The European Arc Flash Guide

Mike Frain CEng FIET MCMI

A practical approach to the management of arc flash risk in electrical power systems for designers, duty holders, consultants, service providers and health & safety specialists

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European Arc Guide Ltd

EA-GUIDE.COM

Version 2.0

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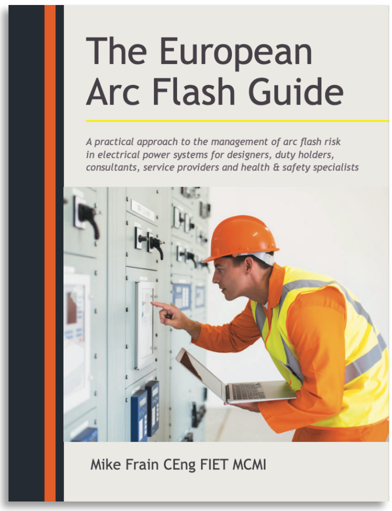
Balboa Press
A Division of Hay House
1663 Liberty Drive
Bloomington, IN 47403
www.balboapress.co.uk
UK TFN: 0800 148647
UK Local: 02036 956325 (+44 20 3695 6325 from outside UK)



About the Author

Mike Frain is one of the most prolific exponents of arc flash risk management and electrical safety in Europe over many years. The author is a dual national of the Republic of Ireland and United Kingdom and has been at the forefront of raising awareness about the management of the arc flash risk in a very practical way in accordance with European law. Indeed, his practical background is one of tremendous pride to him, having received a first-class electrical apprenticeship and then contributing to electrical training and qualifications nationally and also by creating new apprenticeships. You can be sure that any advice he gives on this subject is not an academic exercise but is the fruit of his own extensive experiences. His personal 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.

Being an authority on the drafting and training of electrical safety procedures and processes, he has been trusted to deliver electrical safety consultancy advice for numerous household names in all sectors of industry across Europe. He has held senior management positions in electrical safety, contracting, utilities, consultancy, and facilities maintenance companies having direct responsibility for putting people to work on a full range of complex and large power electrical systems and founded Electrical Safety UK in 2004. An author of electrical safety articles and papers for several organisations such as the IET, IEEE and several engineering, utilities and HSE publications, he has been credited with raising awareness about electrical arc flash risk assessment within Europe and beyond.

The author is a Chartered Engineer, a Fellow of the Institution of Engineering & Technology and a Corporate Member of the Chartered Management Institute. He is an Expert for the British Standards Institute and IEC UK National Committee on TC 78: Live Working. He is the Convener for the International Electrotechnical Commission 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, is Vice Chair of the IET Engineering Safety Policy Panel and leads the IET Arc Flash Working Group.

Dedication and Acknowledgements

This book would never have been published was it not for my beautiful wife Mary. For all her support throughout my career and also for her stoicism that she displayed both in sickness as she did in health. Whilst her illness meant that I would no longer be travelling the world, peering into various switch boards and small wiring panels or training engineers on electrical safety, my life was greatly enriched in many ways. Instead of her being my carer and that of our wonderful children, I became hers. I could not have been prouder than on the day that she was honoured by the Lord Mayor of Sheffield and given an award for "outstanding contribution to the community". I know that she would approve of the time that I have spent in researching and writing this book. Mary, I love you so much for the love, support, compassion, and care that you've shown to me, your family, friends, and also those countless people in need.

My grateful thanks go out to the following people for their help in by their reviews, proof reading and helpful comments.

- Claire Brady
- Michael Whitham
- Jackie Wooldridge
- Chris Ross
- Tony Pierce
- Jim Phillips
- Sean Johnson
- Dominic Parr

With deep gratitude - Mike Frain

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Introduction

In 1989, I was summoned by the Health and Safety Executive (HSE) to attend court as a prosecution witness in a case against an electrician, which was brought under the Health and Safety at Work Act. The electrician's apprentice had been injured in an electrical flashover, or arc flash as it is often referred to nowadays and I was the first on the scene to take charge and make things safe. It was over a year later that the case came to court, and I remember feeling compassion for the electrician concerned, knowing that he was a family man who had many years in the industry. At that time, he must have suffered sleepless nights as he awaited his fate. His apprentice went on to make a full recovery thank goodness. I had by that time, amassed 19 years of experience, firstly as an electrician and then as a senior manager and electrical engineer, putting people to work on complex electrical systems. I had knowledge of other electrical flashover incidents and indeed there were the tragic deaths of two electrical workers from arc flash at that same company in the late 80s. A third person was seriously injured in the incident that involved in an explosion to 11,000-volt oil filled switchgear which was being put back in service following maintenance.

In the same year that I was to give evidence in court, the Electricity at Work Regulations 1989 were published and 12 months later I was involved in writing and publishing new low voltage codes of practice for my company and training 400 contracting electricians.

My practical background had served me well in my contributions to the new safety rules and I went onto serve related working parties such as writing the National Vocational Qualifications competence standards for the electrical contracting industry and involvement with various apprenticeship schemes in addition to my day job. Indeed, my interest in the safety of electrical workers continued and 15 years later I founded Electrical Safety UK Ltd which became highly successful in writing electrical rules and supporting procedures delivering advice to large blue-chip companies in countries across Europe and the Middle East.

I have been so fortunate in the acquaintances and friendships that I have made over the years of professionals who have been passionate about the subject of electrical safety. My views on the management of electrical safety have been forged by many such people whose own practical experiences and advice have given me the incentive to write this book and pass on that knowledge.

This book is not an academic exercise or about crunching numbers through computer software, it is about identifying real hazards in the workplace and developing strategies to eliminate harm to individuals. It is with this in mind, that I have endeavoured to look globally at research and standards that could be of help. My view has been that arc flash is very simply a hazard which should be approached in the same way as any other, such as working at height for instance. If you were to put somebody to work at height you would need to know what they are doing, how high they are working and what they could fall into or onto if something went wrong. The cornerstone of European Health and Safety Directives and UK law is risk assessment, which should include an evaluation of the severity of the hazard whether it be a fall or the damaging effects of an electrical arc.

It was clear to me that there was not a great deal of research within the United Kingdom into predicting the level of harm from an electrical arc and so began my research further afield. This led me to the United States where I met my very good friend Jim Phillips who is presently the IEC international chair of the Live working committee and vice chair of the IEEE 1584 committee responsible for the guide for performing arc flash calculations. Jim and I co-authored our first article on the subject back in 2007 in the Institute of Electrical Engineer's Power Engineer magazine. It caused quite a stir at the time among professional engineers and inspired various debates and even conferences on the subject in the UK. I realised then that there was an aversion to the use of US standards in Europe as there was a perception that the first line of defence was always PPE (Personal Protective Equipment). That was never my intention, but my motivation was to use white papers and auditable standards such as the IEEE 1584 Guide for Performing Arc Flash Hazard Calculations to carry out a prediction of the level of harm. It is from that first step in the risk assessment process, that I would advocate the use of a hierarchy of risk controls always removing the hazard as the first line of defence and the use of PPE as a very last line of defence.

I am reminded of a passage from the superb book "Introduction to Health and Safety at Work" by Phil Hughes and Ed Ferrett, which is the NEBOSH National General Certificate textbook. When they address the European Council Directive 89/391/EEC (EU Workplace Health and Safety Directive), they make it clear the need to take into account such globally available information. There are nine principles of prevention specified in Schedule 1 and number 5 is "Adapting to Technical Progress". Their interpretation of this principle of prevention 5 is "it is important to take advantage of technological and technical progress, which often gives designers and employers the chance to improve both safety and working methods. With the internet and other international information sources available, a very wide knowledge going beyond what is happening in the UK or Europe, will be expected by the enforcing authorities and the courts". This guide will be based upon the European Health and Safety Directives and will be very practical in approach. It is about identifying real hazards in the workplace and developing strategies to eliminate harm to individuals. It is with this in mind that I have endeavoured to look globally at research and standards that could be of help.

Jim Phillips and I became engaged in providing guidance on how quantitative methods of arc flash risk assessment could be used to predict the level of harm from arc flash, to prevent it from causing harm and to protect individuals in the event of a flash over. Guidance was produced to comply with the law in the UK initially and eventually across Europe. Five years later, Jim and I went onto produce a paper called a European View of Arc Flash Hazards and Electrical Safety which was presented to an audience of 500 delegates at the IEEE Electrical Safety Workshop in Florida. More discussion, this time from the US side of the Atlantic and it is no coincidence that there was the adoption of a more European style risk assessment process into the US electrical consensus standards NFPA 70E Standard for Electrical Safety in the Workplace.

I knew that I was on the right track when, sharing a platform with the HSE at an IET conference in Glasgow in 2011, a question was asked by one of the delegates whether there was any likelihood that guidance on the subject of arc flash would be issued in the near future. I was pleased to hear the endorsement that if guidance was needed then I had just given it in my presentation to the conference.

Why did I write this book?

My answer to that question is: because I care passionately about electrical safety. Arc flash risk management is sometimes seen as a difficult subject with responsible persons and duty holders often confused about what they have to do to keep their workplaces safe and to comply with the law. In addition to that, there is a perception that there is great expense required in managing the hazard through time and software in particular. This is a subject area that has been very PPE centric in the last 10 years and I wanted to get the message across that preventative techniques will always be prioritised. In addition, personal injury, while being devastating for the individuals concerned is just one item on a long list of potential losses from an arc flash accident.

I have been one of the most prolific exponents of arc flash risk management and electrical safety in Europe over many years, and my desire is to share my experience and knowledge of the subject. My experience, garnered by trudging around cement mills, power stations, steel works, food companies, quarries, electrical distribution networks and countless other sectors, together with the hours of debate with foremost experts in the arc flash arena has taught me a great deal. Things like the over complication of the risk assessment process and also the common myths and mistakes that I have come across. That is why I was particularly keen to document them under a chapter of the same name, Chapter 12, Myths and Mistakes.

There is, therefore, a need to simplify the process and to make the access to the predictive tools accessible to all. Because of that, I felt that I possessed the knowledge and experience to meet this need and my personal 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.

When I founded Electrical Safety UK Limited in 2004, one of my objectives was to be able to predict the level of harm from an arcing incident. After all, “if you can't measure it, you can't manage it”. That is what first led me to the USA to learn about applying the IEEE 1584 Guide for Performing Arc Flash Hazard Calculations from first principles and using written worksheet and a calculator. Improvements in predictive techniques for the arc hazard requires designers in particular to understand that they have a duty to reduce the level of harm to people and equipment from arcing faults. Indeed, it has been my experience that more than 90% of dangerous conditions can be reduced by simple protection device alterations and adjustments. With that in mind, it is technically feasible to protect against excess current in the majority of arcing situations. Whilst this book is predominantly about arc flash from arcing faults, there is much evidence to prove that low level arcing accounts for a great deal of loss of human life and property due to fires.

