The IEE

WIRING MATTERS

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ACHIEVING COMPLIANCE WITH THE BUILDING (SCOTLAND) REGULATIONS 2004

USING BS 7671 : 2001 (2004)

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ACHIEVING COMPLIANCE WITH THE BUILDING (SCOTLAND) REGULATIONS 2004 USING BS 7671: 2001(2004)

By Geoff Cronshaw

Introduction
This is part 1 of a two-part article, which gives an overview of how the Building Regulations affect electrical installations and how the requirements of the mandatory standards in schedule 5 are met. Part 2 of the article will deal with the new system of building standards and certification, the role of the Scottish Building Standards Agency, the various technical handbooks and the warrant system, etc.

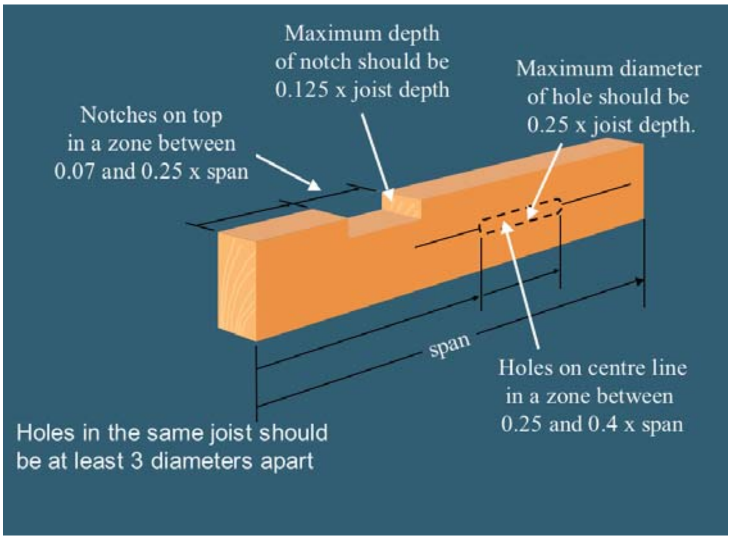
1. Overview of how the Building Regulations affect electrical installations.
The Building (Scotland) Regulations 2004 apply to domestic and non-domestic buildings.

- **Regulation 8**
  – Fitness and durability of materials and workmanship.
- **Regulation 9**
  – Standards applicable to construction.
- **Regulation 10**
  – Standards applicable to demolition.
- **Regulation 11**
  – Standards applicable to provision of services, fitting or equipment.

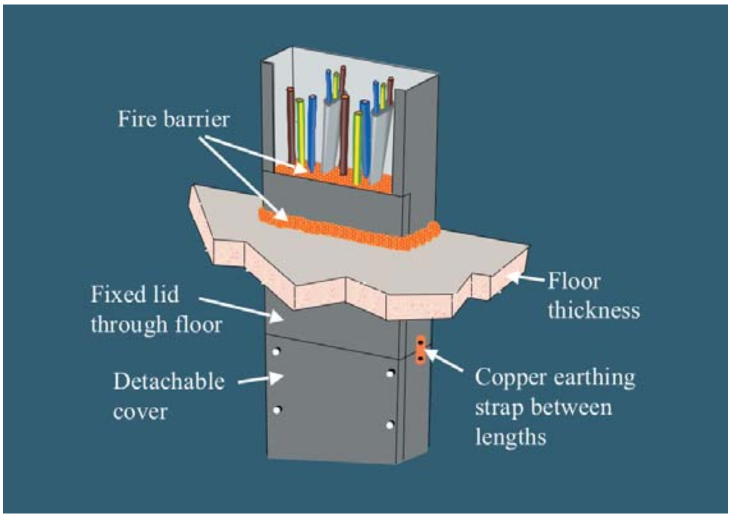
2. Overview of how the requirements of the mandatory standards in schedule 5 of the Building Regulations are met.

Standard 1.1 Structure. This has Structural requirements – cutting, drilling, chasing, penetrating or interfering with the structure.

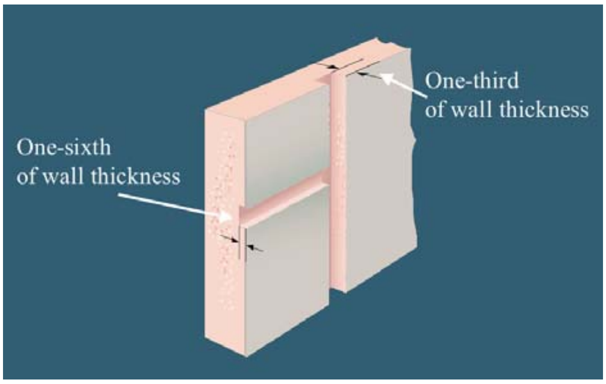
- The basic requirement for those installing electrical installations in a building is not to



Notches and holes in wooden joists



Cable trunking fire sealed where it passes through a floor penetration



Chases in walls

cut, drill, chase, penetrate or in any way interfere with the structure so as to cause significant reduction in its load bearing capability.

Vertical chases should not be deeper than one-third of the wall thickness or in cavity walls one-third of the thickness of the leaf. Horizontal chases should not be deeper than one-sixth of the thickness of the leaf or wall. Chases should not be so positioned as to impair the stability of the wall particularly where hollow blocks are used.

Standard 2.1 Compartmentation, Standard 2.2 Separation, Standard 2.3 Structural protection, and Standard 2.4 Cavities, have requirements for the protection against fire.

- Regulation 527-02 of BS 7671 has requirements as regards the sealing of wiring system.
- Regulation 522-12-03 of BS7671 has requirements where wiring systems penetrate load bearing elements of a building.

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Standard 2.5 Internal linings, has requirements for protection against fire spread on internal linings.

- Every building must be designed and constructed in such a way that in the event of an outbreak of fire within the building, the development of fire and smoke from the surfaces of walls and ceilings within the area of origin is inhibited.
- This clause has requirements regarding thermoplastic materials in light fitting diffusers.
- Where light fitting diffusers form an integral part of a fire-resisting ceiling which has been satisfactorily tested, the amount of thermoplastic material is unlimited.
- Where light fittings with thermoplastic diffusers do not form an integral part of the ceiling, the amount of thermoplastic material is unlimited provided the lighting diffuser is designed to fall out of its mounting when softened by heat.

Standard 2.10 Escape lighting – Every building must be designed and constructed in such a way that in the event of an outbreak of fire within the building, illumination is provided to assist in escape.

- The emergency lighting should be installed in accordance with BS 5266.

Standard 2.11 Communication, has requirements for alerting occupants in the event of an outbreak of fire within the building.

Example of fire alarm call point

- BS 5839 is the British Standard to refer to.
- Clause 2.14 has requirements to provide facilities to assist fire-fighting or rescue operations. This includes requirements for smoke extract equipment etc.

Standard 3.3 Flooding and Ground water – has requirements for every building to be designed and constructed in such a way that there will not be a threat to the building or the health of the occupants as a result of flooding and the accumulation of ground water.

Illustration of flooding and groundwater

- In compliance with this requirement, the electricity distributor and installer may be required to take into account the risk of flooding. Distributor's equipment and the installation consumer unit/fuseboard should be installed above the flood level. Upstairs power and lighting circuits and downstairs lighting should be able to be installed above the flood level. Upstairs and downstairs circuits should have separate overcurrent devices (fuses or circuit breakers).

