Wiring Matters

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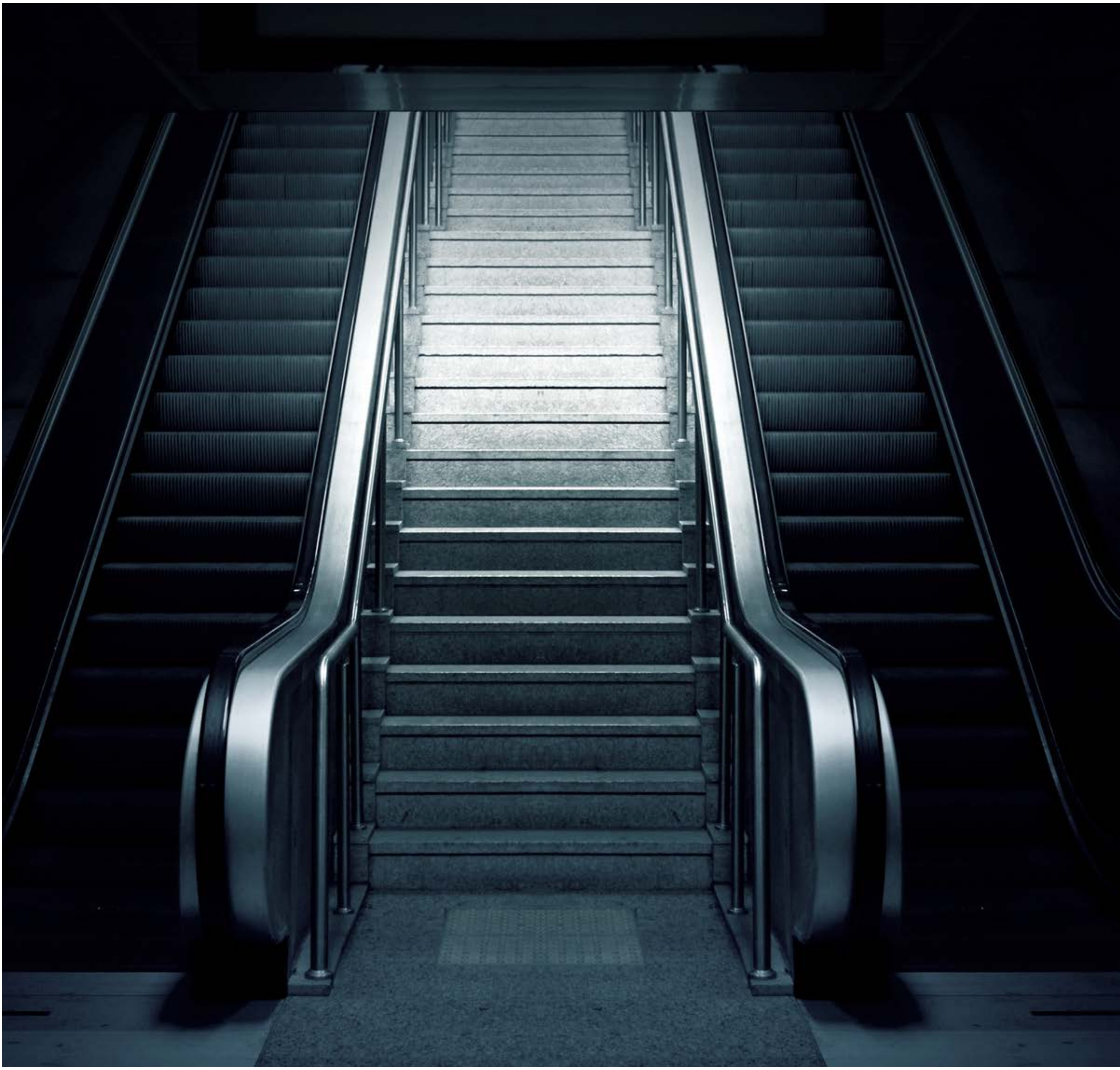
02

Emergency lighting in rail

A brief overview of emergency lighting in rail



In this article, Paul Meenan discusses emergency lighting in rail – the background, how different companies address emergency lighting and how you can get involved in this line of work.

There are a lot of misconceptions around emergency lighting, one being that it's purely down to the lighting designer – well, no it isn't, unless it is in his client brief or remit! Maybe it's in yours, after all you are a sparky, a man or woman of many, many skills! Domestically, there isn't a huge demand for an emergency lighting specialist, but there is a huge demand within other sectors – rented accommodation, commercial and industrial premises. So what do you do?

Perhaps one of the biggest problems we find in many places is the poor application of the principles involved. Emergency lighting isn't just about BS 5266, BS EN 1838, and BS EN 60598-2-22 compliance – the principles, system and product standards involved with emergency lighting. It's also down to how those principles are applied to specific contexts.

No matter where you roam, into the Magical World of Kings Cross or on a London underground train, or the DLR winding your way around east London's ever-changing skyline, emergency lighting is riding along with you, ensuring that in any event of power loss you could still see your way clear. How is it installed? *Read on…*

First, a bit of background

Emergency lighting goes as far back as Paris 1903, to the Couronnes disaster: a terrible tragedy when a train short-circuited, was engulfed in flames and resulted in the loss of 84 lives. Following on from this the French government acted swiftly as the lighting failed, having been fed from a single source with no back up! Within 15 days all stations had to have back-up supplies to protect lighting as this was the main cause of people losing their lives and not being able to evacuate the station safely.

Move forward to 1904 in England, legislation was brought in that recommended emergency lighting into railways. Hence there has been what is known as 'lighting mains' cables in tunnels for many years on London Underground, for example.

Fast forward to 1987 and the tragic Kings Cross fire: 31 deaths. From this arose a whole suite of measures recommended in the Fennel report.

Today, the rail industry uses the lessons learned and is equipped with fantastic teams of fire engineers to ensure safety is paramount for all users, staff and public. Fire engineering is used on new builds to ensure mandatory standards are met and/or even exceeded.

London Underground

No better example is on London Underground, where we have what is known as the Off Line Battery Inverter (OLBI) systems across all major London Underground sites. These are huge battery systems that act as an alternate supply in case of the DNO failure. In addition to these, there are normally at least two power supplies to each station, and also a central connected back-up generator located in Greenwich, so even if the national grid failed, London Underground stations would still have essential power.

Docklands

Moving to the docklands, currently, if power was lost you would never know as each station has 100 % emergency lighting.

National rail

National rail – the term used for Network rail and all the train operator companies. Well, they use central battery systems as well as local bulkhead fitting where required; you will find that as stations are rewired due to the size of infrastrure, emergency lighting is introduced on the more suburban stations that currently have minimal emergency lighting. Remember: the BS EN 1838 standard only requires 1 lux in some places!

Fortunately, buses have huge battery capacity on newer stock and as such will keep you safe even in the event of engine failure.

Maintenance of emergency lighting

The industry is ever changing alongside technology. The advent of LEDs makes emergency systems support so much easier to implement and maintain, and makes the traveling public feel more confident and safe.

Another change in our approach to how we use lighting could involve the use of low level lighting or building it into existing systems as a primary rather than secondary light source.

The advent of LEDs allows you to install discreet emergncy lighting systems in hand rails, for example, making use of existing infrastructure and reducing the need to work at height!

Working as an electrician on railways

Working as an electricain on railways is an amazing adventure but also an enormous responsibility; not only do you have to hold permits and licences to do the role and access rooms regularly but you have to demonstrate competence and understanding of the impact your work has – for example, isolating a board could shut a station! So you need to understand complex distribution drawings, know how how to write your own isolation plans and understand the unique electrical properties and numerous systems that are found when working on railways.

With HS2 Crossrail in full swing and Crossrail 2 perhaps on the horizon, getting an opportunity to work in this area has never been better and, once in, you may find that, having worked on buliding the railways, you wish to maintain the railways systems or even engineer future systems.