Anything that I can do to shine a light on these issues and prompt more debate and future research about arcing has got to be welcomed in my view.

Chapter 1

Purpose and Scope

1.1 What is the purpose of this guide?

This guide is a practical risk assessment tool for the European Engineer, which is primarily designed to evaluate and manage dangerous levels of arc flash incident energy in electrical distribution systems.

It is clear from the European Council Directive 89/391/EEC (EU Workplace Health and Safety Directive) that there is an obligation on behalf of the employer to assess levels of risk involved in the workplace and the effectiveness of the precautions to be taken. For electrical work, this should include all the hazards of electricity, including the arc flash hazard, and not purely shock, as is often the case. A key element of risk assessment for electrical work is that hazards are identified and evaluated as part of a decision-making process, beginning with the justification for working on or near energised equipment.

A major objective of this guide is to provide the predictive tools to determine the arc flash hazard severity and the means to prevent it causing harm. For hazard severity, the guide provides calculators and tables to assist engineers in evaluating the magnitude of the arc flash incident energy – the first step in the risk assessment process. Whilst simple in nature, the calculators are also accurate to the extent that they are based upon the latest research. Where requirements for assessment are more complex in nature, then there is guidance on how to approach the subject of outsourcing system studies and the choices of software for modelling complex electrical engineering systems. There are several advantages to using the guide which are:

- The guide will identify significant risks quickly.
- It will provide scalability, flexibility and be a steppingstone to a more complex approach, should it be necessary.
- It is a very low cost and accessible alternative and inclusive of more members of the engineering team.
- It can easily be adopted into dynamic risk assessments.
- Easy “What if” scenarios for those times when the accuracy of input data is questionable.
- It provides a source of awareness, training & information which is in my view the biggest step change that duty holders can make.
- The guide is web based as well, so updates to standards and legislation will allow the reader to be kept up to date.
- Information is provided in developing a strategy for managing the risk.

- In depth information for carrying out complex system studies. This includes planning and pitfalls as well as information on the protective relays that may be encountered.
- There is benefit of years of shared practical experience throughout and there is a separate section on arc flash myths and mistakes.
- Use of the guide will reduce costs through:
  - Low Initial cost of the guide with associated calculator tools and accompanying tables. This is deliberately based upon the strategy of making the advice as accessible as possible.
  - Optimising PPE by taking the reader through a process of practically avoiding or reducing the risk which will often lead to more comfortable and less expensive solutions.
  - Complex software and training costs are expensive, so the use of this guide is not only highly beneficial in other ways but extremely cost effective as well.
  - Cost reduction strategy, commercial contracts, and vendor advice should a more complex approach be required.
  - Identify and group low level circuits into categories that can be excluded from complex arc flash studies.

1.2 Scope of the guide

It is important to state that the scope of the guide specifically covers the arc flash hazard and in particular the thermal effects onto a worker in case of exposure to an electric arc event, but clearly there are other electrical and non-electrical hazards associated with the task. These other hazards are outside the scope of this guide although references will be made to them where necessary and particularly helpful.

Whilst the guide is based upon European Council Directives there are some specific references to United Kingdom and Irish regulations/standards as well. Clearly, the United Kingdom left the European Union on the 31st January 2020, but their basic approach to health and safety law is unlikely to change in the near future. As the guide gives access to the tools and tables through the web version of the guide, updates to standards and legislation will allow the reader to be kept up to date. The assumption is that users of the guide will be familiar with risk assessment as defined in the European Commission document “Guidance on Risk Assessment at Work”.

The guide covers the majority of situations where electrical workers may be engaged in activities where exposure to the arc flash hazard may occur. The guide is specifically applicable to working on control circuits, diagnostic testing & fault finding, live jointing, metering, LV operations, electrical installation work and maintenance activities near energised conductors and equipment. Companies who provide service engineers and electricians to client sites will find the guide to be particularly helpful in their risk assessments where intimate knowledge of the client’s distribution system is not available. There is a dedicated chapter on service providers and contractors (Chapter 10) which recognises and deals with this issue in detail.

1.3 Sharing Best Practice

There is a good deal of practical experience and Chapter 12: Myths and Mysteries is based upon much of the author's personal involvement and knowledge with arc flash. The aim is to provide ongoing updates via the web version of the guide. This will cover updates to standards, regulations and calculations as mentioned previously.

1.4 Who can use the guide?

The guide is aimed at competent electrical engineers and particularly those who are responsible for putting electrical workers to task on, or in, the vicinity of live conductors and equipment. It may also be used by qualified electrical designers to supplement good design technique in order to engineer the reduction of electrical arc flash hazards and, where possible, to limit any requirement for future exposure to arc flash hazards. The calculator tools to determine incident energy within this guide are well within the capability of electrical engineers with minimum electrical design experience. For electrical networks that involve more complex feeder arrangements, the guide provides information on the procurement of software and/or service providers. The individuals named on the following non exhaustive list may find this guide useful.

- Electrical Duty Holders
- Electrical Designers
- Electrical Contractors
- Electrical Safety Consultants
- Health and Safety Managers
- Electrical Engineering Managers
- Electrical Maintenance Engineers and Technicians
- Distribution Company Employees and Service Providers
- Electrical Engineering Students

Chapter 2

What is Arc Flash?

An arc flash is usually caused by inadvertent contact between an energised conductor such as a busbar or wire with another conductor or an earthed surface. When this occurs, the resulting short circuit current can melt the conductors and produce strong magnetic fields that blow the conducting objects apart. The resultant fault current ionises the air and creates a conducting plasma fireball with arc temperatures that can reach upwards of 20,000 degrees centigrade at its centre (four times the surface temperature of the sun), which will vaporize all known materials close to the arc immediately and the incident energy emitted may ignite the worker's clothing and/or cause body burns to the worker even without igniting the clothing. Severe injury and even death can occur, not only to persons working on the electrical equipment, but also to people located nearby.

2.1 Arc Flash Injury

Arc flash injury can include external burns (i.e., severe burns to the skin), internal burns and 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 upon 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 kilopascal (kPa) and could cause the propulsion of molten metal, equipment parts and other debris at speeds of up to 300 metres per second (m/s).

The severity of the thermal effect of an arc flash is defined by the amount of "incident energy" that a victim, standing at a given distance away from the arc, could receive to the skin surface. The "incident energy" is the value calculated which defines the severity of the arc flash. It can be quantified in units of kilojoule/metre^2 (kJ/m^2), Joule/centimetre^2 (J/cm^2) and calories/centimetre^2 (cal/cm^2). One cal/cm^2 is equal to 4.184 J/cm^2 and is equal to 41.84 kJ/m^2. Units of cal/cm^2 will be used throughout this guide, since this is the unit, which is specified to be put on the PPE garment labels according to IEC 61482-2.

As a frame of reference for incident energy, an exposure to heat flux of 5.0 J/cm2 (equivalent to 1.2 cal/cm^2) during a 1 second exposure can produce the onset of second degree burn to the skin. This value is used by many standards as the benchmark that defines protection against the thermal effects of arc flash and the threshold of a zone which is commonly known as the arc flash boundary. This is where the predicted incident energy is calculated to be 5.0 J/cm^2 (1.2 cal/cm^2).

2.2 Causes of Arc Flash

The following is a simplified description that I have used many times to explain the phenomena to delegates at seminars and in magazine articles. I find that the ubiquity of the components highlighted strikes a chord to give some practical understanding of the preceding description of the phenomena. As stated earlier, an arc flash is usually caused by inadvertent contact between an energised conductor such as a busbar or wire with another conductor or an earthed surface. Put simply, it is insulation breakdown and very often, the insulation in question on low voltage systems is simply air. Sadly, the cause of insulation breakdown is, very often, human intervention.

In Figure 2.1 you can see two copper busbars that are separated by 3 cm air gap. The busbars are connected to an electrical source operating at 400 V, with a prospective short circuit capacity of 25,000 A. This is roughly the type of output that you would get from a 1000 kVA, transformer. As you can see there is no protective device in circuit, only a switch. Connecting the two busbars is a piece of heavy gauge fuse wire.

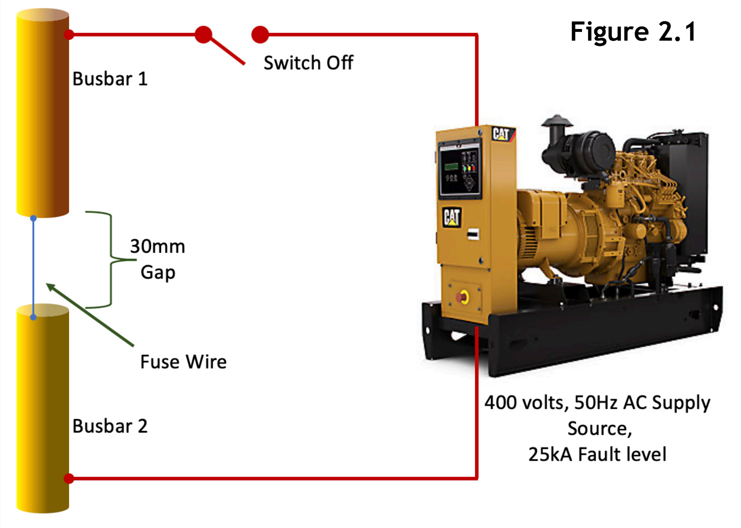


Figure 2.1

When I ask electrical workers the question "What will happen when the switch is closed," they often say that a large amount of current will flow, and the fuse wire will simply rupture and disconnect the circuit.

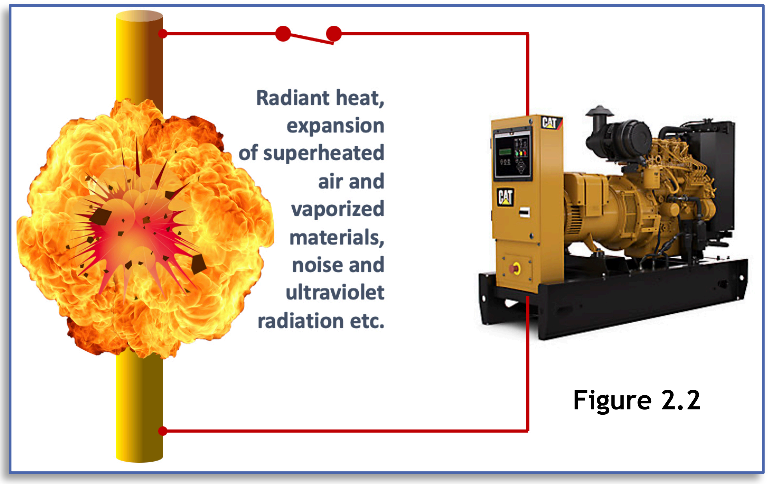


Figure 2.2

What actually happens is that the fuse wire will vaporise and in so doing so will ionise the air between the two conductors creating a low impedance path, see Figure 2.2. Large amounts of current will flow creating temperatures as high as 20,000°C at the arc which will immediately vaporise any element known to man as described previously. There will be a massive expansion of air and vaporised conductor material which causes an electrical explosion. For instance, copper will expand up to 67,000 times its original volume in a split second. The thermal effects can cause horrific burns, ultraviolet radiation which can cause arc eye and the ballistic effects can cause blunt force trauma to anyone standing close by.