- The Electricity Safety, Quality and Continuity Regulations 2002 require the electricity distributor to install the cut-out and meter in a safe location, where they are mechanically protected and can be safely maintained.

Standard 3.10 Precipitation, has requirements that every building must be designed and constructed in such a way that there will not be a

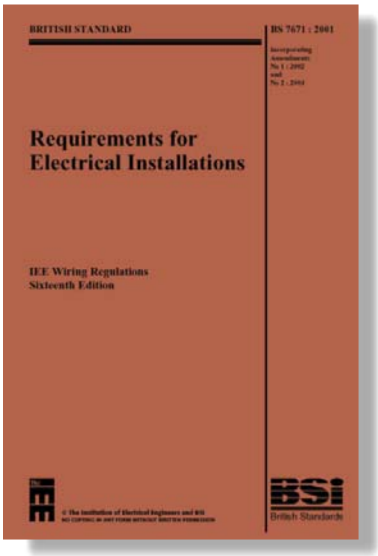
threat to the building or the health of the occupants as a result of moisture from precipitation penetrating to the inner face of the building.

- Ensure that holes for electrical services entering a building are sealed.

Standard 4.5 Electrical Safety – has requirements that every building must be designed and constructed in such a way that the electrical installation does not:

(a) threaten the health and safety of people in and around, the building; and
(b) become a source of fire.

- An electrical installation, whether at extra low or low voltage should be designed, constructed, installed and tested such that it is in accordance with the recommendations of BS 7671 : 2001 as amended.



BS 7671 : 2001 (2004). Requirements for electrical installations

Standard 4.6 Electrical fixtures – has requirements that every building must be designed and constructed in such a way that lighting points and socket outlets are provided. (Domestic only).

- A dwelling to be provided with a minimum number of lighting points.
- Switching arrangements to be provided for lighting serving stairways at each storey.
- Light switches to be provided for common areas.
- Light switches in common access corridors or stairways or other communal area should be accessible, and operable by, disabled people.

Standard 5.1 Resisting sound transmission to dwellings using appropriate constructions – This has requirements that Every building must be designed and constructed in such a way that each wall and floor separating one dwelling from another, or one dwelling from another part of the building, or one dwelling from a building other than a dwelling, will limit the transition of noise to the dwelling to a level that will not threaten the health of the occupants the dwelling or inconvenience them in the course of normal domestic activities provided the source noise is not in excess of that from normal domestic activities.

- Note: This standard does not apply to:

a) fully detached houses
b) roofs or walkways with access solely for maintenance, or solely for the use of the residents of the dwelling below.

Specific guidance is given in SBSA Technical handbook (domestic) on the installation of down-lighters for the various types of floor that are likely to be encountered.

- A secondary ceiling should be fitted if down lighters are to be installed in a separating floor, to avoid penetration of the main ceiling layers.
- The ceiling layers should be fixed directly to the joists.
- Secondary ceiling: 50 mm x 50 mm battens, resilient ceiling bars perpendicular to battens, and 12.5 mm gypsum based board.

Standard 6.5 Artificial and display lighting – has requirements that every building must be designed and constructed in such a way that artificial or display lighting must operate and be capable of being controlled to achieve optimum energy efficiency.

- Consider using compact and tubular fluorescent fittings.
- Consider using discharge fittings.

More information of achieving compliance with the Building (Scotland) Regulations will be given in the second part of this article which will be published in the next edition of *Wiring Matters*. ■

THE ORIGIN OF THE BS 1363 PLUG AND SOCKET OUTLET SYSTEM

By Malcolm Mullins (MK Electric Ltd)

THE BRITISH ring final circuit system and BS 1363: *13 A plugs, socket-outlets, connection units and adaptors* plug and socket-outlet system were introduced into the UK in 1947 following many years of debate which began in June 1942 with the first meeting of 'The Electrical Installations Committee' of the IEE. This committee was formed by the Minister of Works and Planning, Lord Reith: "...with the object of securing a comprehensive and co-ordinated review of building techniques for the guidance of those who would be responsible for the direction and organisation of building after the war."

Part of the Terms of Reference were "to review existing information and practice concerning installations in buildings".

The committee held 22 meetings between 1942 and 1944 which resulted in the publication of 'Post War Building Study No. 11 – Electrical Installations' in January 1944 and the 'Supplementary Report' in July 1944.

This study is by far the most significant process which led to the UK ring final circuit and which resulted in the development of the BS 1363 13 ampere fused, flat-pin plug and socket-outlet system by BEAMA. The Study is very detailed and covers the whole area of electrical installation, not just plugs and sockets. It makes very clear the reasoning process at the time which led to our present system of plugs and sockets.

The study is remarkable in terms of its foresight – it refers to such topics as energy efficiency and environmental protection, and makes proposals for single pole fusing, a novel compact design of consumer control unit, the cooker control unit which we are familiar with today etc., and even proposed that: "The haphazard arrangement of different pieces of equipment of odd types and sizes attached to walls in positions regardless of convenience or appearance should no longer be tolerated" – which we are still waiting for in many premises today.

Revolutionary outlook

In its day, it must have been almost revolutionary in its outlook with many radical proposals aimed at providing improved amenities in post-war housing.

The reasons for proposing a radical change in wiring practices were made clear:-

Experience had shown that the existing 2, 5 and 15A BS 546 socket-outlets were: "...wholly unsatisfactory from the standpoint of the convenience of the consumer. The absence of an intermediate size between 5 and 15 amperes and the cost and dimensions of the 15 ampere [plug], have contributed

to the use of non-standard socket-outlets and plugs to fill a gap in which there is substantial demand.'"
BS 546 is entitled: *Specification. Two-pole and earthing pin plugs, socket-outlets and socket-outlet adaptors*.

Improved safety was of course a major objective of this whole exercise. Particular reference was made to children and the need for shutters and to the reduction of the likelihood of damage by flush-mounting and by mounting well above floor-level.

Recognition of the rapid moves towards the use of more and more electrical appliances in the home with the resulting need for a multitude of socket-outlets in post-war housing which the 'new' ring-circuit could provide was a major factor. Even in 1944, there was concern over "...the rapidly increasing number of these small consumption appliances...".

The emphasis throughout this study has been the economical provision of many sockets-outlets as well as the supply of heating loads. The Study states: "the installation should allow the occupier to use electricity, if he so desires, for providing 'topping up' heat. Bearing in mind the limited cubic capacity and the load diversity of the small dwelling under review, it is considered that they could be adequately heated electrically using portable or inset electrical fires or convectors up to 2 kW rating from the ring circuit.

"This [substantial demand] applies to the smaller classes of dwellings in which 2 kW radiant electric fires are commonly used, and in which fires or other appliances exceeding this rating are seldom required due to the limitations imposed by the size of the room."

The ring final circuit

It was decided during this study that the alternative of providing a separate circuit fused at 15 amperes for each principal room which would feed all socket-outlets in that room: "is attractive as compared with pre-war practices but is less flexible in installation than the ring-circuit, provides less flexibility in loading and, except possibly in the smaller type of house, is not so economical."

It was realised that a post-war Britain would continue to suffer from a massive shortage of raw materials and it was estimated that the proposed changes to the ring-circuit and single-pole fusing would show a saving of approximately 25% compared with pre-war regulations. The opportunity to improve both consumer safety and convenience due to the interruption in new building during the war and the massive programme of building which would be required after the war was recognised at an early stage. Initially, a majority favoured a new British Standard for a 10 A, fused, shuttered socket-outlet and a plug with round pins conforming to BS 546. The final unanimous decision was for a 3 kW (230V; 13 A) socket-outlet with fused plugs.

