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The framework for energy efficiency in electrical installations

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Energy efficient design and control as a process

The international standard IEC 60364-8-1 *Low Voltage electrical installations – Part 8-1: Energy Efficiency* provides a system diagram which provides an overview of the various energy sources and control inputs to an electrical installation. Analysis of this shows how energy efficient electrical installations should have an optimum energy path and a comprehensive control path.

The purpose is to ensure that the electrical infrastructure is designed to safely support the load whilst being located correctly and minimise unnecessary losses in the distribution system. The controls should be configured to ensure the electrical installation operates when the user requires it, whilst also minimising wasted energy consumption when the user is away. There are two key areas to consider when designing and operating an energy efficient electrical installation: the energy path and the control path. How these are set up and work together will determine how successful the efficiency will be.

The energy path is from the main intake through the main switchgear, distribution infrastructure and finally to the point of use e.g., a fixed electrical machine, water heater, luminaire, socket outlet. Historically the electrical supply would always be from a grid connection and some specialist installations, such as hospitals, would also have a standby generator for essential services.

Now electrical supplies may come from multiple sources including from a traditional grid connection, or via local onsite generation (including wind turbines or photovoltaic), or perhaps local on-site energy storage facilities. With careful controls an optimized installation may use a combination of all these supplies. Monitoring of these energy sources allows users to adjust their requirements, or to deploy automatic controls, and optimize the energy to the electrical installation. For those installations with standby generators there could also be revenue opportunities, through special contracts, to supply their electricity at times of peak demand on the mains electrical grid.

Electrical distribution systems should be carefully designed to avoid wasted energy. Using a barycentre approach to locating the supply near to distribution switchboards and onwards to electrical loads can reduce copper infrastructure costs and lower energy losses too. In practice energy efficient distribution means the point of supply should be as close as possible to the point of use. The reality is that a DNO will invariably provide a supply on the boundary of a site sometimes far from the point of use. For larger sites there may be opportunities to negotiate this with the DNO to provide a compromise solution.

An analysis of electrical load power factor and harmonics is necessary. Local measures to deal with this, instead of a centralized approach at the main intake, can improve the overall site efficiency. Adverse effects from power factors and harmonics also reduce efficiency and ideally should be dealt with at the point of use, especially with larger loads such as chillers and air handling units. Ensuring that electrical cables are correctly sized has always been necessary to improve safety and reduce fire risks. Correct cable sizing will also mitigate the effects of harmonics, although the connection of filters may be required.

The concept of load inertia describes the load's reaction to first being switched off to shed load and subsequently being reinstated; however, this may have consequences and effects on the levels of service to the end users.

For example, from an energy efficiency perspective, shutting down a large or complex plant for only a short period could be counterproductive, as it would require more energy to bring it back up to speed than was saved by shutting it down. This load would be known as a low inertia load. Other examples may include:

- Manufacturing machinery with fine tolerances might not respond well to a loss of power either to save energy at peak times or though line faults.
- Safety critical loads could be described as low inertia loads and should not be used to shed load and save energy. They should ideally have UPS back up too.

On the other hand, most LED lighting installations would be known as high inertia because of their ability to energize quickly after an interruption on supply. Some older lighting technologies, such as those using inert gas, would be low inertia because they need to cool down sufficiently before being reused.

Instantaneous water heaters would be high inertia because they will operate satisfactorily as soon as the electrical supply is restored. Other hot water systems using storage tanks are by definition low inertia because of the length of time it takes to reheat. However, for short interruptions in supply they might be largely unaffected.

Operating characteristics of electrical loads can be varied too. They will react differently to a temporary loss of power and subsequent reinstatement of supply. This can affect their response to load management when an installation's maximum capacity is reached (ability to load shed) or pause operation when if electrical tariffs change adversely.

The energy path below shows the energy sources through the electrical installation and on to the point of use – the electrical loads.



Figure 1 – Energy Path

The control path shows the influence of the control inputs on the use of energy through the energy management systems and on to any control outputs such as billing or just user feedback interfaces.

Control inputs to an electrical installation are increasingly important in a modern installation. They provide analysis, in real time, of the environmental conditions, the availability of different types of electrical energy source and the local demand.

Electrical energy demands need to be controlled as much as possible at the point of use and should respond to local requirements when the area is occupied. Whilst automatic controls should be considered to optimize energy efficient operation, where necessary the needs of end users must be taken into account. Local override controls may be necessary, for instance on lighting or local direct electrical heaters in certain situations. Occupancy detectors can reset the system from manual control back to automatic control to prevent wasted energy.

Influences on controls might be the availability of an energy source, the energy tariff (cost) at any particular time of day, automated responses to changes in environmental conditions or the need of the end users to use the space differently from the predefined automated settings (controls override).

Controls design philosophy should respond to how the building is to be used:

- what is being used types of loads or usage
- where it is used zones
- integration of load types and geography meshes
- technical constraints and risks
- economic requirements

The controls philosophy of an energy efficient electrical installation should provide a number of outputs that enable the user to monitor performance of usage, zones and meshes, and then make informed decisions to improve those operations. Three key outputs would be:

- trends and monitoring as an energy management tool to track normal and abnormal energy use;
- energy billing using appropriate fiscal meters only to track energy costs and cost recovery in multi-user installations
- user guidance or alerts using controls to assist with first line maintenance monitoring and local alerts of equipment still in use when not needed.

Operational requirements for controls should be carefully considered. The outputs from control systems can assist with monitoring energy consumption. Tracking trends can highlight wasted energy consumption and areas for improvement. Energy monitoring can provide granular details of usage in various cost centres and assist with local billing mechanisms.

Controls are an integral part of electrical energy efficiency; however, it is important to note that:

- they should not compromise safety,
- they should respond to user requirements. Overrides to automatic energy efficiency controls to adapt to immediate user needs may be necessary.

Critically, all energy efficiency controls should still be subject to safe systems of work and work in conjunction with normal electrical isolations for the purposes of reactive and planned maintenance. Safety remains of primary importance and any measures taken to make an electrical installation more energy efficient must not compromise the safety of any occupants, property, or livestock. Likewise, efficiency of an installation should not impair the acceptable levels of service for a user or the availability of an electrical supply at times of maximum demand.

The control path in Figure 2 shows the influence that controls will have on an electrical installation from the point of supply, through the infrastructure to the point of use.



Figure 2 – Control path

The energy path and the control path interact closely and integrate as a typical circular "plan, do, check act" process: energy input at the top, control inputs on the left, energy outputs on the bottom and control outputs on the right.

From top to bottom the requirements of an energy efficient design can be fulfilled ensuring that the electrical distribution and electrical installation are satisfactory and meet the necessary criteria. From left to right, the control process ensures that control over energy consumption is carefully considered and correctly commissioned.

An ongoing control sequence of process control and process monitoring should ensure that electrical energy efficiency is optimized and has the opportunity to be gradually improved.

Maintenance activities are periodic checks on the continued safe and satisfactory operation of an electrical installation. It should also be a check on the operational efficiency of the electrical installation and a reminder to recommission as necessary.





Other design tools and techniques

Load management

The designer, in the early stages of the project, should consult with key stakeholders, such as the client and end user, to categorize relevant zones, usage and meshes throughout the electrical installation to identify opportunities for energy efficiency.

1) Zones: this identifies where electrical equipment or appliances will be used. Typically based on the geography of the building, for example a paint shop in a factory, main staircase or

corridor in a building, a zone could be controlled as one entity and switched off without necessarily impacting on the use of neighbouring zones.

- 2) Usage: this identifies what type of appliances, or particular electrical loads, will be operated not just in any one zone but across the whole installation. IEC 60364-8-1 identifies the largest electrical consumer usages as
 - hot water production
 - heating, ventilation and air conditioning
 - lighting
 - motors,
 - appliances

The designer should use the consultation period to ensure that all major loads are identified in respect of their rating (kW) and their hours of operation.