The consequences of an arc flash to such a person are clearly personal injury or even death but this can also result in fines and compensation claims to companies and individuals. A damaged brand name may also be an outcome, for instance an electrical contractor being prosecuted or served notices for a matter of core competence. If the equipment is so severely damaged that it is put out of action, then this will usually counter the reason for working live on equipment in the first place, which is to keep production flowing.

In a practical situation, the distance between busbars or conductors in low voltage switchgear can be half that stated in the example given. It is easy to imagine that the arc can be initiated not by a piece of fuse wire but by dropped tools or materials or by a short circuit in an electrical test instrument.

Once we have initiated an electrical arc, how can we extinguish it? Well, either the source of energy will collapse, or there will be such damage that an electrical arc cannot be sustained or more commonly a protective device will be used which will cut off the current, preferably to limit the damage and effect of the arc. Here is where designers have a problem. We design over current protective devices at low voltage based upon available prospective short circuit current into a zero-impedance fault. Whilst the current in an arc at high voltage is almost equal to the prospective short circuit current, the three-phase fault current at low voltage is likely to be much lower than the prospective value. The arcing fault may in fact present itself as an overload rather than a dangerous short circuit which will result in a long disconnection time.

So, what is the significance of this fact? The energy released in the arc is directly proportional to the amount of current flowing and the amount of time that the current will flow. So, if you double the disconnection time, you will double the energy released and double the amount of damage sustained. For Low Voltage circuit breakers, the difference between the device sensing a short circuit and an overload can be a factor of hundreds which will in turn create hundreds of times more energy released in the arc. More about this later.

2.3 Consequences of an Electrical Arc Flash

There is evidence to show that the majority of direct arc flash incidents occur due to and with individuals in the vicinity of the arc. My own research has revealed that the majority of fatalities due to electricity are in fact from shock but that the majority of injuries in industry are due to electrical burns. I speak about incidents that have led to loss of life in this guide that I am personally aware of and also of incidents causing injury and those where no injury has been incurred. It has been my experience, that whether individuals have been injured or not, arcing incidents cause huge losses in many instances. I have categorised some of those losses as follows.

2.3.1 Injury or death

You do not need to inquire much further than a quick internet search to reveal masses of material including photographs and videos depicting horrendous arc flash injuries to individuals. Put it simply, electrical burns are horrible. They are very slow healing and leave lasting physical and mental scars.

2.3.2 Classification of Burns.

Burns are classified differently and as the subject of a second-degree burn is used in arc flash severity evaluation, it is worth briefly describing the terms used for the sake of clarity. The mildest classification is the first degree burn also called a superficial epidermal burn. The epidermis is the only skin which is affected and there may be reddening and slight swelling but no blisters. The next is a second degree burn or a partial thickness burn which affects the second layer of skin or dermis. The symptoms are as the first degree burn but blistering may occur either immediately or sometime later. Next in severity is a third degree burn also called a full thickness burn which goes through all layers of skin to subcutaneous tissue (or fat) below. A fourth-degree burn goes through all layers of tissue and affects muscles and bones. The more severe burns often result in nerve damage which means that the patient may not feel pain, but risks of life-threatening infections are a common feature depending upon how much of the body is affected.

The inhalation of toxic and superheated products of combustion are an often-overlooked consequence of arc flash. I am aware of one case where a young man was affected in this way and the damage to his lungs was so severe that he would never work again. Blindness due to ultraviolet light, thermal burns and blast is another outcome. The effects of ultraviolet light can cause cataracts to appear years later, the injuries that the apprentice forementioned in the introduction suffered temporary blindness.

2.3.3 Age and Burns

I became fascinated by the correlation between electrical accidents, age and the survivability of electrical burns. You would think that with age would come wisdom and experience but for electrical accidents that does not follow. A colleague of mine used to roll his eyes when somebody would say to him that they had 25 years' experience in the industry. He used to retort "Is that 25 years' experience or is it 1 years' experience repeated 25 times?" The following graph (Figure 2.3) shows the relationship between age and fatal electrical based accidents in the UK over a 12-year period up to 2008. What stands out for me is the fact that the highest fatal accident rate is between ages 40 to 54. But it does not stop there because the number of fatalities above the age of 60 has got to be out of step with the age demographic in the electrical industry in that period.

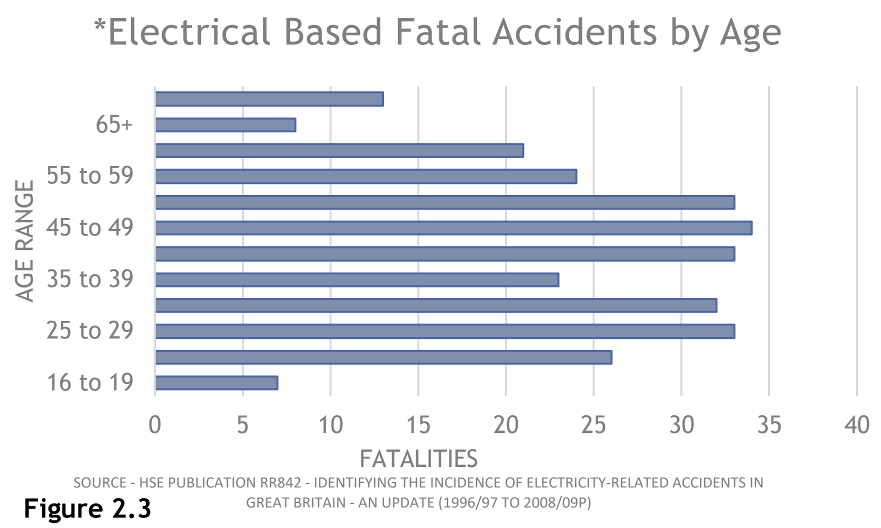


Figure 2.3

*Note - Electrical based includes all fatalities due to direct contact with electricity as well as accidents reported under other electricity-related RIDDOR categories (e.g., industries such as electricity production, installation of wiring/fitting, manufacturing of electrical appliances; occupations such as electrical engineers, electroplaters, etc.).

So, then we come back to the issue of age and the survivability of burns. An arc flash injury to seniors such as myself is definitely bad news. Even for those in their 50s the chances of survival have diminished fourfold from 60% down to 14% for 75% burns. There is a system called the Baux Score which looks at both factors of the percentage burn to the body and the person's age to forecast mortality due to burns. It simply adds the percentage of the body surface burned to the patient's age to create a score which is a prognosis indicator and a score over 140 would not be considered survivable.

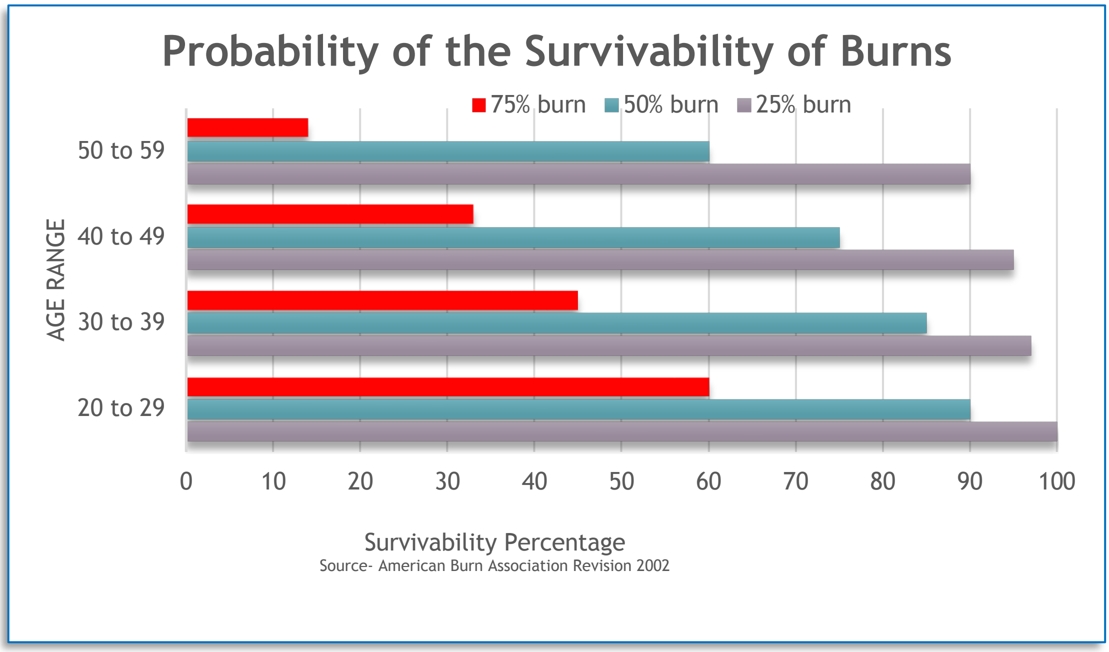


Figure 2.4

2.3.4 Fines and Compensation Claims

Whilst the financial penalties due to fines are not always as severe and eye watering as they should be, they are becoming more noteworthy. Just recently, an electrical contractor was fined £1,000,000 plus costs for breaches of section 2(1) of the Health and Safety at Work Act 1974. This was following burns to an electrician who was undertaking routine testing. In mitigation, the contractor said that a full review of electrical safety processes and systems across its sites had since been carried out, with "actions being taken to minimise the risk of recurrence". The costs of arc flash accidents do not stop there however, and compensation claims can run into many hundreds of thousands of pounds depending upon severity.

In the UK, there does not even have to be personal injury to provoke legal action by the authorities. This comes out of the requirement to report an arc flash event under the UK Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR). This places a duty to report certain serious workplace accidents, occupational diseases and specified dangerous occurrences (near misses). To give an example, a formal report will need to be made of any explosion or fire caused by an electrical short circuit or overload which either: results in the stoppage of the plant involved for more than 24 hours; or causes a significant risk of death. There is a good chance of subsequent investigation and theoretically, the Health and Safety Executive (HSE) may wish to serve legal notices or even prosecute.

