Arc flash risk management

A structured approach to performing arc flash risk assessments for electrical power equipment and ensuring safety

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1 https://www.hse.gov.uk

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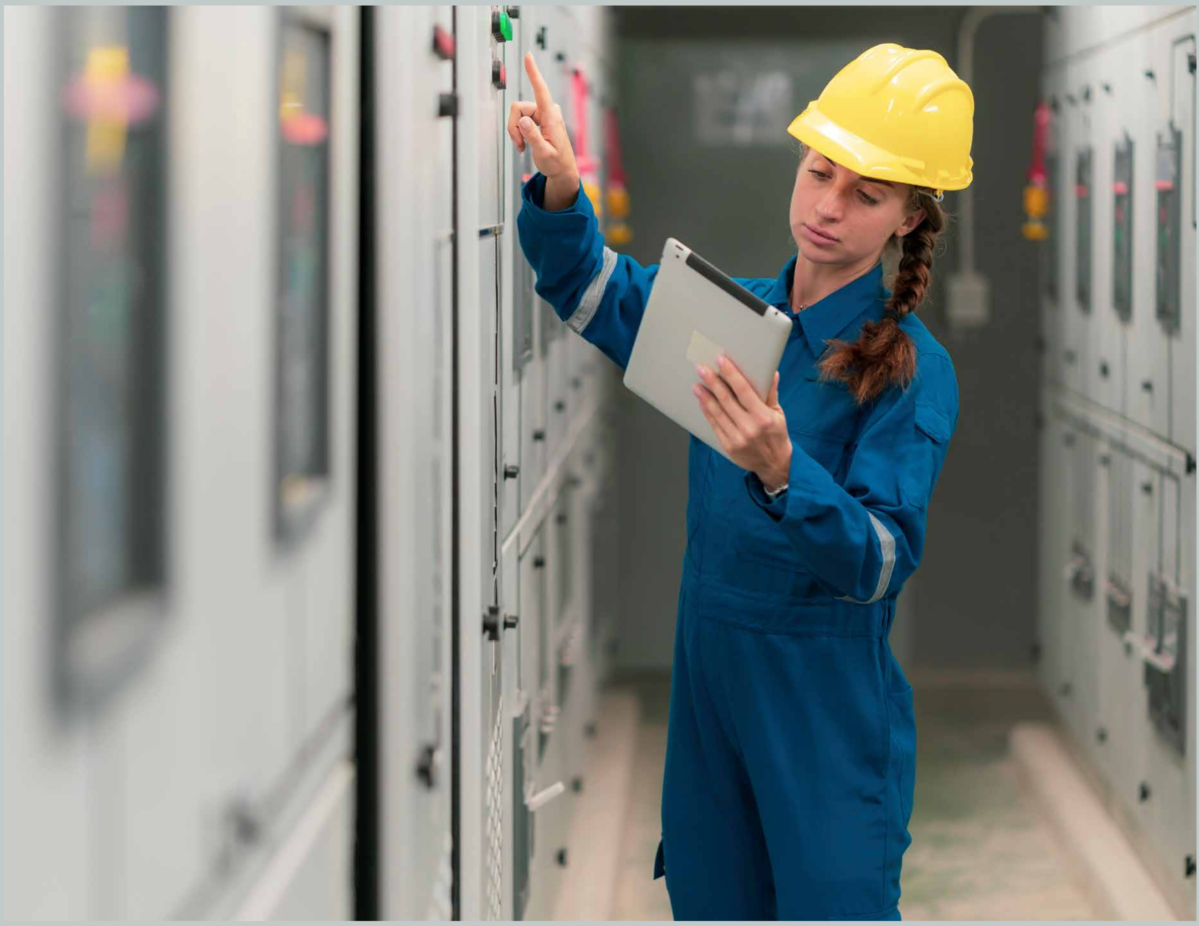


This IET document seeks to set out the key principles of arc flash risk management using a risk-based approach. It is aimed at persons with responsibility for the management of safety in the control and implementation of work on electrical power equipment.

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

2. What is arc flash?

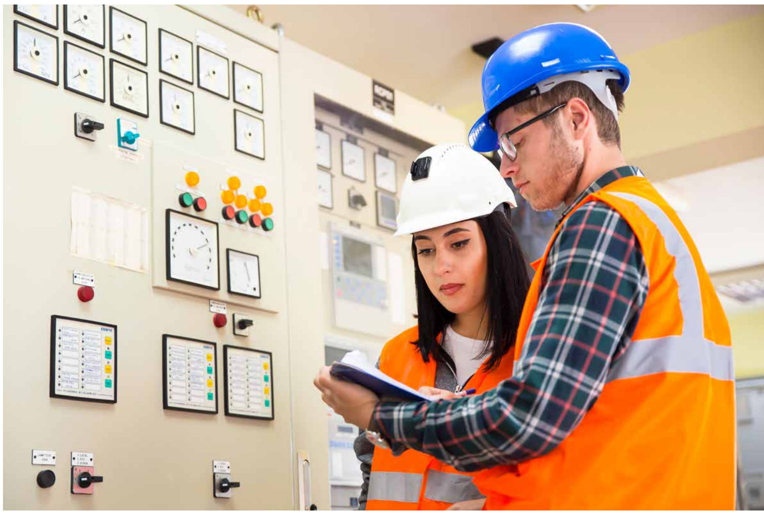
Arc flash is a non-contact short circuit between an energised conductor such as a busbar or cable with another conductor or an earthed surface. Put simply, arc flash is precipitated by insulation breakdown and very often, the insulation in question on low voltage systems is air.