3) Meshes: this identifies what common control inputs will be provided for electrical equipment. This could be across one or more zones with one or more usages. An example could be interleaved lighting circuits in adjacent hospital corridors, with separate zones, single usage, multiple circuits and one mesh for energy efficiency purposes.

Meshes are an important component with any electrical energy efficiency regime. Another example could be a hotel suite with a bedroom being one zone and a bathroom being another. Various usages can be identified in both spaces. However, an energy saving control system by the rooms main entrance will simultaneously switch off agreed circuits, with a number of usages, as the occupant withdraws their card key. Another mesh, though, will retain power to other circuits such as the fridge that should not be switched off or some lighting for reassurance.

IEC 60364-8-1 describes a number of criteria that are relevant to the development and implementation of meshes. Ensuring these criteria are all considered correctly demonstrates the efficiency of the installation. Using these criteria the designer must consider how the installation loads will be managed to optimize the electrical energy efficiency measures. This includes responding to:

- a. defined time controls to stop certain loads at certain times, or moderate maximum demand, or run at off peak periods,
- b. daylighting in the case of lighting especially externally and near windows,
- c. external temperature in the case of electrical heating,
- d. wasteful switching by the occupants (occupancy detection),
- e. the connection of loads (absence detection),
- f. switching using inputs from external sources (environmental sensors, thermostats, humidity sensors, air quality sensors).

Load management, using meshes, is the process by which the electrical supply to the installation is distributed to the connected loads. These may have multiple usages and be located across several zones. To be energy efficient the load management process will activate them at the right time, with appropriate automated controls and measurements, to optimize the use of the energy and reduce wasted energy.

Purpose of electrical meters

The deployment of electrical meters throughout the installation will assist with both Building Control compliance (Approved Document Part L) and operational energy efficiency through the lifetime of the installation. Electrical designs should consider metering for fiscal purposes at the head end of the installation and for energy management.

Fiscal metering for electrical supplies for larger installations will be subject to half hourly monitoring. This data can be requested as an aid assess energy consumption through certain points of the day or week. This information in turn can aid improvements in energy efficiency.

On smaller installations analysis of just the main intake energy meter may be justified. However, on more complex installations with multiple tenants or internal departments, it will be necessary to provide load profile analysis closer to the point of use at sub-distribution level. In Part L of the UK Building Regulations new installations over a certain size require 90% of the installation to have specific sub-meters. The use of meters throughout the installation demonstrates the ability to closely control the load and will score additional points in the design appraisal of the electrical installation. It will improve the operational efficiency of the installation too

Sub-meters should be embedded throughout the installation to:

- a. measure and record the load profile for the installation to understand when the energy is being used during set periods, for zones, usage or meshes; and
- b. measure the load characteristics to understand what effect the load has on efficiency of the incoming power supply infrastructure. This involves periodically measuring the demands placed on the supply by the electrical loads' power factor, energy consumption, current, voltage and harmonics.

IEC 60364-8-1 cross references several other standards to define the type of meters that would be used at different parts of the installation and the level of information that may be required. Ethernet connections for embedded metering systems enable all meters to be monitored remotely and data to be collected. This allows loads to be analysed in real time and monitoring of trends and patterns of load behaviour. Result of this analysis can influence when the load is connected to the grid and hence use cheaper electrical tariffs where possible or load shed non-essential loads at times of supply constraints.

Some electrical meters assist with power quality analysis (PQA). This is important for understanding power factors and harmonics and the associated energy losses with these aspects. Harmonics caused by non-linear loads are a major concern. Measuring power quality is important so a solution can be provided where harmonic distortion is found.

Setting up a basic electrical maintenance regime

By Richard Giddings IEng MIET ACIBSE

Introduction

Electrical installations and the components within them are sometimes taken for granted and once installed, have an expectation to provide reliable, continuous service indefinitely.

To many people, the concept of electrical maintenance conjures up nothing more than failed lamps being replaced. A good maintenance regime however needs to cover so much more.

This article attempts to give an overview of basic electrical maintenance activities, as may befit a typical installation serving a small / medium sized commercial premises. Activities relating to large scale industrial or specialist installations are beyond its scope, although many of the concepts would apply.

It is important with the imminent re-occupancy of many places of work after lengthy Covid shutdowns that steps be taken to ensure that electrical installations are thoroughly checked and any outstanding maintenance brought up to date. This is a basic safety requirement.

Benefits

Many electrical systems now play a significant role in the decarbonization and sustainability agenda, but such systems need regular monitoring to ensure they are still performing as intended over their lifecycles and hence providing the energy savings intended.

Effective maintenance can also provide other benefits, some of which are not immediately apparent:

- longevity and improved life cycles of equipment,
- reduction in downtime,
- end-user confidence,
- equipment manufacturers' warranties being upheld,
- fulfilment of legal obligations.

Legal obligations

Legislation is a driver regarding maintenance of electrical installations and equipment in places of work.

Whilst some may argue that an electrical installation only deteriorates with usage, sometimes the opposite is true – particularly with buildings which may have been out of service for prolonged periods, infrequently occupied or where upkeep may have been neglected.

The Health & Safety at Work Act (1974) places the duty of care on employers, employees and the self-employed to provide for health and safety at work premises. Electrical installations fall under this.

https://www.hse.gov.uk/legislation/hswa.htm

The Electricity at Work Regulations (1989) under its Regulation 4, requires electrical systems to:

- be safe at all times to prevent danger,
- be maintained to prevent danger,
- have work activities relating to them to be carried out in such a manner to prevent danger,
- comprise of equipment which is suitable for its use, be maintained in a condition suitable for that use and be properly used.

https://www.hse.gov.uk/pUbns/priced/hsr25.pdf

The Regulatory Reform (Fire Safety) Order 2005 sets requirements for firefighting, fire detection, fire escape and emergency lighting. It requires the 'responsible person' for the building to ensure that equipment and facilities associated with these provisions are maintained and kept in a good state of repair.

https://www.legislation.gov.uk/uksi/2005/1541/contents/made

The Provision and Use of Work Equipment Regulations 1998 (PUWER) requires equipment that is provided for use at work to be suitable for its intended use, safe for use, maintained in a safe condition, inspected regularly and used by persons that have been adequately trained.

The regulations apply to machinery, appliances, apparatus and tools.

https://www.hse.gov.uk/work-equipment-

machinery/puwer.htm#:~:text=PUWER%20requires%20that%20equipment%20provided,and%2 Odoes%20not%20subsequently%20deteriorate&text=accompanied%20by%20suitable%20heal th%20and,as%20protective%20devices%20and%20controls.

Workplace (Health, Safety and Welfare) Regulations 1992 and The Management of Health & Safety at Work Regulations 1999 may also be relevant.

https://www.hse.gov.uk/pUbns/priced/l24.pdf

https://www.hse.gov.uk/pubns/hsc13.pdf

BS 7671:2018+AMD 1:2020 (The IET Wiring Regulations) devotes its Chapter 34 to maintenance. Regulation 341.1 requires the electrical designer where possible to select suitable materials and equipment based on likely maintenance.

Elsewhere, Regulation 301.1 requires suitable equipment appropriate to external influences to be provided.

Continuity of service

A good electrical maintenance regime isn't just about ticking boxes relating to legislative requirements.

The consequences of an electrical breakdown should play a crucial part in determining the level of maintenance that will be needed. Without a fully functioning electrical installation, commercial or industrial activities can be interrupted. Consequently, it should be the owner of the installation who has to determine suitable risk mitigating measures.

Developing a strategy

One of the first steps to take will be to consider the pattern of maintenance required. Consequences of failure may set the parameters. Do not forget that as installations change in use or design, then maintenance planning and policies must adapt too. Good maintenance should be driven by a robust maintenance management structure.

The basic criteria are to consider if it will be acceptable to wait and then deal with a failure after it has happened, or if steps need be taken to prevent a failure occurring in the first place.

Life safety systems, such as fire alarms and emergency lighting, are expected to offer a high level of reliability and if failing in an occupied building could lead to far more significant consequences than perhaps failure of general lighting or small power provisions in a seldomused room.