2.3.5 Damaged Brand Name

When I was working with a certain large electrical and mechanical contractor, it became very clear to me that a recent arc flash incident could potentially threaten the viability of their company. They were very well established and had a large blue-chip client base in the UK and beyond. Unfortunately, they were being investigated by the HSE following an arc flash incident involving an electrician who had been connecting a cable into a supermarket main switch panel out of hours. I was engaged by them to help them to put in place policies and procedures which should have been in in force in the first place to prevent anything like that happening. It was a bit like shutting the stable door after the horse had bolted. Senior management spent countless hours in investigations, discussions and legal representations to mitigate against the threats that a prosecution under the Health and Safety at Work Act would mean for them. From my experience as a former electrical contractor and also as a client I realised that once a prosecution had been secured, the company would have to declare that fact for every pre-qualification that they would have to complete, either for new works or for ongoing maintenance of existing contracts. When I worked as a client, I would find it extremely off-putting to see a pre-qualification from a prospective electrical contractor which declared a failure to demonstrate adherence to their own core competence criteria. The pre-qualification process is very much centred around the contractor being able to demonstrate that core competence. My message to contractors is to be mindful of the damage to your brand that could occur when working on energised equipment.

2.3.6 Severe equipment damage

I give several examples in this guide of damage to electrical equipment which has required complete replacement due to the effects of arcing. Replacement of electrical switchgear carries a high price tag not only in cost but procurement time and outages. Repairs are not often possible due to lack of replacement parts. I did some research some time ago on the age of high voltage electrical equipment in service in the UK in industrial/commercial sites. Over 40% of equipment was over 20 years old and 20% over 30 years old so there was likely to be a high level of obsolescence. I was staggered to find that there were switchgear and transformers still in service from before World War 2. (Sample size 1200 industrial and commercial sites in an estimated total of 26000 sites)

2.3.7 Lost Production

Very often the reason cited for working on live equipment is that production is so important that it would not be possible to shut the equipment down to work on it safely. I am not saying that continuity of production is not a valid reason in every circumstance, but I would say that it is not a valid reason in most circumstances. Having a shutdown in a planned way will stop production for the duration of the work whereas having an electrical flashover in switchgear will result in an unplanned event. In most cases, it is not going to be possible to resume production in a reasonable amount of time if the damage is severe because of the points made in my previous paragraph. It is for the business concerned to determine the risk through a proper risk assessment and there are the tools here to provide a measure of severity should things go wrong as part of that assessment.

2.3.8 Fires

In recent years, the subject of arcing appears to have been concentrated on the protection of an individual standing in front of energised equipment. As a result, the debate has been polarised around personal protective equipment. What we sometimes forget is that arcing is responsible for huge losses due to electrical fires and I was staggered by the statistics. In England alone in the year 2018/19 there were 4199 fires in non-domestic premises where the source of ignition was named as electrical distribution and a further 1826 fires attributable to other electrical appliances. The majority of non-domestic fires that were specified as having “non-human factors” were in fact from electrical distribution causes. I would estimate that most electrical fires are the result of electrical arcing. (Source UK Home Office)

2.3.9 Environmental Impact

As indicated previously, the justification for carrying out live work is often influenced by the essential nature of the equipment which is being serviced. For instance, a 24-hour production facility which will require some planning in order to de-energise the electrical system. What I have established is the severe consequences of an arc flash event. The same mindset of preserving power at all costs could be applied to processes that rely on power to protect the environment. There are many obvious examples in the water industry such as treatment plants and storm sewage pumping stations or the nuclear industry, but also right across industry wherever power is required to control potentially environmentally damaging processes. In my Chapter 12: Myths and Mistakes, I give the example of an arc flash event whereby a serious situation was narrowly averted when polychlorinated biphenyls (PCBs) could have been discharged into a water course following an electrical flashover in a high voltage capacitor. As always, the safer option of a planned outage is preferred to an unplanned event following an expedient quick fix repair under live conditions.

2.4 Which Factors affect the Severity of an Arc Flash?

An understanding of factors which will affect the severity of an arc flash is the key to the management of the phenomena. The distance from the arc, the arc duration and arcing current all have an effect on the severity of the arc flash in terms of incident energy but also determine the severity of ultraviolet radiation, sound pressure and blast pressure. The following describes, in simple terms, the relationship between each one of these factors.

2.4.1 Time and Current

Incident energy is directly proportional to arcing current and also the duration of the arc. In other words, if we double the arcing current then the incident energy will also double providing the arc duration stays the same. If we halve arcing current, then the incident energy will also reduce by a half.

Exactly the same thing happens with the duration of the arc and by reducing the time to trip by a half will halve the incident energy. Whilst it is not that easy to attenuate the arcing current in most cases, the arc duration can be limited by faster disconnection of protective devices. This is the one very commonplace answer to reducing incident energy and therefore severity.

It may be worth mentioning here that higher fault levels may lead to faster disconnection of a protective device which can lead to a reduction of incident energy. This phenomenon, which I first identified and have referred to for many years as the “fault level paradox” will be explored in more detail in later chapters.

2.4.2 Arc in an Enclosure

When an arc occurs within an enclosure, the emission from the arc is focused outwards towards the operator. There is more likelihood that the directed effect of heat, but also the effect of hot metal particles and splashes that accompany actual electric arc faults may cause greater injury than an arc in open air. Furthermore, the size of the enclosure has an effect as well. Calculations of incident energy take into account not only whether the arc is in an enclosure or in open air, but also the dimensions of an enclosure.

2.4.3 Conductor geometry

Current studies and standards have also taken into account the configuration of the electrodes. The intensity of an electrical arc and the resultant level of incident energy is affected by the conductor geometry or electrode configuration. For instance, horizontal versus vertical conductors, open air versus enclosed and also how the conductors terminate. As we explore the topic of predicting incident energy, there will be more detail about how to apply electrode configuration in a practical setting.

2.5 Blast pressure, sound attenuation & distance

As mentioned previously, there could also be an explosive force called arc blast which can be responsible for blunt force injuries. (There are a few myths around the subject of arc blast which will be explored in more detail later) Increased distance has the effect of attenuation of the blast pressure wave and according to theoretical formulae developed by Ralph Lee in 1987 the pressure is inversely proportional to the distance to the power of 0.9. In other words, to double the distance will roughly halve the blast pressure.

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.

Although there is much debate about how Lee’s theoretical formulae can be interpreted in the real world, I have first-hand knowledge of where the ballistic effects of arc flash have caused tremendous damage and potential for injury. In addition, the fact that doors are closed on equipment will most certainly affect the likelihood of an arc flash event but will not guarantee reduced injury as closed doors will not contain the blast unless the equipment is arc protected. Arc protected equipment is discussed in Chapter 5: Prevention.

The accompanying sound pressure wave can cause permanent deafness through the rupturing of eardrums. It is sometimes incorrectly assumed that damaging sound pressure decreases as an inverse square of distance in the same way as sound intensity. In fact, it approximates to being inversely proportional meaning that a doubling of distance will result in a halving of sound pressure.

The intensity of any illumination declines as the inverse of the square of the distance. Twice as far 1/4 as strong three times as far 1/9 as strong etc. If there is smoke or dust suspended in the air it would be even faster, but these are things you would not want to count on.

Learning Points

- It is very easy for an arc to be initiated when working on energised equipment.
- It cannot be taken for granted that the electrical protection will limit the damage caused.
- The consequences of arcing incidents are far greater than personal injury.

Chapter 3

Risk Assessments & the Four P Guide

In my introduction to this guide, I explained my view that arc flash is, very simply a hazard which should be approached in the same way as any other. The arc flash hazard needs to be determined by risk assessment out of which, the decision to work live or dead and the required precautions will be derived. Other electrical hazards such as electric shock obviously need to be assessed but are not the focus of this guide.

A risk assessment must be performed where there could be danger which may include performing an arc flash calculation study to define the severity of the hazard. It is a fact that many workers are put to work on very high incident energy equipment without a thought for the consequences which results in a huge risk to the company and the individual. There is a need to evaluate the arc flash risk and the methods for controlling that risk as part of the process. The amount of energy that could be released in an electrical flashover is the starting point in that evaluation. Once that is known then risk control measures can be explored to determine the test of reasonableness in working live and also suitable precautions that will be required to prevent injury.

In 1989, what would be known as the "European Framework Directive" number 89/391/EEC (Workplace Health and Safety Directive) was passed which introduced measures to encourage improvements to the safety and health of workers. A cornerstone of this directive is risk assessment which means that any employer must evaluate all the risks to the safety and health of workers. For electrical safety, this means that the arc flash hazard cannot be simply ignored even though there are no prescriptive standards in place, such as in the US and Canada and certainly no direct link from the hazard directly to arc flash PPE.

Directive 89/391/EEC creates an obligation on behalf of the employer to assess the level of risk involved in the workplace and the effectiveness of the precautions in place. For electrical work, all hazards should be considered, including the arc flash hazard and not purely shock, as is often the case with many European companies. Arc flash risk assessment for workers who operate in proximity to, or on, energized electrical equipment, cables and overhead lines, is an essential part of electrical safety management. Electrical work must be carried out with conductors de-energized and isolated wherever possible and there is an extremely low tolerance for live working in many European countries.

As a result, many manufacturing plants restrict live working to inspection, diagnostic testing and commissioning purposes. There are, however, many tasks that require working either on, or near to energized equipment. Even then, it should also be acknowledged that the process of de-energization often requires exposure to the hazard through interactions such as switching, racking, and testing of equipment.

The need for risk assessment is embodied in Law through Directive 89/391/EEC and UK Management of Health and Safety at Work Regulations 1999 and the associated guidance which identifies electrical work as a “high risk” activity. As a minimum you must:

1. Identify what could cause injury or illness in your business (hazards).
2. Decide how likely it is that someone could be harmed and how seriously (the risk).
3. Take action to eliminate the hazard, or if this is not possible, then control the risk.

3.1 Hazard and Risk

Before we consider the subject further, it may be worth defining what we mean by the terms hazard and risk in the context of arc flash.

The European definition for the term hazard means anything that has the potential to cause harm. In the case of arc flash the potential to cause harm will vary with the current that can flow in an arc, the amount of time that the arcing fault is sustained, the length of the gaps between the conductive parts, which are bridged by the arc, electrodes, the confinement around the arc, the chemical compositions of the conductors and the materials around the arc, and the distance of the worker from the arc. Arc flash hazard is generally derived by system parameters.

The term risk is the chance (or likelihood), high or low, that someone might be harmed by the hazard as expressed above. Arc flash risk is generally derived from system conditions and the task being performed.

Although the arc flash hazard may be high, control measures can be adopted to reduce both the hazard, and subsequently the associated risk, to as low as possible. (Note: There is, in Great Britain and in international health and safety standards, the term as low “as is reasonably practicable” or ALARP for short. The concept of “reasonably practicable” lies at the heart of the British health and safety system and is a key part of the general duties of the Health and Safety at Work etc. Act 1974). However, many readers may not be governed by standards or laws that are influenced by such an approach and therefore, the advice that I would offer, is to ensure compliance with local and company risk tolerance when making final judgments regarding the residual degree of risk.