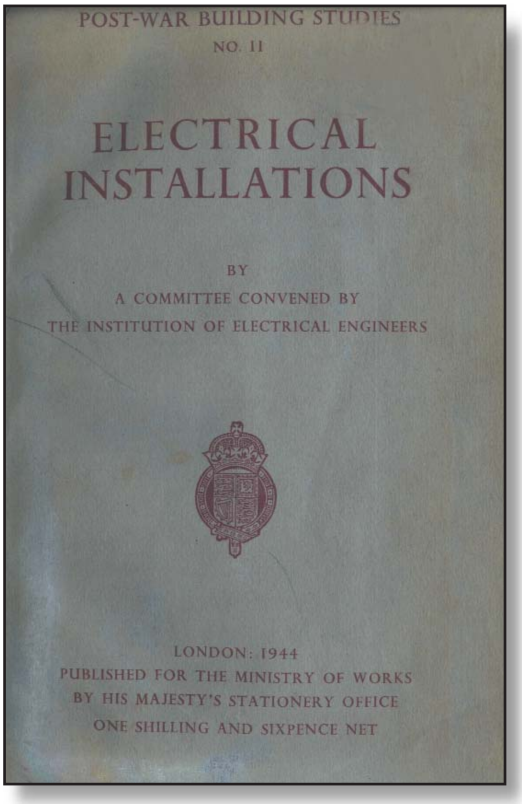
BEAMA were invited to propose suitable designs or standards which they accepted.

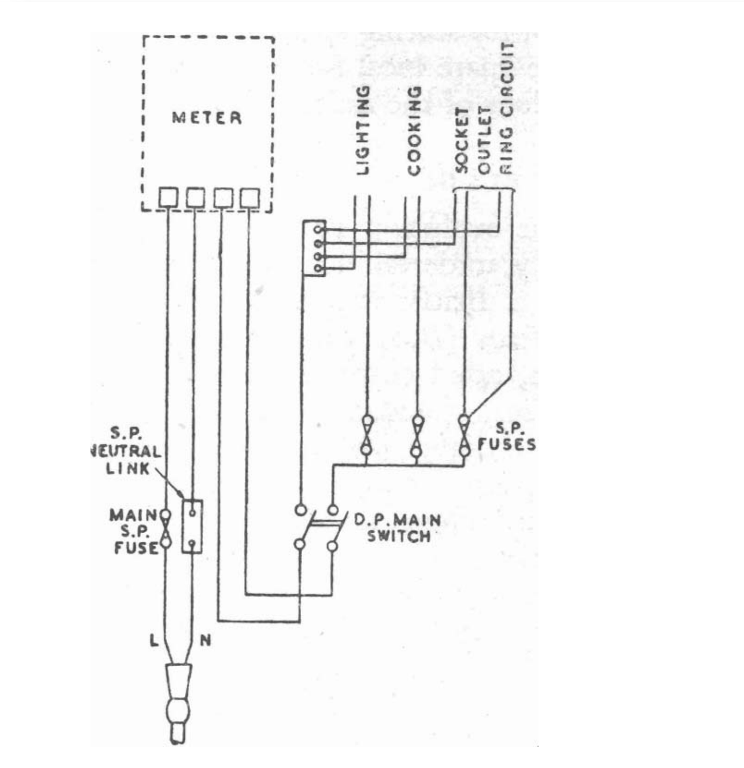
The following observation was made in the report: "The general benefit to be obtained from the widest use of a single standard is so great as to call for the subordination of individual preference, or even of comparatively minor technical consideration, to the choice of the alternative most likely to meet with general acceptance." This is just as valid today as long as safety is assured.

Much has been written about ring final circuits and BS 1363 accessories since the second world-war. Of particular interest is '*Ministry of Works Technical Note No. 4*' published in 1957. This pamphlet begins in its opening paragraph: "Socket-outlets should provide a safe and convenient means of plugging in portable appliances to the electric supply, but unfortunately they have long been regarded as an expensive luxury and it is sometimes wrongly thought that economy can be achieved only by reducing their number. Nowadays, however, because of the increasing use of domestic electrical equipment, more socket-outlets than ever before are needed."

Later in the pamphlet the danger of too few socket-outlets is again highlighted where householders are tempted to use trailing sockets which become regarded as permanent wiring, but are susceptible to damage and present a serious fire and shock rise. As regards to the ring-circuit and BS 1363 accessories, the pamphlet continues: "The ring circuit system of wiring takes full advantage of domestic load diversity because one circuit serves an unlimited number of standard socket-outlets (BS 1363 type of 13 Amp rating) which may be used at any time and added to after if required. A large fuse at the meter end of the installation that has to be capable of carrying the full load of current drawn from several socket-outlets at once may not protect a flexible cord leading from an individual socket. The way to ensure adequate and selective protection is to connect each flexible cord to a separately fused plug."

The pamphlet highlights cost-savings between the pre-war system where a typical 3 bedroom urban home would require at least nine 15 amp fuses whereas a ring-circuit system required one 30 amp fuse for the required number (15 in this case) of socket-outlets. Although modern radial or tree circuits can supply more than one socket-outlet, they





Above left: Study no 11

Above right: Circuit diagram for a 1944 house, including a ring final circuit, from Study no 11

would still require more overcurrent protective devices, a larger consumer unit, more cable and are usually more expensive to install.

The pamphlet emphasises that the ring circuit system required 30% less cable and can save about 25% in the cost of the wiring of a house and concludes: "There is no doubt that in modern domestic premises that are to be adequately provided with electric points, the cheapest and safest system is to use a ring final circuit."

Modern wiring needs are obviously different to what was envisaged in 1944 but (apart from the even greater increase in small portable appliances originally seen as a justification for ring final circuits) the main change has been the increase in size (i.e. area) of installations which utilise ring final circuits. The reasoning in 1944 centred on the tendency before the war for an increase in small domestic dwellings with an expectation that this would increase after the war. The emphasis was on a new system for housing that would allow a multitude of socket-outlets without a corresponding need for many final circuits. Remember that pre-war usual practice was to supply a single socket from one fuse and to use different size plugs and sockets (usually to BS 546) to ensure that the maximum allowable current loading of the flexible cable and appliance was not exceeded so as to provide overload protection. Not until the 12th Edition of the Wiring Regulations did the UK accept the Continental practice of increased risks of damage in radial circuits due to overload and small over-currents due to the rating of the overcurrent protective device being greater than the rating of the flex and appliances.

The Post-War Study could not have foreseen the massive increases in commercial wiring needs in offices due to information technology. The sophisticated wiring systems now available (e.g. perimeter trunking, underfloor powertrack systems) mean that large numbers of socket-outlets are required. Ring final circuits are often used in such installations and a BSRIA report commissioned by the DTI in 1994 shows clearly that ring final circuits cost less to install than the equivalent radial circuits.

The British plug and socket and ring final circuit system has proven itself over many years. Its development was due to the recognition of an opportunity seen by leaders during a time of war and mass destruction. A truly unique, innovative, world class system was developed by people of vision. A system that cannot be equalled in terms of safety, performance and convenience. ■

EARTHING AND BONDING IN HAZARDOUS LOCATIONS

By Mark Coles

1. Introduction
The IEE's Technical Helpline receives numerous calls from contractors requesting information on the earthing and bonding requirements for hazardous locations. This article will give an overview of the hazards and problems encountered in those locations and gives information on the performance requirements of earthing and bonding to ensure that the potential for gas ignition, from low voltage electrical sources and equipment, is reduced.