A cause of insulation breakdown is commonly by human intervention when performing, either deliberately or inadvertently, unjustified live working activities. This can be fleeting through the dropping of uninsulated tools and cable armours or the use of damaged instruments. It can also be caused by neglect or moisture ingress.

Once initiated, the insulating medium will be ionised providing a low impedance path. The resultant fault current creates a conducting plasma fireball with arc temperatures that can reach upwards of 20,000 degrees centigrade at its centre which will vaporize all known materials close to the arc immediately. The thermal energy emitted may ignite materials at a distance from the arc which may include a worker's clothing and/or cause life changing burns.

3. Who does it affect?

Around 10% of all fatal accidents and 6% of all major injuries in the UK are electricity related[2].



The number of arc flash injuries cannot be easily determined from these statistics, but it is certain that the greatest prevalence is among electrically qualified workers. Therefore, it is important that this group of workers are made aware of the hazard and the safeguards.

[2] Identifying the Incidence of Electricity Related Accidents in Great Britain. UK Health and Safety Executive An update (1996/97 to 2008/09). https://www.hse.gov.uk/research/rrpdf/rr842.pdf

4. What are the consequences of arc flash?

Arc flash injury can cause severe personal injury including external burns, internal burns, intoxication from inhaling hot gases and vaporised metal, hearing damage, eye damage and blindness from the ultraviolet light of the flash, as well as many other devastating injuries.

Depending on the severity of the arc flash, an explosive force known as an arc blast may also occur. This is due to the rapid expansion of air, dispelling a force that may exceed 100 kilopascals (kPa) and could cause the propulsion of molten metal, equipment parts and other debris at speeds of up to 300 metres per second.

When a worker is harmed by arc flash the consequences for their employer may also be severe. The employer might be fined and have legal and compensation costs. Their reputation may be significantly damaged, and they might lose business as a result.

Finally, the loss of power caused by an arc flash incident itself could create some additional risk of harm to people or the environment. It can also be costly and time consuming to replace arc damaged equipment and/or other assets effected by the arc flash.

5. What effect does voltage have?

The higher the voltage, the greater the gap that can be bridged by an arc. In laboratory tests, voltages below 208 volts in three phase alternating current systems can propagate an arc but tend to be more difficult to sustain.

However, at voltages above this level, not only does the arc sustain, but the thermal effects multiply in direct proportion to the time span until either: the power source collapses, or the damage to equipment becomes too great to sustain the arc, or the protective device will operate and disconnect the circuit. There are many injuries at low voltage, typically at 400 volts on alternating current systems.

6. What do the legislation and international standards say?

A risk-based approach to arc flash is almost universal today. This statement could not be made 10 years ago, and it is in fact due, in part, to the efforts of IET members in influencing the global community that has contributed to a consensus of dead working as the primary means of prevention with PPE as a last resort.

The need for risk assessment is embodied in law in many countries across the globe. International standards and norms discourage live working and promote dead working as the principal risk control measure. There are differences in which this is applied however, and readers are encouraged to familiarise themselves with local requirements.

7. Risk assessment and the 4P approach

When carrying out a risk assessment, as a minimum we must:

1. **Identify what could cause injury (hazards).**
   - This is derived from system parameters such as voltage, fault level and electrical protection arrangements.
2. **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.
   - It is also directly related to the task to be performed.
3. **Take action to eliminate the hazard, or if this isn't possible, control the risk.**
   - Use the following 4P approach to eliminate or control the risk.

The 4P approach to the arc flash risk assessment will ensure that these three steps are fulfilled. That is through a quantitative **prediction** of the hazard, **prevention** and minimisation to eliminate or significantly minimise the risk, **process**, policies and procedures to reduce likelihood and **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 be more lightweight optimum solutions.

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.

7.1 Prediction

The first step in the 4P approach is to **Predict** the severity of an arc flash. By predicting the severity of the thermal effects of an arc flash, a measure of incident energy levels can be obtained at a specific working distance from a prospective arc source. This is usually measured in joules/cm^2 and is also expressed in calories/cm^2. The figure of 5.0J/cm^2 (1.2cal/cm^2) is the level at which there is a 50% chance of the onset of a partial thickness or minor second-degree burn. This figure is important as it is used to determine the attenuation of heat energy on the skin afforded by protection systems and also to determine the arc flash protection boundary, which is distance from a prospective arc source at which the incident energy is calculated to be 5.0J/cm^2 (1.2cal/cm^2).

Predicting the severity of the arc hazard has been made more reliable in recent years through the publication of *IEEE 1584 Guide for Performing Arc-Flash Hazard Calculations 2018*. It is an auditable standard and widely accepted in the global electrical engineering community. 200 technical experts were involved in the development of the guide over many years and was based on over 1860 tests performed at different voltage levels in high current laboratories. To quote from the scope of the guide: "The purpose of the guide is to enable qualified person(s) to analyse power systems for the purpose of calculating the incident energy to which employees could be exposed during operations and maintenance work". It gives no recommendations for PPE. *IEEE 1584:2018* is therefore the flagship standard for determining the incident energy (thermal hazard) from an arc at three phase voltages in the range of 208 volts to 15,000 volts AC. There are other theoretical peer reviewed papers for determining higher voltages, direct current and ballistic effects of arcing in Appendix 1.