A fundamental safety principle is to design out, eliminate or remove the hazard at its source. This leads to the conclusion that the majority of electrical tasks must be carried out with the equipment made dead. To work dead, the electricity supply must be isolated in such a way that it cannot be reconnected or inadvertently become live again for the duration of the work. As a minimum, this will include the positive identification of all possible supply sources, the opening and locking of suitable isolation points preferably by personal padlocks and for proving dead at the point of work.

3.2 Arc Flash Risk Model

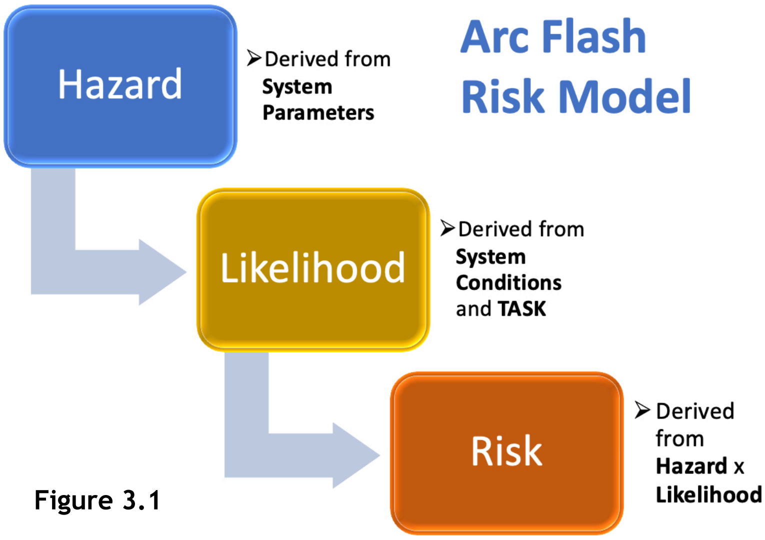


Figure 3.1

Where the arc flash hazard cannot be eliminated then suitable risk controls should be in place (preventative and/or protective measures). Figure 3.1 illustrates a simplified risk model as applied to arc flash. The hazard 'arc flash' which can be further subdivided into several hazardous effects such as thermal, ballistic, noise, and optical.

As demonstrated earlier this is expressed by the parameters of the electrical system. It is the thermal effects that are generally used to provide the potential to cause harm by way of calculations. The input to the calculations is the **system parameters** such as voltage and prospective short circuit current but equipment specific parameters as well. The protective devices such as fuses and circuit breakers are also classed as system parameters because as will be explored in later chapters, the time to clear the arcing fault is very important in regulating the severity of the hazard.

As mentioned earlier, the risk is the likelihood that this hazard may cause harm. I have therefore found it useful to highlight the likelihood separately in the arc flash risk model.

There was a time when some standards advocated the estimation of the hazard severity and providing personal protective equipment to the level of severity, regardless of likelihood. This would lead to the wearing of heavy-duty PPE to carry out normal routine operations on electrical equipment which was designed and built to an extremely high standard. What was missing were the **system conditions** and also the nature of the **task** to be carried out.

The condition of the equipment, the quality of the installation, how well it has been maintained and whether it is being operated in accordance with its original design are all factors to do with the **system conditions** and therefore will influence the likelihood. Furthermore, the physical **task** to be carried out on or near energised equipment is a hugely significant factor as it is very often worker activities that initiate a damaging arc flash event. An example of where the task can influence the likelihood is that of excavations or civil works around live cables. I remember a case which was being investigated by the UK Health and Safety Executive in the UK. It involved work within a substation and a new cable was to be drawn into a concrete duct alongside some existing live high voltage cables. Where the cables passed from one room to another, the duct had been made up with cement as a fire and moisture break. The workers proceeded to use a jack hammer to break out the cement and succeeded in penetrating the sheath, armouring and insulation of one of the live cables. The resultant fireball caused severe injury.

Having asked the question about what constitutes live work on many training courses, it is very rare that an example of working around live armoured cables would ever be mentioned. The specific references to live work in the UK (and Irish) regulations highlights work on or near a live conductor (or live part) other than one suitably covered with insulating material so as to prevent danger. Clearly the cables in my example are insulated but not suitably to withstand a power tool such as a jack hammer.

As stated above, the activities associated with the physical task can often lead to the initiation of an arc flash event. For low voltage work 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. Whilst some of the following activities are common in industry, practices such as connecting cables into live equipment would be very difficult to justify.

1. Connecting cables into live equipment
2. Testing; especially with substandard instruments and test methods
3. Testing on damaged cables and equipment. There are several known cases of arc flash due to using voltage indicators on faulted cables
4. Inspections or any interactions which involves the exposure of live low voltage conductors
5. Work on or adjacent to live low voltage conductors that are insulated but where the work may adversely affect the integrity of that insulation. Some examples would be drilling into panels and drawing cables into cable management systems. My earlier example about civil works around live cables also falls into this category
6. Custom and practice activities such as Installing or repairing equipment which is adjacent to exposed live low voltage conductors
7. Removal and replacement/insertion of live components such as circuit breakers in panel boards and large power bus bar tap off units
8. Live underground cable jointing
9. Live overhead line work
10. Switching and racking out poorly maintained or legacy LV switchgear
11. Replacement of fuses and links especially onto faults

We have a legal duty to carry out risk assessments in the workplace. (Note that EN 50110-1 Operation of electrical installations also states, “Before carrying out any operation on an electrical installation, an assessment of the electrical risks shall be made”) We are guided that the risk assessments have to include the following steps.

1. The identification of hazards
2. The identification of those at potential risk from those hazards
3. An estimation of the risk involved
4. Considering if the risk can be eliminated; and if not;
5. Making a judgement on whether further measures to prevent or reduce the risk need to be introduced.

The first step is to define the hazards. Electrical flashover is a known hazard, which will need to be taken into account when dealing with interactions with high energy electrical systems.

There are means available within this guide to evaluate the risks in line with point 3 above, which will include an assessment of the severity of the arc flash. Note that the steps are about elimination, prevention and reduction of risk and deciding on precautions does not mean a direct link into personal protective equipment. Only when prevention techniques have been exhausted should PPE be considered.

Arc flash risk assessment for workers who operate in proximity to, or on, energised electrical equipment, cables, and overhead lines, is an essential part of electrical safety management. Electrical work should be carried out with conductors dead and isolated wherever possible but there are tasks that require working either on, or in close proximity to, energised equipment. Even then it should also be acknowledged that the process of de-energisation often requires exposure to the hazard through interactions such as switching, racking and testing of equipment.

As founder of Electrical Safety UK, I was the lead consultant for The DuPont(TM) Arc-Guide which was written by European experts. This would take the user through a step-by-step approach to the management of the arc flash hazard and includes the application of the latest developments in prevention and mitigation measures. This will always start with a dead working policy as a matter of principle and then through a range of risk control measures before considering Personal Protective Equipment (PPE) as a last resort to protect individuals should an arc flash occur. I have refined the model, which is shown in the following diagram.

3.3 Four Ps Approach to Arc Flash Management.

This cycle matrix diagram 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 personal protective equipment as a last resort which, if the previous three steps have been correctly applied, will cover residual risk and hopefully, result in more lightweight optimum solutions.

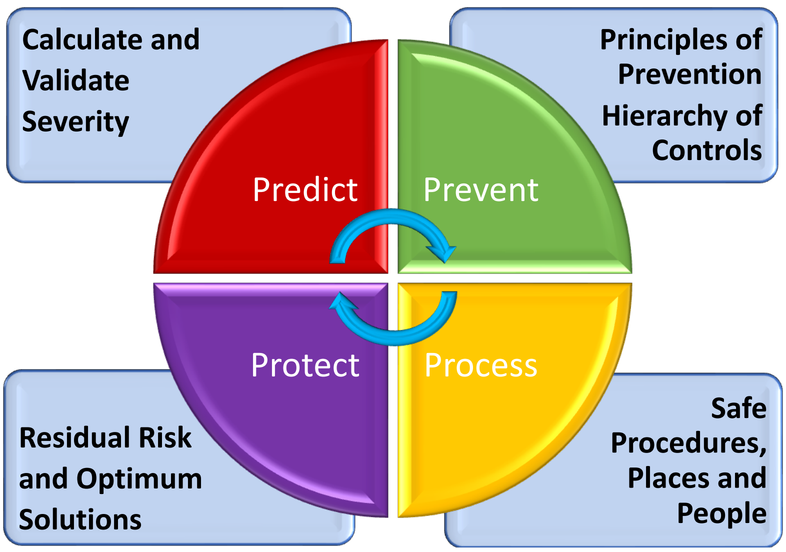
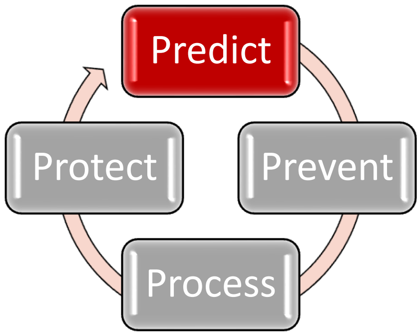


Figure 3.2 4P Risk Management Cycle

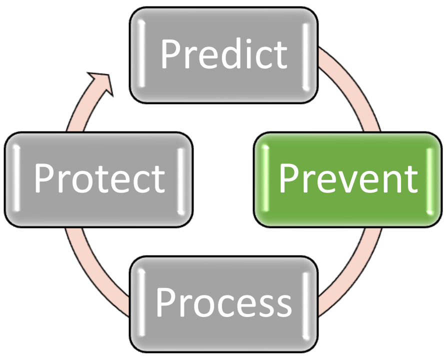
3.3.1 Predict



The first step in the 4P approach is to **Predict** the severity of an arc flash. In predicting the severity of the thermal effect of an arc flash, I recommend that the calculation methods are taken from the IEEE 1584 Guide for Performing Arc Flash Hazard Calculations 2018 which is an auditable standard and widely accepted in the electrical engineering community. Also covered and provided with this guide are other calculation means such as the commonly named German Box Test Method and the Ralph Lee Theoretical equations for voltages over 15kV.

The IEEE 1584 calculations take into account distance to worker, conductor gap and configuration, enclosure type voltage, prospective short circuit current and disconnection time. The output relates to the amount of “incident energy” that a victim, standing at a given distance away from the arc, could receive to the skin surface. There are also accurate calculators provided with this guide to determine prospective short circuit current, which is always a key element in predicting arcing current and therefore the incident energy levels. There are calculators and tables that will help even when site data is limited such as for circuit breakers and common European style fuses.