Applying this concept leads to consideration of the following fundamental categories:

-Preventative maintenance

This is maintenance that attempts to prevent a failure occurring in the first place, often referred to as a 'fix before failure' regime. This approach would apply to life safety systems, but could equally be applied to other systems, where there may be factors, perhaps operational or commercial which support it.

A good example here would be replacing all the high level lamps in a large hall or public building, where access to the area is not always convenient, as well as the practical issues associated with setting up access equipment. Such an approach can sometimes seemingly fly in the face of sustainability but can offer overall benefits if properly implemented.

-Reactive maintenance

Maintenance of this nature is generally waiting for an item or system to fail and then dealing with it individually, in the process ignoring any drop in its performance. Such an approach would be wholly unsuitable with life safety systems or in business-critical areas, but the concept can help win the sustainability argument.

Further considerations in this respect would be shaped by considering the likelihood of several visit per breakdown together with the associated cost. This may not be economically viable in some instances, although the benefits of keeping selected spares on site may assist.

-Predictive maintenance

This approach monitors a system, accepts some individual failures which are tolerable, but then at a given point, deals with issues before complete failure. An example here would be to wait for a certain percentage of lamps to fail and then renew lamps to all luminaires. Such an approach could help balance sustainability weighed up against practicalities and cost.

Careful monitoring is a key factor in this method – which may need to feature regular inspections or perhaps hours-run data being collated. More complex systems could monitor via automated systems.

Documentation & record keeping

Before commencing any maintenance regime, detailed information and records need to be pulled together.

Broadly speaking, such information can be split into three categories:

-Information regarding the buildings and the site

This should include layout plans for the premises where the maintenance will be required and may need to be of sufficient size and scale to detail the equipment being maintained.

Such plans could already be in existence, perhaps as having been produced in the past as part of 'Operating and Maintenance' (O&M) manuals, or from previous maintenance activities.

Very often, no information is available – in which case it should to be produced. This may be either from scratch via site survey, or based on information that could be available elsewhere, such as legacy drawings that have been produced for other purposes.

In all cases, information needs to clearly show what requires maintenance – especially critical items like fire alarm or emergency lighting equipment – and where it is located. Such

equipment, or 'assets' depending on the complexity of the installation, may benefit from unique referencing or tagging. This aids traceability – especially if multiple operatives carry out the maintenance work, but also for overall management of the regime - and of course auditing!



Fig 1 Simple layout drawing showing uniquely referenced emergency lighting & fire alarm call points

Information relating to equipment on the site

An asset list detailing equipment on site should then be drawn up. The complexity of the installation will dictate how detailed it needs to be. Again, this may be available in the form of existing O&M information languishing somewhere on site. Enquiries may prove fruitful and save much work.

Good O&M literature should ideally contain sufficient information detailing maintenance requirements and operating information, but this is not always the case. Additionally, lists of spares, etc. – as well as the manufacturer's contact details may be included. Such information may be hopelessly out of date. In this case manufacturer's archives could be sourced, or, if nothing else, generic information be gathered.

It may even be that asset details are held elsewhere in a company – for perhaps financial or tax planning reasons. Again – keep asking questions!

Record logs of maintenance activities undertaken

Once a new maintenance regime has commenced, information is needed that accurately records the activities actually carried out.

As a minimum:

• the individual services being maintained, including details of when a task is due and what it entails,

- records of site visits showing date, tasks completed, operative responsible and any follow up works needed,
- meter readings to monitor energy consumption. (Note -Fitment of additional meters may assist with this).

Such information is the key to:

- be able to monitor and control any maintenance contract in place,
- enable effective maintenance to take effect, especially relevant where multiple operatives are involved,
- to assist in future maintenance planning,
- to monitor energy consumption and assess plant condition,
- to be able to prove that legal obligations have been met.

An additional and often overlooked benefit here is that BS 7671:2018+AMD 1:2020, under its regulation 652.2, allows effectively managed preventative maintenance to negate the need for separate BS 7671 periodic inspections.

In-house or outsourced?

Once it has been decided that maintenance will be needed, in what form that maintenance will take and the documentation gathered, the next decision to make will be whether the work is to be carried out by in-house staff (either already employed or newly acquired), outsourced to specialist providers or use a mix of both.

This decision making process would be driven by:

- the scale and complexity of the systems needing maintenance,
- consequences of failure,
- overall commercial viability.

Further factors that may steer any decisions may be:

- skill set and competency of any existing staff already on site,
- whether in-house staff (either existing or newly employed) could be utilized in other parts of the business and / or trained accordingly,
- procedures/policies or other contracts in place, perhaps in other parts of the business.

Life safety systems such as fire alarms, or any system of a more complex nature, will likely have very specific maintenance needs, often defined in continually-evolving industry standards and codes of practice. Specialist testing and inspection equipment and techniques are often also needed. Modern systems may also incorporate access codes and software functionality as well as having warranty stipulations. Such factors are important to address when considering who is to undertake routine service and maintenance.

Regardless of how the maintenance is resourced, remember that Regulation 16 of the Electricity at Work Regulations (1989), requires persons to be competent to prevent danger and injury.

The remainder of this article is intended to act as an aide-mémoire, covering the type of electrical systems that often require maintenance and considerations to make.

Electrical systems requiring maintenance

Fire alarms

Fire alarm systems, as one of the principle life safety systems in a building, have very specific defined maintenance needs.

Apart from on very basic manual systems, any party contemplating such work, would need a detailed knowledge of **BS 5939-1:2017** 'Fire detection and fire alarm systems for buildings'. Section 6 of this standard defines maintenance, recognizing that it will cover aspects ranging from daily user checks through to very specific tasks at stipulated intervals.

At the outset of a new fire alarm maintenance regime, a detailed inspection of the premises should be made, as well as its fire risk assessment document, to assess:

- any specific system needs, matched to building layout, usage and escape routes,
- existing fire alarm system, previous records or logs and any evidence of departures from BS 5839-1:2017.

Once this has been undertaken, where required:

- provide a site log book if not in place,
- carry out repair of any existing faults or damage,
- make arrangements for responding to emergencies, agreeing required response times.

At this point, the ongoing regime can be formulated, to include:

- weekly manual call point (and if applicable, voice alarm) tests,
- monthly tests and checks on power supplies and review of log book entries,
- quarterly detailed checks of certain battery systems,
- six-monthly checks/tests of logbooks, building usage, call points, automatic detectors, false alarm records, battery condition, correct operation of control and signaling equipment,
- annual checks to at least cover radio signaling, cause and effect operations and accuracy of zone charts and unique identification of all devices.

Further information can be found in the new forthcoming 3rd Edition of the IET's Electrician's Guide to Fire Detection and Fire Alarm Systems.

https://shop.theiet.org/electrician-s-guide-to-fire-detection-and-fire-alarm-systems-3rd-edition

Emergency lighting

Emergency lighting, also a life safety service, has essential defined maintenance needs. As with fire alarms, firstly, the premises' Fire Risk Assessment document should be studied.

The following two standards apply:

BS 5266-1: 2016 'Emergency lighting. Part 1 Code of practice for emergency lighting of premises'

BSEN 50172: 2004 (BS 5266-8:2004) 'Emergency escape lighting systems'

Sections 12 and Section 7 of these respective standards require:

- daily checks of charge indicator lights where applicable,
- monthly short duration tests of lighting on a simulated supply failure,
- annual tests of all lights, for their full rated duration, as well as detailed visual examination.

Maintenance should include logging of all results, follow up repairs, as well as works that may apply to central battery systems or other standby supplies such as generators. Unique identification of all equipment is necessary.

Consideration should be given when undertaking full duration tests, of the need for batterydriven systems to recharge, before such lighting can again become fully effective. Such tests should therefore consider building occupancy immediately following the test.

Where self-testing or so-called 'intelligent' systems are encountered, it will be essential for the maintainer to be fully aware of exactly how the system operates, and especially what respective indicators mean as these may differ depending on manufacturer.

Non-internally illuminated escape signage should be checked for adequate illumination and cleaned where necessary.