2. The Regulations
BS 7671, *Requirements for Electrical Installations*, is intended to be applied to electrical installations generally but, in certain cases, they may need to be supplemented by the requirements or recommendations of other British Standards or by the requirements of the person ordering the work. Such cases would include the following:

- Electrical apparatus for explosive gas atmospheres – BS EN 60079
- Electrical apparatus for use in the presence of combustible dust – BS EN 50281

3. Definitions
Often, there is great confusion over earthing, bonding and even use of the nonsensical term, earth-bonding! BS 7671, *Requirements for Electrical Installations*, defines:

Earthing – 'Connection of the exposed-conductive-parts of an installation to the main earthing terminal of that installation.'
Bonding – the correct title is 'Equipotential bonding'. 'Electrical connection maintaining various exposed-conductive-parts and extraneous-conductive-parts at substantially the same potential'

There are two categories of equipotential bonding:

Main equipotential bonding
Regulation 413-02-02 of BS 7671 states: In each installation, main equipotential bonding conductors shall connect to the main earthing terminal *extraneous conductive-parts* of that installation.

Supplementary equipotential bonding
Regulation 413-02-27 of BS 7671 states: Where supplementary equipotential bonding is necessary, it shall connect together the *exposed conductive-parts* of equipment in the circuits concerned *and extraneous-conductive-parts*.

Supplementary equipotential bonding is not required on every installation, generally however, it is required in areas of increased risk; BS 7671 recognises these areas as 'Special Locations'. A hazardous location, of course, would be considered as a special location.

BS 7671 further defines:

An extraneous-conductive-part – "a conductive part liable to introduce a potential, generally earth potential and not forming part of the electrical installation"

An exposed-conductive-part – "a conductive part of equipment which can be touched and which is not a live part but which may become live under fault conditions"

Defining Hazardous Locations
BS EN 60079-14: 2003, Electrical apparatus for explosive gas atmospheres – *Part 14: Electrical installations in hazardous areas (other than mines)*, defines the following:

- Explosive atmosphere
- Explosive gas atmosphere
- Hazardous area

Note – The ATEX 137 Directive has adopted the concept of space instead of area; by definition, area is a two-dimensional concept, space is a three-dimensional concept.

In line with BS EN 60079-10: 2003, *Electrical apparatus for explosive gas atmospheres – Part 10: Classification of hazardous areas*, this article will consider hazardous locations where **gas ignition from low voltage electrical sources is possible** but, for the purposes of this article, the following locations will not be considered:

a) mines susceptible to firedamp
b) the processing and manufacture of explosives
c) areas where a risk may arise due to the presence of ignitable dusts or fibres
d) catastrophic failures which are beyond the concept of abnormality
e) rooms used for medical purposes
f) areas where the presence of flammable mist may give rise to an unpredictable risk and which require special consideration

Explosive atmosphere
Mixture with air, under atmospheric conditions, of flammable substances in the form of gas, vapour, mist or dust, in which after ignition, combustion spreads throughout the unconsumed mixture.

Explosive gas atmosphere
Mixture with air, under atmospheric conditions, of flammable substances in the form of gas or vapour, in which after ignition, combustion spreads throughout the unconsumed mixture.

Hazardous area
Area in which an explosive gas atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of apparatus.

4. The Zonal Concept
Locations where flammable gases are, or may be, present, are defined by a Zonal concept. The definitions, shown in the table below, of the particular Zones are taken from BS EN 1127-1:1998, *Explosive atmospheres. Explosion prevention and protection. Basic concepts and Methodology*. Each site will have drawings that will indicate the extent of the Zones. The extent of the Zones is established at the design stage by the competent person who is experienced in this line of work.

5. Hazards and Problems
The prime danger in explosive atmospheres is that of explosions due to incendive sparking. Sparking can be caused by any of the following:

Fault currents and high protective-conductor currents
'Flashovers' could occur on poorly earthed circuits where expected and non-expected protective-conductor currents are present.

Static electricity
Static electricity is the retained charge on a

Zone	Definition	Example
Zone 0	A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist, **is present continuously or for long periods or frequently**	Typically, the space above the liquid in a storage vessel.
Zone 1	A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the formof gas, vapour or mist, **is likely to occur in normal operation occasionally**	The space immediately around a storage vessel's vent-pipe openings which vent during filling.
Zone 2	A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist, **is NOT likely to occur in normal operation but, if it does occur, will persist for a short period only.**	Around Zone 1, it is usual to consider the surrounding space to be Zone 2

conductor. All the energy stored on the conductor can be released in one arc or 'spark' to catastrophic effect. To retain charge on a conductor, it has to be insulated from other conductors and insulated from earth by means of a non-conductor. Sparking, due to static electricity, can be avoided by using recognised earthing and equipotential bonding techniques.

Static electricity is generated in many ways, including:
- the flow of liquids
- the mixing of powders
- the production of sprays
- the contact and separation of solids

Static electricity causes problems in many industries, such as chemical, pharmaceutical, petroleum, etc.

Static electricity-discharges from a person can be minimized by providing an adequately-conducting path between the person and earth through their footwear and the floor. BS 7193 gives requirements for two types of rubber footwear. Specifications for conducting-flooring materials and for such floors after laying are given in BS 2050 and BS 3187.

The phenomena that is Static Electricity is covered in great depth in two parts of BS 5958: 1991, Code of practice for *Control of undesirable static electricity: Part 1: General considerations,* and *Part 2: Recommendations for particular industrial situations.*

Lightning protection system

Regulation 413-02-02 of BS 7671 requires that in each installation, main equipotential bonding conductors shall connect to the main earthing terminal extraneous-conductive-parts of that installation, including the lightning protection system. However, the designer of the installation, who is a competent person, may decide that, due to particular risks, main equipotential bonding of the lightning protection system should be avoided. For further information, consult: BS 6651, Code of practice for protection of structures against lightning and BS 7430, Code of practice on earthing.

The electrical supply

The following electrical systems are **NOT** suitable for use in hazardous locations:
- TN-C
- TN-C-S (PME)

In TN-C and TN-C-S (PME) supplies, the neutral conductor is also the earthing conductor, therefore, there could be a potential difference between the main earthing terminal of the installation and the general mass of earth. Incendive sparking could then occur between the earth of the electrical installation and any extraneous metalwork which is in contact with the general mass of earth.

Electrical equipment

Electrical apparatus for use in hazardous locations must be suited for the gas group, the temperature classification and that particular protection concept.

6. Performance requirements of earthing & bonding conductors in hazardous locations

In this section, we'll look at the sizing of conductors and desired values of resistance.

Sizing of earthing conductors

In accordance with Regulation 543-01-03 of BS 7671, two methods may be used to size earthing conductors or circuit protective conductors (CPCs); the first is the adiabatic equation, the second is Table 54G.

Sizing of equipotential bonding conductors

In accordance with Regulation 547-02-01 of BS 7671 and excluding PME as previously stated, a main equipotential bonding conductor shall have a CSA not less than half the CSA required for the earthing conductor of the installation and not less than 6 mm^2. The cross-sectional area need not exceed 25 mm^2 if the bonding conductor is of copper or a CSA affording equivalent conductance in other metals.