Designers

The designer does not necessarily need to know the actual incident energy or arc flash boundary but definitely needs to have confidence that his or her electrical protection arrangements will clear dangerous faults. This includes arcing faults! For traditional overcurrent protection, the information that will be required to fulfil this duty will be the amount of current that will flow in an arcing fault. With that information, it can be assured that the protective device will operate in the instantaneous zone of the associated time current characteristic. A few amperes can be the difference between safe clearance or destructive energy let through.

Electrical system managers

When undertaking single dynamic risk assessments, the means to do so is now accessible and affordable to competent engineers (EA-Guide[3]). For more complex system studies for the mapping of the electrical system, including fault levels and protection, this will be aided with commercially available software and also through qualified service providers. It should be pointed out that 90% of the effort that is required to predict the hazard severity is in providing a single line diagram, protection coordination and fault level information, all of which should be available to an electrical system manager.

7.2 Prevention and minimisation

Prevention must be the fundamental safety principle for the management of arc flash hazard. What this means is that the Duty Holder must always seek to design out, eliminate or remove the hazard at its source. This leads to the conclusion that most electrical tasks must be carried out with the equipment made dead, isolated and where appropriate, earthed.

This section is dedicated to prevention starting with the elimination of live working but then going on to describe various practical solutions to help the reader to understand methods and technologies that are available. The risk control measures listed below are categorised as:

- **Dead working** – The elimination of live working and removal of the hazard.
- **ADS** - Automatic disconnection of supply by early detection and rapid de-energisation.
- **Equipment design** – To reduce likelihood of arcs or to dissipate arc flash energy safely.
- **Operational** – Reduce likelihood through good system operations, audits and maintenance.

The following prevention and minimisation table gives more detail about specific risk reduction measures set against the above categories.

Partial discharge testing used as an element of a holistic approach to risk reduction.

Courtesy of Megger Ltd.

[3] European Arc Guide is a risk-based approach to the arc flash hazard and comprises practical in-depth guidance and simple calculator tools to determine incident energy. www.ea-guide.com

Prevention and minimisation table - risk reduction measures		
Risk reduction measures	**Description**	**Brief overview**
Dead working	**Elimination of live working**	By far the most effective risk reduction method. Note: creating a safe working condition to facilitate dead working is not risk free and demands a high level of care and competence.
Automatic disconnection of supply (ADS)	**Adjusting protection settings**	For low voltage systems, this has been proven to reduce the need for PPE in the majority of cases in industry. The low hanging fruit of arc flash risk management.
	Arc fault maintenance systems	Circuit breakers incorporating temporary instantaneous settings for maintenance activities. This can also be achieved by retrofitting instantaneous relays to override normal protection devices.
	Improved protection schemes	Bus Differential Protection Schemes have been used for many years, predating much of the work of arc flash calculations. They are very reliable but can be expensive.
	Arc detection	Instantaneous tripping using an optical sensor to detect UV light emitted from an arc flash together with rate of increase in fault current.
Equipment design	**Active internal arc suppression**	Reacts to an arcing fault by effectively creating a zero-impedance short circuit across the busbars of equipment. Sometimes the energy is dissipated to earth.
	Improved forms of separation in power switchgear and control gear assemblies	Forms of separation in low voltage power switchgear and controlgear assemblies can reduce likelihood. Care required; high spec equipment is often involved in incidents depending on the quality of operation and maintenance.
	Arc protected equipment	Arc free and arc proof equipment. Still not mandatory in HV equipment. Arc proof does not prevent the arc, it mitigates the effect.
	Improved racking design	Equipment selection requiring racking on to live bars to be either done remotely or interlocked behind closed doors.
Operational measures	**Holistic approach to system design, installation and maintenance**	Much more than designing out the arc flash risk through switchgear design. Minimising the risk of arcing requires whole life care involving distribution philosophy, system design, commissioning, maintenance, auditing and operation. Needs clarity of policies, leadership and control. Neglectful dilapidation of equipment such as control panels is a tangible indicator that the policy is not working.
	Operations sequence alterations	Needs an assessment to determine the effects of operations sequencing in complex systems. Issues such as paralleling of supplies, alternative infeed arrangements can be analysed to minimise risk.
	Remote operation	Can be simple lanyards, umbilical cords to control actuators or remote racking devices.
	Nonintrusive diagnostics	Partial discharge, infra-red testing and gas in oil analysis can give warning of impending failure. Visual inspection by experienced competent engineers is also most important.

7.3 Process, policies and procedures

As stated earlier, the activities associated with the physical task can often lead to the initiation of an arc flash event. The following list describes some activities that have the potential to initiate an arc and some of which have been shown to be common causes of electrical flashover:

- Connecting cables into live equipment.
- Testing; especially with substandard instruments and test methods.
- Testing on damaged cables and equipment. For instance, there are several known cases of arc flash due to using voltage indicators on faulted cables.
- Inspections or any interactions which involves the exposure of live low voltage conductors.
- Work on or adjacent to live low voltage conductors that are insulated but where the work may adversely affect the integrity of that insulation. Examples are drilling into panels and drawing cables into cable management systems.
- Civil works around live cables including the highway but also inside buildings.
- Custom and practice activities such as installing or repairing equipment which is adjacent to exposed live low voltage conductors.
- Removal and replacement/insertion of live components such as circuit breakers in panel boards and large power bus bar tap off units.
- Connecting equipment to live bus bars other than by switching (to be avoided wherever possible with these operations carried out on dead bars).
- Live underground cable jointing.
- Live overhead line work.
- Switching and racking out poorly maintained or legacy switchgear.
- Replacement of fuses and links especially onto faults.