Detailed record keeping will reinforce evidence that tasks have completed as well assisting long term with any predictive maintenance work, such as planned battery or lamp replacements.

Further information can be found in the IET's Electrician's Guide to Emergency Lighting.

https://shop.theiet.org/electricians-guide-to-emergency-lighting-3rd-edtion

Other alarm, signaling systems or monitoring systems

Other alarm or monitoring systems - sometimes life safety-related - are often encountered. These should be maintained to ensure continued reliable operation.

Examples may include:

- gas or carbon monoxide detection systems,
- security and intruder systems,
- CCTV systems,
- lift alarm systems,
- disabled toilet alarms,
- personnel alarms,
- access control systems,
- class change systems,
- building services control systems & building management systems.

Routine maintenance should follow the manufacturers' requirements.

Lightning protection

These systems will require specialist knowledge, access, and test equipment to maintain. Consequently these activities are best entrusted to specialist providers.

BS EN 62305-3: 2011 'Protection against lightning Part 3 - Physical damage to structures & life hazard' - Section 7 and Annex E7 defines maintenance and inspection requirements.

Typically this would include checks for:

- system components in good order, (not corroded, damaged, or subject to theft),
- system compliance with the relevant design standard,
- earthing continuity.

Although such an inspection is often undertaken annually by default, best practice is to arrange for visits at differing intervals, which enables the system to be evaluated at varying times of year, where ground and climatic conditions may have a bearing on system performance. Surge protection devices (SPDs) must not be overlooked. These are designed to protect electronic equipment of the building's electrical installation and should also form part of this regular maintenance regime. If no lightning protection is provided SPDs should be checked with the fixed wiring installation. All SPDs should be checked against their specific manufacturers' instructions – especially regarding indicator status and fuse protection.

Fixed wiring installation

Electrical installations deteriorate with time and usage. The concept of periodically inspecting and testing a fixed wiring installation should feature strongly in any maintenance regime either as part of defined preventative maintenance tasks or as a stand-alone activity. BS 7671:2018+AMD 1:2020 covers this in its regulations 135.1 and 652.2 as well as guidance in its Part 6 and Appendices.

Such an inspection by a competent person will include visual checks and detailed electrical tests and measurements. The outcome, especially if a stand-alone exercise, will usually be recorded on an Electrical Installation Condition Report (EICR).

Guidance on this topic can be found via the following link:

https://www.electricalsafetyfirst.org.uk/media/2149/bpg4-1.pdf



Fig 2 Visual checks of circuit details before electrical testing

The IET's BS 7671 Guidance Note 3 gives more information on undertaking the actual tests as well as suggested initial frequencies. The person undertaking the inspection should determine subsequent testing frequencies, based on the condition and use of the installation.

https://shop.theiet.org/guidance-note-3-inspection-testing-8th-edition

Where larger switchboards or control panels are encountered, **BS 6423: 2014** 'Code of practice for maintenance of low-voltage switchgear and controlgear' should be referenced.

Due to the need to isolate supplies to complete tests, careful planning will be necessary, which may involve the input of many parties and end users. The concepts of splitting the inspections over time may help, particularly on larger sites. When adopting this approach careful planning will be needed to ensure no area is subjected to excessive timescale between inspections.

Sampling is another concept but can be open to errors and abuse and as such is not considered best practice. If a sampling approach has to be used, it will be essential to involve all stakeholders at the outset, and clearly detail what is included and excluded, being mindful of long term risks and liabilities.

Thermal imaging checks, subject to safe methods of working can also feature in an inspection regime – but only where the equipment to be checked is suitable.

Lighting installations

Despite the widespread shift to LED-based lighting solutions which claim longer life and elimination of traditional lamp changing, lighting maintenance cannot be disregarded.

Equally, maintenance-hungry non-LED luminaires are likely to be encountered for many years to come.

Lighting will vary considerably depending on application, and contribute a life safety role with certain critical tasks, as well as general personnel security and safety.

Regardless of the technology used, the performance of all lighting will deteriorate over time, this process usually going unnoticed until complete failure. Lighting designers refer to this concept as 'maintenance factor' and when designing take into account issues such as lamp technology, environment in which the lighting is provided as well as intervals between cleaning. Maintenance should acknowledge this, but often doesn't!

All these aspects will feature strongly when setting up a proposed regime, balancing maintaining lighting efficacy against the practicality of accessing the luminaires in question.

Fig 3 High level lights – needing specialist access equipment and the area vacated



Practicalities include:

- safe working practices especially when working at height; fittings may have large physical dimensions or weight, and/or may be situated in areas with either pedestrian or vehicular traffic adjacent,
- access to a given area, with sufficient time to safely erect scaffolds, access platforms etc.,
- electrical isolation and lock-off particular where supply is remote,
- fire integrity especially relevant with recessed luminaires in certain ceilings,

• lamp disposal – glass breakage risks as well as disposal aspects under WEEE legislation.

It is for these reasons that a 'preventative' rather than 'reactive' maintenance regime can sometimes prove beneficial.

Appliances

Electrical appliances provided in a place of work will require inspection, testing and sometimes maintenance. Where applicable PUWER regulations will apply.

Although colloquially referred to as 'PAT testing' and very often assumed to be an annual task, there have been recent changes to guidance and requirements.

The latest version of the IET's code of practice details further:

https://electrical.theiet.org/wiring-matters/years/2020/81-july-2020/the-all-new-5thedition-of-the-iet-code-of-practice-for-in-service-inspection-and-testing-of-electricalequipment/

Remember that with built-in or permanently connected equipment or appliances, for example water heaters, cookers, air conditioning, fans, refrigeration, etc. it will be essential to ensure that these items do get checked!

Solar photovoltaic (PV) power supply systems

These systems are seldom maintenance free and should be regularly inspected and maintained by a specialist provider.

Inspections would normally check for equipment damage, fixings, cleaning and system performance monitoring.

Electrical testing should also be undertaken to ensure continued safety.

Further guidance can be found in:

https://shop.theiet.org/code-of-practice-for-grid-connected-solar-photovoltaic-systems

Lifts

Maintenance of lifts is a requirement under Regulations 5 and 10 of the PUWER regulations. The extent of the maintenance will depend on the lift type, its age and condition. Invariably this work should be entrusted to a specialist lift maintainer, often included as part of an all-embracing servicing, maintenance, and call-out contract.

In addition, regulation 9 of the Lifting Operations and Lifting Equipment Regulations 1998 (LOLER) requires a 'thorough examination and inspection'. For passenger carrying lifts this is at least every 6 months, and for other lift types it is at least every 12 months.

Further guidance can be found in:

https://www.hse.gov.uk/pubns/priced/l113.pdf

Waste Electrical and Electronic Equipment (WEEE) Regulations 2013

Maintenance of electrical installations invariable involves the removal and safe disposal of spent or failed equipment, especially lamps. Most supply-chain providers offer facilities for dealing with such waste products. Alternatively most local councils can be approached.

More details can be found at:

https://www.electricalsafetyfirst.org.uk/guidance/safety-around-the-home/recyclingelectrical-items/?gclid=EAIaIQobChMI2fayod7V7wIV82DmCh1s4gF3EAAYASAAEgJkzPD_BwE

Summary

This article has shown that there is so much more to electrical maintenance than just replacing lamps!

As well as myriad of legislative requirements needing to be met, robust electrical maintenance ultimately leads to increased levels of electrical safety and efficiency.

With many buildings now seeing increasing occupancy and use once again, now is definitely the time to put such work on the agenda, and for those who can provide such services, there will be increasing business opportunities.

Further reading on this wide ranging subject can be found in:

- BS 8210:2020 Facilities maintenance management. Code of Practice
- BSRIA BG53 Business-focused maintenance
- The IET's Guide to Electrical Maintenance:

https://shop.theiet.org/guide-to-electrical-maintenance



Hot Tubs

By Michael Peace CEng MIET MCIBSE

The IET has recently received an influx of calls on the helpline regarding the confusion surrounding hot tub installations. In this article we try and provide clarity by examining the facts available to assist the designer in making an informed decision to avoid finding themselves in hot water.