Further, Regulation group 547-03 of BS 7671, requires that supplementary equipotential bonding conductors are sized according to both their particular application and whether they are mechanically protected. NOTE – Table 10B of the IEE publication, *The On-Site Guide*, is a handy reference guide for sizing such conductors.

Further, *Guidance Note 3, Inspection and Testing*, published by the IEE, advises that supplementary equipotential bonding conductors should have a resistance of 0.05Ω, or less.

Eliminating static electricity

BS 5958-1: 1991, *Code of practice for Control of undesirable static electricity – Part 1: General considerations*, states that to retain a significant electrostatic charge, a resistance to earth in excess of 1MΩ is required. Generally, resistance between metals in good contact rarely exceeds a few ohms. A value less than 100Ω is readily attainable and is unlikely to deteriorate with time to a level above 1MΩ unless serious corrosion is present.

Equipotential bonding connections
BS EN 60079-0:2004, *Electrical apparatus for explosive gas atmospheres – Part 0: General requirements*, requires that equipotential bonding connections should only be made through designed connection points and not rely on fortuitous contact. All connections should be secure against self-loosening. This requires the use of materials that are designed for that particular application and fit for purpose.

It is worth noting that equipotential bonding conductors would not be required where insulation ensures that circulating currents cannot flow. However, provision shall be made for adequate earthing of isolated exposed-conductive-parts. The insulation of such parts shall be capable of withstanding a test of 100 V r.m.s for 1 min.

Potential equalisation
BS EN 60079-14:2003, *Electrical apparatus for explosive gas atmospheres – Part 14: Electrical installations in hazardous areas (other than mines)*, states that potential equalization is required for installations in hazardous areas. In effect, this means that all exposed and extraneous conductive parts are connected to the equipotential bonding system. Like other installations in non-hazardous locations, the bonding system may include protective conductors, metal conduits, metal cable sheaths, steel wire armouring and metallic parts of structures. Exposed conductive parts need not be separately connected to the equipotential bonding system if they are firmly secured to and are in metallic contact with structural parts or piping which are connected to the equipotential bonding system.

Intrinsic safety
One type of protective system used in hazardous locations is Intrinsic safety. There are two categories of intrinsic safety, namely, Category ia; may be used in hazardous area Zones 0, 1 & 2, and category ib; may be used in hazardous area Zones 1 & 2. By definition, an intrinsic safety system will limit the energy available in the hazardous location to a level such that ignition of the flammable atmosphere could not occur. Limitation of energy is achieved by using one of two types of barrier; a Shunt Diode Barrier or Galvanically Isolated Barriers. The intrinsic safety earth is a direct connection between the earth terminal of the shunt diode and the main earthing terminal of the electrical supply.

BS EN 50020:2002 – *Electrical apparatus for potentially explosive atmospheres – Intrinsic safety 'i'*, states:

- CPC to be ≥ $4mm^2$ (length & further mechanical protection may warrant larger CSA)
- Insulation of dedicated CPC
- 1 Ω maximum (current practice is to achieve 0.1 Ω)
- All screens to be earthed
- All unused cores to be terminated at both ends and earthed as documentation stipulates

7. Summary
To summarise, earthing and bonding is required on all circuits, unless the site documentation or design states otherwise. Equipotential bonding should connect all exposed and extraneous-conductive parts, unless, again, the site documentation states otherwise. All conductors should be sized appropriately, in accordance with Regulation 543-01-03 of BS 7671. All earthing and bonding connections should be correctly installed and connections made at the designed-connection points; never rely on fortuitous contact. Where mechanical connection points, such as threaded conduit and SWA cable armouring lugs are utilised, continuity should be assured

8. Bibliography and further reading
The following publications will provide further information:

- *BS 7671: 2001 (2004) Requirements for electrical installations*
- *Guidance Note 3 – Inspection and Testing, Inc AMD No.2 : 2004, IEE Publications*
- *On-Site Guide to BS 7671: 2001 (2004), IEE Publications*
- *BS 7430: 1998 Code of practice for earthing*
- *BS EN 60079 Electrical apparatus for explosive gas atmospheres (suite of standards)*
- *ATEX 95 Directive*
- *ATEX 137 Directive*
- *BS EN 1127-1:1998 Explosive atmospheres. Explosion prevention and protection. Basic concepts and Methodology.*
- *BS 5958 Code of practice for Control of undesirable static Electricity (suite of standards)*
- *BS 7193 Specification for lined lightweight rubber overshoes and overboots*
- *BS 2050 Specification for electrical resistance of conducting and antistatic products made from flexible polymeric material*
- *BS 3187 Specification for electrically conducting rubber flooring*
- *BS 6651 Code of practice for protection of structures against lightning*
- *BS EN 50020:2002 Electrical apparatus for potentially explosive atmospheres – intrinsic safety 'i'*
- *DSEAR Regulations 2002* ■

PERMITTED FORMS OF SUPPLY FOR PORTABLE AND HANDHELD EQUIPMENT

By Jon Elliott

MOST PORTABLE equipment being used outdoors is supplied via a flexible cord fed from either a socket-outlet or a flexible cable/cord outlet plate. This cable/cord may have a high susceptibility to damage for the following reasons:

- the lead is trailed whilst the equipment is in use giving rise to abrasion, twisting and straining influences
- connected items such as lawnmowers, hedge-cutters and power tools have moving parts capable of causing damage that may expose live parts
- equipment and the supply cables/cords in exterior installations are prone to exposure to moisture as a result of precipitation

The presence of moisture as a result of rain or even heavy dew can result in users of portable equipment outdoors having damp feet. This will inevitably result in a lowered contact resistance of the person with the general mass of earth, further increasing shock risk, particularly in the case of handheld equipment.

BS 7671 requirements for portable equipment

These increased risk factors mentioned above are reflected in the specific requirements of 471-16 which relates to supplies to portable equipment outdoors supplied via a socket-outlet and is reproduced below:

471-16-01 *A socket-outlet rated at 32 A or less which may reasonably be expected to supply portable equipment for use outdoors shall be provided with supplementary protection to reduce the risk associated with direct contact by means of a residual current device having the characteristics specified in Regulation 412-06-02(ii).*

This regulation does not apply to a socket-outlet supplied by a circuit incorporating one or more of the protective measures specified in items (i) to (iii) below and complying with the Regulations indicated:

(i) protection by SELV (see Regulations 411-02 and 471-02)
(ii) protection by electrical separation (see Regulations

413-06 and 471-12)
(iii) protection by automatic disconnection and reduced low voltage systems (see Regulation 471-15).

Regulation 471-16-02 relates to supplies to portable equipment outdoors supplied by means other than a socket and is reproduced below:
471-16-02 *Except where one or more of the protective measures specified in items (i) to (iii) of Regulation 471-16-01 are applied in compliance with the corresponding regulations stated therein, a circuit supplying portable equipment for use outdoors, connected other than through a socket-outlet by means of flexible cable or cord having a current-carrying capacity of 32 A or less, shall be provided with supplementary protection to reduce the risk associated with direct contact, by means of a residual current device having the characteristics specified in Regulation 412-06-02(ii).*

Both of the above Regulations make reference to the use of RCDs that meet the requirements of Regulation 412-06-02 (ii) to provide supplementary protection against direct contact. That is, the RCD should have a rated residual current (I∆n) not exceeding 30 mA and an operating time not exceeding 40 mS at 5 I∆n.

