

RCDs for electric vehicle supply equipment (EVSE)

By: Michael Peace CEng MIET MCIBSE

The installation of EVSE is becoming common place but installers still have many questions on the subject. This article focuses on RCD protection for Mode 3 charging of electric vehicles (EVs) and looks at the requirements of BS 7671:2018+A2:2022.

What are the RCD requirements for the different charging modes?

Mode 1 and Mode 2 charging utilizes BS 1363 socket-outlets and a Type A RCD is required at the socket-outlet or for the circuit, installed within the consumer unit. Mode 3 charging is provided by a dedicated circuit, typically single-phase 7 kW or three-phase 22 kW. This is the most common type of EV charger installed in domestic (household) premises. The RCD requirements are covered in detail in this article.

Mode 4 charging is provided by a dedicated AC supply circuit to the EVSE. The EVSE uses switch mode power supplies (SMPS) to convert the AC to DC which is used on the output circuit. Mode 4 charging is typically used for publicly available fast charging 50 kW to 350 kW. Requirements for the selection and erection of RCDs in the case of supplies using DC vehicle connectors according to the BS EN 62196 series are under consideration, Note 2 to Regulation 722.531.3.101 of BS 7671:2018+A2:2022 refers. For Mode 4 charging, RCDs may be required for the AC supply circuit, for example, if it forms part of a TT system or where disconnection times cannot be met using circuit-breakers. RCDs, however, are not required on the DC side as electric shock protection is provided by the manufacturer of the EVSE.

Figure 1 Mode 4 DC fast charger



What are the standards and regulations for EVSE?

In order for electrical equipment to be sold in the UK, the electrical equipment must conform to the Electrical Equipment (Safety) Regulations 2016 and the Electromagnetic Compatibility Regulations 2016 (as amended). The Electric Vehicles (Smart Charge Points) Regulations 2021 also apply to Mode 3 EVSE. These are statutory regulations and must be adhered to by manufacturers of EVSE.

Compliance with standards is voluntary but it can help to demonstrate conformity with the relevant legislation. This is known as [presumption of conformity](#).

The series of standards for the design and performance requirements for EV conductive charging equipment is the BS EN IEC 61851/BS EN 61851 series.

Section 722 of BS 7671:2018+A2:2022 provides requirements for the installation of EVSE, in addition to the general requirements of Parts 1 to 6.

What are the RCD requirements in BS 7671 for EVSE?

Regulation 722.531.3.101 of BS 7671:2018+A2:2022 states that unless the circuit is supplied using the protective measure of electrical separation, each **charging point** incorporating a socket-outlet or vehicle connector complying with the BS EN 62196 series is to be protected individually by an RCD of Type A, Type F or Type B and having a rated residual operating current not exceeding 30 mA. The RCD is also required to disconnect all live conductors.

The definition of an electric vehicle charging point in BS 7671:2018+A2:2022 is “the point where the electric vehicle is connected to the fixed installation”. This means that the requirement for RCD protection applies to the socket-outlet or connector and not the circuit supplying the EVSE. A note clarifies that the point is the socket-outlet supplying the electric vehicle, or a connector where the charging cable is not part of the EVSE.

There may be other reasons why RCD protection is required to protect the final circuit, such as where the installation forms part of a TT earthing system, where cables are buried in walls at a depth of less than 50 mm or where a high earth fault loop impedance requires an RCD in order to achieve fault protection.

What type of RCD is required?

EVSEs are likely to produce DC residual current during operation. This is due to the design of the electronic equipment for the charging circuit within the EVSE. The DC residual current will be superimposed on the AC waveform which will affect the operation of RCDs. The type of RCD required depends on the protection against DC residual current installed in the EVSE.

Where no protection against DC residual current is provided in the EVSE, Regulation 722.531.3.101 of BS 7671:2018+A2:2022 requires a Type B RCD to be installed. Where protection against DC residual current is provided in the EVSE, a Type A or Type F RCD can be used. This is typically provided by a Type A RCD in conjunction with a residual direct current detecting device (RDC-DD), complying with BS IEC 62955 as appropriate to the nature of the residual and superimposed currents and recommendation of the manufacturer of the charging equipment.

BS EN 62955:2018 provides requirements for RDC-DDs to be used for Mode 3 charging of electric vehicles. RDC-DDs are detection devices for DC residual current which do not incorporate a

mechanical switching function. Switching is provided by an external device, such as a contactor which is actioned by the RDC-DD.

It is also important to consider any RCDs installed upstream as they could also be blinded by DC residual current. The hierarchy of RCDs with respect to DC residual current should be observed. For example, a Type AC RCD should not be installed upstream of a Type A RCD. The [BEAMA GUIDE - selection and application of RCDs](#) provides useful information. There is also a BEAMA guide specific to EV charging installations, [BEAMA guide - RCD selection for protection of electric vehicle charging installations](#).

As with all electrical equipment, account should be taken of the EVSE manufacturer's instructions.

Figure 2 Type B RCD conforming to BS EN 61008



Can I use an EVSE with an integrated RCD?

Some manufacturers state that EVSE contains integrated RCDs.

A question often asked is “if additional protection by an RCD is integrated within the EVSE could RCD protection be omitted in the dedicated/final circuit?”

After all, the requirement for RCD protection is to be provided for the socket-outlet and not the final circuit.

BS 7671:2018+A2:2022 does not dictate the location for the RCD. Regulation 722.531.3.101 of BS 7671:2018+A2:2022 states that “except where provided by the EV charging equipment”, protection against DC fault current shall be provided by a Type B RCD or a Type A or Type F in conjunction with an RDC-DD. This is further clarified in Note 3 to Regulation 722.531.3.101. So, it is clear that it is acceptable to locate an RCD within the EVSE.

The type of RCD, however, is specified in Regulation 722.531.3.101 of BS 7671:2018+A2:2022. RCDs are required to comply with one of the following standards, BS EN 61008-1, BS EN 61009-1, BS EN 60947-2 or BS EN 62423. If the RCD included in the EVSE complies with one of these standards, then it could be used for additional protection for the electric vehicle charging point without the need for additional RCD protection upstream.

Often RCDs built in to EVSE, i.e. integrated into the printed circuit board (PCB), do not fully conform to any of the standards required by Regulation 722.531.3.101 of BS 7671:2018+A2:2022 or Clause 8.5 of BS EN IEC 61851-1:2019.

What is an ‘integrated’ RCD?

In simple terms, an ‘integrated’ RCD is an electronic device controlled by an algorithm programmed to operate in a similar way to how a traditional RCD operates according to the relevant product standards.

Some EVSE incorporates a residual direct current protective device (RDC-PD), a protective device with integrated AC, pulsating DC and 6 mA DC detection, evaluation and mechanical switching in one unit. The requirements for RDC-PDs are provided in Annex O (normative) of BS IEC 62955:2018. With the exception of a couple of clauses modified by BS IEC 62955, RDC-PDs must conform to all the requirements of either IEC 61008 or IEC 61009.

An RDC-DD/RDC-PD is not one of those devices cited in Regulation 722.531.3.101, which leaves the installer in a difficult position. BS 7671 and BS EN IEC 61851 mandate that RCDs shall comply with one of the following standards: BS EN 61008-1, BS EN 61009-1, BS EN 60947-2 or BS EN 62423.

Figure 3 Mode 3 EV charger with integrated electronic RCD



Can I install equipment which does not comply with any British Standards?

Yes, but any intended departure requires special consideration by the designer of the installation in consultation with the client and other interested parties. It is important to note that the resulting degree of safety of the installation shall be not less than that obtained by compliance with BS

7671:2018+A2:2022, Regulation 120.3 refers. Any intended departures along with the justification must be recorded on the electrical certification.