How I got involved

The start of my journey seems so easy when I look back: I started by ringing an agency and becoming an electrician's mate. Got my apprenticeship and hey presto 20+ years later I specfy lighting schemes and oversee a railways emergncy lighting system and beyond.

My recommendation for anyone wanting to enter this industry is to start out using Google to find electrician contractors that have rail accreditations, which mean that they are authorised to work in the indutsry – it doesn't matter where; it's getting your foot in the door that counts, your ability to learn and excel will do the rest.

Agencies are eaily accesible via your phone and web searches but do not be afraid to do the old-fashioned ring up and ask for an apprenticeship if you are young and, if older, be honest and go in as an adult learner and work as a mate to pick up skills. If you have the right attitude your employer will support, embrace, train and devlop you.

Do a great job, stand up for first principles and you will excel; be trusted, continue to train and you will grow your career quickly. You may have heard of the 'ABA effect' (attitude, behaviour, agenda); for me it was all about being friendly, open and keen to learn as much as I could to build my confidence. My behaviour grew with my knowledge and my agenda was to serve the industry in doing the right things. Electrical competence is a rare discipline in rail; this line of work can be complex but also very rewarding.

05

06

18th Edition

The impact of the 18th edition (BS 7671:2018)

Chapters 41, 46, 53 and Regulation 542.2.2

Steven Devine, author of the Student's Guide to the IET Wiring Regulations and Secretary of Sub-Committee C (JPEL/64), looks at some of the proposed changes in the DPC (draft for public comment) for electrical installations, focusing on Chapters 41, 46, 53 and Regulation 542.2.2.

Note: the following are draft proposals only at this stage and may or may not be included in the 18th edition (BS 7671:2018), depending on the decision of the national committee, JPEL/64. This article is based on the DPC that is now available (on the BSI website) to anyone to view and to comment on.

Changes to Chapter 41

410 Introduction

You will see some subtle differences with some of the words and phrases, such as "in use without a fault" being replaced with "under normal conditions". These changes usually happen when the committee members agree improvements or that modernisation is required so that BS 7671 is more readable by those who need to use it.

You may have also noticed that the following lines have been deleted in BS 7671:2001:

(i) 'protection in use without a fault' (now designated 'basic protection') was referred to as 'protection against direct contact'; and
(ii) 'protection under fault conditions' (now designated 'fault protection') was referred to as 'protection against indirect contact'.

The terms 'basic protection' and 'fault protection' have been around for many years now and the need to identify the change is no longer necessary.

New words are introduced and terminologies change over the years. The Wiring Regulations are over 130 years old and therefore these changes are important in keeping up to date with current use and language, despite how subtle such changes may seem.

Regulation 411.3.1.2

It's proposed that this Regulation should have an additional line in the 18th Edition due to the increase in the number of services to buildings that have insulating inserts, such as water pipes and gas pipes. In most cases, such an increase could result in the service pipes not meeting the characteristics of an extraneous-conductive part (a conductive part that is liable to introduce an earth potential into the installation) and, as the risk of introducing earth potential is reduced, the pipes no longer require protective equipotential bonding. The following line has been included in Regulation 411.3.2:

Metallic pipes entering the building having an insulating section at their entrance need not be connected to the protective equipotential bonding.

This means that electrical installers will need to identify whether or not an incoming service pipe has an insulating insert to determine if it is required to have protective equipotential bonding or not.

Regulation 411.3.3 Additional protection requirements for socket-outlets and for the supply of mobile equipment for use outdoors

According to the current requirements in AC systems, additional protection by means of an RCD in accordance with Regulation 415.1 shall be provided for socket-outlets with a rated current not exceeding 20 A, and mobile equipment with a current rating not exceeding 32 A for use outdoors. However, there is currently an exception to this requirement as long as a documented risk assessment is carried out to justify that RCD protection will not improve the safety of the circuit. There has been a significant change proposed so that there is no longer an exception for the provision of RCDs for socket-outlets with a current rating not exceeding 32 AAs the availability of RCDs has increased and the cost gradually decreased over the years it is commonly found in modern installations that all circuits including lighting are provided with RCD protection. There is no doubt that they are a very efficient protective device and, where practicable, they are a valuable addition to the electrical installation. This means that electrical installers will need to find alternative solutions to provide a power supply to equipment that is required to be on a non-RCD protected circuit, such as switch fused connection units.

Regulation 411.3.4

The proposed new 411.3.4 requires that all luminaires within domestic (household) premises are to have additional protection by a 30 mA RCD when installed in an AC final circuit. Back in the

1950s it was not required that a lighting circuit have a cpc provided; you may even still come across lighting circuits today that do not have a cpc, so we can see how the requirements are continually reviewed and amended to improve the safety of electrical installations.

This new proposal means that electrical installers will now have to provide RCD protection on all new lighting circuits as well as those that are significantly altered.

Chapter 46

You're probably thinking that you have seen this before and you would be right. Chapter 46 appeared in the Wiring Regulations up until 2008 when the 17th edition was published. It consisted of two pages titled 'Isolation and Switching'. In 2008, when the 17th edition was published, Chapter 46 was adopted by Chapter 53 Protection, Isolation, Switching, Control and Monitoring. Ten years on a lot has changed and Chapter 46 is no exception; it is proposed that Chapter 46 Isolation and Switching is to appear again, only this time it will consist of three pages covering Isolation, Functional Switching (Control), Auxiliary Circuits, Motor Control, Switching Off for Mechanical Maintenance, and Emergency Switching Off. All of these were previously covered in Section 537 of the 3rd Amendment of the 17th edition of BS 7671. Chapter 46 provides requirements for the function while Chapter 53 provides requirements for the devices.

Chapter 53 has received a lot of attention during the development of the 18th Edition. You will find a number of changes – not only the relocating of some parts of Section 537 to Chapter 46, but also the introduction of Annex A 53 (informative), which provides information about devices and their associated functions. It is proposed that this Annex include Table A 53.2, which shows the types of combination of devices and cells and how various modes of co-ordination can affect the operation of devices. This section will prove extremely useful for those who are involved with the design and installation of systems that consist of a wide range of protective devices where consideration to selectivity is required.

Regulation 542.2.2

Another significant change to Part 5 is a new note that strongly recommends the provision of a foundation earthing system in new buildings. Regulation 542.2.3 requires that, where foundation earthing earth electrodes are installed, the materials and dimensions of the earth electrodes are to be selected so that they can withstand corrosion and have adequate mechanical strength.

The installation of a foundation earthing system has been a requirement in a number of other countries around the world for some time. In Germany the primary purpose behind installing foundation earthing systems is to improve earth fault loop impedance for TT systems. However, there are some other benefits, including the reduction of potential difference between the general mass of Earth and any exposed- or extraneous-conductive-parts in the event of a PEN conductor failure.

This means that electrical installers will have to consider installing a foundation earthing system in new installations, if it is reasonably practicable to do so.

Conclusion

This article only gives an overview of draft proposals, which may or may not be included in the 18th edition (BS 7671:2018), depending on the decision of the national committee, JPEL/64.

The DPC (draft for public comment) is now available to the public (on the BSI website) for comment.

Sections 722, 753 and [new] 730

In this article, Geoff Cronshaw looks at the impact that some of the proposed changes in the DPC (draft for public comment) of BS 7671 will have on electrical installations, focusing on Section 722, Section 753, and the new Section 730.

Note: the following are draft proposals only at this stage and may or may not be included in the 18th edition (BS 7671:2018), depending on the decision of the national committee, JPEL/64. This article is based on the DPC that is now available (on the BSI website) to anyone to view and to comment on.