The use of such RCDs to provide supplementary protection against direct contact is commonly employed. However, as can be seen from reference to the two Regulations reproduced above, the use of such RCDs is not the sole method of protection suitable for supplies to portable equipment outdoors.

The use of a 30 mA RCD is not required where the source of supply originates from a circuit that is protected by

- SELV
- electrical separation
- automatic disconnection and reduced low voltage systems

SELV

SELV is defined in BS 7671 as "An extra-low voltage system which is electrically separated from Earth and from other systems in such away that a single fault cannot give rise to the risk of electric shock".

The supply for a SELV system may be derived from the following sources:

- a safety isolating transformer in which there is no connection between the output winding and the body or to earth
- a motor-generator set in which the windings provide isolation equivalent to that provided by the windings of an isolating transformer
- a battery

The maximum permitted voltages of 50 V a.c. or 120 V ripple-free d.c. limit the employment of SELV as a source of supply for portable tools and equipment. However, there are a number of instances where the use of SELV is the only means of supply permitted for handheld or portable items of electrical equipment. These are summarised later within this article.

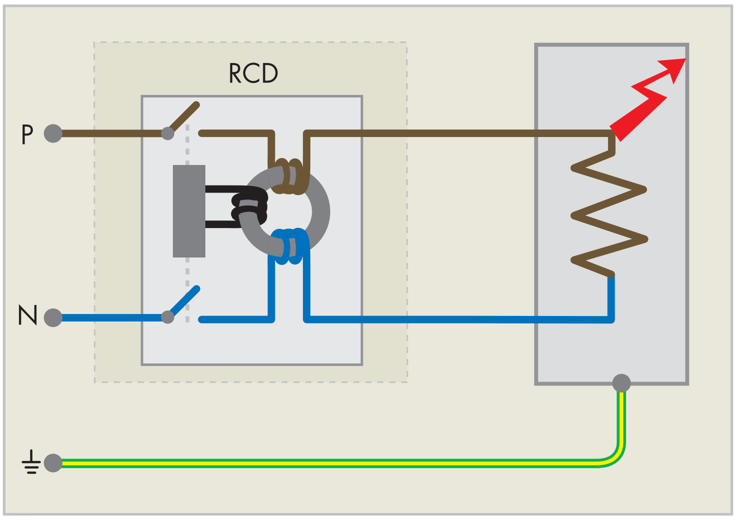


Figure 1: RCD under fault conditions

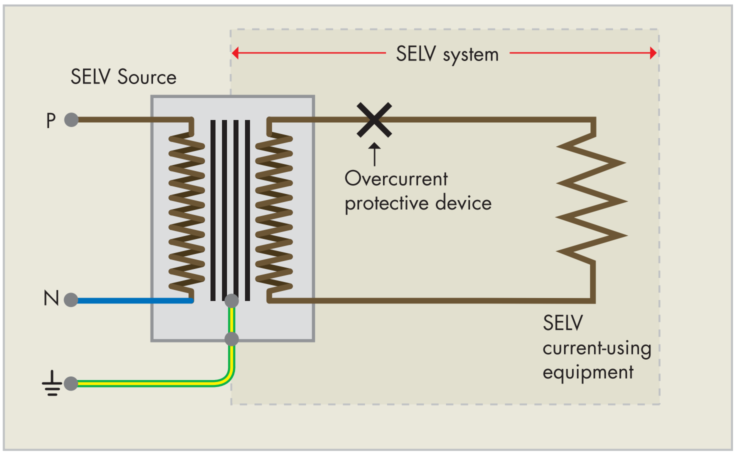


Figure 2: Separated extra-low voltage supply derived from a transformer

Electrical separation

In the case of using electrical separation it is necessary to make reference to Regulation 471-12-01 which is reproduced below:

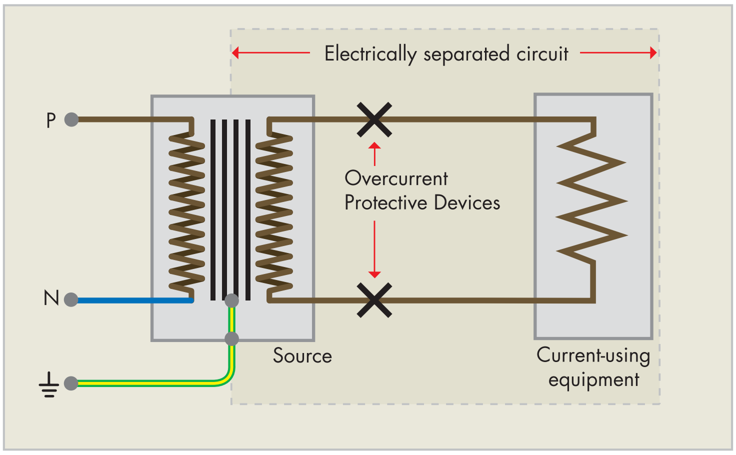


Figure 3: Electrically separated supply derived from a transformer

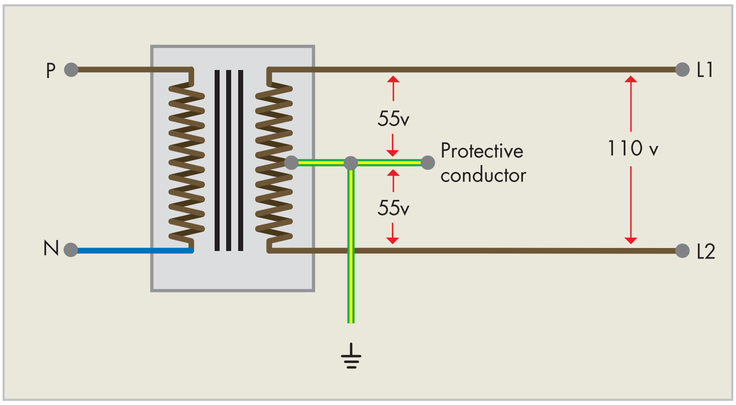


Figure 4: Reduced low voltage supply derived from a transformer centre tapped to earth

471-12-01 *This measure is intended, in an individual circuit, to prevent shock current through contact with exposed-conductive-parts which might be energised by a fault in the basic insulation of that circuit. It may be applied to the supply of any individual item of equipment by means of a transformer complying with BS 3535 the secondary of which is not earthed, or a source affording equivalent safety. Its use to supply several items of equipment from a single separated source is recognised in the Regulations only for special situations under effective supervision, where specified by a suitably qualified electrical engineer. Where the measure is used to supply several items of equipment from a single source, a warning notice complying with Regulation 514-13-02 shall be fixed in a prominent position adjacent to every point of access to the location concerned.*

The actual requirements placed upon the designer of the installation vary depending upon the number of items of equipment that is intended to supply.

Where only a single item of equipment is supplied by an isolating transformer to BS 3535 requirements, the following measures are required by 413-06-03

- There should be no connection between the separated circuit and any other circuit, or to Earth
- A flexible cable/cord liable to mechanical damage should be visible throughout its length
- It is preferred that a separate wiring system should be used for the separated circuit (although multicore cables without magnetic sheath or insulated conductors in an insulated enclosure are permitted if the rated voltage of the cables is not less than the highest voltage likely to occur and each circuit is protected against overcurrent)
- Every live part of each separate circuit shall be electrically separated from all other circuits to a standard not less than that provided between input and output windings of an isolating transformer to BS 3535

Regulation 413-06-04 requires that no exposed-conductive-part of the separated circuit shall be connected to either the protective conductor of the source circuit, or to any exposed-conductive-parts of any other circuit.