Regulation 122.1.2 states that where there are no applicable standards, the item of equipment concerned shall be selected by a special agreement between the person specifying the installation and the installer. This route requires careful consideration as it could result in liabilities at a future date.

Regulation 133.5 provides requirements for new materials and inventions, and Regulation 133.1.3 provides requirements for equipment which does not comply with any British or Harmonized Standard or used outside the scope of its standard. Again, the resulting degree of safety of the installation shall be not less than that obtained by compliance with the BS 7671:2018+A2:2022, and the chances of the EVSE manufacturer putting this clearly in writing is unlikely.

Regulation 722.411.4.1 of BS 7671:2018+A2:2022 recognizes that equipment can be used which is not covered by a British or Harmonized Standard, in this case, open PEN detection devices. It is required that the equipment meets the requirements of statutory legislation, the Electrical Equipment (Safety) Regulations 2016 (as amended), the Electromagnetic Compatibility Regulations 2016 (as amended) and other relevant legislation, and the equipment has either a CE, UKCA or UKNI mark and a Declaration of Conformity (DOC). The DOC is to be appended to the certification for initial verification and where this is satisfied, it is *not* considered to be a departure from BS 7671:2018+A2:2022.

What is a declaration of conformity?

When installing any item of electrical equipment, it is important the manufacturers supply a DOC. A DOC is a mandatory document provided by manufacturers to declare their products comply with the law.

The CE, UKCA or UKNI mark accompanied by the DOC document confirms that the manufacturer takes full responsibility for the products compliance with the applicable laws. The DOC is usually available on the manufacturer's website or available on request. The DOC will specify the relevant regulations and standards to which the product conforms.

What if the manufacturer states an RCD is not required?

Be wary of claims by manufacturers that an external RCD is not required for EVSE. Some manufacturers of EVSE declare on their website that the equipment does feature an integrated RCD which operates 'similar' to a traditional RCD complying with BS EN 61008 or BS EN 61009. If the RCD, however, is integrated into the circuit board, it will not conform to the RCD product standards.

When inspectors of competent person schemes carry out their audits, they will be looking for compliance with BS 7671 and will expect to see an external RCD installed in such circumstances.

Sweden bans EV chargers with integrated RCDs

Swedish authorities have recently placed a sales ban on a manufacturer of electric vehicle charge points. One of the issues raised is regarding the use of integrated electronic RCDs. The manufacturer has provided [a robust response](#) and maintains that their products are safe and it is a matter of correct documentation.

Summary

Regulation 722.531.3.101 of BS 7671:2018+A2:2022 requires RCDs to protect the charging point, i.e. the socket-outlet or connector and not, necessarily, the circuit supplying it.

The RCD can be installed at the distribution board or within the EVSE. RCD functionality built into circuit boards does not conform to the relevant product standards required by BS 7671:2018+A2:2022 or BS EN IEC 61851-1:2019.

RCDs shall disconnect all live conductors and comply with one of the following standards, BS EN 61008-1, BS EN 61009-1, BS EN 60947-2 or BS EN 62423.

For Mode 3 charging, a Type A or Type F RCD is required where protection against DC residual current in the form of an RDC-DD is provided within the EVSE.

Where the EVSE does not incorporate such protection, a Type B RCD is required. When installing EVSE, account should be taken of manufacturer's instructions.

Further reading

- [UKCA marking: conformity assessment and documentation - GOV.UK \(www.gov.uk\)](https://www.gov.uk/guidance/ukca-marking-conformity-assessment-and-documentation)
- [Designated standards](#)
- [Elsälerhetverket imposes sales ban on Easee wall boxes in Sweden | electrive.com](https://www.electrive.com/news/elsalerhetverket-imposes-sales-ban-on-easee-wall-boxes-in-sweden)
- [Exclusive: IEC expert contradicts Easee on wall box safety | electrive.com](https://www.electrive.com/news/exclusive-iec-expert-contradicts-easee-on-wall-box-safety)
- [22EV1261 – Response letter from Easee AS.pdf \(dagbladet.no\)](https://www.dagbladet.no/2022/07/22/22EV1261-response-letter-from-easee-as)
- [BEAMA GUIDE - selection and application of RCDs](#)
- [BEAMA guide - RCD selection for protection of electric vehicle charging installations.](#)

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The arc flash hazard and UK guidance

By: Mike Frain CEng FIET MCFI

There have been recent calls on social media platforms for the Institution of Engineering and Technology (IET) and the Health and Safety Executive (HSE) in the UK to do more to address the issue of arc flash* (electrical flashover) when protecting electrical workers. I've written this article to highlight what the UK legislation on electrical safety says about the subject and what credible information is out there right now to help duty holders** to comply with the law. The views expressed are my own and are not intended to represent the IET or other organizations mentioned.

*"Arc flash is a non-contact short circuit between an energised conductor such as a busbar or cable with another conductor or an earthed surface. Put simply, arc flash is precipitated by insulation breakdown and very often, the insulation in question on low voltage systems is air." IET Factfile - *Arc flash risk management*.

**As defined in *Memorandum of Guidance on the Electricity at Work Regulations: HSR25 (Health and Safety Guidance)*, "Regulation 3, Persons on whom duties are imposed by these Regulations".

Firstly, it is unlikely that the HSE will be publishing a specific guidance document on arc flash in the near future, although it is clear from the current HSE guidance, that the arc flash hazard must be treated very seriously. Whilst not a spokesman for the HSE in any way, I am aware that they have been willing to add to the debate of arc flash risk management and I have shared platforms with HSE representatives since 2007. I'm the convenor for the IEC TC 78 Working Group 15 Arc Flash Protection and on my group, there are 44 experts from 19 countries around the world. Only one National Committee has an HSE government regulator on this working group and that is Great Britain (British Standards Institute). The help given from the same regulator in publishing the IET *Arc flash risk management* Factfile has also been gratefully received.

The legislation in the UK is primarily risk based, goal setting and non-prescriptive. The strategic approach of the HSE is that of simplification, meaning that duty holders are expected to manage the risks that they create, as they are best placed to control them. They are expected to do so in a proportionate and practicable way, meaning that a one size fits all approach to arc flash risk management will not meet the needs of every industry or environment.

IET Arc flash risk management Factfile

In the UK, it can be said, and with certainty, that the greatest prevalence of arc flash injuries is among electrically qualified workers. Often, those working with or near electricity do not appreciate the risk of serious injury or damage to equipment that can arise from arcing. It is important therefore, that this group of workers are made aware of the hazard and the safeguards. The IET Engineering Safety Policy Panel, of which I was the Vice Chair, created a Factfile in 2021 called *Arc flash risk management*. The Arc Flash Working Group consisted of senior electrical engineers including an HM Principal Specialist Inspector (Electrical Engineering) and Professional Lead at the Office for Nuclear Regulation. The Factfile is free to all and can be obtained from the IET via the following link: [IET Arc flash risk management Factfile](#)

Figure 1 The IET Arc flash risk management Factfile



The IET Factfile provides a helpful appreciation of the principles of arc flash risk assessments. It is an awareness document, ideally leading those who require an arc flash assessment to seek competent advice. It seeks to set out the key principles of arc flash risk management using a risk-based approach. It is aimed at persons (duty holders) with responsibility for the management of safety in the control and implementation of work on electrical power equipment.

The document describes an approach, based on a hierarchy of risk control measures. It adopts a holistic risk management methodology using the 4Ps of Predict, Prevent, Process and Protect to ensure that arc flash hazards are systematically identified, analyzed, and prevented from causing harm.