Changes to Section 722

Section 722 (electric vehicle charging installations) provides requirements for the supplies to electric vehicles. There are a number of significant changes in Section 722 of the DPC:

Protection against electric shock

Regulation 722.411.4.1 concerning the use of protective multiple earthing (PME) supply has changed. The exception for a dwelling if none of (i), (ii), or (iii) is reasonably practicable has been deleted. This now means that PME cannot be used unless you meet (i), or (ii), or (iii) of 722.411.4.1. As a reminder of those regulations:

– Regulation 722.411.4.1(i) refers to a situation where a connecting point is supplied from a 3-phase installation used to supply loads other than charging points and where the load is sufficiently well balanced.
– Regulation 722.411.4.1(ii) requires a very low resistance earth electrode to mitigate the effects of an open circuit PEN conductor fault on the supply.
– Regulation 722.411.4.1(iii) refers to protection by a voltage operated device. An important change is that the regulation now makes the point that this device could be included within the charging equipment. It is worth noting that this device will also require an earth electrode.

The touch voltage threshold of 70 V mentioned in 722.411.4.1(i), 722.411.4.1(ii) and 722.411.4.1(iii) is on the basis that Table 2c (Ventricular fibrillation for alternating current 50/60 Hz) of IEC 60479-5{ed1.0} gives a value of 71 V for both-hands-to-feet, in water-wet conditions with medium contact area (12.5 cm²).

What is PME?

The Electricity Safety, Quality and Continuity Regulations 2002 (as amended) permit the distributor to combine neutral and protective functions in a single conductor provided that, in addition to the neutral to Earth connection at the supply transformer, there are one or more other connections with Earth. The supply neutral may then be used to connect circuit protective conductors of the customer's installation with Earth if the customer's installation meets the requirements of BS 7671.

This PME has been almost universally adopted by distributors in the UK as an effective and reliable method of providing their customers with an earth connection. Such a supply system is described in BS 7671 as TN-C-S. Whilst a protective multiple earthing terminal provides an effective and reliable facility for the majority of installations, under certain supply system fault conditions (external to the installation) a potential can develop between the conductive parts connected to the PME earth terminal and the general mass of Earth.

The potential difference between true Earth and the PME earth terminal is of importance when:

(a) body contact resistance is low (little clothing, damp/wet conditions); and/or
(b) there is relatively good contact with true Earth.

Contact with Earth is always possible outside a building and, if exposed-conductive-parts and/or extraneous-conductive-parts connected to the PME earth terminal are accessible outside the building, people may be subjected to a voltage difference appearing between these parts and Earth.

External influences

In addition to IPX4 (protection against presence of water), Section 722 now requires IP4X as well to protect against presence of solid foreign bodies (AE3 – i.e. very small), and protection against impact (AG2 – i.e. medium severity).
Any wiring system or equipment selected and installed must be suitable for its location and able to operate satisfactorily without deterioration

during its working life. Suitable protection must be provided, both during construction and for the completed installation.

RCD protection

Regulation 722.531.2.101 has been redrafted concerning RCD protection. The regulation now contains further requirements for both Type A and Type B RCDs to take account of DC fault current.

Socket-outlets and connectors

It is now required that where a BS 1363-2 socket-outlet is used for EV changing it must be marked 'EV' on its rear, except where there is no possibility of confusion, a label shall be provided on the front face or adjacent to the socket-outlet or its enclosure stating: 'suitable for electric vehicle charging'.

Socket-outlets must be fit for purpose. They must be suitable for the load, and for the external influences such as protection against mechanical damage and ingress of water.

Changes to Section 753

Extension of scope – embedded electric heating systems for surface heating

The scope of Section 753 has been extended to apply to embedded electric heating systems for surface heating. They also apply to electric heating systems for de-icing or frost prevention or similar applications, and cover both indoor and outdoor systems. These include heating systems for walls, ceilings, floors, roofs, drainpipes, gutters, pipes, stairs, roadways and non-hardened compacted areas (for example, football fields, lawns). Heating systems for industrial and commercial applications complying with IEC 60519 and IEC 62395 are not covered.

Consequently, Section 753 now includes additional requirements to cover wall heating, heating conductors and cables where laid in soil and concrete etc. Additional requirements are also included to cover prevention of mutual detrimental influence.

Documentation is also covered. The designer will be required to provide appropriate information about approved substances in the surroundings of the heating units.

Additional requirements for wall heating systems

For wall heating systems (which may be more vulnerable than floors and ceilings from penetration) the standard contains additional requirements to protect against the effects of overheating caused by a short circuit between live conductors due to penetration of an embedded heating unit.

Regulation 753.424.101 requires that for wall heating systems the heating units shall be provided with a metal sheath or metal enclosure or fine mesh metallic grid. The metal sheath or metal enclosure or fine mesh metallic grid shall be connected to the protective conductor of the supply circuit.

Regulation 753.424.102 requires special care to be taken to prevent the heating elements creating high temperatures to adjacent material. This may be achieved by using heating units with temperature self-limiting functions or by separation with heat-resistant materials. Separation may be accomplished by placing on a metal sheet, in metal conduit or at a distance of at least 10 mm in air from the ignitable structure. A note adds that a larger separation distance may need to be considered depending on adjacent material.

A new Section 730: Onshore units of electrical shore connections for inland navigation vessels

Section 730 applies to onshore installations that are dedicated to the supply of inland navigation vessels for commercial and administrative purpose, berthed in ports and berths.

Most, if not all, of the measures used to reduce the risks in marinas apply equally for electrical shore connections for inland navigation vessels. One of the major differences between supplies to vessels in a typical marina and electrical shore connections for inland navigation vessels is the size of the supply needed. For example, vessels used on inland waterways in Europe can be up to 10, 000 tonnes, which are considerably larger than the average size of vessel used in a marina, which are generally small recreational craft (up to 24 m long). Generally socket-outlets with a rating of 16 A will be provided for each craft in a marina. However, many of the risks associated with electrical installations in marinas, such as the presence of water, movement of structures and harsh environmental conditions, are the same as for electrical shore connections for inland navigation vessels. In this article we summarise some of the key requirements of Section 730.

Supplies

Section 730 requires that the nominal supply voltage shall be 400 V 3-phase AC 50 Hz. Important: where the supply system is protective multiple earthed (PME), Regulation 9(4) of the Electricity Safety, Quality and Continuity Regulations 2002 (as amended) prohibits the connection of the neutral to the metalwork of any caravan or boat in the UK.

Galvanic separation

The immersion of metal components of a vessel in water, particularly in salt water, provides the natural mechanism of galvanic corrosion. Where there are dissimilar metals on the electro-chemical series in proximity the detrimental effect of galvanic couples can be exacerbated and for this reason small vessels, recreational craft, houseboats, ships and many immersed metal structures are provided with sacrificial anodes (zinc for salt water) to which the more valuable/essential immersed metal parts such as propellers, shafts, hull fittings and fixings are electrically bonded and the sacrificial anode(s) preferentially deplete as a consequence of providing galvanic corrosion protection to such immersed parts.

Section 730 recognises that there is an additional risk of electrolytic corrosion resulting from circulating galvanic currents in the protective conductor from the shore supply to a vessel. There have also been reports of increased rate of depletion of the sacrificial anodes of vessels that are connected on a longer-term basis to shore supplies, which is believed by some observers to be associated with the connection of the vessel’s protective earth terminal (to which immersed components and sacrificial anodes are bonded) to the shore supply earth in an inland waterway or marina.

Section 730 recognises the use of an isolating transformer to prevent galvanic currents circulating between the hull of the vessel and the metallic parts on the shore side. Where a fixed on-shore isolation transformer is used to prevent galvanic currents circulating between the hull of the vessel and metallic parts on the shore side, equipment complying with BS EN 61558-2-4 shall be used.

Protection against electric shock

As you would expect, the protective measures of obstacles, placing out of reach, non-conducting location and protection by earth-free local equipotential bonding are not permitted in Section 730. These measures are not for general application. They are only for application in installations controlled or supervised by skilled or instructed persons.

Operational conditions and external influences
Any wiring system or item of equipment selected and installed must be suitable for its location and able to operate satisfactorily without deterioration during its working life. In ports and berths consideration must also be given to the possible presence of corrosive or polluting substances.

Section 730 requires that equipment shall be selected with a degree of protection of at least IP44.