Where it is intended to use a single separated source to supply a number of items of equipment, where this protective measure is permitted by BS 7671, it will be necessary to meet the relevant requirements of 413-06 (Protection by electrical separation).

Reduced low voltage

Regulation 471-15 states the requirements for automatic disconnection and reduced low voltage systems, which are summarised below:

In situations where it is impracticable to employ extra-low voltage and there is no requirement for the use of SELV, a reduced low voltage system may be used (471-15-01).

The nominal voltage of reduced low voltage circuits shall not exceed 110 V a.c. rms between phases (either three-phase 63.5 V to earthed neutral or single-phase 55 V to earthed midpoint) (471-15-02).

The supply for a reduced low-voltage system may be derived from:

- a double wound isolating transformer
- a motor-generator set in which the windings provide isolation equivalent to that provided by the windings of an isolating transformer
- an engine driven generator (471-15-03)

The neutral (star) point on secondary windings of three-phase transformers or generators, or the mid-point of the secondary windings of single-phase transformers or generators shall be connected to earth (471-15-04).

Protection against direct contact should be provided by insulation or by a barrier/enclosure (471-15-05)

Protection against indirect contact shall be provided by an overcurrent protective device such as a fuse or MCB, or by an RCD placed in each phase conductor such that the earth fault loop impedance at any point of utilisation permits a disconnection time not exceeding 5 seconds. Where an RCD is used, the product of rated residual current ($I\Delta n$) and the earth fault loop impedance shall not exceed 50 (471-15-06).

All plugs, socket-outlets and cable couplers used in a reduced low voltage system shall have a protective conductor contact and not be dimensionally interchangeable with plugs, socket-outlets and cable couplers within the same installation for use at other voltages or frequencies (471-15-07).

Summary of BS 7671 requirements for supplies to portable and handheld equipment

There are a number of instances where BS 7671 makes specific reference to the type of protection that is suitable for supplies to portable and handheld equipment. These are summarised below:

Supplies for portable equipment outdoors (471-16-01 & 471-16-02)

- RCD having a rated residual operating current ($I\Delta n$) not exceeding 30 mA and an operating time not exceeding 40 mS at 5 $I\Delta n$ (412-06-02)
- SELV (411-02 & 471-02)
- Electrical separation (413-06 & 471-12)
- Automatic disconnection and reduced low voltage systems (471-15)

Swimming pools (Section 602)

Note: Socket-outlets provided in a swimming pool location are provided for the intention of cleaning/maintenance purposes carried out when the pool is not in use.

- Zone A – None permitted
- Zone B – BS EN 60309-2 socket-outlets may only be installed if it is not possible to position them outside zone B if they are:
  - More than 1.25 m beyond the border of zone A, and
  - At least 0.3 m above the floor level, and
  - Protected by either:
    - 30 mA RCD
    - Electrical separation, where the safety isolating transformer is placed outside zones A, B and C
- Zone C – BS EN 60309-2 socket-outlets

Construction sites (section 604)

Note: All plugs and sockets used should comply with BS EN 60309-2 regardless of voltage being supplied (604-12-02)

- Supplies for portable hand lamps for use in confined or damp locations – SELV
- Portable hand lamps for general use; portable hand-held tools and local lighting up to 2 kW – 1-phase reduced low voltage
- Portable hand-held tools and local lighting up to 2 kW; small mobile plant up to 3.75 kW – 3-phase reduced low voltage

The use of 230 V to supply portable equipment supplied via a 30 mA RCD, although not stated in BS 7671 is permitted (HSE Guidance Note HSG 141 refers). However, the use of automatic disconnection and reduced low voltage supply as prescribed in BS 7671 is the preferred system for use on construction sites in the United Kingdom.

There is a possibility of damage occurring to the sensitive operating mechanism of the RCD as a result of the harshness of the environment inherent on a construction site. Any such damage may render the RCD inoperative, removing any protection that it was intended to provide. As such, attention must be given to correct positioning of RCDs and to the choice of enclosures employed. Where an RCD is provided on a construction site, for reasons of safety, its correct operation should be confirmed prior to each use.

Agricultural and horticultural premises (section 605)

- SELV
- Socket-outlets protected by 30 mA RCD (605-03-01)

Restrictive conductive locations (section 606)

- Socket-outlets or other supplies for hand lamps
- SELV (606-04-02)
- Socket-outlets or other supplies for hand-held tools (606-04-04)
  - SELV
  - Electrical separation where only one socket-outlet or piece of equipment is connected to each secondary winding of a transformer (606-04-01(iv)) ■

POWER FACTOR CORRECTION (pfc)

By John Ware

POWER FACTOR is the ratio between the useful (true) power (kW) to the total (apparent) power (kVA) consumed by an item of a.c. electrical equipment or a complete electrical installation. It is a measure of how efficiently electrical power is converted into useful work output. The ideal power factor is unity, or one. Anything less than one means that extra power is required to achieve the actual task at hand.

All current flow causes losses both in the supply and distribution system. A load with a power factor of 1.0 results in the most efficient loading of the supply. A load with a power factor of, say, 0.8, results in much higher losses in the supply system and a higher bill for the consumer. A comparatively small improvement in power factor can bring about a significant reduction in losses since losses are proportional to the square of the current.

When the power factor is less than one the 'missing' power is known as reactive power which unfortunately is necessary to provide a magnetising field required by motors and other inductive loads to perform their desired functions. Reactive power can also be interpreted as wattless, magnetising or wasted power and it represents an extra burden on the electricity supply system and on the consumer's bill.

A poor power factor is usually the result of a significant phase difference between the voltage and current at the load terminals, or it can be due to a high harmonic content or a distorted current waveform. A poor power factor is generally the result of an inductive load such as an induction motor, a power transformer, a ballast in a luminaire, a welding set or an induction furnace. A distorted current waveform can be the result of a rectifier, an inverter, a variable speed drive, a switched mode power supply, discharge lighting or other electronic loads.

A poor power factor due to inductive loads can be improved by the addition of power factor correction equipment, but a poor power factor due to a distorted current waveform requires a change in equipment design or the addition of harmonic filters. Some inverters are quoted as having a power factor of better than 0.95 when, in reality, the true power factor is between 0.5 and 0.75. The figure of 0.95 is based on the cosine of the angle between the voltage and current but does not take into account that the current waveform is discontinuous and therefore contributes to increased losses.

An inductive load requires a magnetic field to operate and in creating such a magnetic field causes the current to be out of phase with the voltage (the current lags the voltage). Power factor correction is the process of compensating for the lagging current by creating a leading current by connecting capacitors to the supply. A sufficient capacitance is connected so that the power factor is adjusted to be as close to unity as possible.

Power factor explained

Consider a single-phase induction motor. If the motor presented a purely resistive load to the supply, the current flowing would be in-phase with the voltage. This is not the case. The motor has a magnet and the magnetizing current is not in phase with the voltage. The magnetizing current is the current that establishes the flux in the iron and, being out of phase, causes the shaft of the motor to rotate. The magnetizing current is independent of the load on the motor and will typically be between 20% and 60% of the rated full load current of the motor. The magnetizing current does not contribute to the work output of the motor.