Removal of the hazard through working only on or near equipment that is made dead and suitably isolated should always be the first-choice risk reduction measure. However, other prevention measures are identified that fall into the categories of automatic disconnection of supply, equipment design and/or operational measures, that can be adopted individually or collectively to provide safety.

Considerations for flame resistant personal protective equipment (PPE), as a risk control measure, should only be adopted as a last resort principle. The document provides an assessment process and there is also a commentary on recognized standards and test methods for PPE in Appendix 2.

The Factfile points out that when carrying out a risk assessment, as a minimum we must:

- **Identify what could cause injury (hazards).** This is derived from system parameters such as voltage, fault level and electrical protection arrangements.
- **Decide how likely it is that someone could be harmed and how seriously (the risk).** This is derived from system conditions such as the condition of the equipment, the quality of the installation, measures used to contain an arc during switching under normal and fault conditions, how well it has been maintained and whether it is being operated in accordance with its original design. Importantly, it is also directly related to the task to be performed.

- **Take action to eliminate the hazard, or if this isn't possible, control the risk.** The document highlights the use of the 4P approach, mentioned previously, to eliminate or control the risk.

The 4P approach to arc flash risk assessment will ensure that the three steps above are fulfilled. That will be through a quantitative prediction of the hazard and then through prevention to eliminate or significantly minimize the risk. Process, policies and procedures are then used to further reduce the likelihood and finally, personal protection against residual risk if needed.

The following model is used to describe how these steps can be implemented. The cycle matrix diagram shown illustrates how the important first step of **Predict** is used to calculate the severity of the arc hazard. This is followed by **Prevent** in that we apply the principles of prevention and order the risk control measures in a hierarchy. The next step is **Process**, policies and procedures where we apply the building blocks of safe procedures, safe places and safe people. The final step is **Protect** which looks at providing PPE as a last resort which, if the previous three steps have been correctly applied, will deal with residual risk only and lead to more lightweight solutions.

Figure 2 Diagram illustrating the 4P approach to arc flash risk assessment



By applying the 4P principles, it has been shown repeatedly that the need for PPE has been removed entirely or reduced to a comfortable and unrestrictive level. Let me give an example.

Figure 3 Clean room



Back in 2007, I carried out an arc flash study for a high-tech manufacturer of computer hard drive recording heads. There were 1,400 staff employed there including 140 electrical maintenance staff and 4 electrical contracting companies. Much of the manufacturing took place in high specification clean rooms and the study identified high incident energy levels in 120 control panels in these areas alone. It wasn't feasible to simply protect individuals with PPE because of the lack of, and expensive nature of, clean room arc flash PPE at that time. The application of the 4P principles successfully reduced the incident energy levels at all the panels to less than 1.2 cal/cm² at a working distance of 450 mm by applying new protection settings, refeeding some circuits from alternative sources, installing local HRC switch fuses and upgrading MCCBs in existing panels to more precise instantaneous settings.

NOTE: 1.2 cal/cm² is a widely used threshold denoting a 50 % chance of the onset of a minor partial thickness burn.

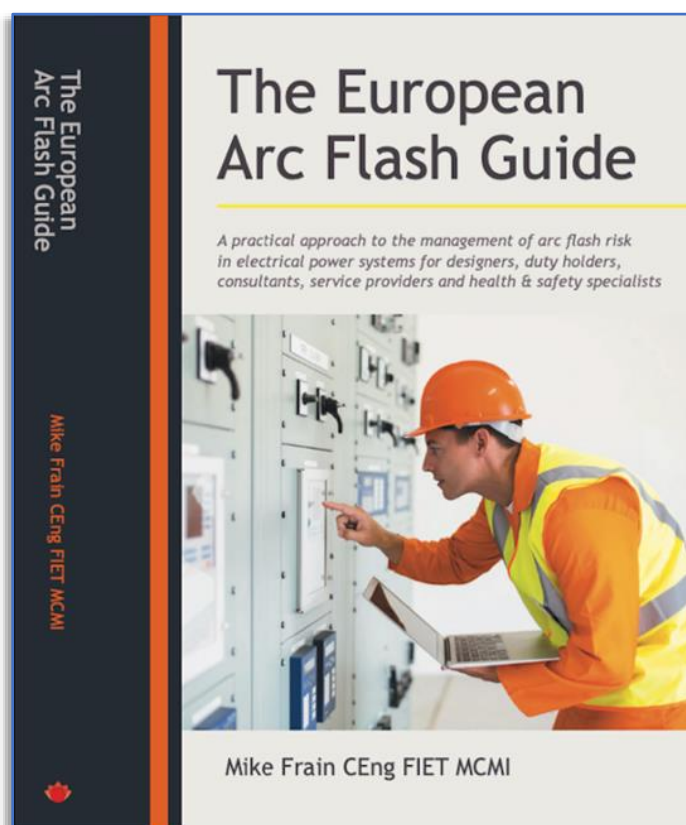
That was, of course, preceded by the introduction of new safety rules and training to remove the need for working near to live conductors in the first place. The 'in house' team were then trained in the use of modelling software so that all future additions and alterations could be assessed at design stage.

The question is, if it was possible to apply the 4P principles to reduce the reliance on PPE because of the cost and availability of clean room arc rated PPE, why can't this be the case for all environments?

The European Arc Flash Guide

The principles outlined in the IET *Arc flash risk management* Factfile are broadly based upon my book, *The European Arc Flash Guide*, which I would recommend for anyone requiring a comprehensive study of the management of arc flash in a UK/European context. It is available from the [IET Library](#) for IET members and from most bookstores.

Figure 4 The European Arc Flash Guide



The mission is to “Inform and influence duty holders, designers and service providers to reduce danger from electrical arcing, by providing quick, simple, accessible and accurate predictive tools coupled with practical advice.”

The book is essential reading for anyone responsible for designing or putting workers to task on, or near, large power electrical systems and is especially relevant where local health and safety law uses a risk-based approach to electrical safety such as in the UK and Europe. It is based upon a bedrock of risk management methodology using the 4Ps of Predict, Prevent, Process and Protect to ensure that arc flash hazards are systematically identified, analyzed, and prevented from causing harm. There are chapters that are dedicated to myths and mysteries as well as separate chapters for electrical utilities, duty holders, service providers, contractors, legislation and data collection.

Alongside the book, there is a set of calculators and charts that require a small subscription to give access to tools to allow simple but accurate prediction of hazard severity. These can be accessed online through www.ea-guide.com and can be managed from phones, tablets and PCs. The purpose of the calculators and accompanying charts is not to provide complex software calculations of entire electrical networks, but rather to help the reader to do dynamic risk assessments on a case-by-case basis.

List of arc flash tools

- IEEE 1584 Incident Energy Calculator.
- LV Circuit-Breaker Calculator.
- Incident Energy HRC Fuse Charts.
- LV Devices (Fuses and MCBs) up to 125 A Calculator.
- DC Incident Energy Calculator.
- Blast Pressure Calculator.
- DGUV Box Test Algorithm Calculator.
- Prospective Short Circuit Current Calculator Tool.
- LV HRC Fuse Time Current Curve Tool.
- IDMT Time Current Curve Calculator.
- Risk Assessment Form.

Registration with the [EA-Guide](http://www.ea-guide.com) site will give free online access to all the step-by-step written instructions and videos plus the first seven chapters of *The European Arc Flash Guide*.

NFPA 70E Standard for Electrical Safety in the Workplace

The American National Standard, *NFPA 70E Standard for Electrical Safety in the Workplace*, is often quoted within the UK as a means of managing the arc flash risk and has been cited in some of the comments on LinkedIn that were referred to previously. I would, therefore, like to clarify that duty holders should be very careful when considering use of the standard.