Types of wiring system

Cables must be selected and installed so that mechanical damage due to tidal and other movement of floating structures is prevented.

Section 730 recognises that the following wiring systems are suitable for distribution circuits in berths and ports:

(a) underground cables;
(b) overhead cables or overhead insulated conductors;
(c) cables with copper conductors and thermoplastic or elastomeric insulation and sheath installed within an appropriate cable management system, taking into account external influences such as movement, impact, corrosion and ambient temperature;
(d) mineral-insulated cables with a thermoplastic protective covering;
(e) cables with armouring and serving of thermoplastic or elastomeric material; and
(f) other cables and materials that are at least as suitable as those listed above.

Section 730 recognises that the following wiring systems and cables are suitable for distribution circuits on floating landing stages:

(a) cables with copper conductors and thermoplastic or elastomeric insulation and installed within an appropriate cable management system taking into account external influences such as movement, impact, corrosion and ambient temperature; and
(b) armoured cables with a thermoplastic or elastomeric covering.

Other cables and materials that are at least as suitable as those listed under (a) or (b) may be used.

Section 730 requires that underground distribution cables shall, unless provided with additional mechanical protection, be buried at a sufficient depth to avoid being damaged, for example, by vehicle movement. Overhead cables are not permitted over waterways. Where overhead conductors are used they must be insulated. Poles and other supports for overhead wiring must be located or protected so that they are unlikely to be damaged by any foreseeable vehicle movement. Overhead conductors shall be at a height above ground of not less than 6 m in all areas subjected to vehicle movement and 3.5 m in all other areas.

Isolation, switching and control (automatic disconnection of supply)

RCD protection

Section 730 gives additional requirements concerning RCD protection:

(a) Socket-outlets with a rated current up to 63 A shall be individually protected by an RCD providing additional protection in accordance with Regulation 415.1 having a rated residual operating current not exceeding 30 mA.
(b) The RCD selected shall disconnect all live conductors, i.e. phases and neutral.
(c) Socket-outlets with a rated current above 63 A shall be individually protected by an RCD having a rated residual operating current not exceeding 300 mA. The RCD selected shall disconnect all live conductors, i.e. phases and neutral.

NOTE: The purpose of these RCDs is to protect the shore supply and the flexible cable. It is not intended to provide protection for on-board circuits, which are outside the scope of Section 730.

Devices for protection against overcurrent

Similar to the requirements in marinas, socket-outlets shall be individually protected by an overcurrent protective device.

Isolation

Similar to the requirements in marinas, at least one means of isolation shall be installed for each distribution board. This device shall disconnect all live conductors.

Requirements for socket-outlets

Section 730 sets out the following requirements for socket-outlets:

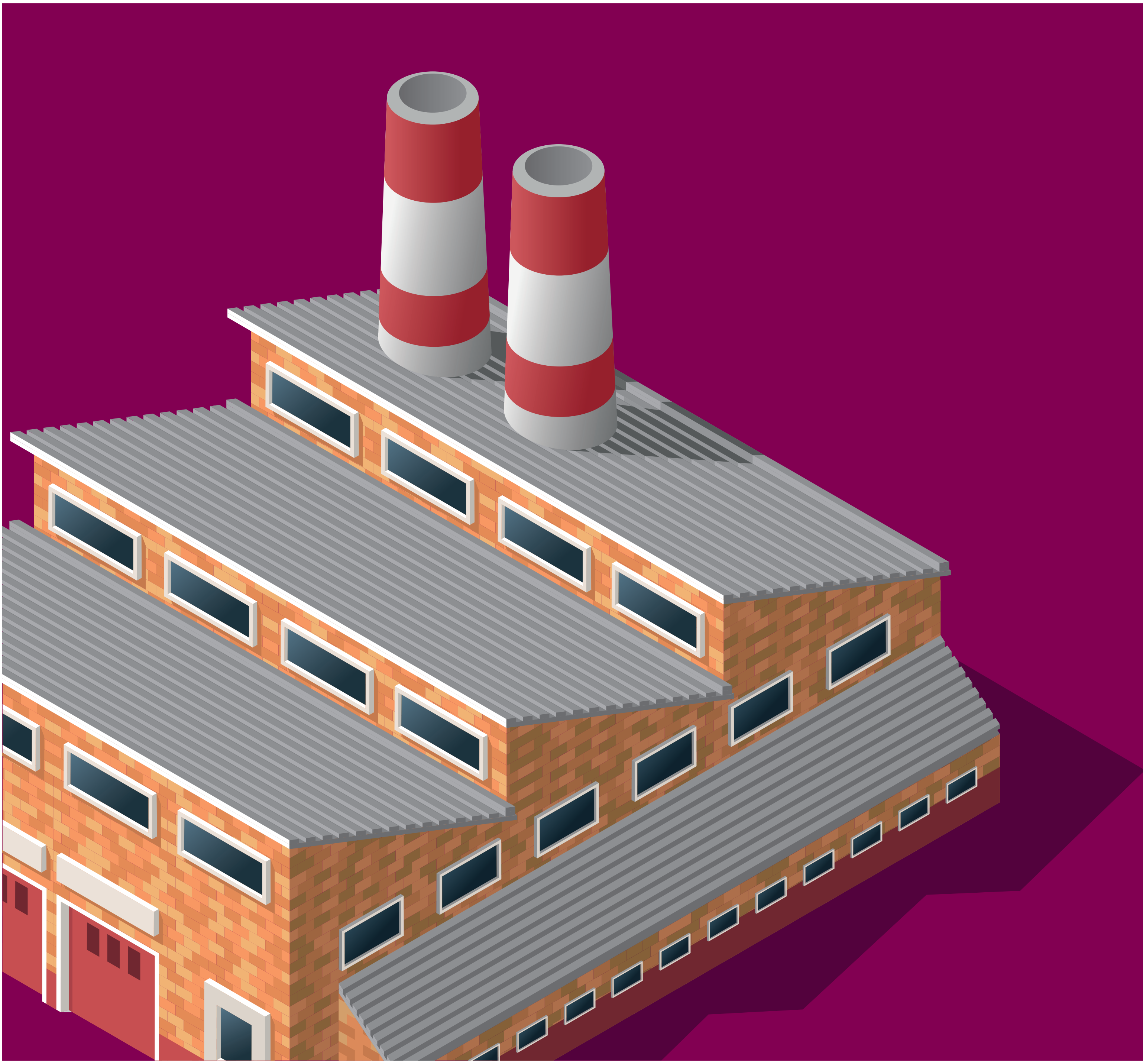
(a) Socket-outlets shall comply with BS EN 60309-1 and BS EN 60309-4 and socket-outlets with a current rating up to and including 125 A shall comply with EN 60309-2.
(b) Where interchangeability is not required, socket-outlets shall comply with BS EN 60309-1 and BS EN 60309-4 and need not comply with BS EN 60309-2.
(c) Socket-outlets shall be located as close as practicable to the berth to be supplied.
(d) No more than four socket-outlets shall be grouped together in any one enclosure.
(e) Each socket-outlet shall supply only one electric circuit of a vessel.
(f) Socket-outlets shall be placed at a height of not less than 1 m above the highest water level.
(g) In the case of floating pontoons or walkways only, this height may be reduced to 0.3 m above the highest water level provided that appropriate additional measures are taken to protect against the effects of splashing.
(h) Socket-outlets shall be placed in an enclosure in accordance with BS EN 15869-2.

Conclusion

This article only gives an overview of draft proposals, which may or may not be included in the 18th edition (BS 7671:2018), depending on the decision of the national committee, JPEL/64. The DPC (draft for public comment) is now available to the public (on the BSI website) for comment.

Energy Efficiency

The impact of the 18th Edition (BS 7671:2018) – New Part 8, Section 801 Energy Efficiency



Mark Coles, Head of Technical Regulations – IET, looks at a proposed new area for BS 7671 – Part 8, Section 801 Energy Efficiency.