3.3.2 Prevent



Once we have estimated the hazard level through the first step of prediction, we are guided to **prevent** the hazard from causing harm. Chapter 5: Prevention is dedicated to the fundamental principle of prevention starting with the elimination of live working but then going on to describe various practical solutions to help the reader to understand and to embrace methods and technologies that are available to reduce that harm to as low as is reasonably practical. Where we cannot eliminate the live working, then application of reduction or minimisation techniques will require a recalculation under the predict step.

3.3.2.1 Principles of Prevention for Electrical Flashover

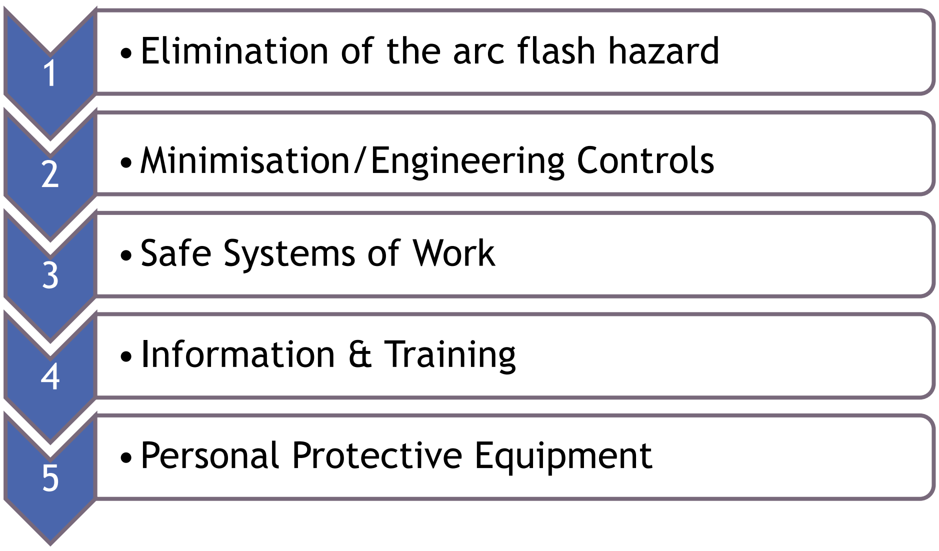
Where the arc flash hazard cannot be eliminated then suitable risk controls should be in place with preventative measures taking the priority. Article 6(2) of European Council Directive 89/391/EEC EU (Workplace Health and Safety Directive) states “Where an employer implements any preventative measures, he shall do so on the basis of the principles” shown below. This is also specified in Management of Health and Safety at Work Regulations 1999 schedule 1. My interpretation of each of the nine principles of prevention when applied to the arc flash hazard is shown in italics.

1. Avoiding the Risk - *which means Dead working, Not energised = No electrical danger*
2. Evaluation of the risks which cannot be avoided - *by arc flash assessment and predicting the level of harm and likelihood*

3. Combating the Risks at Source - *by designing out the arc flash hazard or reducing it to an acceptable level, even as a temporary measure for the period of work*
4. Adapting to the individual -*limiting exposure to the hazard*
5. Adapting to Technical Progress/Information - *take advantage of technological and technical progress to improve both safety and working methods. The evaluation of the hazard has progressed, as have mitigation and protection techniques in respect of arc flash*
6. Replacing the dangerous with the non-dangerous - *replace vulnerable legacy switchgear and control panels preferably with arc protected equipment and/or high levels of insulation and segregation of control and power circuits. Using safer equipment (e.g. test equipment) and tools (e.g. insulated)*
7. Developing a coherent overall prevention policy - *create a **safe procedures** approach which is specific to structure environment, workforce and equipment issues and developing risk-based investment to reduce exposure to the hazard*
8. Giving collective protective measures priority over individual protective measures - *create a **safe place** of work approach by screening live parts and by good design. Any measure that is not dependent upon the individual's choice*
9. Giving appropriate instruction to employees - *create a **safe people** approach by documenting safe systems of work and training employees in safe work practices. Highlight the arc flash hazard and provide information such as in the labelling of switchgear*

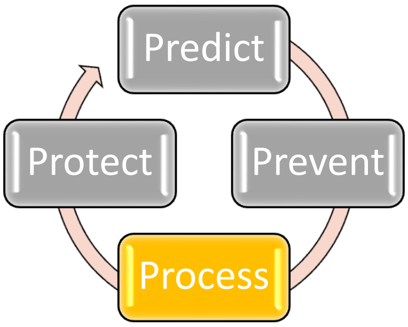
These general principles of prevention should be considered against a hierarchy of risk controls with priority as given below. The top of the list should always take priority with PPE as a last resort.

3.3.2.2 Hierarchy of Risk Controls for Electrical Flashover



All these measures should be properly monitored and reviewed, and this is particularly important when considering the lower order risk controls such as personal protective equipment.

3.3.3 Process

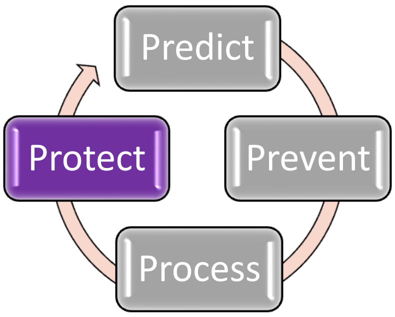


The next step is to review policies and procedures. A review of electrical procedures and safe systems of work can substantially raise the profile and understanding of the arc flash hazard and associated control measures. Periodic awareness and refresher training, toolbox talks and specific training in the policy, rules and procedures are essential elements of arc flash risk management.

Chapter 6: Process, Policies and Procedures, and Chapter 9: Electrical Duty Holders introduce the concept of the three building blocks of electrical safety which are safe procedures, safe people and safe places. I highlighted these three facets of electrical safety in the list of principles of prevention above. (3.2.1 points seven, eight and nine)

The Process, Policies and Procedures chapter gives practical guidance on how these three facets address the specific issues of arc flash management. In particular, there is detailed information on a practical approach to risk assessment. Risk Assessments need to document the hazard severity and the risk control measures. Wherever possible these should be dynamically produced, and task based. In other words, be available to the person carrying out the work who will reassess such things as environmental conditions and equipment state. The chapter also provides guidance on competence (safe people) and maintenance (safe places). The Electrical Duty Holder chapter breaks down and explains the concept of safe procedures, safe people and safe places in much greater detail when applied to arc flash risk management.

3.3.4 Protect



Where the risk cannot be 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. Where protection against the thermal effects becomes necessary it must be emphasised that PPE does not prevent the accident happening in the first place.

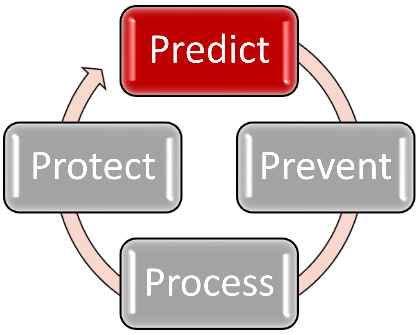
Non-flame-resistant clothing may ignite or melt at lower incident energy values and once ignited will continue to burn after the electrical arc has been extinguished. Burning material next to the flesh can result in serious third degree burns even for very short durations. This means that ordinary clothing could actually become a hazard and for this reason it should be considered within the risk assessment. Part of the risk assessment is to define the level of PPE that should be worn by the worker. However, the removal of the hazard is always the first choice.

Learning Points

- Risk assessments are a mandatory part of safety management which require an evaluation of risk in every case. That includes arc flash in the same way as any other hazard.
- Prevention is the first key principle. If the equipment is dead and correctly isolated, then there is no hazard.
- Never use PPE as a first line of defence against electrical flashover. It should be used as a last line of defence and any protection against residual risk using PPE is likely to be more comfortable, cheaper, and easier to justify if the 4 Ps approach is used.

Chapter 4

Prediction



The severity of the thermal effect of an arc flash is defined by the amount of incident energy that a victim, standing at a given distance away from the arc, could receive to the skin surface. In Chapter 2: What is Arc Flash, I said that an exposure to heat flux of 5.0J/cm^2 (equivalent of 1.2 cal/cm^2) during a 1 second exposure, can produce the onset of second degree burn to the skin. This value is used by many standards as the benchmark that defines protection against the thermal effects of arc flash and the threshold of a zone which is commonly known as the arc flash boundary. This is where the predicted incident energy is calculated to be 5.0J/cm^2 (1.2 cal/cm^2). 1.2 calories per square centimetre is often depicted as the amount of incident energy that one could receive if you were to hold your finger in the hottest part of a match or candle flame for one second. Not to be recommended but it is unlikely that you would receive anything more than mild superficial burns. Whilst the SI unit used (International System of Units) is joules per square centimetre (J/cm^2), most of the references to incident energy within this guide will be in calories per square centimetre (cal/cm^2) as this unit of measure tends to be universally used for protective measures.

> 1.2 calories per square centimetre.

So, to truly understand the risks of the arc flash hazard, you need to be able to calculate the incident energy level at the worker. This first P, **Predict**, is fundamental to the whole risk assessment approach. To paraphrase Peter Drucker; “if you can’t measure it, you can’t manage it”. This is the reason why I have put so much effort into providing the tools, calculators and tables to provide the means to predict incident energy. In using these hazard severity tools to calculate the incident energy at the point of work, this will provide the bedrock of information from which decisions can be made in respect of safely managing the risk. Once you can identify and quantify the hazard, you can decide if work can proceed and if so, what preventive or protective measures need to be in place. In addition, there are hazard severity calculators for prospective short circuit current, DC arc flash and quick tools for circuits with circuit breaker protection or fuse protection. This will allow for a figure to be obtained very quickly and easily. Once this is completed, you can continue to manage the risk by using the **Prevent**, **Process** and **Protect** chapters.

4.1 What Does Arc Flash Hazard Prediction Tell Me?

The debate about arc flash hazard management in Europe has been polarised around the need for personal protection and in the UK especially, the aversion to PPE has suppressed the true losses due to arcing faults. It is time to move on and to focus on predicting hazard severity to assist in avoiding serious injury and other consequences such as production losses, equipment/building damage, fines and compensation claims. All this before considering the provision of personal protective equipment as a last line of defence to protect against residual risk. As mentioned previously, there are tools appended to this guide which will allow you to undertake a hazard severity prediction and the following will outline what this will tell you.

4.1.1 How Big is the Bang?

Firstly, and bluntly it will tell you just how big the bang will be. You can be standing in front of two identical electrical switch panels, with one being a relatively low-level of arc flash hazard and the other one could be extremely high. In other words, one contains the equivalent of a domestic cat behind the locked panel doors whilst the other one contains a raging tiger. So, if the electrical panels are identical, what is it that causes this to be so? The answer could be very small differences in fault level or protection device characteristics or settings. The only way you will find this out is by the risk assessment process and by doing the maths. Why would you want to know?