Like all NFPA (National Fire Protection Association) codes and standards, NFPA 70E is based upon a consensus-based process. First published in 1979, it was created at the request of the Occupational Safety and Health Administration (OSHA) of the United States of America Department of Labor.

Whilst the document is creditable in many ways, there needs to be caution when applying this consensus document in the UK. Issues such as energized electrical working permits fly in the face of the current UK guidance, *Electricity at Work: Safe Working Practices*, HSG85, which states: “An electrical permit-to-work is primarily a statement that a circuit or item of equipment is safe to work on and it has been isolated and, where appropriate, earthed. You must never issue an electrical permit-to-work for work on equipment that is still live or to authorise live work.”

That said, the standard has, in recent years, promoted hazard elimination and dead working as the first priority in the implementation of safety related work practices. I first presented a paper on *Electrical Safety and Arc Flash in Europe* alongside Jim Phillips to the IEEE Electrical Safety Workshop over 12 years ago in Daytona Beach, Florida. The paper included the UK/European style hierarchy of risk controls and three years later, this was adopted into NFPA 70E.

The document has useful information that a discerning UK electrical engineer would find useful when considering the arc flash hazard. But beware that the document is written for those countries that follow a US electrical safety model and the differences with the UK legislation could lead to confusion. For instance, energized work is still permitted by NFPA 70E where the employer can demonstrate that “the task to be performed is infeasible due to equipment design or operational limitations”. Regulation 14 from the *Electricity at Work Regulations 1989* would arguably present a much tougher test of reasonableness in allowing live work to proceed. In addition, NFPA 70E relies on American standards only such as ASTM, ANSI and UL. The UK regulations, British Standards and IEC standards for issues such as PPE, fault current estimation, design of electrical installations, shock protection boundaries, operation of electrical installations, electrical test equipment, labelling, signs and signals are all very different. That includes many of the electrical definitions that we use.

The advice is, if considering the implementation of any part of NFPA 70E, to ensure that it is incorporated into UK style safety rules and amended with caution. Competent advice should be sought where necessary.

Relevant UK legislation and HSE guidance including Northern Ireland

The following is a list of UK legislation which is pertinent to arc flash risk management. This is not exhaustive but provides a basis for discussion with comments shown in bulleted italics.

The ***Electricity at Work Regulations 1989*** (NI 1991) (EAWR) are made under the **Health and Safety at Work etc Act 1974*** the purpose of which is to require precautions to be taken against the risk of death or personal injury from electricity in work activities. The following guidance is free of charge through the HSE website, <https://www.hse.gov.uk>.

***NOTE:** The primary legislation in Northern Ireland is the Health and Safety at Work (Northern Ireland) Order 1978.

The Electricity at Work Regulations 1989 Guidance HSR25, published October 2015. The purpose of this guidance is to highlight what can be done by duty holders to achieve electrical safety compliance with the duties imposed by the regulations. In respect of the design of electrical installations, HSR25 states “BS 7671 is a code of practice which is widely recognised and accepted in the UK and compliance with it is likely to achieve compliance with relevant aspects of the *Electricity at Work Regulations 1989*.”

- *In respect of specific arc flash design considerations, this is a forum in which willing individuals can engage to improve new innovative solutions through the IET.*

Regulation 11 of the EAWR, “Means for protecting from excess of current”, says that “efficient means, suitably located, shall be provided for protecting from excess of current every part of a system as may be necessary to prevent danger.”

- *Whilst HSR25 cites the difficulties in protecting against arcing currents as a possible defence in criminal proceedings, they can be predicted with much more accuracy in recent years and so the goal should be to disconnect such faults quickly and remove the danger.*

Electricity At Work: Safe Working Practices, HSG85 (Third Edition), published 2013. The guidance covers the key elements to consider when devising safe working practices and is for people who carry

out work on or near electrical equipment. There is a requirement that, “if there is a risk of burns from arcing or flashover that cannot be avoided, consider the use of adequately rated, thermally insulating, flame-resistant PPE”.

- *In respect of the determination of adequate ratings, consult the IET Arc flash risk management Factfile and/or The European Arc Flash Guide.*

The need for risk assessment comes from the **Management of Health and Safety at Work Regulations 1999 (NI 2000)** (MHSWR), the process for which was first established in 1992. Regulation 3(1)(a) states “Every employer shall make a suitable and sufficient assessment of the risks to the health and safety of his employees to which they are exposed whilst they are at work.”

- *Whilst the Electricity at Work Regulations (EAWR) predates this, the risk assessment process is still required for electrical hazards. Is the arc hazard being identified as part of a risk assessment process?*

In addition, Regulation 7 of MHSWR requires employers to ensure that people who have health, safety and welfare responsibilities in the workplace are competent. This includes appointing people to assess risks under Regulation 3 of the Management Regulations. Where the organization does not have the competence to manage health and safety in-house, “for example, if it's large, complex or high risk,” they can get help from a consultant or adviser.

- *Are those undertaking arc flash risk assessments competent?*

Regulation 4 of the **Personal Protective Equipment at Work Regulations 1992 (as amended 2022) (NI 1993)** introduces the last resort principle, and that engineering controls and safe systems of work should be considered first. The guidance on the regulations HSE L25, sets out the hierarchy of risk controls.

- *Can the arc flash hazard be eliminated and if not, how can the risk be controlled so that harm is unlikely?*

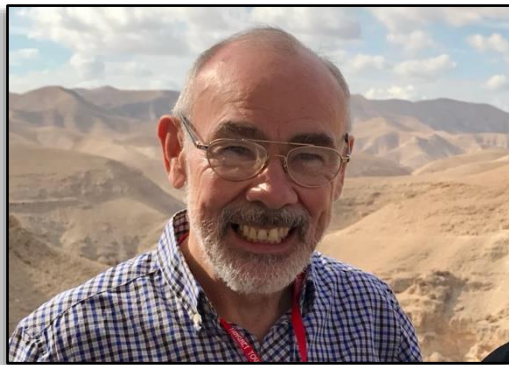
Regulation 4 of the PPE Regulations also requires that PPE takes account of ergonomic requirements and the state of health of the person or persons who may wear it and that it is effective to prevent or adequately control the risk or risks involved without increasing overall risk.

- *Have these factors been considered bearing in mind the restrictive nature of very heavy PPE?*

Conclusions

- Carry out a risk assessment using the tools that are available to understand the severity of the hazard and the risk. Secondly, take action to eliminate the hazard, or if this isn't possible, control the risk. Make sure that control measures follow a hierarchy putting elimination of the hazard first and that those control measures follow the local secondary legislation.
- The greatest prevalence of arc flash injuries is among electrically qualified workers. Therefore, it is important that this group of workers are made aware of the hazard and the safeguards.
- Use the IET Factfile on *Arc flash risk management* as an appreciation of the principles of arc flash risk assessments. For a deeper understanding, consult *The European Arc Flash Guide*.
- Exercise caution when considering the implementation of NFPA 70E into UK facilities and seek competent advice where necessary.

Mike Frain Bio



Mike Frain is the author of *The European Arc Flash Guide* and expert for the British Standards Institute and International Electrotechnical Commission (IEC) TC 78: Live Working Committees. He is the Convener for the Arc Flash Working Group (TC 78 WG 15) and the Team Leader for the IEC Arc Flash End User Guidance Project Team. He is the Secretary for the IET South Yorkshire Local Network, and former Vice Chair of the IET Engineering Safety Policy Panel and led the IET

Arc Flash Working Group. He is a Chartered Engineer, a Fellow of the Institution of Engineering and Technology, and a Corporate Member of the Chartered Management Institute.