Note: the following are draft proposals only at this stage and may or may not be included in the 18th Edition (BS 7671:2018), depending on the decision of the national committee, JPEL/64. This article is based on the DPC that is now available (on the BSI website) to anyone to view and to comment on.

It's nothing out of the ordinary to see new requirements coming into the Regulations but energy efficiency takes a different approach.

Traditionally, BS 7671 has had requirements for "the safety of persons, livestock and property against dangers and damage which may arise in the reasonable use of electrical installations" and this stance, of course, will continue. The introduction of the concept of energy efficiency breaks from tradition but, don't worry, it's nothing really new to us.

Like all British Standards, BS 7671 is not a statutory document but, as cited in the Electricity at Work Regulations 1989 (EWR), by following the requirements of BS 7671 you are likely to meet the requirements of the law. The requirements of the proposed new section, Section 801 Energy Efficiency, is not safety related so it doesn't sit conventionally under EWR but, however, it aids in the meeting of requirements of Part L (Conservation of fuel and power) of the Building Regulations of England and of Wales and the conservation requirements of Scotland and of Northern Ireland. Irrespective of one's political stance or opinions on climate change and global warming, it is fundamentally important that we conserve energy. International and European standards on energy efficiency, such as IEC 60364-8-801 and HD 60364-8-801, have already been published and, regardless the inclusion in BS 7671, the UK still has to implement the requirements.

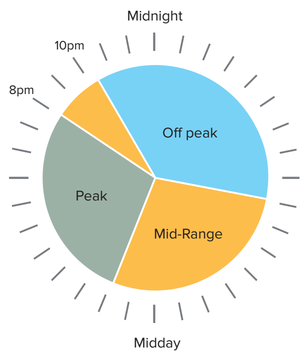
Design and installation practice

From a design and installation point of view, energy efficiency can be applied to all installations, i.e. domestic, commercial and industrial. The main question is – how does it affect the designer or the installer? The good news is that most of the principles within are common parlance already. Let's look at the concepts.

I. Consumer demand

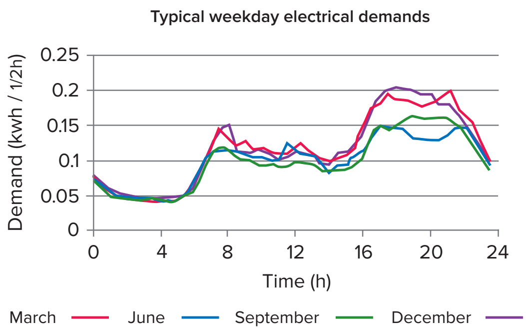
At design stage, particularly for larger installations, it's important to know the consumer (or maximum) demand, for example, in kWh. With the application of diversity, the consumer demand can be assessed. This will help determine the size of the electrical supply required for a new building; larger supplies, of course, cost more to install and tariffs are generally higher.

II. Tariff structure



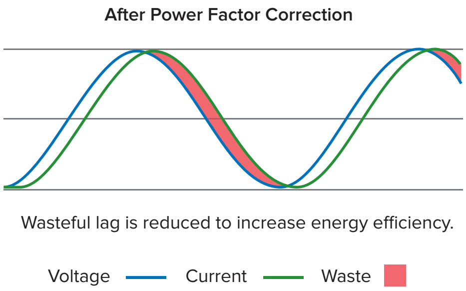
The tariff structure will need to be agreed with the supplier. Based on the maximum demand, a tariff structure will set the parameters in which the installation is expected to operate. This could include on- and off-peak tariffs. If the client exceeds the maximum demand, even for a very short period of time, they will be financially penalised for the whole period, i.e. a month.

III. Load profile



As the graph shows, knowledge of the load profile allows us to identify when peak loads can occur and if particular loads can be operated during quieter periods. Keeping the graph as 'flat' as possible means that peaks are avoided and consumer demand is kept low.

IV. Power factor correction



Wasteful lag is reduced to increase energy efficiency.

When the power factor is at unity, all the energy supplied by the source is consumed by the load. Power factors are usually stated as 'leading' or 'lagging'. Capacitive loads are leading (current leads voltage) and inductive loads are lagging (current lags voltage). When power factor is poor, the client will be heavily penalised by the electrical supplier on larger commercial installations. Modern equipment is likely to have its power factor corrected within but if, for example, older equipment without internal power factor correction is used, such as relocated industrial equipment, it would be beneficial to install suitable correction equipment. Conversely, as a point of note, altered circumstances may mean that, where power factor correction is already in operation in an older installation, the equipment is ineffectual and the operator may be regularly penalised by the supplier for operating at a poor power factor.

V. Location of equipment

Often on large sites HV/LV transformers are located on the outskirts or periphery of a large building. In order to distribute electricity across the site, large low voltage distribution cables are run to feed distribution boards, etc. Theses cables will be sized to allow for volt drop but there will be losses in the cables. Now consider the same site with the HV/LV transformer sited in the centre of a large building. Low voltage distribution cables that are run to feed distribution boards, etc. are far shorter than the previous example. Applying this logic to the positioning of heavy and frequently used loads will result in a more efficient distribution system.

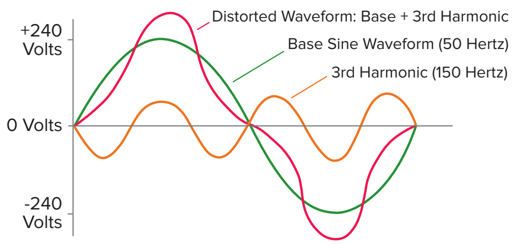
VI. Lighting and controls

It's well established that newer 'low energy' light sources, such as LED, are far more efficient than incandescent lamps, however, colour rendering may not be equivalent but that's another issue. Efficient lighting systems will 'harvest' natural light wherever possible and will dim or increase the illuminance when natural light is low. Occupancy detectors will switch off the lighting when a room is not occupied. Part L of the Building Regulations of England and of Wales has specific statutory requirements for lighting controls, luminous efficacy and/or W/sq m/year that are well in advance of the requirements of the proposed Section 801. Note that you wouldn't comply with UK lighting energy conservation requirements if you followed the content of Section 801 alone.

VII. Harmonic reduction

Where harmonics occur in the electrical system, it means that non-linear loads are being supplied. A linear load could be something as simple and straightforward as an incandescent lamp. When the incandescent lamp is supplied, current is drawn at the same frequency as the supply voltage.

Non-linear loads, such as rectifiers, switch mode power supplies and variable speed drives result in a non-sinusoidal waveform, which can cause many problems – typically overheating waveforms and overloading of neutral conductors. Where triplen harmonics are present, currents add in the neutral conductor because part of the waveform is at a peak at the same time as the fundamental; this image is a simplification of how triplen harmonics add in the neutral conductor:



Harmonic reduction is therefore of great importance in achieving an energy efficient installation.

VIII. Motor control

When motors start they can draw a very large current. Drawing a large current for even a very short period of time could mean a breach of the tariff structure agreement. Using energy-efficient soft starters dramatically reduces the starting current.

IX. Cable sizing

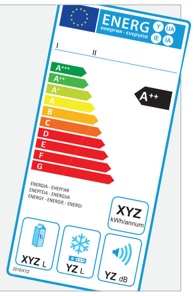
When we design circuits, we tend to use conductors with the smallest cross-sectional area (csa) possible to keep initial costs down. By using the smallest csa conductor, however, the cable may be close to its maximum running temperature, which for PVC/PVC, is 70 ˚C. When a cable runs hot, the heat generated is lost energy, which has to be paid for. Choosing a larger csa conductor would mean the cables run cooler so there are fewer losses.

Choosing a larger csa cable at the point of installation puts the initial cost of the installation up but it can be demonstrated over time, say the twenty year lifecycle of a building, that the increased installation costs can be recouped over a period of time as less energy is lost.