What is a hot tub?

The product standard for hot tubs is IEC 60335-2-60:2017 Safety of household and similar electrical appliances, particular requirements for whirlpool baths and whirlpool spas. In this standard hot tubs are called 'whirlpool spas', the definitions from the standard are provided below:

Whirlpool bath

Appliance used by persons to immerse themselves in water and which incorporates provisions for blowing air or water circulation and which may have provisions for water heating, the appliance intended to be drained after use.

Whirlpool spa

Appliance used by one or more persons at the same time to immerse themselves in water and which incorporates provisions for blowing air or water circulation and provisions for water heating, the appliance not intended to be drained after use.

The main difference between a bath and a spa is the latter is intended to be used by one or more persons and it is drained after use, neither of which is much help for the electrical designer.

How many hot tubs are sold each year in the UK?

There has been a surge in sales of hot tubs in the UK recently, it is understood that there are approximately 2,500 swimming pools, 25,000 hot tubs and 250,000 portable hot tubs sold each year in the UK. To put this into perspective, these numbers are similar to the numbers of electric vehicle sales from 2016.

Hot tub construction

Hot tubs come in many different forms from soft inflatable to a more permanent hard-shell construction. Inflatable hot tubs are usually sold as 'plug and play' and, the theory is, they do not need to involve an electrician for installation but that is another issue and not covered in this article.

Hard-shell hot tubs are typically class I appliances due to their construction and require a protective earth connection. One of the reasons for this is being the water heating element is immersed in the water.

Whilst it could be argued that a hot tub has insulated panels which prevent access to any metal parts, however, the exposed-conductive-part in this case is the water. The electrical conductivity of the water is increased by chemicals or minerals that are added for sanitization.

What are the risks to persons using a hot tub?

The risk of electric shock is increased when a person is wet due to the decreased body resistance which allows an increase in current through the body in the event of contact with live parts. This risk is further increased when a person is using a hot tub outdoors due to the possibility of contact with Earth. Which is exactly the same risk as for a person using a swimming pool.

What does the product standard say?

The product standards are there to ensure safety of the product but do not take account of the local installation, which is a task for the electrical designer. BS EN 60335-2-60 requires manufacturer's instructions to refer to National Wiring Regulations, in the UK this is BS 7671:2018+A1:2020.

What are the requirements for hot tubs in BS 7671:2018+A1:2020?

Hot tubs are not specifically defined in BS 7671:2018+A1:2020, therefore, the designer must consider the risks and make an engineering judgement to select the most appropriate protective measures. Deciding on the required protective measures to apply will depend on the location of the installation and the associated risks.

Indoors

If a hot tub is installed indoors, the risk is a person is or has been immersed in water, therefore their body resistance is reduced. Section 701 applies to locations containing a bath or shower and the surrounding zones and would be applicable to a hot tub installed indoors.

Outdoors

In the UK, it is probably more likely for a hot tub to be installed outdoors. The risks associated with an outdoor hot tub is similar to indoors with respect to reduced body resistance, but with the additional risk of barefoot contact with Earth, which significantly reduces overall resistance, and cause an increase in the body current in the event of contact with a conductive part made which has become live under normal or fault conditions.

Section 702 of BS 7671:2018+A1:2020 applies to the basins of swimming pools, fountains and paddling pools. The scope of Section 702 states that 'in these areas, in normal use, the risk of electric shock is increased by a reduction in body resistance and contact of the body with Earth potential.'

This risk is exactly the same for a person using a hot tub, the fact that the person is wet will reduce their body resistance significantly, which combined with it being installed in a garden, increases the potential for contact with Earth.

How could an electrical designer claim as a defence that the risks of electric shock for a hot tub installed outdoors is any less than that of a swimming pool, fountain or paddling pool, as defined in the scope of Section 702?

What are the requirements of Section 702 in BS 7671:2018+A1:2020?

Section 702 imposes zoning requirements for the installation and surrounding areas as detailed in Figure 702.2, for basins of water above ground level. This could have implications

for any exposed-conductive-parts or extraneous-conductive-parts installed in close proximity to the hot tub such as lighting or metallic structures.

-For zone 0 and 1

Switchgear, accessories and junction boxes shall not be installed in zone 1, with the exception of SELV junction boxes.

The only wiring permitted in zone 0 and 1 is of that necessary to supply equipment in those zones. It is preferable for cables to be installed in a conduit made of insulating (i.e. non-metallic) material.

-For zone 2

Electrical equipment, socket-outlets, switches and accessories are permitted to be installed in zone 2 providing they are protected by electrical separation, SELV or a 30 mA RCD and of course suitably IP rated. Again, it is preferable for cables be installed in a conduit made of insulating material.

Any electrical equipment installed outdoors and in zone 1 or 2 requires a minimum IP rating of IPX4, or IPX5 where water jets are likely to occur for cleaning purposes.



Figure 1

Section 702 recognizes the increased risk and the following Note is included in Regulation 702.410.3.4.3 ;

NOTE: Where a PME earthing facility is used as the means of earthing for the electrical installation of a swimming pool or other basin, it is recommended that an earth mat or earth

electrode of suitably low resistance, e.g. 20 ohms or less, be installed and connected to the supplementary protective equipotential bonding.

This is describing an earthed metallic grid installed under poolside areas and connected to the supplementary bonding as required by ENA G12/4 for swimming pools and outdoor shower locations, which is similar to the metallic grid depicted in Figure 705 of BS 7671:2018+A1:2020 for cattle sheds in agricultural locations. This protective measure is likely to be expensive and impractical for hot tub installations.

Can I install a socket-outlet for a hot tub?

Whilst the installation of a socket-outlet is not precluded in BS 7671:2018+A1:2020, socketoutlets installed in close proximity to basins of water are not generally a good idea due to the potential for misuse. In some cases, a socket-outlet could be specified by the manufacturer, in which case it is permitted to be installed in zone 2 if the protective measure automatic disconnection of supply (ADS) is applied, using an RCD specified in Regulation 415.1. In other words, an RCD with a rated residual operating current of 30 mA is installed.

Best practice is to install fixed wiring for connection of the hot tub, so as prevent misuse of a socket-outlet. An isolator should be provided and installed outside of zone 1, 2 m from the edge of the basin, as seen in Figure 1.

It is important to remember that where containment for wiring, such as conduit is used, it is preferable that it is made from insulating material i.e. non-metallic. (Regulation 702.522.21 of BS 7671:2018+A1:2020).

Can I install lights around a hot tub?

Regulation 702.55.4 provides special requirements for the installation of electrical equipment in zone 1 (2 m horizontally from edge of basin to a height of 2.5 m) of swimming pools and other basins. Whilst it is preferred to install lighting outside of zone 1, Regulation 702.55.4 states:

For swimming pools where there is no zone 2, lighting equipment supplied by other than a SELV source at 12 V AC rms or 30 V ripple-free DC may be installed in zone 1 on a wall or on a ceiling, provided that the following requirements are fulfilled:

- The circuit is protected by automatic disconnection of the supply and additional protection is provided by an RCD having the characteristics specified in Regulation 415.1.1
- The height from the floor is at least 2 m above the lower limit of zone 1.

In addition, every luminaire shall have an enclosure providing Class II or equivalent insulation and providing protection against mechanical impact of medium severity. This means that it is not permitted to install metallic class I luminaires within 2 m of a basin. As described above, luminaires must be mounted on the wall or ceiling, not flush in the floor surrounding the basin as is frequently seen for hot tub installations.

What type of RCD is required for a hot tub?

It is important that the correct RCD is selected according to manufacturer's instructions. The correct type of RCD required will depend on the type of electronic circuits used within the product. Different electronic circuits are used for functions such as speed control of pumps which may dictate a particular type of RCD.

Residual DC leakage current can cause blinding of AC and other type RCDs depending on the amount of leakage current, but that is another story, see <u>IET Wiring Matters 'Which RCD?'</u> <u>article</u> for further information. If an RCD with resilience to DC leakage is required, such as a type A, it is important to ensure any RCDs upstream of this device are also selected to prevent blinding by DC residual current.