Why are the values of maximum earth fault loop impedance different in BS 7671 to the IET's On-Site Guide and Guidance Note 3: Inspection & Testing? Which should be recorded on the Electrical Installation Certificate (EIC)?

By: Craig O' Neill BEng (Hons) MIET

The effect heat has on electrical circuits is an important concept for electricians to understand.

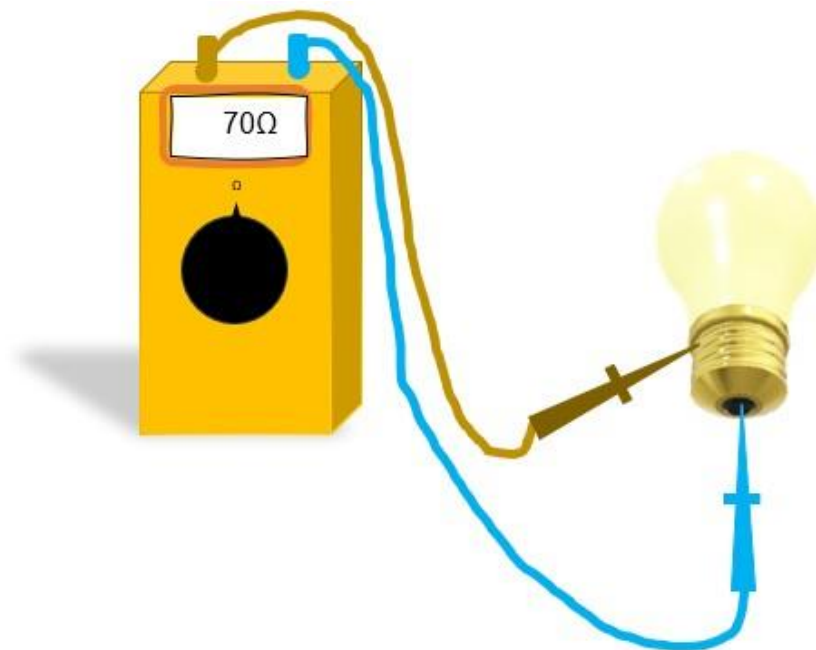
An increase in heat affects all aspects of a circuit. Temperature limits of the insulation, protective devices, switchgear, accessories, etc., can be compromised and the resistance of the conductors can increase.

Rating factors are published in BS 7671:2018+A2:2022 which enable the designer keep temperature limits in check. These can be found in Tables 4A1-4C6 and Tables 4D1-4J4 of BS 7671:2018+A2:2022.

This article, however, is focussing on the effect heat has on the resistivity of conductors and therefore, their resistance.

Heat and resistance theory

Figure 1 A low ohm resistance meter measuring the resistance of the lamp's element



The effect heat can have on resistance of conductors can be seen in a simple experiment.

Using a low ohm resistance meter, a resistance of approximately 70 Ω would be displayed for a 60 watt @240 V tungsten lamp at around 20 °C, if measured across the element.

Using Ohm's law, we can see that we could expect a current of:

$$V = IR \therefore I = \frac{V}{R} \therefore \frac{240}{70} = 3.43 \text{ Amps}$$

However, the manufacturer has stated the voltage and output wattage of the lamp for a reason. This is to enable a simple calculation of the expected current when the lamp is energized to the stated voltage.

$$P = VI \therefore I = \frac{P}{V}$$

We can see we get a different result of:

$$\frac{60}{240} = 0.25 \text{ Amps}$$

Where:
V = Voltage in volts.
I = Current in amperes.
R = Resistance in ohms (Ω).
P = Power in watts.

NOTE: The reason for using 240 V in these calculations instead of U_o of 230 V is because most of these older lamps are rated at 240 V rather than 230 V.

If 230 V was applied, the power output would be 55.2 watts and draw a current of approximately 0.24 amps based on element measuring 70 Ω at 20 °C.

The reason for the difference is that the temperature change was not considered in the first calculation. The resistance was measured at 20 °C but, when the lamp is energized with 240 V, the high resistance element gets hot – very hot! In fact, some types of elements could reach a temperature of up to 3,000 °C.

It is possible to alter the 20 °C resistance measurement and predict the approximate resistance value when the lamp is operating using the following equation:

$$R_{final} = R_o + (R_o \beta (\Delta t)) \quad (\text{Equation 1})$$

Where:
R_{final} = Predicted final resistance.
R_o = Original resistance at 20 °C.
β = The temperature coefficient of resistance in ohms per degree centigrade increase.
(For copper, the temperature coefficient of resistance is approx. 0.00393 $\Omega/^\circ\text{C}$. BS 7671 uses a value of 0.004 $\Omega/^\circ\text{C}$, whilst tungsten is 0.0044 $\Omega/^\circ\text{C}$.)
Δt = Change in temperature.

Substituting the values, we obtain a more realistic resistance reading:

$$R_{final} = 70 + (70 \times 0.0044 \times 2,980)$$

$$R_{final} = 988 \Omega$$

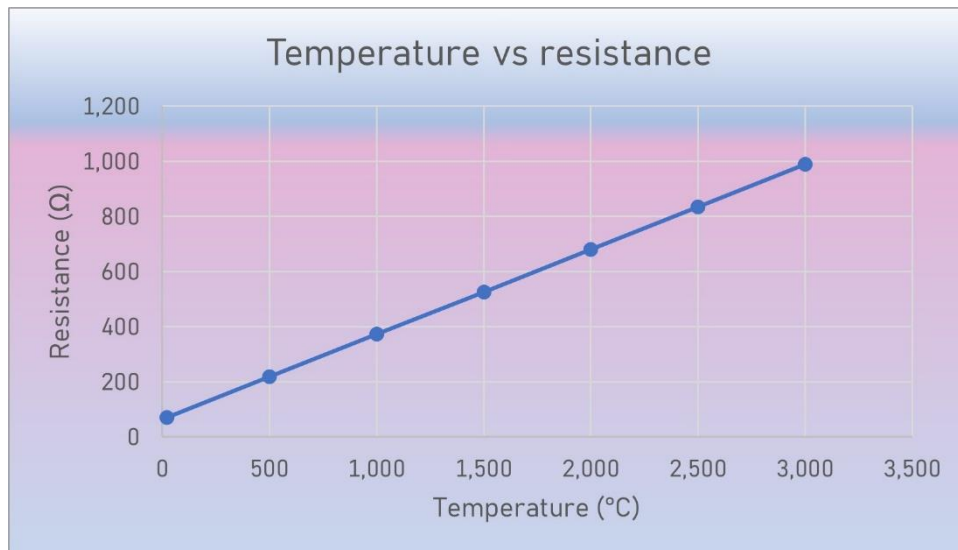
And then applying Ohm's law, we get:

$$I = \frac{V}{R}$$
$$\frac{240}{988} = 0.243 \text{ Amps}$$

This is much closer to reality. This simple experiment shows how temperature needs to be considered with any resistance measurements.

If we calculate a few other temperatures along the way and create a quick graph, we can see a very linear relationship between an increase of heat and an increase of resistance.

Figure 2 The linear relationship between heat and resistance



Why are the values of maximum earth fault loop impedance ($\max Z_s$) different depending on which publication you read?

You may now be able to answer this but let's look in a bit more detail about those differences.

Designing a circuit and calculating earth fault loop impedance (Z_s)

BS 7671:2018+A2:2022 has tables in Chapter 41 stating $\max Z_s$ values for some of the most common protective devices. Tables 41.2-41.4 refer to values of impedance when the circuit is running at full capacity. This is commonly 70 °C however, some cables can run higher in certain circumstances, so it is important to understand Notes 2 and 3 below Tables 41.2-41.4 (see Figure 3).