Strategic approach

So, as you can see, much of this is not new and by putting it all together we can achieve an energy efficient installation. We're all familiar with energy ratings (shown below) on appliances, such as ovens and fridges:

We can approach energy efficient electrical installations in a similar way, i.e. design an installation to a particular energy rating. Energy efficiency measures are classified according to five levels (from 0 to 4). Level 4 is considered to be the highest attainable level and the requirements for each level include requirements for the preceding ones.



Consider the following table is from Section 801 of the DPC of BS 7671:2018:

Lighting, required optimization analysis

Sector of activity	EM0	EM1	EM2	EM3	EM4
Residential buildings (dwellings)	No consideration	No consideration	To consider lamp type and position	To consider lamp type and position with natural lighting Control according to natural lighting source or building use or lamp type	Control according to natural lighting source and building use and to consider lamp type
Commercial, Industrial, and Infrastructure	No consideration	To consider lamp type and position	To consider lamp type and position with natural lighting	Control according to natural lighting source or building use or lamp type	Control according to natural lighting source and building use and to consider lamp type

This approach, across all aspects of an electrical installation, allows us to describe an electrical installation in terms of efficiency and to design to a particular efficiency level.

Summary

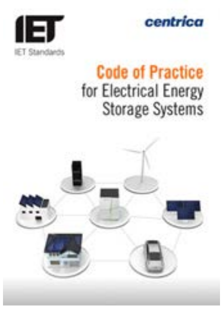
Part 8, Section 801 Energy Efficiency of DPC BS 7671:2018 takes a different approach to electrical installations and is a result of the need to use energy more efficiently. The concepts within the section are nothing new to electrical designers and installers but this section pulls the relevant aspects together and allows us to describe an electrical installation in terms of efficiency and to design to a particular efficiency level.

This article only gives an overview of draft proposals, which may or may not be included in the 18th Edition (BS 7671:2018), depending on the decision of the national committee, JPEL/64.

The DPC (draft for public comment) is now available to the public for comment at this url: https://standardsdevelopment.bsigroup.com/

Electrical Energy Storage Systems

Code of Practice for Electrical Energy Storage Systems
– the thought leaders behind the new publication



In August the IET publishes Code of Practice Electrical Energy Storage Systems – an invaluable resource for those involved in the planning, procurement, design, installation, commissioning and maintenance of electrical energy storage systems. The work behind the Code of Practice required the industry's thought leaders to come together and interrogate the overall framework of operations for energy storage systems, so perhaps it is no wonder that this work already achieved a streamlined and cost-effective connection process between building and DNO – before the Code of Practice had even gone to print!

We introduce some of these thought leaders – including engineers, installers, trainers, manufacturers and academics – interview them to find out about what this Code of Practice means for them and for the industry at large.

EUR ING Graham Kenyon BEng(Hons) CEng MIET TechIOSH, Principal & Director – G Kenyon Technology Ltd (One of the Lead Authors of the Code of Practice)

Graham, you're one of our popular authors, both for our IET Standards work and our Wiring Matters articles. What personal benefit is there in working on Codes of Practice and Guides?

The principal benefit is the ability to meet other professionals from a very broad spectrum of backgrounds and professional interest, and work on something that will be of benefit to as wide a variety of practical applications as possible.

A common set of guidance must ensure that the various challenges presented by different applications can be addressed. It is sometimes far from easy to achieve this without revisiting the same problem from a variety of practical perspectives. Overall, I feel that in doing this, I am able, at the same time, to both use my own broad experience, and learn and develop individually.

Finally, it must be acknowledged that, in working to develop and maintain standards, Codes of Practice and guidance, you are ensuring you are keeping up to speed with the latest developments in the industry.

This committee work on this Code had the unusual consequence of making a significant change to the process of installing energy storage systems. Can you explain that change?

There has been a variety of approaches to notification of generation that falls under the scope of ENA Engineering Recommendation G83. In conjunction with colleagues across the industry, including the electrical supply industry, the Code of Practice has been able to clarify the requirements. It is hoped that this will help ensure that the right notification process is used for each system.

What electrical installation safety challenges had to be considered for the Code of Practice?

When an electrical installation with energy storage moves from 'on-grid' (connected to the public supply) to 'island mode' (stand-alone operation, with the public supply disconnected from the live conductors in the installation), there are two main challenges for a designer.

First, the characteristics of supply alter. The prospective fault current drops (often dramatically) and earth fault loop impedances increase accordingly, because the supply is from a power converter rather than a public supply transformer. The challenge was to look at guidance for designers to ensure that required disconnection times continue to be met for electrical safety. In addition, the supply earthing arrangements may change, for example to TN-S in island-mode, from TN-C-S or TT, and the guidance had to address that also. The Code of Practice therefore discusses design options for protection against electric shock and faults in island-mode.

Second, in island-mode, it is not possible to rely on the supplier's means of earthing, and indeed BS 7671 requires alternative or supplementary earthing arrangements are in place. With smaller (lower power) electrical energy storage installations, it is not always practicable to achieve low earthing resistances. Practical guidance was developed for system earthing of low power electrical energy storage systems. This may be an enabler for increased take-up of safe electrical energy storage.

Paul Chandler MEng MSc MIET MEI, Director – T4 Sustainability Ltd

You've played a significant role in making sure that energy storage batteries are fit for purpose, having helped to test the installation of 35 domestic energy battery systems last year, and so far this year 10 for an EU-funded university research project. What was this experience like – and what is your view of energy storage battery systems?

It has been very exciting to be involved in something new which has the potential to change the energy landscape. Prices, specifications and understanding has changed a lot over the last year and with continued improvements in efficiency and price we could see a large number of systems installed. There is still some uncertainty about the environmental benefit of storage systems at present, but the UK will need more storage as we continue to move away from fossil fuels.

As part of the committee for this Code of Practice, were you able to contribute this experience and so shape the development of the Code?

My experience installing systems meant I could offer opinions on the draft Code and provide examples of typical system configurations and installation issues based on practical experience.

Do you think that this Code of Practice will make it easier for installers to fit energy storage systems?

As the technology is new in the UK, there has been a limited understanding in the electricity industry and little technical guidance on best practice. In my mind there is no doubt that the Code of Practice will help installers design systems correctly.

Dani Strickland, Lecturer Loughborough University

Dani, you've been very involved with researching energy storage for many years. How much academic research has gone in to energy storage?

A significant amount of academic research has been undertaken into energy storage in recent years. This is more apparent in the USA where the energy market is different and it makes more commercial sense to include energy storage within a domestic and grid environment. However, there is significant work being undertaken within the UK. The research in academia is very much divided into chemistry based research looking at new battery chemistries and more applied research, for example, looking at grid connection issues including both modelling and hardware prototyping. This academic research into grid connection issues is clearly evidenced by the introduction of academic papers on energy storage within IET-run conferences, such as PEMD, RTDN and ACDC, and journals. There is also a much greater emphasis on larger scale hardware related research, for example, the Willenhall energy storage system funded by the EPSRC, to help with innovation in this area.

How far did this research, and an academic understanding of energy storage, help to shape the Code?

From my perspective, I've been closely involved with energy storage research for several years, including working on the Western Power Distribution run FALCON project and the ongoing EPSRC Willenhall project. The knowledge gained from working with batteries in a grid environment, in my opinion, was very important to helping to shape the Code. There was a significant amount of learning that transferred across into the Code from all parties, including myself, who have previously worked on batteries, even down to issues such as terminology.

Would this book be useful for engineering students?

There is an increasing trend in Universities to deal with project based learning. I'm a strong advocate of this and my personal opinion is that students should understand much more about practical issues like connecting energy storage. I think that where students cover issues relating to practical issues, including, for example, aspects of the IET wiring regulations, this would be a valuable addition to their learning. Unfortunately, many students do not cover such material in their courses and would probably find it quite dry reading.

Serkan Kaniturk MSc BSc CEng MIET, Head Of Engineering – Distributed Energy UK&I at Centrica

Serkan, as Head of Engineering at Centrica, do you see a consumer shift towards renewables and energy storage?