IET guidance

Chapter 13.8 of IET *Guidance Note 7 Special Locations* states that where a hot tub is installed indoors, the requirements of Section 701 should be applied and where it is installed outdoors, it is recommended that the requirements of Section 702 should be applied in full.

Chapter 14 of IET *Guidance Note 5* provides information on PME earthing arrangements with respect to wet locations where persons may be barefoot. In addition to normal electric shock hazards, persons may experience low-level shocks or tingles from the out-of-balance voltages imported via the neutral/earth conductor of the DNO TN-C-S system when in barefoot contact with Earth.

Can I connect a hot tub to a PME earthing arrangement?

BS 7671:2018+A1:2020 does not preclude connecting a hot tub to a PME earthing arrangement. However, when the facts are examined it is easy to see why it may not be considered appropriate.

Let's take a look at the risks associated with PME earthing arrangements and wet locations such as swimming pools. Usually when we mention the dreaded abbreviation PME, we are considering loss of the PEN conductor. However, with swimming pools and similar wet locations where persons can access barefoot, problems can exist under normal operating conditions. IET *Guidance Note 5 Protection against electric shock*, provides guidance on perceived electric shock. Perceived electric shock may be experienced on PME earthing arrangements under normal operating conditions due to a potential difference which may exist between the PEN conductor and Earth.

This can occur if an installation is supplied from a long distribution and/or service cable. Depending on the load on the circuit and the ratio of the load on the network, a potential difference could exist between the PME earthing terminal and Earth. Whilst it may only be a few volts, in combination with reduced body resistance, due to wet skin, and the additional possibility of contact with Earth, it can be enough to cause a 'perceived electric shock'.

If the designer chooses not to use the PME earthing arrangement and decides to install a TT earthing system, special care must be taken to avoid simultaneous contact between accessible metallic parts connected to different earthing arrangements, see Regulation 411.3.1.1 of BS 7671:2018+A1:2020. In some cases, it may be necessary to install a TT earthing system for the whole installation to prevent the risk of contact with metallic parts at different potentials.

What are the voltages that can be expected between the Protective Earthed Neutral (PEN) conductor and Earth?

For this we need Ohm's Law, the prospective touch voltage (U_{tp}) is limited by the product of neutral current x PEN conductor resistance.

For a supply in accordance with Electricity Safety, Quality and Continuity Regulations (ESQCR) 2002 (as amended), i.e. 230 V +10%/-6%, the upper limit for prospective touch voltage between PME and Earth is 18.4 V. Let me explain, the maximum volt drop permissible on the LV network is 253 V – 216.2 V which is 36.8 V. If we assume that half of the voltage drop is in the line conductor and half in the PEN conductor equates to 36.8/2 which is 18.4 V.

It is important to remember that this is prospective touch voltage, the voltage and current across the body is determined by the combined resistance of the body and additional resistances such as footwear or surface materials.

There are many factors which affect the prospective touch voltage between the Main Earthing Terminal (MET), connecting the PME earthing arrangement and Earth, such as the network impedance and the ratio of load, which will affect the magnitude of neutral current on the distribution network.

A typical 100 A supply with a line to neutral impedance of 0.1 Ω at full load current, the voltage drop on the distribution network is 10 V (100 x 0.10 = 10 V). If the impedance is 0.368 Ω , the voltage drop increases to 36.8 V (100 x 0.368 = 36.8 V).

As the line neutral impedance is increased, the potential for prospective touch voltage is also increased. It is not uncommon for the recommended values of Z_e to be exceeded for some installations. Some premises may have an external impedance of up to 0.6 Ω and above, for

further information see <u>IET Wiring Matters article Earth fault loop impedance revision of ENA</u> <u>Engineering Recommendation P23</u>.

Neutral current is probably the biggest factor when determining the magnitude of prospective touch voltage, which on a balanced three phase distribution network should not be an issue. However, it's important to note that in practice a balanced three-phase system with single-phase loads connected is unlikely. It is suspected that there is a high level of imbalance across the distribution network as identified in <u>HV and LV Phase Imbalance Assessment</u> <u>Report No 7640-07-D4 produced by Scottish Power Energy Networks (SPEN).</u> Imbalance is more likely to affect networks consisting of mixed commercial and residential loads and networks in rural locations as less customers reduce load diversity.

What level of touch voltage is dangerous for a wet person?

Touch voltage thresholds are related to touch current by the body impedance and ohms law. It is a very complicated subject and is affected by many factors such as:

- (a) AC or DC;
- (b) the magnitude of touch voltage;
- (c) the current pathway through the body;
- (d) the area of contact with the skin;
- (e) the condition of the skin contact area; and
- (f) duration of the current flow.

The IEC 60479 series studies the effects of current on human beings and livestock. IEC TR 60479-5:2007-11 *Touch voltage threshold values for physiological effects* covers touch voltage threshold values.

Table 1 indicates touch voltage thresholds for different conditions. IEC TR 60479-5 considers a large contact area to be a full hand contact with a surface area of 82 cm², medium contact are might represent the palm of the hand (12.5 cm²) and a small contact area might represent touching a small conductive part with the hand (1 cm²).

The environmental conditions are an important factor when determining touch voltage thresholds. Dry condition corresponds to normal indoor conditions, water-wet skin condition corresponds to skin that has been immersed for more than 1 minute in normal water and saltwater-wet skin condition is considered to be skin that has been immersed for more than 1 minute in a solution of 3 % NaCl in water (average value ρ = 0,25 Ω × m, pH = 7,5 - 8,5).

When considering the relevant conditions, it's important to remember that additional safety margins may apply. An important factor to consider for hot tubs is the conductivity of the water, which is likely to have higher conductivity than tap water due to chemicals or minerals added for sanitisation purposes.

The report states voltage thresholds are not easily used for applications which involve immersion of body parts, Annex C Clause C.2 provides common situations and for swimming pools as below:

Water from swimming pools contains chemicals which will increase conductivity and swimmers have bare hands and bare feet. When playing, wet people may touch electrical appliances and could support for a long period a touch voltage less than 11 V a.c. which corresponds to medium contact area for inability to let-go. For swimmers immersed in a pool, the allowable touch voltage threshold will be **much lower**.

Table 2 – Tables providing minimum touch voltage threshold or a.c. and d.c. corresponding to startle reaction, strong muscular reaction and ventricular fibrillation (see Table 1 notes)

Startle reaction			AC touch voltage thresholds for long duration V									
Current threshold	mA	Saltwater-wet			Water-wet			Dry				
		Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact		
Hand-to-hand	0,5	1	1	3	1	4	21	2	9	40		
Both-hands-to- feet	0,5	0,3	1	2	0,4	3	13	1	5	23		
Hand-to-seat	0,5	0,3	0,5	2	0,4	2	11	1	4	20		

Table 2a - Startle reaction for alternating current 50/60 Hz

Table 2b – Strong	, muscular r	eaction for	alternating	current 50/60 Hz
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Muscular effects			AC touch voltage thresholds for long duration V							
Current threshold	mA	S	altwater-w	et	Water-wet			Dry		
		Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand-to-hand	5	5	9	27	7	25	93	11	40	104
Both-hands-to- feet	10	5	9	27	7	25	93	11	40	104
Hand-to-seat	5	3	5	13	3	13	46	6	20	52

Table 2c – Ventricula	r fibrillation for	alternating	current 50/60 Hz
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Ventricular fibrillation			AC touch voltage thresholds for long duration V							
Current threshold	mA	Saltwater-wet			Water-wet			Dry		
		Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand-to-hand	100	90	160	257	98	165	260	99	99	260
Both-hands-to- feet	40	20	36	94	24	71	149	33	82	149
Hand-to-seat	57	27	49	99	31	65	100	34	65	100

What if a PEN conductor becomes open circuit?