Figure 3 The Notes found below Tables 41.2-41.4 in BS 7671:2018+A2:2022

NOTE 2: The circuit loop impedances given in the table should not be exceeded when:

- (i) the line conductors are at the appropriate maximum permitted operating temperature, as given in Table 52.1, and
- (ii) the circuit protective conductors are at the appropriate assumed initial temperature, as given in Tables 54.2 to 54.5.

If the conductors are at a different temperature when tested, the reading should be adjusted accordingly. See Appendix 3.

NOTE 3: Where the line conductor insulation is of a type for which Table 52.1 gives a maximum permitted operating temperature exceeding 70 °C, such as thermosetting, but the conductor has been sized in accordance with Regulation 512.1.5:

- (i) the maximum permitted operating temperature for the purpose of Note 2(i) is 70 °C, and
- (ii) the assumed initial temperature for the purpose of Note 2(i) is that given in Tables 54.2 to 54.4 corresponding to an insulation material of 70 °C thermoplastic.

These maximum Z_s values in Tables 41.2-41.4 of BS 7671:2018+A2:2022 are useful when designing a circuit. The current carrying capacity tables, rating factors and volt drop values in BS 7671 are all comparative in keeping safely, yet economically, within the declared maximum permitted operating temperatures of any cable or equipment. Therefore, it makes sense to list the same values assuming similar conditions in BS 7671 for comparing max Z_s .

Guidance on how to calculate the max Z_s of a circuit is not provided within BS 7671:2018+A2:2022. However, Section 7.3 of The IET's *Electrical Installation Design Guide, 5th Edition* shows how this can be calculated and confirmed to comply with BS 7671. The IET's *Electrical Installation Design Guide, 5th Edition* states:

“Circuits are designed to meet the shock protection requirements by limiting the earth fault loop impedances to the end of the circuit (Z_s) to the maximum values given in Tables 41.2 to 41.4 of BS 7671 (Z_{41}). “

$$Z_{41} \geq Z_e + Z_1 + Z_2 \quad (\text{Equation 2})$$

Where:
Z_{41} = The max Z_s as listed in Tables 41.2-41.4 of BS 7671:2018+A2:2022.
Z_e = The external part of the earth fault loop path (usually controlled by the DNO/DSO).
Z_1 = The impedance of the line conductor of the installation.
Z_2 = The impedance of the circuit protective conductor (cpc) of the installation. These are all measured in ohms (Ω).

It then shows how to calculate the earth fault loop impedance and the Z_1 and Z_2 . The Z_e is usually out of the control of the designer.

The equation is shown arithmetically as:

$$Z_e + \sqrt{[(R_1'' + R_2'')^2 \times C_r^2 \times L^2] + [(X_1'' + X_2'')^2 \times L^2]} \leq Z_{41} \quad (\text{Equation 3})$$

Where:
Z_{41} = The max Z_s as listed in Tables 41.2-41.4 of BS 7671:2018+A2:2022 (Ω).
Z_e = The external part of the earth fault loop path (Ω) (usually controlled by the DNO/DSO).
R_1'' = The resistance per metre of the line conductor (Ω/m) (see Tables F.1 and F.7 of the <i>Electrical Installation Design Guide</i> , I1 of the <i>On-Site Guide</i> and B1 of <i>Guidance Note 3</i>).
R_2'' = The resistance per metre of the protective conductor (Ω/m) (see Tables F.1 and F.7 of the <i>Electrical Installation Design Guide</i> , I1 of the <i>On-Site Guide</i> and B1 of <i>Guidance Note 3</i>).
C_r = The correction factor for temperature (see Table F.3 of the <i>Electrical Installation Design Guide</i> , I3 the <i>On-Site Guide</i> and B3 of <i>Guidance Note 3</i>).
L = The length of cable in circuit (m).
X_1'' = The reactance per meter of the line conductor (Ω/m) (See Table F.7 of the <i>Electrical Installation Design Guide</i> and Tables 4d1-4J4 of Appendix 4, BS 7671).

X_2'' = The reactance per meter of the protective conductor (Ω/m) (See Table F.7 of the *Electrical Installation Design Guide* and Tables 4d1-4J4 of Appendix 4, BS 7671).

Note that the temperature correction factor is only applied to the resistive part of the conductor and not the reactive component.

The heat of a conductor will have no effect on reactance. Cables under 16 mm² will have negligible reactance, so for the purposes of simplicity in this article, the equation below will be used for examples:

$$Z_e + [(R_1'' + R_2'') \times C_r \times L] = Z_s \text{ (Equation 4)}$$

Example

Consider a theoretical **77 m** circuit consisting of **1.5 mm²** line and neutral conductors and a **1.0 mm²** cpc. $Z_e = 0.35 \Omega$, $R_1'' + R_2'' = 0.0302 (\Omega/m)$ (Found in Table I1 of the *On-Site Guide* or Appendix B of *Guidance Note 3*), $C_r = 1.2$ (Found in Table I3 of the *On-Site Guide* or B3 of *Guidance Note 3*).

With temperature correction = $0.35 + [(0.0302) \times 1.2 \times 77] = 3.14 \Omega$.

Without temperature correction = $0.35 + [(0.0302) \times 77] = 2.68 \Omega$.

If our protective device had a max Z_{41} of 2.73 Ω and we didn't adjust for temperature in our calculations for our circuit Z_s , then we could wrongly consider the result compliant when it may not be.

Confirming a circuit max Z_s after installation

When circuits are tested, the circuit will rarely be at the max operating temperature. For initial verification, a common method is to calculate the actual Z_s value of circuit based on the R_1+R_2 reading and a measured Z_e reading. This is sensible because it proves the circuit will likely be compliant before energizing and removes any possibilities of parallel paths such as metallic services or structural framework of a building which could skew the results and have a reduction effect on the Z_s . In this case, the conductors would have never been energized so the possibility of being at max operating temperature is unlikely to say the least!

We are therefore required to alter these values to the temperature we are testing at to ensure we are comparing the actual measurement value with the max Z_s of that temperature. Otherwise, we could pass an unsatisfactory circuit.

Some engineers like to do an additional live Z_s measurement after initial verification. This can highlight any high impedance parts of the busbar, protective devices or switchgear assemblies which may not get highlighted using a calculation method of obtaining the Z_s value. There are always safety precautions to consider with any live working and appropriate risk assessments and methods of operating are essential.

Example

The max Z_s of a 32 A B-type circuit-breaker to BS EN 60898 is listed in Table 41.3 of BS 7671 as 1.37 Ω .

If the measured Z_s on the circuit was recorded as 1.25 Ω then you could assume, possibly incorrectly, that was a pass. However, the temperature at the time of measurement was not likely to be maximum permitted operating temperature so we would need to find the maximum Z_s for the temperature we measured the Z_s .

Using guidance in Appendix 3 of BS 7671

Appendix 3 of BS 7671 simplifies this by taking into account the increase of the conductor resistance with increase of temperature due to load current which may be used to verify compliance with the requirements of Regulation 411.4 for TN systems (TT systems generally wouldn't comply with this without the use of residual current devices (RCDs)).