It is essential that the organisation controls all tasks and activities which will be embodied in policies and procedures. As a very minimum, there needs to be a written policy in place which will set out leadership and commitment to electrical safety at a senior level in the organisation. Safety rules are often the means by which this control can be assured for electrical workers, firstly to prohibit high risk activities outright and secondly to regulate all other activities to ensure that they are carried out safely. This needs to establish; policy, dead working as a principal requirement, controlled circumstances for live proximity work such as diagnostic testing, running adjustments and inspections, competence of staff and contractors, clear responsibilities and authorisation of individuals and finally, audit and review.

These rules should incorporate the following controls as a minimum:

1. Implementation of a comprehensive permit system to control access.
2. Restriction of access to live switchgear to those workers who are specifically authorised only.
3. Restriction of circumstances in which access to live switchgear may be granted.
4. Requirements for risk assessments before access to live equipment.
5. Specify tasks or interactions that are prohibited.

Where the duty holder has jurisdiction over an electrical network, then written policy and accompanying procedures should outline asset management, maintenance, inspections, records and drawings and electrical protection arrangements and methodology. The goal is safe competent people, working to specific rules and procedures with a high degree of supervision, working on safe well designed, maintained and documented equipment.

The following diagram may act as a checklist in respect of a dynamic risk assessment which can be incorporated into rules and procedures. Having identified the hazards arising from live working, this may help to decide how likely it is that harm will occur and the severity of injury that may arise. The check list shows some of the issues that need to be considered that may impact on the likelihood of the hazards to cause harm.

Dynamic risk assessment checklist.

EQUIPMENT
- Condition?
- Strength and capability?
- Operated and maintained properly?

INCIDENT ENERGY
- Incident energy levels established?
- Arc flash boundary established?
- Upstream device maintained?

ENVIRONMENT
- Slipping/tripping hazards removed?
- Ignition hazards?
- Dust, moisture, vermin present?
- Working at height? special precautions required?

PEOPLE
- Competent and authorised?
- Is accompaniment required?
- Demarcation and barriers to secure the work area?

SAFE SYSTEMS
- Tools and instruments approved?
- Test leads approved and checked for condition?
- Is PPE required to protect against residual risk?

(Diagram reproduced courtesy of the European Arc Guide)

7.4 Protection through PPE

Where the risk cannot be avoided by other means or controlled by prevention or where there is a residual risk of injury, then it may be necessary to consider mitigation to prevent injury to the worker. The requirement for and suitability of mitigation techniques must form an essential element of any risk assessment. PPE alone will not prevent the accident and it is therefore seen as a last line of defence but, where it used properly, there is evidence that it has prevented injury to individuals.

The analysis of risks which cannot be avoided by other means will begin with a quantitative assessment based on incident energy as outlined in the prediction step. This data can then be used to determine the protection level of the PPE which has to be greater than the predicted level of incident energy. The protection level of the PPE will be expressed as an arc thermal performance value (ATPV) which means that it is designed to limit the incident energy level on the skin to a maximum of 5.0J/cm^2 (1.2cal/cm^2). This is the threshold at which there is a 50% chance of second-degree burn. So, put simply, an 8cal/cm^2 burn on the outside of a garment with an ATPV of 8cal/cm^2 will limit the incident energy to 1.2cal/cm^2. In Europe there is a requirement for a slightly more conservative measure which means that there is 0% chance of a second degree burn and this is called the incident energy limit (ELIM).

Before choosing PPE, we need to assess whether the PPE that we intend to use will satisfy the following requirements.

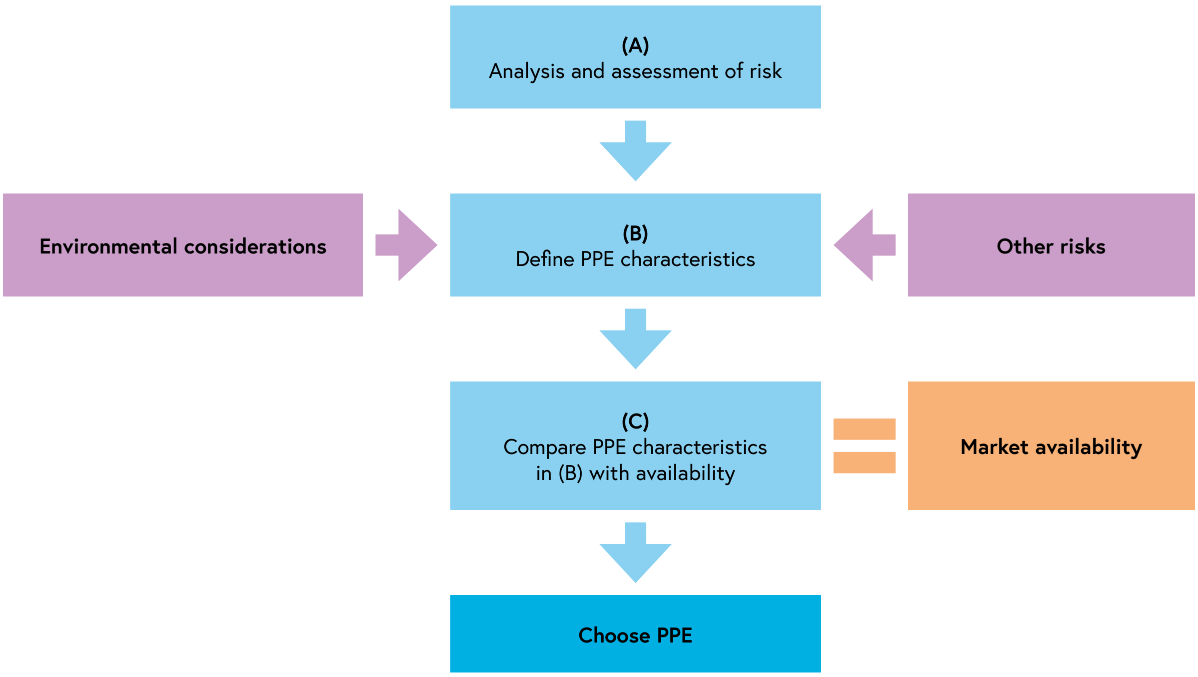
1. PPE must comply with country provisions on design and manufacture with respect to safety and health. For instance, in the UK and Europe all PPE must:

   - Be appropriate for the risks involved, without itself leading to any increased risk.
   - Correspond to existing conditions at the work place.
   - Take account of ergonomic requirements and the worker's state of health.
   - Fit the wearer correctly after any necessary adjustment.

2. Where the presence of more than one risk makes it necessary for a worker to wear simultaneously more than one item of PPE, such equipment must be compatible and continue to be effective against the risk or risks in question.

The following diagram outlines the PPE analysis and assessment process.

PPE analysis and assessment process.



(Diagram reproduced courtesy of the European Arc Guide[4])

[4] www.ea-guide.com

An assessment of PPE needs to meet the requirements shown in this flowchart and involves a three-step process starting with an analysis and assessment (A) of risks which cannot be avoided by other means.

HOW?

By predicting the severity of the arc. If the risk assessment has been carried out in accordance with the four Ps principle, we are left with a residual risk which will be as small as possible making the next steps easier and lead to a more comfortable and less expensive solution.

The next step is a definition of the characteristics (B) which PPE must have in order to be effective against the risks referred to in (A), taking into account any risks which the equipment itself may create.

HOW?

Whilst the arc flash attributes can be established by straightforward calculations, there are other characteristics that need to be considered before we can go to the marketplace with a shopping list for suitable PPE. For instance, the PPE may be required in a clean room environment, outdoors or perhaps a very dirty area which may degrade or compromise the type of flame-resistant (FR) materials available. This needs to be identified as environmental considerations. Finally, the characteristics need to include all other risks that have been identified previously such as ergonomics, compatibility with other protection and fit.

Comparison of the characteristics (C) of the PPE available with the characteristics referred to in (B).

HOW?

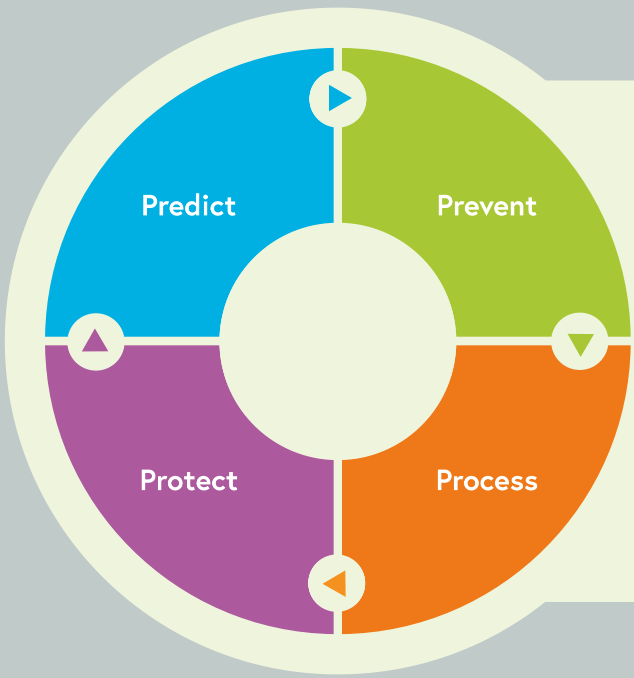
Compliance is required with *Standard IEC 61482-2: 2018, Live working - Protective clothing against the thermal hazards of an electric arc - Part 2: Requirements.* This standard will give some assurance that the garments comply with rigorous minimum standards of inspection and testing. In addition, compliance with country provisions on design and manufacture such as CE marking in Europe and UKCA (or Northern Ireland protocol) in the UK should be the starting point when making comparisons in the marketplace. However, depending on the environmental considerations and other risks, there may have to be compromises when considering the available choices. One of the issues that will arise when choosing FR fabrics will be how the flame-resistant qualities are achieved. There are permanently treated fabrics, predominantly cotton which is chemically treated, and then those that are inherently flame resistant. There will be fabric weight, comfort and life expectancy and all this needs to be factored in.

There needs to be a sensible approach to the type of everyday clothing that should be adopted for electrical workers. For instance, synthetic clothing can introduce an additional hazard whereby ignition of materials close to the skin can very quickly cause serious full thickness burns to the individual. This is where basic everyday clothing should comprise a minimum of non-synthetic materials such as cotton.