4.1.2 Legal Requirements.

To satisfy legal requirements for risk assessment which is embodied in law through European Council Directive 89/391 (EU Workplace Health and Safety Directive) and how this directive is interpreted in secondary legislation in member countries. (This is regardless of EEC past membership and further information can be found in Chapter 16: Rules, Codes and Legislation) In Chapter 3: Risk Assessment and the Four P Guide it was established that this required an identification of the hazard and then to decide how likely it is, that someone could be harmed and how seriously (the risk). Finally, we are called on to take action to eliminate the hazard, or if this is not possible, to control the risk.

4.1.3 Arc Flash Boundary

By performing hazard severity calculations, the onset of where a second-degree burn can occur, (or partial thickness burn) may be predicted at a distance from the possible arcing source. As explained earlier this figure is 1.2 cal/cm^2.

The distance at which this figure is calculated is called the arc flash boundary and is used within US and Canadian safety standards to determine the measures that will be required to protect workers. (See Chapter 16: Rules, Codes and Legislation) In Europe, this is a very useful piece of information and will allow duty holders to determine risk control measures such as a boundary within which PPE may be required as part of specific safe working procedures. Another example may be designers who need to determine working distances around electrical equipment.

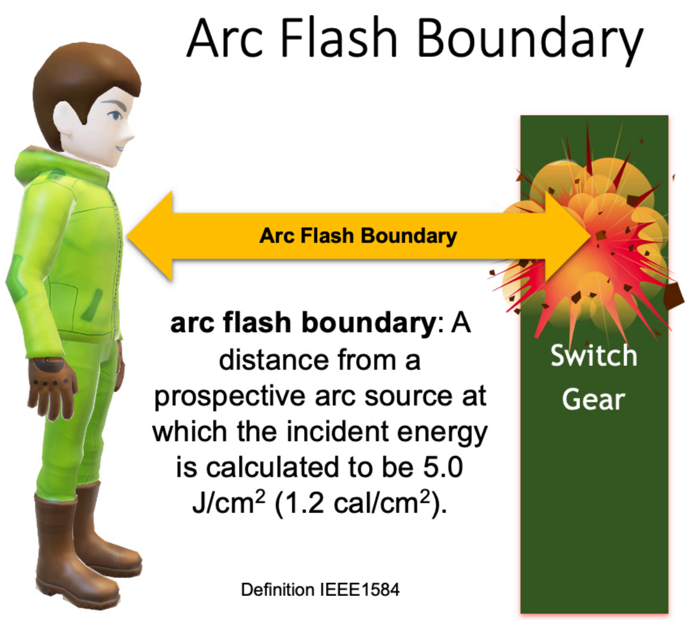


Figure 4.1

4.1.4 Fault Level Information and the Strength and Capability of Equipment.

When predicting the incident arc flash hazards, knowledge of fault levels will be required. If the information is available, that is fine, but there is an online prospective short circuit current calculator to assist if not. The determination of prospective short circuit current levels is required by designers and duty holders to ensure that equipment is capable of clearing fault currents safely. This may look like a spin off from carrying out the arc flash hazard calculations, but as can be seen from the instructions, a check on the strength and capability is a necessary part of the risk assessment.

4.1.5 Competence

Technical knowledge and experience about the system to be worked on or near is a key ingredient in the assessment of competence of the individual undertaking that work. Among other things, the scope of technical knowledge or experience may include an understanding of the hazards which may arise during the work and the precautions which need to be taken. In addition, the worker must be able to recognise at all times whether it is safe for work to continue. The hazard assessment provides good information about how severe the outcome of an unplanned event will be. Although the aim must always be to avoid the hazard in the first place, there is now the technology available based on sound research to determine the protection measures for workers. There is much more information about competence in Chapter 6: Process, Policies and Procedures.

4.1.6 Personal Protective Equipment Requirements

To be able to comply with the European Council Directive 89/656/EEC (Use of Personal Protective Equipment), the selection of control measures including PPE would be very difficult to achieve without some measure of the actual hazard. (You can find the specific legislation in Chapter 16: Rules, Codes and Legislation for the UK and Ireland). PPE can only be prescribed after the employer has analysed and assessed the risks which cannot be avoided by other means. For arc flash this means that an employer must consider other means of achieving safety prior to considering the use of PPE, such as the elimination of hazard, engineering controls and safe systems of work. For further information, See Chapter 7: Protection.

4.1.7 Ballistic Effects or Arc Blast

As described within the Chapter 2: What is Arc Flash, 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. 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 is conservative at best, but this is discussed in the earlier Chapter 2: What is Arc Flash.

4.2 Hazard Calculation Methods

The accompanying calculators, tools and tables follow various published formulae and white papers but by far the most prominent is the IEEE 1584 Guide for performing Arc Flash Hazard Calculations.

4.2.1 IEEE 1584 Guide for Performing Arc Flash Hazard Calculations.

The IEEE, Institute of Electrical and Electronic Engineers, is the largest professional engineering body in the world and is responsible for the IEEE 1584 Standard. IEEE 1584 is widely seen within the worldwide electrical engineering community as a valid means of determining incident energy levels and arc flash boundaries and calculations are auditable against this standard. The standard does not offer any advice or recommendations in respect of personal protective equipment or any other mitigation measures.

The IEEE 1584 calculations are based upon an empirically derived model and statistical analysis to produce mathematical equations and provides a reasonable degree of accuracy. The 2018 guide was developed from over 1860 short circuit tests performed at various voltage levels. It is important to understand however, that there are limitations to calculations based upon the standard.

The model is valid for systems having: -

- Voltages in the range of 208 V – 15000 V, three-phase.
- Frequencies of 50 or 60 Hz.
- Bolted fault current (Prospective Short Circuit Current) in the range of:

    - 700 A to 106,000 A for voltages between 208 and 600 volts.
    - 200 A to 65,000 A for voltages between 601 and 15,000 volts.
- Working Distances greater than or equal to 305mm.
- Grounding of all types and Ungrounded. (Earthed and Unearthed systems)
- Equipment enclosures of maximum height and width 1244.6mm. The width needs to be larger than four times the gap between the conductors.
- Gaps between conductors in the range of:
    - 6.35 to 76.2mm for voltages between 208 and 600 volts.
    - 19.05 to 254mm for voltages between 601 and 15,000 volts.
- Faults involving three phases only.
- AC (Alternating Current) faults only.

There are some key points to be made when interpreting the results from the arc flash calculations which are summarised as follows:

a) **Arcing Duration** has a linear effect on the incident energy explains why lower prospective short circuit current does not always correlate to low incident energy levels.
b) **Distance** from the arc has an inverse exponential effect meaning that small changes in distance can have large changes in incident energy.
c) **X/R ratio, supply frequency and electrode material.** Variations in X/R ratio of the system, the supply frequency or electrode material do not affect the results. Although the testing was at 60Hz the system of equations for calculating arcing current and incident energy should be accurate over the range of 50 Hz to 60 Hz. Conductor material was not found to be significant although other testing standards do use copper and aluminium electrodes.
d) **Arcing Current** depends primarily on available short-circuit current, bus gap (the distance between conductors at the point of fault), electrode configurations, enclosure size, and system voltage.
e) **Incident Energy** depends primarily on calculated arc current, arcing duration, and working distance. Electrode gap is a smaller factor.
f) **Earthing.** In the IEEE 2002 model there were different factors for earthed (grounded) and unearthed (ungrounded) systems. This has now changed, and the IEEE 1584-2018 model does not have system earthing configuration as an input parameter. The test results did not show any significant impact of the system grounding or bonding on the incident energy released by the arc.
g) **Arc Sustainability**. The commentary to the earlier IEEE 1584 2002 guide stated that it was very difficult to sustain arcs at lower voltages they were only able to sustain an arc once at 208 volts. The 2018 model states that "Sustainable arcs are possible but less likely in three-phase systems operating at 240 V nominal or less with an available short-circuit current less than 2000 A". At lower voltages, there is always the possibility that the arc will self-extinguish but that would be very difficult to model.
h) **Single Phase Systems**. At European single-phase harmonised voltages, (220/230 volts) we do know that severe burns have been caused to operators. However, IEEE 1584 deals with three phase faults only. Although there have been various papers that have suggested applying a correction factor to a three-phase result, I remain sceptical that this would be meaningful or accurate. A conservative approach would be to use the single-phase voltage and prospective

short circuit current and then base a prediction of hazard level on a calculation of the three-phase incident energy.

i) **DC systems** are not included in the IEEE 1584 model although there has been a desire at committee level for many years to include DC testing. It is possible that DC testing will be developed in the future.

j) **Fault Types**. All testing used in the basic incident energy model was three-phase testing because three-phase arcs produce the greatest possible arc flash hazard in ac equipment. Open LV Boards and bare conductor lines where single-phase faults are likely can only be addressed as three-phase faults using the models in this guide. Other possibilities are; (i) It is widely recognised that line-to-line faults in equipment or cables often quickly escalate into three-phase faults. (ii) Low voltage system earth faults will also often escalate very quickly into three-phase faults.

k) **Arcing Current Variation Factor**. The model relies upon a calculation of the predicted arcing current value so that the operating time for the upstream protective device can be determined. I explain the fault level paradox later which talks about very large variances in incident energy due to very small changes in the operating time of protective devices due to settings or tolerances. The solution is to make two arcing current and energy calculations; one using the calculated expected arc current and one using a reduced arcing current that is lower. This is achieved by using an arcing current variation factor and then calculating a second incident energy level and arc flash boundary. The hazard severity is therefore, based upon the higher results of energy level and arc flash boundary.

The IEEE 1584 Guide for Performing Arc Flash Hazard Calculations can be purchased from the Institute of Electrical and Electronic Engineers. https://standards.ieee.org

4.2.2 German Guide DGUV-I 203-078 Arc Flash Calculations

Unlike the IEEE 1584 Guide described previously, the German guide DGUV-I 203-078 (Thermal Hazards from Electric Fault Arc) is very different in approach and the two standards cannot be compared with each other. The calculations used by DGUV-I 203-078 are derived from the box test method for PPE which is detailed in the standard IEC 61482-1-2:2014 Live Working – Protective Clothing against the thermal hazards of an electric arc. This test standard is discussed in detail in Chapter 7: Protection, but in summary, it is a simple pass/fail against just two fixed parameters of fault current, 4kA and 7kA. In other words when tested according to box test, a sample of the material that the protective clothing is made of is assigned one of two arc protection classes (APC). This will either be APC 1 which is subjected to a prospective short circuit current of 4 kA for 500ms or APC 2 at a prospective short circuit current of 7 kA for 500ms. The test is fairly simple and can be replicated on many industrial sites unlike the open arc method that requires serious decoupled motor/generator supplies.