It displays an equation:

$$Z_s(m) \leq 0.8 \times \frac{U_0 \times C_{min}}{I_a} \quad (\text{Equation 5})$$

Z₄₁ Values

Simple multiplier to reduce Z₄₁ values

Where:
Z ₄₁ = The max Z _s as listed in Tables 41.2-41.4 of BS 7671:2018+A2:2022.
Z _s (m) = The measured impedance of the earth fault current loop up to the most distant point of the relevant circuit from the origin of the installation (Ω).
U ₀ = The nominal AC rms line voltage to Earth (V).
I _a = The current in amps (A) causing operation of the protective device within the time stated in Table 41.1 of BS 7671:2018+A2:2022 or within 5 s according to the conditions stated in Regulation 411.3.2.3.
C _{min} = The minimum voltage factor to take account of voltage variations depending on time and place, change of transformer taps and other considerations.
0.8 = The factor to take into account the increase of resistance of the conductors with the increase of temperature due to load current.

NOTE: For a low voltage supply given in accordance with the Electricity Safety, Quality and Continuity Regulations (ESQCR) as amended, C_{min} is given the value of 0.95.

For the example above of a 32 A Type B circuit-breaker to BS EN 60898, applying the equation in Appendix 3 of BS 7671:2018+A2:2022 would give a max Z_s of:

$$1.37 \, \Omega \times 0.8 = 1.096 \, \Omega$$

Therefore, the measured Z_s of 1.25 Ω would indicate a non-compliant circuit.

This method, incidentally, provides the same values you will find in the *On-Site Guide* and *Guidance Note 3* as these publications are designed to be used in the field so publishing design values makes little sense.

Figure 4 Max Z_s values for various circuit-breakers at ambient temp (10 °C). Guidance Note 3 (Table A5) and the On-Site Guide (B6)

▼ **Table A5** Circuit-breakers. Maximum measured EFLI (in Ω) at ambient temperature where the overcurrent device is a circuit-breaker to BS 3871 or BS EN 60898 or RCBO to BS EN 61009

For 0.1 to 5 s disconnection times (includes 0.4 s disconnection time)

Circuit-breaker type	Circuit-breaker rating (amps)														
	3	5	6	10	15	16	20	25	30	32	40	45	50	63	100
1	14.57	8.74	7.29	4.37	2.92	2.74	2.19	1.75	1.46	1.37	1.10	0.98	0.88	0.70	0.44
2	8.33	5.00	4.17	2.50	1.67	1.57	1.25	1.00	0.84	0.79	0.63	0.56	0.50	0.40	0.25
B	11.66	7.00	5.83	3.50	2.34	2.19	1.75	1.40	1.17	1.10	0.88	0.78	0.70	0.56	0.35
C and 3	5.83	3.50	2.92	1.75	1.17	1.10	0.88	0.70	0.59	0.55	0.44	0.39	0.35	0.28	0.18
D (0.4 s)			1.46	0.88		0.55	0.44	0.35		0.28	-	-	-	-	-
D (5 s)			2.92	1.75		1.10	0.88	0.70		0.55	0.44		0.35	0.28	0.18

▼ **Table B6** Circuit-breakers. Maximum measured earth fault loop impedance (in Ω) at ambient temperature where the overcurrent device is a circuit-breaker to BS 3871 or BS EN 60898 or RCBO to BS EN 61009

0.1 to 5 second disconnection times

Circuit-breaker type	Circuit-breaker rating (amperes)														
	3	5	6	10	15	16	20	25	30	32	40	45	50	63	100
1	14.57	8.74	7.29	4.37	2.92	2.74	2.19	1.75	1.46	1.37	1.10	0.98	0.88	0.70	0.44
2	8.33	5.00	4.17	2.50	1.67	1.57	1.25	1.00	0.84	0.79	0.63	0.56	0.50	0.40	0.25
B	11.66	7.00	5.83	3.50	2.34	2.19	1.75	1.40	1.17	1.10	0.88	0.78	0.70	0.56	0.35
C and 3	5.83	3.50	2.92	1.75	1.17	1.10	0.88	0.70	0.59	0.55	0.44	0.39	0.35	0.28	0.18
D (0.4 s)			1.46	0.88		0.55	0.44	0.35		0.28	-	-	-	-	-
D (5 s)			2.92	1.75		1.10	0.88	0.70		0.55	0.44		0.35	0.28	0.18

Regulation 434.5.2 of BS 7671 requires that the protective conductor csa meets the requirements of BS EN 60898-1, -2 or BS EN 61009-1, or the minimum quoted by the manufacturer. The sizes given in Table B7 are for energy limiting class 3, Types B and C devices only.

Adjusting max Z_s for various conductor temperatures based on ambient temperatures using Guidance Note 3

Alternatively, guidance is provided in Appendix A of *Guidance Note 3* to help calculate the max Z_s at a variety of temperatures.

The simplest method is shown at the end of Section A1 which explains that the correction factors in Table A7 can be multiplied by the max Z_s values from Tables A1-A5 in *Guidance Note 3* or B2-B6 of the *On-Site Guide* to alter the max Z_s for a given ambient temperature.

Figure 5 Table A7 of Guidance Note 3 to correct 10 values of max Z_s to other temperatures

▼ **Table A7** Ambient temperature correction factors

Ambient temperature (°C)	Correction factor (from 10 °C) (Notes 1 and 2)
0	0.96
5	0.98
10	1.00
20	1.04
25	1.06
30	1.08

Notes:

- 1 The correction factor is given by: $\{1 + 0.004 (\text{ambient temp} - 20)\} / \{1 + 0.004 (10 - 20)\}$ where 0.004 is the simplified resistance coefficient per °C at 20 °C given by BS EN 60228 for both copper and aluminium conductors. (Alternatively, the correction factor is given by $(\text{ambient temp} + 230) / (10 + 230)$).
- 2 The factors are different from those of Table B.2 because Table A7 corrects from 10 °C and Table B.2 from 20 °C.

The ambient correction factor of Table A7 is applied to the EFLI of Tables A1 to A5 if the ambient temperature is other than 10 °C.

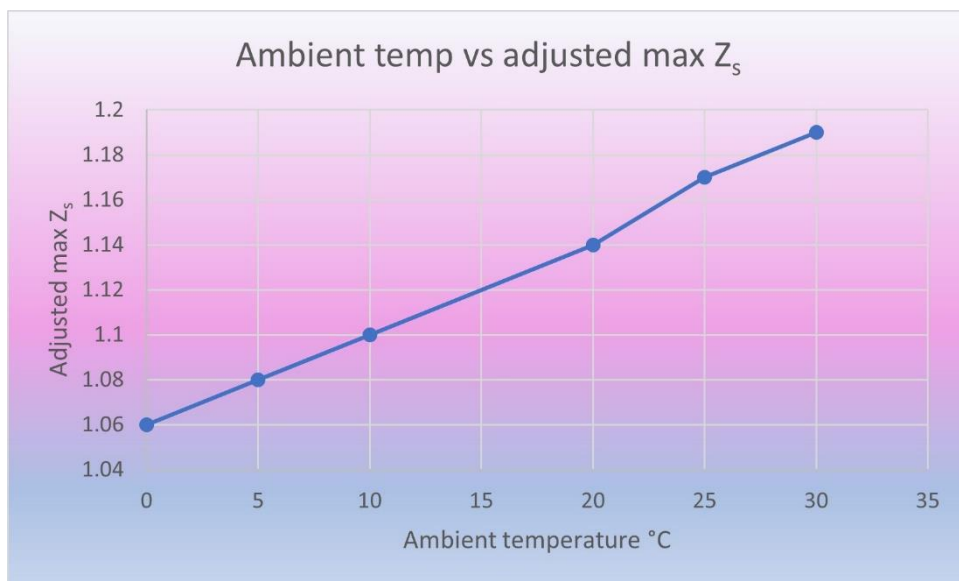
For example, if the ambient temperature is 25 °C, the measured EFLI of a circuit protected by a 32 A Type B circuit-breaker to BS EN 60898 should not exceed $1.1 \times 1.06 = 1.17 \Omega$.