In addition, the hands of someone undertaking routine diagnostics and commissioning tests on low voltage equipment can be very close to a possible arcing source that has perhaps been overlooked in the risk assessment process. The wearing of leather over gloves is a very inexpensive but effective precaution that, if fitted correctly, will not reduce dexterity to the wearer. A similar conclusion for eye protection would be arrived at for anyone undertaking work in any industrial environment.

Underpinning all of the above, when making decisions on PPE, user acceptability is most important. Some of the best examples of successful implementation of PPE as a risk control measure have been where the workforce has been fully involved in the process from the start.

8. Conclusion



Arc flash is a serious hazard that has the potential to cause injury and death, but also catastrophic damage to valuable equipment and loss of critical supplies. A risk-based approach using the 4P model will ensure that elimination is always given priority, in tandem with sound engineering practices. PPE will always be the last line of defence. In this way, not only will workers be protected, but essential supplies will be maintained.

9. Appendix 1 - Other predictive techniques

Direct current arc flash

There have been a number of papers that have addressed the calculation of incident energy in direct current systems. There are as yet, no standards that have the same standing as *IEEE 1584*, but it is likely that this will be addressed in the coming years. That is of course, driven by the increasing demand for calculations as DC systems become more abundant because of advances in solar and storage technology. IET member and *IEEE 1584* Vice Chair Jim Phillips P.E. carried out research into the various available methods and in 2010, introduced DC arc flash calculations into arc flash training and as an addendum to his book, Complete Guide to Arc Flash Calculation Studies.[5] This was based upon two technical papers which were Arc Flash Calculations for Exposures to DC Systems by D.R. Doan[6] and DC Arc Models and Incident Energy Calculations by R.F. Ammerman, T. Gammon, P.K. Sen and J.P. Nelson.[7] Following on from this initiative, these methods were introduced by commercial software companies. More recently, Jim Phillips published an update to the earlier guidance on DC Arc Flash Calculations.[8]

5 Complete Guide to Arc Flash Hazard Calculation Studies by Jim Phillips P.E – Brainfiller Inc. 2010.
6 Arc Flash Calculations for Exposures to DC Systems by D.R. Doan – IEEE Transactions on Industry Applications, Vol.46 No 5.
7 DC Arc Models and Incident Energy Calculations by R.F. Ammerman, T. Gammon, P.K. Sen and J.P. Nelson – IEEE Transactions on Industry Applications, Vol.46 No 6.
8 DC Arc Flash Calculations by Jim Phillips – Posted on Brainfiller.com, November 20, 2019.

Ballistic effects or arc blast

As described within Section 4, there could also be an explosive force called arc blast which can be responsible for blunt force injuries. Whilst there are a few myths around the subject of arc blast, there are the means to calculate blast pressure in accordance with theoretical formulae developed by Ralph H Lee, IEEE Life Fellow, in 1987.[9] According to the same formulae, the blast pressure is directly proportional to the arcing current. Therefore, a doubling of the arc current will result in a doubling of blast pressure. There needs to be some caution about the use of the formulae which are conservative.

In addition, Ralph Lee is often seen as a pioneer behind much of the research into arc flash and the development of equations for predicting the severity of the hazard. His theoretical equations are still widely used for electrical systems that are outside the range voltages of empirically derived formulae of today.[10]

Warning

Arcing faults in oil filled equipment has led to the ignition of the insulating medium leading to catastrophic explosions and fires resulting in the loss of life. Whilst these possibilities should always be borne in mind when carrying out risk assessments, it is not possible to calculate severity from the above methods. The prediction of the arc flash thermal hazards given in this paper do not take into account the possibility of toxic gases, projectiles and molten metals from an arcing event.

10. Appendix 2 - PPE standards and test methods

IEC 61482-2 Protective Clothing against Thermal Arc Hazards of an Electric Arc[11] is the overall international standard for FR PPE garments. There are two tests for PPE that are used to determine the level of protection against the thermal effects of electrical arcs. These are colloquially referred to as the Open arc test and the Box test. The following is a description of the tests and outputs as applied to clothing.

Open arc test - *IEC 61482-1-1: Live working – Protective clothing against the thermal hazards of an electric arc – Part 1-1: Test methods – Method 1: Determination of the arc rating (ELIM, ATPV and/or EBT) of clothing materials and of protective clothing using an open arc.* Specimen garments or samples of material are placed around an open arc source at a distance of 300mm. The arc source is provided by two stainless steel electrodes with an arc gap of 30mm to 300mm using a decoupled source giving a prospective short circuit current between 1kA and 20kA. The duration of the arc is used to vary the effective energy on the surface of the specimen to be tested or the protective clothing which can be typically between 200ms and 2000ms.

Box test - *IEC 61482-1-2: Live working - Protective clothing against the thermal hazards of an electric arc - Part 1-2: Test methods - Method 2: Determination of arc protection class of material and clothing by using a constrained and directed arc (box test).* The box test is set up as a directed arc from a plaster box and consists of a vertical arrangement of a pair of electrodes between which the arc is ignited. The open circuit voltage is 400V (50Hz) and the arc gap is fixed at 30mm, with an aluminium upper electrode and a copper lower electrode. In this case the duration of the arc is also fixed for a period of 500ms.

9 Lee, R. H., "Pressures Developed by Arcs," IEEE Transactions on Industry Applications, vol. IA-23, no. 4, pp. 760–763, July 1987.
10 Lee, R. H., "The Other Electrical Hazard: Electrical Arc Blast Burns," IEEE Transactions on Industry Applications, vol. IA-18, no. 3, pp. 246–251, May 1982.
11 IEC 61482-2 Protective Clothing against Thermal Arc Hazards of an Electric Arc.