There are significant changes expected to our electricity systems in the near future. The EU, for example, unveiled its climate change targets of cutting greenhouse gas emissions by 40 % by 2030 compared with 1990 levels, with 27 % of energy to be met by renewable sources. By 2050, greenhouse gas emissions should be reduced by 80 % and the electrical power sector will need to be almost entirely decarbonised. Noticeably, fossil fuel generation is already being replaced with renewable energy systems, such as wind and solar power. Such generating technologies are characterised by intermittent output that is correlated with the variable wind and solar resource. This introduces further variability to the system, and adds further challenges to system balancing. Furthermore, if electric vehicles are adopted in large numbers, then the transport sectors will become increasingly electrified. This could lead to more peaky demand; as everyone gets home from work around the same time, plugs in their electric vehicles to charge, and switches other loads to warm up their homes, etc.

If these issues are left unmanaged, electric vehicles and other loads could result in demand profiles that are difficult to supply. These future scenarios indicate that the task of matching supply and demand will become increasingly challenging for the network. We certainly believe that introducing more energy storage to the network system is one way of mitigating this challenge.

Centrica sponsored the IET's Technical Briefing Electrical Energy Storage: An Introduction and has been very involved with the Code. What benefits does this Code provide Centrica?

Centrica aims to help customers take control and be more informed about how, where and why they use their energy and we are already doing this by encompassing a mixture of technologies and services across our group. Energy storage is one of those mixtures of technologies that we provide. Thus, it was essential for us to be able to participate in the development of this Code. The immediate benefit of the Code came about through access to technical resources, communication and networking with experts in the industry. Due to knowledge and experience shared among participants, our engineering and commercial risks are already reduced through lower development costs and the Code provides assurance that the energy storage systems can be designed and installed safely when the Code is followed correctly.

Do you think that this Code might make it easier for building owners and installers to consider energy storage solutions?

Adherence to standards helps ensure safety, reliability and environmental care. The Code will raise user confidence, increasing sales and the take-up of energy storage technologies. Besides that, there will be significant business benefits for both installers and consumers. The Code will provide a solid foundation for energy storage development and will enhance existing practices. It will increase awareness of technical developments and initiatives amongst installers and help them open up market access as well as encouraging innovation in the energy industry. More importantly, the Code is aimed at contributing to the enhancement of our daily lives and energy system.

Allan Burns, Founder and Director – Telemental

Allan, you've participated in two committees – one for the Guide to Energy Management, and this one, for the Code of Practice Electrical Energy Storage Systems. How valuable do you find participation in these committees, and how much influence can you have on the work that the IET does in these areas?

The value of participating in these committees, for me, is getting the wider context of the field in question.

As a practitioner, that context helps me to understand what influences best practice recommendations. This increases my confidence, particularly when I have to implement solutions where there is no black-and-white answer. The best engineering can take one off-piste, depth of understanding will keep you buoyant on fine powder, rote learning and following prescriptions can sometimes leave you up to your waist a long way short of the finish line.

As a campaigner for sustainability in construction, contact with the kind of individuals and organisations inclined to participate in the forums that the IET creates has been inspirational and illuminating. I'm a fringe operator, geographically, technologically and intellectually. Participation in all of the IET activities in the last year has helped me to connect to, and integrate with, other operators, some fringe, some not but we all add value to each other when we come together.

What is your vision for the installer market in five or ten years' time – do you foresee this Code helping to change attitudes towards renewables and energy storage?

Well, if I consider both committees I've been party to, my vision for ten years' time is that there will be a significant merge between energy management and energy storage. I think microgeneration and storage will be the norm, if not a requirement, for new build in 10 years' time. Forces that will drive this include innovation enhancements, political changes, digitisation and online availability of resources and the ongoing work of organisations such as the IET, in developing best practice.

Dr Aikaterini Chatzivasileiadi, Research Associate – Cardiff University

Energy storage is a fast moving technology. What kind of academic research has been taken on the topic?

In light of the move towards a low carbon economy and the higher uptake of renewable energy technologies, energy storage – both electrical and thermal – has been attracting interest and is being researched in a number of universities around the globe. Research is being undertaken for different technologies and at different scales, i.e. from materials research, through applications in electrical devices, electric cars and homes to regional level and grid applications. Although energy storage is currently a complex and expensive challenge, it is considered a promising growth sector in the UK economy and so academic capacity and funding has been gaining increasing support. It is thus essential that the research outputs are accessible and disseminated in order to assist with future endeavours in this area and increase public awareness.

Cardiff University's inter-disciplinary research in energy storage draws expertise from engineers, architects, building physicists and social scientists, among others, and is considered to have a far-reaching impact on future energy innovation. The Welsh School of Architecture in Cardiff University, in particular, has partnered with industrial and other organisations, leading cutting-edge projects on practical applications. In these projects, researchers investigate the energy storage and renewable energy technology systems' integration in the built environment in respect to the end-users' energy demand profiles.

What applications do you think this technology might have in future?

It is likely that there will be a diverse mix of storage technologies and applications, matching the changing energy needs in a future low-carbon built environment. This could provide the required flexibility in terms of energy quantity and time frame. Using storage devices, such as batteries, in-demand response applications including peak shaving and peak shifting, in single buildings, communities or the grid could strengthen this flexibility.

An example where demand response and thus storage could play a key role is the smart grid, which is an electricity network integrating the behaviour and actions of all users connected to it in a cost-efficient way. In addition, complementary battery technologies could be coupled to form hybrid systems, so as to increase the range of services that a single storage system can provide. Hybrid storage systems would be expected to provide increased operational safety, greater efficiencies, improved lifetime and reduced costs. Moreover, the electrification of the transport sector could have a significant impact on the electricity system, both as a flexibility solution where electric vehicles would be considered as mobile modular units for energy storage, but also as an additional load.

However, for the above applications to become viable, there are techno-economic challenges that would need to be addressed. These could be tackled through coordinated efforts and collaborative research between universities and industrial partners at a national and international level.

How well do you think the Code of Practice can tally with such a fast-moving technology?

The Code of Practice covers currently available types of electrochemical energy storage systems in domestic, commercial and industrial applications and addresses technical, operational and safety issues. I believe it provides an excellent reference to practitioners on the safe, effective and competent application of energy storage systems. Furthermore, it is an essential document, as not only does it include common terms and operating modes of storage systems, but it also provides detailed information on the their specification, design, installation, commissioning, operation and maintenance. It is the result of the successful contribution by academic and industrial experts in the field, as well as manufacturers, practitioners, certification and regulatory bodies, which covers a vast spectrum of energy storage stakeholders. As a result of the accelerated pace of innovation and development, energy storage is a fast-moving technology. Hence, this Code provides an effective tool to consolidate current practices and support future planning, while establishing a robust foundation informing decision-making and embracing new technologies and applications.

Yselkla Farmer, International Policy Manager – BEAMA

What does BEAMA do and what is its role in the development of energy storage systems?

BEAMA is the leading trade association which represents manufacturers of electrical infrastructure products and systems from transmission through distribution to the environmental systems and services in the built environment. We therefore represent companies who supply storage systems into the market at varying scales, and across a wide range of applications, including heat, hot water, phase change and electrical battery storage. Our members also manufacturer the systems required for the integration of storage assets (for example, inverters, controls).

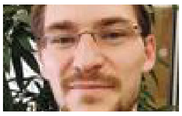
BEAMA's role is therefore to represent our members in developing a market for storage across the range of applications. We represent our members in the development of policy, regulation and technical standards to ensure they are fit for purpose, remove existing market barriers and ensure the growth of the UK supply chain for export.

What did you bring to the committee for this Code?

BEAMA represented the interests of our members on the committee for the Code of Practice to ensure the guidance met the requirements of the industry.

You are part of the Emerging Markets team at BEAMA. How helpful will this Code be in bedding down energy storage systems and allowing the market to work with this new technology more easily and with greater confidence?

This Code will be very helpful in providing clarity on the installation procedures for electrical storage systems, especially as we hope that in coming years the number of installations will grow and the application of storage in the built environment will become common place.