Consider a motor with a current draw of 10 Amps and a power factor of 0.75. The useful current is 7.5 A. The useful power from the motor is 230 × 7.5 = 1.725kW but the total power that has to be supplied is 230 × 10 =

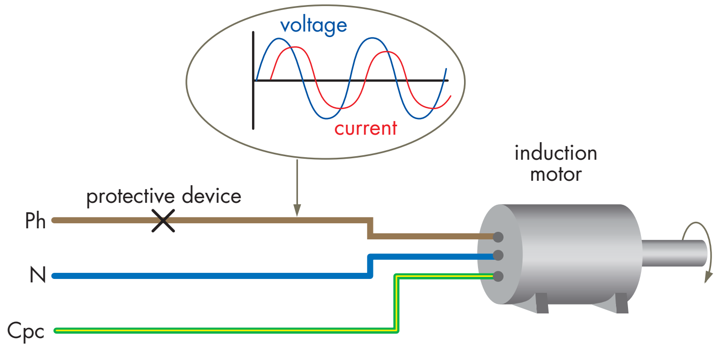
2.3 kVA. Without power factor correction, to achieve the required output of 1.725 kW (7.5 A) a power of 2.3 kVA (10 A) has to be supplied. A current of 10 A is flowing but only 7.5 A of that current is producing useful output.

The power factor can be expressed in two ways:
Power factor (pf) = Useful power (kW) divided by the total power (kVA), or

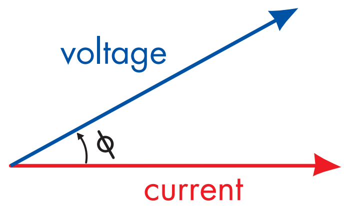
Power factor (pf) = The cosine of the angle between useful power and total power = cos ø.

Power factor correction
Power factor correction is the term given to a technology that has been used since the turn of the 20th century to restore the power factor to as close to unity as is economically viable. This is normally achieved by the addition of capacitors to the electrical network which compensate for the reactive power demand of the inductive load and thus reduce the burden on the supply. There should be no effect on the operation of the equipment.

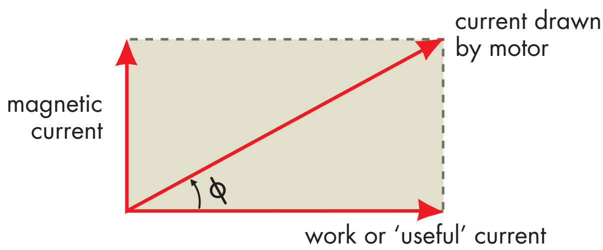
To reduce losses in the distribution system, and to reduce the electricity bill, power factor correction, usually in the form of capacitors, is added to neutralize as much of the magnetizing current as possible. Capacitors contained in most power factor correction equipment draw current that leads the voltage, thus producing a leading power factor. If capacitors are connected to a circuit that operates at a nominally lagging power factor, the extent that the circuit lags is reduced proportionately. Typically the corrected power factor will be 0.92 to 0.95. Some power distributors offer incentives for operating with a power factor of better than 0.9, for example, and some penalize consumers with a poor power factor. There are many ways that this is metered but the net result is that in order to reduce wasted energy in the distribution system, the consumer is encouraged to apply power factor correction. Most Network Operating companies now penalize for power factors below 0.95 or 0.9.



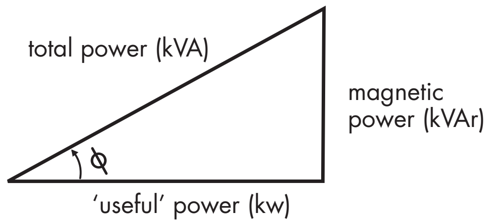
Power supply to induction motor



Phaser diagram of voltage and current



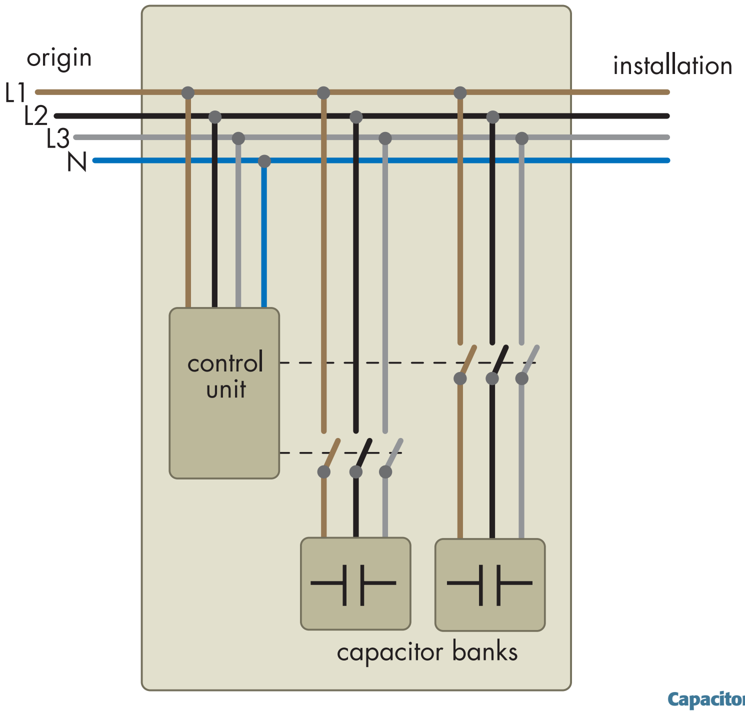
Phaser diagram of currents



Phaser diagram of KW, KVA, and KVAr

Why improve power factor ?
The benefits that can be achieved by applying the correct power factor correction are:

- Environmental benefit. Reduction of power consumption due to improved energy efficiency. Reduced power consumption means less greenhouse gas emissions and fossil fuel depletion by power stations.
- Reduction of electricity bills
- Extra kVA available from the existing supply
- Reduction of I^2R losses in transformers and distribution equipment
- Reduction of voltage drop in long cables.
- Extended equipment life – Reduced electrical burden on cables and electrical components.



Power Factor Correction Unit

Capacitor module designed for local correction of individual loads such as single motors, starters or control gear incorporating an integral circuit breaker for independent isolation and overload protection.
[Illustration courtesy of PFC Engineering Ltd]

A 324 kVAr, automatic power factor correction unit.
[Illustration courtesy of PFC Engineering Ltd]

How to improve power factor

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor or lighting circuits and can be applied at the equipment, distribution board or at the origin of the installation.

Static power factor correction can be applied at each individual motor by connecting the correction capacitors to the motor starter. A disadvantage can occur when the load on the motor changes and can result in under or over correction. Static power factor correction must not be applied at the output of a variable speed drive, solid state soft starter or inverter as the capacitors can cause serious damage to the electronic components.

Over-correction should not occur if the power factor correction is correctly sized. Typically the power factor correction for an individual motor is based on the non load (magnetizing) power since the reactive load of a motor is comparatively constant compared to actual kW load over compensation should be avoided.

Care should be taken when applying power factor correction star/delta type control so that the capacitors are not subjected to rapid on-off-on conditions. Typically the correction would be placed on either the Main or Delta contactor circuits.

Power factor correction applied at the origin of the installation consists of a controller monitoring the VAr's and this controller switches capacitors in or out to maintain the power factor better than a preset limit (typically 0.95).

Where 'bulk' power factor correction is installed, other loads can in theory be connected anywhere on the network. ■