It's a very simple test, easy to replicate and does not require decoupled power supplies. The only variability is the prospective short circuit current which is either 4kA or 7kA which contributes to a pass/fail criterion for an Arc Protection Class 1 and 2 respectively.

The open arc and the box tests are entirely different in their methodology and application. Furthermore, it is not easy to determine equivalence between the output of both methods and the risk assessment process uses a different approach in each case. The 4Ps approach that is described in this fact file uses the open arc test.

Open arc test outputs

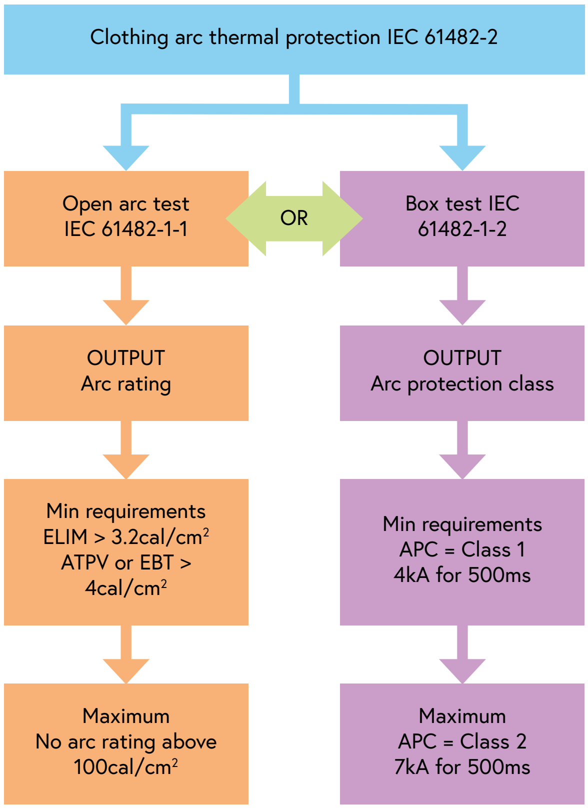
Arc thermal performance value (ATPV) is the most commonly used output from the open arc test and is a numerical value of incident energy attributed to a product (material or equipment) that describes its properties of attenuating the thermal effect of energy generated by an open arc. For example, if the ATPV is 12cal/cm^2, then that particular specimen or item of PPE is capable of attenuating an incident energy of that same level or less to a "safer" value of 1.2cal/cm^2 for the wearer. Therefore, anyone undertaking a numerical risk assessment of incident energy level on site, can directly compare the results obtained to the thermal withstand properties of available PPE.

The value of 1.2cal/cm^2 has been derived from work which was carried out by biophysicist Alice Stoll and Maria Chianta in the 1950s who from their experiments in the US Navy, created the Stoll Curve. They carried out experiments on volunteers by subjecting them to heat on their forearms and recorded the temperature and time at which the individuals responded to pain. This was performed across a range of radiant heat fluxes, and the burns that developed blisters after 24 hours were recorded as second-degree burns. The Stoll Curve is used with a graph of heat flux against exposure time. The point at which the heat flux crosses the Stoll Curve is identified as the point at which a human would feel pain and be at risk of second-degree burns.

Incident energy limit (ELIM) is the numerical value of incident energy attributed to a product (material or equipment), below which the values of all product responses are below the Stoll Curve and without breakopen. Put simply, the ELIM differs from the ATPV in that there is 0% chance of a second-degree burn rather than a 50% probability. Where this is applied to a garment, this additional safety factor will usually result in a derating of approximately 10%.

Breakopen threshold energy (EBT) is the numerical value of incident energy attributed to product (material or equipment) that describes its breakopen properties when exposed to heat energy generated by an electric open arc test. It represents the highest incident energy exposure value on a fabric where the garments do not exhibit breakopen and is the value of incident energy at which breakopen occurs with 50% probability. A breakopen is defined as a minimum of a 1.6cm hole formation. Various fibre types act in different ways but each one can breakopen before the burn prediction level is reached.

Summary of IEC 61482-2 arc test outputs for protective clothing.



Box test outputs

The main output from the box test is an arc protection class. The box test method defines two arc protection classes - APC 1 which uses a prospective fault current of 4kA and APC 2 which uses 7kA. To pass there must be no melting of the specimen, or after flame over 5 seconds in duration, and no hole larger than 5mm. In addition, measured heat transfer through the specimen must not cross the Stoll Curve as described previously. The two classes cannot be linked to numerical risk assessment of incident energy level on site in the same way as the open arc method and do not provide an arc thermal performance value (ATPV).

Other PPE standards

For those readers whose local standards are based upon American Society for Testing and Materials (ASTM) standards, the above *IEC 61482-1-2 (Box Test)* standard is unlikely to be of relevance. The approximate equivalent of *IEC 61482-1-1 Open Arc Test* is *ASTM F1506 Standard Specification for Flame Resistant and Electric Arc Rated Protective Clothing.*[12] Both standards provide an ATPV and EBT but *ASTM F1506* does not specify an ELIM rating.