Another concern regarding PME earthing arrangements is the risk of an open-circuit neutral PEN conductor. In this situation, all metal parts connected to the main earthing terminal (MET) could rise up to 230 V with respect to Earth, this includes the hot tub heater element which in turn is 'connected' by means of the water within the hot tub. The water is effectively an exposed-conductive-part with an extremely large surface area.

The current would be significantly higher under open-circuit PEN conductor conditions, in the region of amps as opposed to milliamps. It is important to remember that an RCD would not operate under open-circuit PEN conductor conditions, if a person makes contact with the water and Earth under open-circuit PEN conductor fault conditions and in bare foot contact with Earth, it is likely to have fatal consequences.

What is the likelihood of a rise in potential on the MET?

Other scenarios which could raise the potential of the main earthing terminal include:

- (a) live to earth faults on HV network with combined HV/LV earthing (Regulation 442.2.2) (Uo+250 V >5s or Uo+1200 V <5s);
- (b) insulation faults on final circuits within the installation (some circuits may have a 5 second disconnection time); and
- (c) lightning strokes.

Whilst the probability of each scenario may be considered relatively low, the probability of a rise in potential on the MET increases when they are combined.

What are the Distribution Network Operator (DNO) requirements?

Section 6.5.2 of Energy Networks Association (ENA) Engineering Recommendation G12/4 provides requirements for network operators regarding special situations such as swimming pools and other basins containing water. The safety issues highlighted are identified in the list and note below.

- Wet locations
- Possibility of contact of the body with true Earth potential
- Presence of wet barefoot persons

NOTE: in addition to normal electric shock hazards, persons may experience low level shocks or tingles from the out of balance voltages imported via the neutral/earth conductor of the DNO TN-C-S system.

ENA Engineering Recommendation G12/4 provides guidance on information to be provided to competent persons enquiring about the suitability of PME for swimming pool supplies. A TT earthing system is recommended, or alternatively PME is permitted providing a metallic grid connected to the main equipotential bonding is installed under the poolside area.

Section 6.2.6.2 of ENA Engineering Recommendation G12/4 sets out the requirements for caravan sites, campsites and amenity shower blocks.

'Due to the higher probability of persons being barefooted at toilet and amenity shower blocks (including sports pavilions with shower facilities) the extension of PME earthing is not recommended unless a buried bonded metal grid has been installed. This requirement also applies to other locations where toilet or shower blocks have been provided for general public use where people are likely to be barefoot e.g. beachside locations, parks etc.

Where outside showers have been provided, provision of PME earthing is not recommended as providing a reliable equipotential cage may prove impractical.'

Looking at the risks outlined above it is difficult to see how the electric shock risks for hot tubs are any different. Ultimately, it is the decision of the designer whether or not to use the PME earth terminal, this is reinforced in ENA Engineering Recommendation G12/4 but it is difficult to see how it could be justified.

Roles and responsibilities

When a hot tub installation is under consideration, a conversation will be required between all interested parties, typically the client, the hot tub supplier and the electrical installer. It is essential that the roles and responsibilities are established before any work takes place.

Electrical contractors are frequently requested to provide a socket-outlet or isolator for the hot tub installer to connect to at a later stage. It is important to remember that whilst it may be acceptable to certify works for which they are responsible comply with the relevant standards, would it be considered acceptable in a court of law to ignore the facts?

Generally, hot tub installers are not qualified electricians and do not usually have sufficient knowledge of BS 7671:2018+A1:2020 to be able to make informed engineering judgements on protective measures such as earthing and zone requirements. It would be unreasonable to expect a hot tub installer to have the same level of knowledge as the electrical designer.

The client should be specifically informed that the person certifying the electrical supply point for the hot tub does not take responsibility for the design of the complete hot tub installation. If it was explained to the client clearly that the final connection could be made by a person who may not be conversant with BS 7671:2018+A1:2020 and may not have taken all risks into consideration, a different view may be taken by the client and it may be preferable for the electrician to certify the complete design.

What is the law?

The Health and Safety at Work etc Act 1974 states 'that it shall be the duty of every employee while at work to take reasonable care for the health and safety of himself and of other persons who may be affected by his acts or omissions at work'.

Failing to provide sufficient information to the client could be seen as an omission. The electrical designer has a moral and legal obligation to discharge their duty of care and pass on their knowledge to ensure the whole installation is safe.

Summary

The increased risks associated with using a swimming pool are reduced body resistance and contact with Earth, hot tubs when installed outside are no different from swimming pools with respect to risk of electric shock. The outside protective measures apply to the hot tub and the zones surrounding the area.

The combination of potential of contact with live parts with reduced body resistance and contact with Earth can be a dangerous. Electrical installations for hot tubs require careful consideration as well as planning and should only be designed and installed by electrically skilled persons.

Whilst connecting a hot tub installation to a PME earthing arrangement is not precluded, it is difficult to see how it could be justified by the electrical designer given the information available.



By Michael Peace CEng MIET MCIBSE

Discussions on renewable energy have made it to the IET Engineering Communities forum several times recently. Renewable electricity will play a crucial part in achieving ambitious UK Government emission targets, but this will mean an increased maximum demand for the electrical installation. In this article we look at the effects of increased temperature and thermal effects on cables and consumer units.

Heat pump technology

Following a recent <u>Future Homes Standard consultation</u>, the UK Government has published a report stating that heat pumps are anticipated to become the primary heating source for dwellings.

The principle of a heat pump is to utilize energy in the air and convert it into heat using electricity. A typical size dwelling requires an air source heat pump with a heat output of 12 kW, this would have an electrical load of 3 kW, if the coefficient of performance (COP) of the heat pump is 4.0.

The COP is dependent on the external temperature and will reduce in the colder weather, making it less efficient. Below certain external temperatures a backup heater is required which consumes an additional 3 kW.

Electric vehicles

<u>The Road to Zero strategy</u> sets out UK Government targets for zero carbon transport by 2050. Car manufacturers have already brought forward the deadline to stop manufacturing petrol and diesel vehicles from 2035 to 2030.

A typical EV charger for a domestic home is rated at 7 kW, but some fast chargers are rated at 22 kW which would require a three-phase supply.

Increased maximum demand for domestic electrical installations

If you consider the diversified maximum demand for a typical domestic electrical installation with gas central heating is likely to be less than 2 kW. The combined load of 13 kW or 56 A for an EV charger and heat pump is a significant additional load for a consumer unit that the installation designer must not ignore.

Unlike other high demand loads, such as electric showers, which are only used for a short period of time, minutes rather than hours, electrical loads such as EV chargers and heat pumps run for considerably longer periods of time, usually several hours. High loads used for an extended period of time produce significant amounts of heat and this must be considered by the electrical designer. Excessive heat in electrical installations can cause overheating of cable terminations and malfunction of equipment.

As the load is increased, the temperature within the consumer unit will rise. It is important to ensure that the temperature rise limits of the manufacturer are adhered to. We are accustomed to applying derating factors for cables installed in groups, but the same can't always be said for grouping of protective devices.

Can I use a spare way on a consumer unit?

Whilst it may be tempting to use a spare way on the consumer unit, before doing so it is important to consider the loading of the existing installed circuits and the rated diversity factor of the consumer unit to make sure there is sufficient spare capacity available.

What is rated diversity factor?

Rated diversity factor (RDF) is a correction factor based on temperature rise limits, that are applied to take account of the heat produced within the enclosure. When circuit-breakers within a consumer unit are grouped the RDF must be applied to the number of simultaneous loaded circuits installed, this is called the RDF and is based on temperature rise limits.

Whether designing a new installation or when adding a new circuit to an existing installation, it is important to consider the RDF. Failure to observe it could lead to overheating and therefore become a fire risk.

It's important to remember that RDF only applies to continuously loaded circuits. This means that adjacent circuit-breakers where the load may exceed 30 minutes or where a load which does not exceed 30 minutes but has an 'off' time which is less than the 'on' time are required to have an RDF applied. Ultimately the correct RDF to apply is subject to agreement with the manufacturer.

