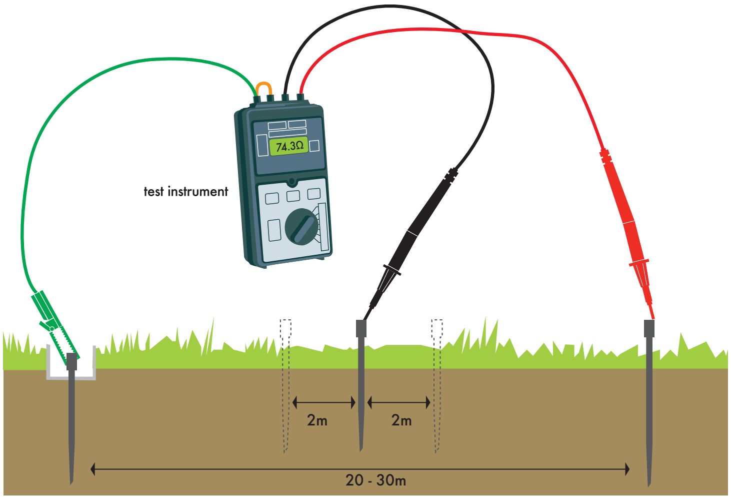


Fig 11: **A four-terminal earth-electrode test instrument**

electrolytic effects. As these testers employ phase sensitive detectors (PSD), the errors associated with stray currents are minimised.

The instrument should be capable of checking that the resistance of the temporary spikes used for testing are within the accuracy limits stated in the instrument specification. This may be achieved by an indicator provided on the instrument, or the instrument should have a sufficiently high upper range to enable a discrete test to be performed on the spikes.

After completion of the testing, the means of earthing for the installation must be re-established before energizing the installation.

2. Periodic inspection

When undertaking an earth electrode test as part of a periodic inspection of an installation, an alternative method would be to use an earth loop impedance test instrument. The value obtained is the earth fault loop impedance, external to the installation, Ze.

The measurement is taken between the phase conductor at the origin of the installation and the earth electrode with the test link open. This ensures that any parallel paths, such as the main equipotential bonding, are eliminated and ensures that all the test current passes through the earth electrode alone.

Before a measurement of resistance is taken, the main switch-disconnector for the installation must be in the open position to ensure that the installation is isolated. The installation will be unprotected against earth faults during the testing which is why secure isolation is essential.

Values of resistance

Regulation 413-02-20 states that, for TT systems, the value of the earth electrode resistance, R_A (Ω), multiplied by the operating current of the protective device, IΔn (A), must not exceed 50 V. Therefore, in the event of a fault to earth, the RCD must operate to prevent a danger of shock from exposed metalwork. The resistance of the earth electrode should be less than 50/IΔn Ω; with an RCD rated at 30 mA, this equates to approximately 1666 Ω.

Using this example, theoretically, it can be shown that a suitably rated RCD will permit high values of R_A, and therefore of Zs, than could be expected by using the overcurrent devices for indirect contact shock protection. Guidance Note 3 advises that in practice, however, measured loop impedance values above 200 Ω will require further investigation. ■

Sources of further information

- *BS 7671: 2001 (2004) Requirements for Electrical Installations*
- *Guidance Note 3 – Inspection and Testing, Inc AMD No.2 : 2004, IEE Publication*
- *On-Site Guide to BS 7671: 2001 (2004), IEE Publication*
- *The electrician's guide to the building regulations, IEE Publication*
- *BS 7430: 1998 Code of practice for earthing*
- *Electricity, Safety, Quality and Continuity Regulations 2002 (ESQCR) – statutory instrument 2002 No. 2665, published by Crown Copyright, can also be obtained from this url: http://www.opsi.gov.uk/si/si2002/20022665.htm*

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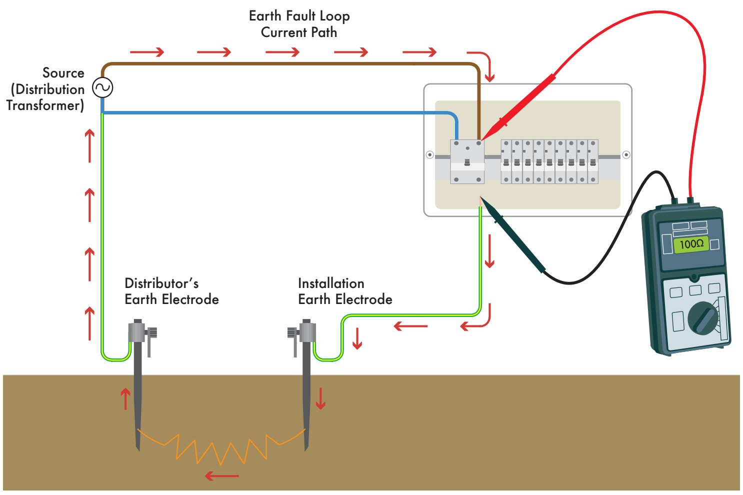

Fig 12: **Measurement of Ze on a TT system**