Standards for arc protection for hands, head, face and eyes are currently being written by the International Electrotechnical Commission (IEC). The new standards will follow the test methodologies as given in *IEC 61482-1-1 (Open Arc)* and *IEC 61482-1-2 (Box Test)* given previously. In the meantime, there are a choice of products available that may give the protection needed by the risk assessment providing that they meet the local PPE standards. There are products on the market that are tested to ASTM standards which will provide an ATPV, and examples are *ASTM F2178 Standard Specification for Arc Rated Eye or Face Protective Products*[13] and *ASTM F2675 for Arc Rated Gloves.*[14]

Responsibilities

Manufacturers, employers and workers have duties and responsibilities for PPE for the mainstream standards detailed above and also for local health and safety regulations and quality requirements.

Use and maintenance of PPE

PPE may be used only for the purposes specified, except in specific and exceptional circumstances. It must be used in accordance with instructions and the instructions should be available and understandable to the workers. It is the responsibility of the manufacturer to give clear instructions about use, care and maintenance of the PPE which should be followed up by the employer and workers. The instructions should specify in particular the cleaning and drying methods and means. They should also detail the storage and inspection regime to be adopted. All basic essential guidance with respect to cleaning should be given on the label or other marking of an item of PPE. More detailed additional information shall be given on instruction for use/manufacturer's instructions/user instructions.

Courtesy of Martindale Electric.

Monitoring and review

When choosing PPE, it is at the bottom of the hierarchy of risk control measures. As such, employers must ensure that all lower order risk reduction measures have stringent monitoring and review processes. The goals of the monitoring and review process for PPE should be as follows:

1. That the PPE is being worn and inspected correctly.
2. Periodic review of the hazard/risk assessment may need a revision of the use of PPE.
3. That the inspection, storage, cleaning and decontamination is being carried out in accordance with manufacturer's instructions.
4. That the PPE is maintained in a safe, usable condition to provide the intended protection to the user.

Training

Workers need to be trained on how to use their PPE correctly, prior to the PPE being introduced into service. As a minimum, the training should include:

1. Information concerning limitations and capabilities of the PPE.
2. How the PPE works and what the PPE will and won't protect.
3. How to follow the risk assessment of which PPE is a part.
4. Issues of sensory deprivation and how they can be mitigated.
5. How to read and correctly interpret the information which is given on labels or other instructions.
6. How to use, wear and inspect the PPE.
7. How to store the PPE when not in use.
8. Information concerning arrangements for handling, cleaning and decontamination.
9. How to determine when the PPE is no longer fit for purpose.
10. How to obtain replacements.
11. The dangers of using PPE which is contaminated by inflammable liquids or substances.

12 ASTM F1506 Standard Specification for Flame Resistant and Electric Arc Rated Protective Clothing Worn by Workers Exposed to Flames and Electric Arc.
13 ASTM F2178 Standard Test Method for Determining the Arc Ratings and Standard Specification for Personal Eye or Face Protective Products.
14 ASTM F2675 Standard Test Method for Determining the Arc Ratings of Hand Protective Products Developed and Used for Electrical Arc Flash Protection.

It is recommended that a holistic approach be adopted for training the users of PPE and that they be engaged in the process of the provision and use of protective measures right from inception. Simply providing written instructions or information may not be effective and practical demonstrations and formal training will lead to better acceptance.

Record keeping

The keeping of records by employers will assist in the management of the arc flash PPE. A full life history can be built for each item, from manufacture to disposal. The record keeping will allow the duty holder to understand the life cycle of the PPE and help with monitoring and review. The life cycle costs can be better understood when the cost of maintenance and durability are built in. This will allow for improvements in future decision making in respect of replacement and maintenance.

Routine examination

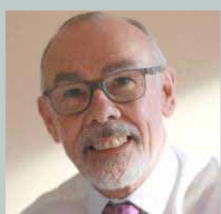
PPE should be examined preferably by the user before and after use. The overall risk assessment should detail the examination and match the thermal protective performance of the PPE. The PPE should also be formally inspected when the item has been cleaned and records kept about condition. Anyone undertaking inspections should be appropriately trained as above.

Cleaning and ageing

Cleaning should be strictly in accordance with the manufacturer's information including care instructions. Based on this information, the employer should determine the arrangements for care and provide a process for the cleaning and decontamination of arc protective PPE. This also gives an opportunity for the formal examinations and recording of condition. Professional or industrial cleaning is the favoured method depending upon the severity of use and allowing home cleaning should only be done under strict considerations. Ageing can be effectively forecasted by the manufacturer by indicating the maximum number of cleaning procedures. Deterioration due to ageing has an effect on the performance of the arc protective PPE and can be accelerated by exposure to chemicals and other agents, physical exposure such as radiation and heavy wear and tear.

11. Acknowledgements

We would like to thank Mike Frain CEng FIET MCMI and the rest of the IET Arc Flash Working Group for their work in compiling this fact file.



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To find out more contact **sep@theiet.org**

The Institution of Engineering and Technology

Our offices

London, UK
T +44 (0)20 7344 8460
E faradaycentre@ietvenues.co.uk

Stevenage, UK
T +44 (0)1438 313311
E postmaster@theiet.org

Beijing, China
T +86 10 6566 4687
E china@theiet.org
W theiet.org.cn

Hong Kong
T +852 2521 2140
E adminap@theiet.org

Bangalore, India
T +91 80 4089 2222
E india@theiet.in
W theiet.in

New Jersey, USA
T +1 (732) 321 5575
E ietusa@theiet.org

@TheIET

theiet.org

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