Frank Gordon, Policy Manager – REA

One of the aims of the REA is to promote the use of renewable energy in the UK. How do you think the Code might contribute to this?

The Code is a very important tool in better equipping the industry to roll out energy storage installations. It will enable better connection of innovative storage devices and provide consumer safety and greater peace of mind. This is especially the case when considered in conjunction with the REAL/RECC Consumer Protection coverage that now also extends to selling storage devices. So overall, the best practice and consumer protection is being put in place and that will help grow the market in the right way.

Where renewables fit in is that many 'behind the meter' domestic storage devices are associated with on-site renewables like solar PV and wind, allowing homeowners to maximise the self-consumption of the power they have generated. Renewable energy and storage are a natural combination because storage can balance out the supply of power from variable sources such as solar and wind, and also generate and store heat, for example, from excess electricity generation, to be used when needed. So energy storage will help us move to a more efficient, lower cost, cleaner energy system – the independent National Infrastructure Commission estimate that 5 GW of storage in conjunction with more renewables could save us billions every year by 2030.

How long do you think it might be before energy storage systems become commonplace in both domestic and non-domestic buildings?

I think this will depend a lot on prices, which are too high for many at the moment – these are rapidly falling and analysis we published last year projected reductions of 30 % in the next three years, and 50 % in the next five, for lithium ion battery prices. Policy is the other big barrier and we have identified and made recommendations for removing many of these, which there is rhetorical support for from Government, at least, with some progress already, although grid access charge reform remains a large concern.

For some larger scale, commercial sites, it already makes strong commercial sense to install storage and for domestic setting, it is exciting to consider the prospects of on-site renewables, energy storage and electric vehicles. There are hundreds of thousands of homes with solar PV installed and this is likely the early market, which will reach a tipping point for installations when prices fall, and then likely take off very rapidly.

Why is a Code such as this important to the energy storage and renewable energy market?

We were very keen to see a Code such as this developed, which is why we worked with the IET, having approached them about writing it. The reason being that as a fast growing industry, energy storage installations need to happen in the right way to prevent the current lack of clear guidance damaging the reputation of the industry. This would not only lead to bad consequences for consumers, but also risk stalling deployment of really promising technologies which can offer great benefits to the UK energy market.

Andrew Crossland, Energy Storage & Microgrid Engineer – Solarcentury

As an engineer for Solarcentury, you must be witnessing first-hand consumer attitudes towards renewables and energy storage. Has there been an increase in building owners wanting energy storage systems?

There is a marked increase in energy storage enquiries and confidence. This extends from residential products all the way through to large commercial customers. It is clear that the reduced costs in energy storage, strong warrantees from suppliers and investor confidence are all creating a market for distributed energy storage.

Will this Code make it easier for engineers such as yourself to speak to consumers and design and install energy storage systems?

The Code is key to providing consumer and installer confidence in how to install energy storage safely in properties around the UK. It is a landmark document.

Ian Murray, CEO – Powerflow Energy

You're the CEO of Powerflow Energy, a company that manufacturers energy storage products. What is the market for energy storage like, and do you think this is likely to increase?

The current market is growing. PowerFlow has seen its turnover double in the last year due to the success of launching our AC battery storage system 'Sundial' in January 2016. Sales of over 450 units in year 1 gives PowerFlow a 20 % share in the domestic storage market, highlighting the current market size to be over 2,000 units. I think the storage market for us will grow at the same rate over the next 12 months, but is set to increase at a much faster rate within 24 months as we introduce cloud-based off-peak charging and energy trading tariffs to the Sundial portfolio.

What questions do installers and designers usually come to you with?

A common question refers to system setup during installation. With so many products on the market designed for global sale, setting them up for a particular UK installation can be difficult and time consuming. Automating setup is key and why the Sundial system has no software setup requirement. Automating this process ultimately leads to quicker more reliable installation and eliminates the risk of inputting incorrect parameters.

Can the Code answer these questions?

Yes, absolutely. The Code has been written to help highlight the important factors that determine the correct selection of equipment and to guide the installer on how to implement these correctly and most importantly safely.

With a huge array of storage equipment available, a deeper understanding of which equipment, how it operates, and how it can be integrated is vital for the continued success of integrating storage technologies.

What next?

The Code of Practice has been carefully developed by the committee and was published for public comment, receiving 450 comments. It is now available for pre-order.

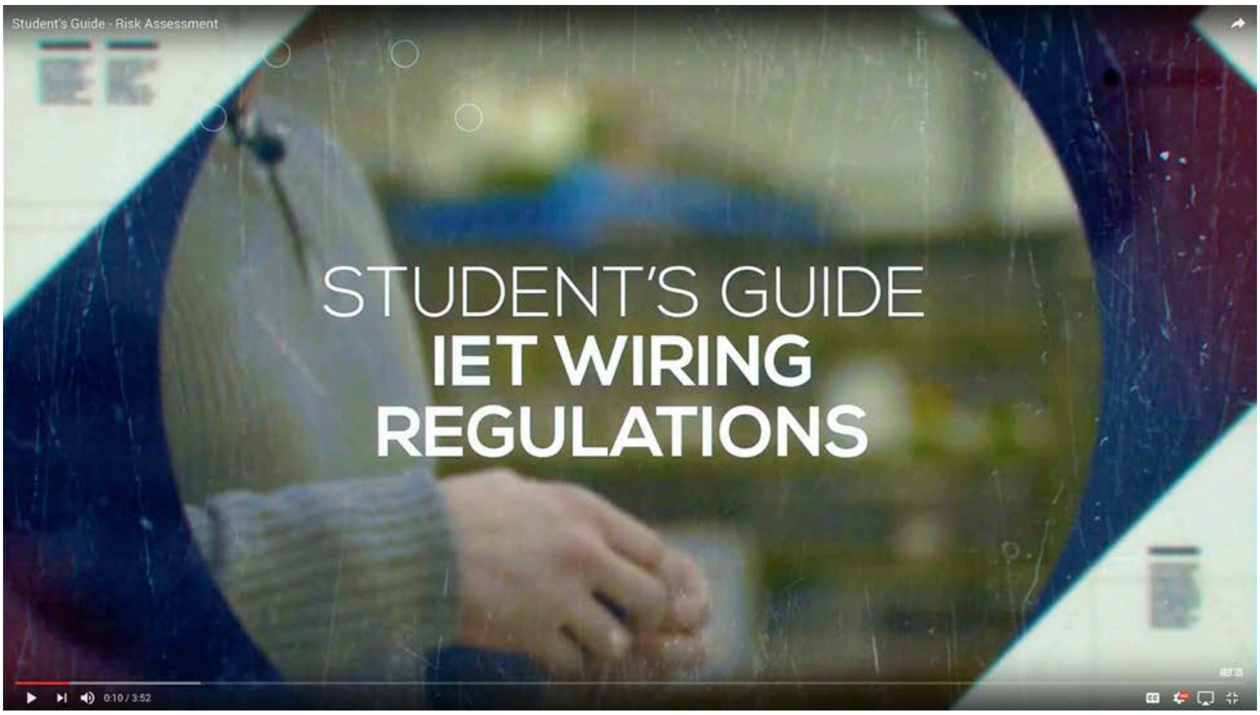
New video – risk assessment

We've published a new video which showcases risk assessment, as part of our Student's Guide initiative.

Commenting on the video, Steven Devine, author of the Student's Guide to the IET Wiring Regulations, and presenter of the suite of technical Student's Guide videos, says:

"We begin assessing risk from the moment we are born. We soon learn how to avoid hurting ourselves and those around us by taking measures to remove, sometimes not so obvious, hazards. In this video we take a look at just one example of electrical work were a number of factors need to be considered and some simple measures applied to reduce the likeliness of injury and inconvenience to staff and members of the public for the duration of the work being carried out."

Our full suite of videos aimed at all electricians – student or practicing – is available here.



Wiring Matters

Your insight into BS 7671 www.theiet.org/wm