The manufacturer may at their discretion declare an RDF for all outgoing circuits, groups or individual outgoing circuits within an assembly. Manufacturers are best placed to provide

guidance on the correct RDF to apply. Failure to observe an RDF could cause overheating issues but it is also likely to affect the operating characteristics of the protective devices.

Ambient temperature correction

Ambient temperatures affect the operating sensitivity of circuit-breakers, because the principle of operation for these devices is a bi-metallic strip which is affected by heat.

For example, a 40 A circuit-breaker to BS EN 60898 as indicated in Figure 1 is designed to operate when overload current exceeds 44 A at an ambient temperature of 20 $^{\circ}$ C. If the temperature within the enclosure increases to 60 $^{\circ}$ C, the circuit-breaker sensitivity is increased, and it is likely to operate closer to 38 A and could cause unwanted tripping.

Figure 1 is an image of a four-way three-phase distribution board taken with a thermal imaging camera. There are three 40 A, three-phase circuit-breakers installed for PV inverters with a maximum output of 36 A per phase. The image was taken on a cloudy day and the ambient temperature of the location of the distribution board was 23 °C. It is evident that the temperature is increased near the protective devices grouped together on the left and it is also increasing the ambient temperature of the enclosure.



Figure 1

Can I use XLPE cable to achieve higher current carrying capacity?

It is often said that cross-linked polyethylene (XLPE) cable can be used to achieve higher current carrying capacity from the same cross-sectional area. However, unless it can be assured by the manufacturer of the switchgear and accessories, which is highly unlikely, conductor temperature must not exceed 70 °C. Therefore, the tables 4E1 to 4E4 from Appendix 4 of BS 7671:2018+A1:2020 cannot be used directly and the tables 4D1 to 4D5 for 70 °C PVC should be used as shown in Figure 2.

Figure 2

	TABLE 4D4A -	- Multicore armo (COPP	oured 70 °C ther ER CONDUCTO	moplastic insula RS)	ated cables		COPPER CONDUCTORS
CURRENT-CARRYI	NG CAPACITY (a	mperes):		Cor	Ambient t Ground ambient t iductor operating t	emperature: 30 °C emperature: 20 °C emperature: 70 °C	0//3
Conductor	Reference (clippe	Method C d direct)	Reference (in free air or on tray etc, horizo	Method E a perforated cable ntal or vertical)	Reference (direct in ground ground, in or ar	Method D d or in ducting in ound buildings)	
area	1 two-core cable, single-phase AC or DC	1 three- or four- core cable, three- phase AC	1 two-core cable, single-phase AC or DC	1 three- or four- core cable, three- phase AC	1 two-core cable, single-phase AC or DC	l three- or four- core cable, three- phase AC	
1	2	3	4	5	6	7	
(mm ²)	(A)	(A)	(A)	(A)	(A)	(A)	
1.5	21	18	22	19	22	18	
2.5	28	25	31	26	29	24	
4	38	33	41	35	37	30	
6	49	42	53	45	46	38	
10	67	58	72	62	60	50	
16	89	77	97	83	78	64	
25	118	102	128	110	00	82	
35	145	125	157	135	119	98	
50	175	151	190	163	140	116	
70	222	192	241	207	173	143	
95	269	231	291	251	204	169	
	1						
120	310	267	336	290	231	192	
150	356	306	386	332	261	217	
185	405	348	439	378	292	243	
240	476	409	516	445	336	280	
300	547	469	592	510	379	316	
400	621	540	683	590	-	-	

What is the rating of an XLPE cable?

Table 4E4A of BS7671:2018+A1:2020 is indicated in Figure 3, the table is used for XLPE multicore armoured 90 °C thermosetting cables. It is important to read the notes to the right of the table, note 1 states that 'where it is intended to connect cables in this table to equipment or accessories designed to operate at the maximum operating temperature of the equipment or accessory (see Regulation 512.1.5).'

Note 2 states that 'where it is intended to group a cable in this table with other cables, the cable should be rated at the lowest of the maximum operating temperatures of any of the cables in the group (see Regulation 512.1.5).' This can sometimes be overlooked by designers.

Some electrical design software provides an option for 90 °C thermosetting cables to be selected but run at 70 °C. This allows the designer to select the particular cable, but it uses the values for thermoplastic cables to comply with BS 7671:2018+A1:2020.

Sizing of cables for circuits with long cyclic loads

When considering sizing of cables for circuits with high loads, increasing the conductor size will not only allow the cable to operate at lower temperatures, it will also reduce I²R losses and can provide a payback when considered against the additional capital expenditure for the increased cable size. This payback time will be reduced as the cost of electricity increases.

Figure 3

	TABLE 4E4	A – Multicore aı (CC	moured 90 °C t	hermosetting in CTORS)	sulated cables			
CURRENT-CAI	RRYING CAPACI	TY (amperes):		Con	Air ambient to Ground ambient to ductor operating to	emperature: 30 °C emperature: 20 °C emperature: 90 °C		
Conductor	Reference (clipped	Method C d direct)	Reference (in free air or on tray etc, horizo	Method E a perforated cable ntal or vertical)	Reference Method D (direct in ground or in ducting in ground, in or around buildings)			
area	l two-core cable, single-phase AC or DC	1 three- or 1 four- core cable, three-phase AC	l two-core cable, single-phase AC or DC	1 three- or 1 four- core cable, three-phase AC	l two-core cable, single-phase AC or DC	l three- or l four- core cable, three-phase AC		
1	2	3	4	5	6	7		
(mm ²)	(A)	(A)	(A)	(A)	(A)	(A)		
1.5	27	23	29	25	25	21		
2.5	36	31	39	33	33	28		
4	49	42	52	44	43	36		
6	62	53	66	56	53	44		
10	85	73	90	78	71	58		
16	110	94	115	99	91	75		
25	146	124	152	131	116	96		
35	180	154	188	162	139	115		
50	219	187	228	197	164	135		
70	279	238	291	251	203	167		
95	338	289	354	304	239	197		
120	392	335	410	353	271	223		
150	451	386	472	406	306	251		
185	515	441	539	463	343	281		
240	607	520	636	546	395	324		
300	698	599	732	628	446	365		
400	787	673	847	728	-	-		



NOTES:

- Where it is intended to connect the cables in this table to equipment or accessories designed to operate at a temperature lower than the maximum operating temperature of the cable, the cables should be rated at the maximum operating temperature of the equipment or accessory (see Regulation 512.1.5).
- Where it is intended to group a cable in this table with other cables, the cable should be rated at the lowest of the maximum operating temperatures of any of the cables in the group (see Regulation 512.1.5).

What are the requirements of Regulation 512.1.5 of BS 7671:2018+A1:2020?

Regulation 512.1.5 of BS 7671:2018+A1:2020 sets out the requirements for compatibility. This requirement is to ensure ratings of equipment are not exceeded by cables operating at higher temperatures. It states that 'every item of equipment shall be selected and erected so that it will neither cause harmful effects to other equipment nor impair the supply during normal service including switching operations.

Switchgear, protective devices, accessories and other types of equipment shall not be connected to conductors intended to operate at a temperature exceeding 70 °C at the equipment in normal service unless the equipment manufacturer has confirmed that the

equipment is suitable for such conditions, or the conductor size shall be chosen based on the current ratings for 70 °C cables of a similar construction.

Note 4 provides clarity on the correct tables to be used, it states that 'where the current rating is to be based on 70 °C, current-carrying capacities given in Tables 4D1 to 4D5 or 4H1 to 4H4 of Appendix 4 may be used for 90 °C thermosetting insulated cables.'

Summary

The maximum demand of electrical installations will undoubtedly increase as heating and transportation energy is switched to electricity.

It is important to check that consumer units, cables and protective devices are adequately rated for the design current considering the load, rated diversity factor and cyclic duty.

Failure to observe RDF is likely to cause unwanted tripping of protective devices, overheating of connections and malfunction of equipment.

The ratings for PVC thermoplastic 70 $^{\circ}$ C cable should be used for XLPE thermosetting 90 $^{\circ}$ C cable unless the appropriate derating factors can be obtained to assure maximum operating temperatures are not exceeded.