Under the notes, it shows an example for a 32 A circuit-breaker to BS EN 60898 and how to adjust the 10 °C value to 25 °C. By applying the same method as the example shown for other values of ambient temperature, a similar graph can be created which shows the same heat and resistance relationship demonstrated at the start of this article.

Figure 6 Table of adjusted maximum values of measured Z_s in ohms (Ω) using simplified correcting method from Guidance Note 3 Appendix A

Ambient temperature (°C)	Correction factor	Calculation	Adjusted max Z_s (Ω)
0	0.96	1.1 X 0.96	1.06
5	0.98	1.1 X 0.98	1.08
10	1	1.1 X 1	1.1
15	1.02	1.1 X 1.02	1.12
20	1.04	1.1 X 1.04	1.14
25	1.06	1.1 X 1.06	1.17
30	1.08	1.1 X 1.08	1.19

Figure 7 Graph using simplified method of ambient temperature adjustment to maximum Z_s in (Ω) from Guidance Note 3 Appendix A



The graph in Figure 7 shows a little wobble through the line. This is because there has been rounding in the process here, so the accuracy is reduced.

Appendix A continues to show a more accurate method which either uses the correction factors in table A7 of *Guidance Note 3* or the correction factors in Table B2. Each table requires a different F factor as they are adjusting from different temperatures.

It displays an equation to use:

$$Z_{\text{test}} \leq Z_e + \frac{\alpha}{F} (Z_{41} - Z_e) \quad (\text{Equation 6})$$

Where:
Z_{41} = The max Z_s as listed in Tables 41.2-41.4 of BS 7671:2018+A2:2022.
Z_{test} = Max Z_s after temperature adjustment (Ω).
F = Temperature correction factor found in Table B3 Appendix B of <i>Guidance Note 3</i> (also known as Cr in the <i>Electrical Installation Design Guide</i>), Table I3 in <i>On-Site Guide, Guidance Note 1</i> .
α = Ambient temperature correction factor Table B2 Appendix B of <i>Guidance Note 3</i> or Table A7 Appendix A of <i>Guidance Note 3, Guidance Note 1</i> .
Z_e = External earth fault loop impedance (Ω).

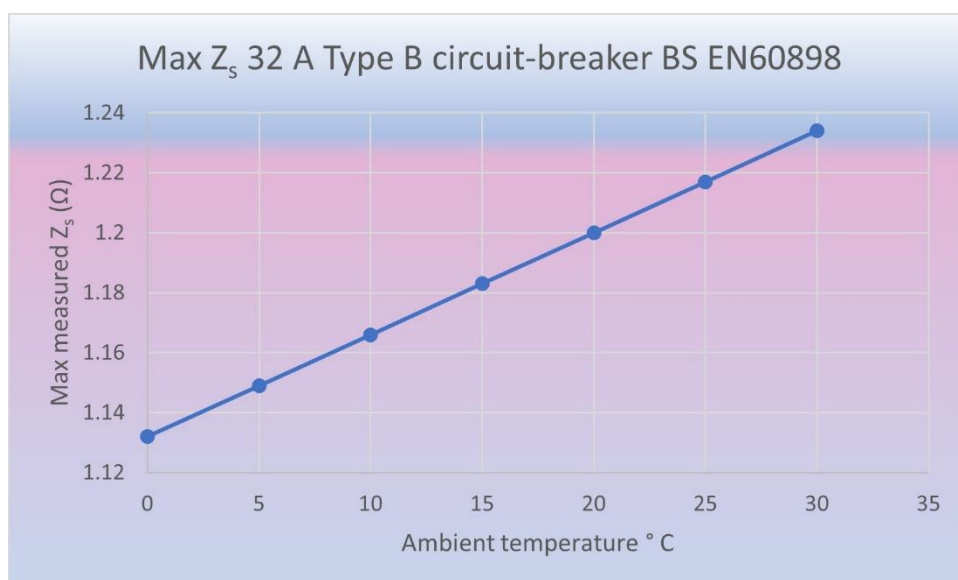
Example

A 32 A Type B circuit-breaker to BS EN 60898 using Table A7 of *Guidance Note 3* for α and a correction factor (F) of 1.25 and assuming a Z_e of 0.35. The graph in Figure 9 now shows a better linear relationship.

Figure 8 The table of adjusted maximum values of measured Z_s in ohms (Ω) using a more accurate correcting method given in Appendix A of Guidance Note 3

Ambient temp ($^{\circ}\text{C}$)	Correction factor	Calculation	Adjusted max Z_s (Ω)
0	0.96	$Z_{\text{test}} = 0.35 + \frac{0.96}{1.25}(1.37 - 0.35)$	1.132
5	0.98	$Z_{\text{test}} = 0.35 + \frac{0.98}{1.25}(1.37 - 0.35)$	1.149
10	1	$Z_{\text{test}} = 0.35 + \frac{1}{1.25}(1.37 - 0.35)$	1.166
15	1.02	$Z_{\text{test}} = 0.35 + \frac{1.02}{1.25}(1.37 - 0.35)$	1.183
20	1.04	$Z_{\text{test}} = 0.35 + \frac{1.04}{1.25}(1.37 - 0.35)$	1.2
25	1.06	$Z_{\text{test}} = 0.35 + \frac{1.06}{1.25}(1.37 - 0.35)$	1.217
30	1.08	$Z_{\text{test}} = 0.35 + \frac{1.08}{1.25}(1.37 - 0.35)$	1.234

Figure 9 Graph using the more accurate method of ambient temperature adjustment to maximum Z_s in (Ω) from Appendix A of Guidance Note 3



Which values need to be recorded on the schedule of circuit details of the model forms?

The model form schedule of circuit details has a column number 12 labelled “Maximum permitted Z_s (Ω)”. In the notes at the bottom of the schedule, it explains what value to input in the column.

“§ Where the maximum permitted earth fault loop impedance value stated in column 12 is taken from a source other than the tabulated values given in Chapter 41 of BS 7671:2018+A2:2022, state the source of the data in the appropriate cell for the circuit in the ‘Remarks’, column 31, of the Schedule of Test Results.”

So, by default, it is expecting the values from Tables 41.2-41.4 of BS 7671:2018+A2:2022 and would expect the testing engineer to adjust and compare their actual readings accordingly. Alternatively, you could use the values stated in *Guidance Note 3*/the *On-Site Guide* but you must clearly state which publication other than BS 7671:2018+A2:2022 you have used in the remarks column.

Further reading

Equation 1	The IET Shop - The Handbook of Electrical Resistivity	Figure 3	BS 7671, Chapter 41, Part 4: The IET Shop - Requirements for Electrical Installations, IET Wiring Regulations, Eighteenth Edition, BS 7671:2018+A2:2022
Equations 2, 3 and 4	The IET Shop - Electrical Installation Design Guide, 5th Edition	Figure 4	<i>Guidance Note 3</i> , Appendix A The IET Shop - Guidance Note 3: Inspection & Testing, 9th Edition The <i>On-Site Guide</i> , Appendix B The IET Shop - On-Site Guide (BS 7671:2018+A2:2022), 8th Edition
Equation 5	The IET Shop - Requirements for Electrical Installations, IET Wiring Regulations, Eighteenth Edition, BS 7671:2018+A2:2022	Figure 5	<i>Guidance Note 3</i> , Appendix A The IET Shop - Guidance Note 3: Inspection & Testing, 9th Edition
Equation 6	The IET Shop - Guidance Note 3: Inspection & Testing, 9th Edition And also The IET Shop - Guidance Note 1: Selection & Erection, 9th Edition		

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