The PPE box test method predates the calculations and more recent refinements of the mathematical models that have been achieved from work at Ilmenau Technical University in Germany. In other words, the results of the box test output have been reverse engineered to provide a quantitative method of matching site conditions to the test method. The tests to produce the IEEE 1584 calculations is discrete from the open arc tests to assess the thermal performance of PPE whereas, the DGUV-I 203-078 calculations are integral to the box test. As of 2021, the time of writing, a 2020 edition of this guide had been published in German and an English translation is expected shortly.

4.2.2.1 Merits and Drawbacks of the DGUV-I 203-078 method

Whilst the DGUV guide is used in parts of Europe for low voltage utility applications, I would recommend the use of IEEE 1584 for industrial and commercial applications. That said, the calculations are fairly simple bearing in mind that IEEE 1584 has a total of 25 formulae some of which have six variables and thirteen coefficients.

DGUV-I 203-078 considers the reactive power component for the power transferred into the arc whereas IEEE 1584 does not. It also highlights the use of arc voltage and resistance.

Unlike IEEE 1584 which is based on empirically derived data, DGUV-I 203-078 is a theoretical model. The voltage range is from 50 volts right up to 110 kV, but it is mainly applied to low voltage applications. The test rig resembles a low voltage utility service point or cut out at a voltage of 400 volts and has an aluminium and a copper electrode. The mixture of aluminium and copper outside of utility distribution termination equipment is relatively rare nowadays.

There is just one electrode configuration in DGUV whereby IEEE 1584 considers five configurations. Some may see that as an advantage but there is considerable variance of arcing current results because of the additional electrode configurations. I would trust the IEEE 1584 results as they emulate real conditions particularly circuit parameters. This is an important consideration when calculating arcing current as the two methods will produce differing results. If the arcing current is incorrect then this will have a huge impact when predicting the severity of the arc hazard.

One of the drawbacks of the DGUV-I 203-078 method is that the algorithm is reverse engineered from a test method which does not emulate field conditions in commercial and industrial setting. It is after all, a single phase 400-volt test whereas the IEEE 1584 formulae are based on real world conditions and are divorced from the PPE open arc tests. In other words, they are independent.

The following table gives a comparison between the two methods.

Comparison between the DGUV-I 203-078 and IEEE 1584 Guides	
DGUV Guide	IEEE 1584 Guide
Theoretically derived from the box test method of testing protective clothing against the thermal hazards of an electric arc to IEC 61482-1-2: Live working.	Empirically derived from actual high power laboratory tests for the full range of the guide.
Linked to the box testing of PPE.	Independent of PPE testing.
The R/X ratio required.	No requirement for R/X ratio.
Requires maximum and minimum fault currents to IEC 60909.	Calculates a minimum arcing current to account for variations in system parameters.
Note: that in all cases when obtaining fault levels, the discovery phase should account for system configuration and of utility variations as a prerequisite for using both methods.	
Arcing current theoretically derived from a single-phase low power source which cannot be matched to site conditions.	3 phase arcing current based upon 5 different electrode configurations which are based upon actual site conditions.
No allowance for enclosure dimensions.	Correction factors calculated for different height, width and depth of enclosures.
Aluminium and copper electrodes used in the box test.	No requirement for aluminium electrodes.
Calculates arc energy.	Calculates incident energy level at a working distance.
PPE restricted to standard protection APC1 or enhanced protection APC2 only.	No restriction on PPE range (except for an upper limit 100 cal/cm^2 -see IEC 61482-2)
Application of correction factors for transmission factor KT (enclosed, semi open and open arc) plus actual distance to the APC1 and APC2 creates an equivalent PPE protection level. This equivalent protection level must be greater than the arc energy.	PPE matched directly to the calculated incident energy.
Does not provide an arc flash protection boundary.	Calculates an arc flash protection boundary
Gives a maximum cut off disconnection time of 1 second for reaction time.	Gives a maximum cut off disconnection time of 2 seconds for reaction time.
Starts the risk assessment with PPE in mind rather than a last resort. Does not give a meaningful severity calculation.	Gives a measure of the severity of the hazard. PPE recommendations are excluded from the guide.

My preference for the IEEE 1584 method for industrial and commercial applications is given by the final point in the above table, where the DGUV method starts the risk assessment with PPE in mind rather than a last resort. The DGUV method does not give a meaningful severity calculation. To give an analogy: if you wanted to know if your workers require ear protectors, you will measure the sound levels in dB and then try to isolate or reduce if above legal limits. As a last resort you would obtain ear defenders capable of providing the necessary protection/attenuation. The DGUV does not give a severity level such as the onset of a second-degree burn. IEEE 1584 on the other hand, gives a severity level and as it says in the scope: "Recommendations for personal protective equipment (PPE) to mitigate arc-flash hazards are not included in this guide". In other words, you do not have to have PPE in mind when using IEEE 1584, it simply answers the question “who may be harmed and how?”. PPE comes several steps later as a last resort.

4.2.3 DC Systems

DC systems are not included in the IEEE 1584 model although there has been a desire at committee level for many years to include DC testing. There have however, been several technical papers that have been published that have produced theoretical formulae for determining the incident energy levels. These are covered in Chapter 14: Hazard and Severity Calculations and the online tools provided by the European Arc Guide.

4.2.4 Warning

The prediction of the arc flash thermal hazards given above do not take into account the possibility of toxic gases, projectiles and molten metals from an arcing event. Arc 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.

4.3 The Fault Level Paradox

Based on the question that I asked earlier, is it the equivalent of a tiger or a domesticated cat inside the panel? The magnitude of incident energy available during an arc flash is directly dependant on the short circuit current flowing through the air gap and the time it takes an upstream protective device to clear the fault. In general, the greater the short circuit current the greater the incident energy, however this is not always the case.

It is a commonly held belief that the greater the available short circuit current is at a given location; the more damage can occur. When it comes to evaluating a protective device’s interrupting and withstand capability, this is a true statement. However, in the case of arc flash, it is quite possible that a lower short circuit current can cause the upstream protective device to take longer to operate and actually increase the overall incident energy exposure.

The time current graph in Figure 4.2 can be used to illustrate this paradox. The horizontal axis of the logarithmic graph represents current in amps and the vertical axis represents time in seconds. The time current curve, also known as the tripping characteristic, defines the relationship between current and tripping time. Time current curves will typically have an inverse characteristic meaning time and current are inversely proportional to each other. The greater the current the less time it takes the device to operate, and the lower the current the longer it takes to operate.

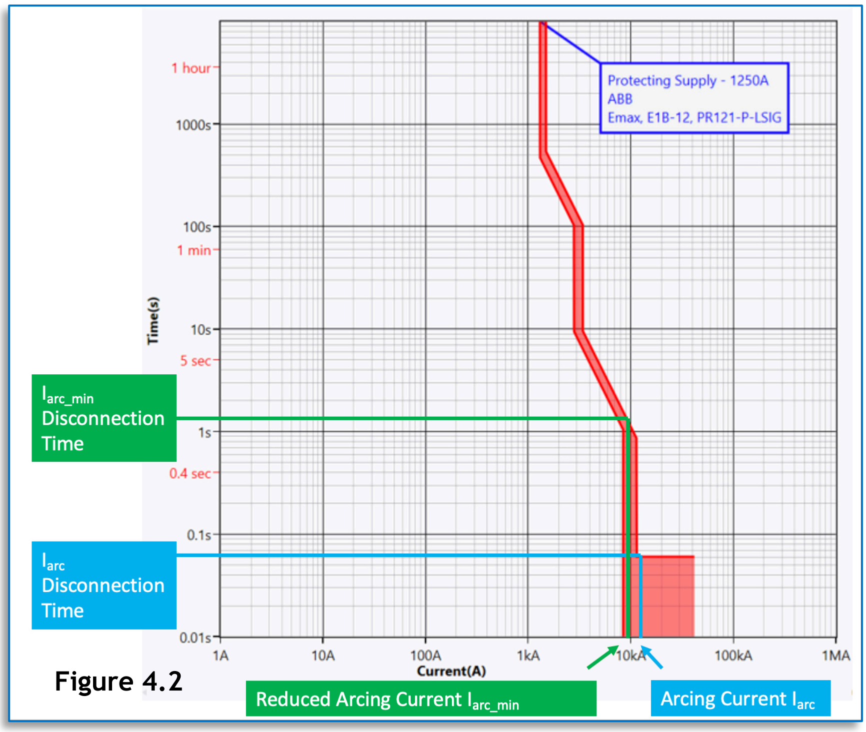


Figure 4.2

Many protective devices will have an instantaneous trip function defined by a vertical band, as shown on the graph. If the current exceeds this value, it will trip in just a few cycles. However, if the current is less than the instantaneous value, the device will trip with some time delay.

This graph illustrates that if the short circuit current flowing to the arc is 16,000 amps, the protective device will trip instantaneously (0.06 seconds) resulting in incident energy of approximately 2.5 cal/cm^2. (Assuming IEEE 1584 VCB electrode configuration, 32mm arc gap and 450mm working distance) If the current drops to 8,000 amps, the device will no longer trip instantaneously, but instead will trip in 2 seconds. Even though the short circuit current is halved, because of the increase in the protective device's tripping time, the overall incident energy increases to over 40 cal/cm^2 which is seriously high in terms of thermal energy. If we were to change the electrode configuration to HCB, then the incident energy would rise to 88 cal/cm^2. This paradox shows how important it is that an arc flash calculation study includes various operating scenarios to evaluate the effect that the short circuit current will have on the device clearing time and ultimately on the incident energy.

I first used the term fault level paradox in several published articles over 10 years ago to describe how high fault levels could determine that the protection would operate more quickly and reduce the time that it takes to clear an arcing fault. *"Wow - who would have thought that I would have been in more danger 460 metres away from the substation than directly outside."* This was a quote from a seasoned distribution engineer when I first revealed the fault level paradox to him. We were looking at incident energy levels for live jointing operations on 400 and 500 ampere, 185mm^2 aluminium waveform low voltage feeders. The thought that the incident energy was actually quite low outside the substation was counter intuitive. It was at its highest nearly half a kilometre away.

4.3.1 What happened to good old I^2t?

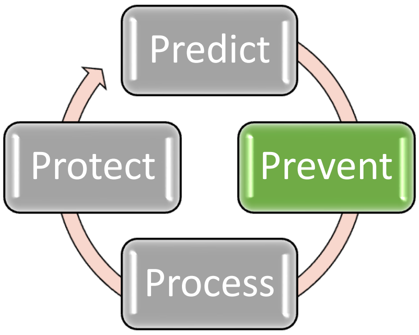
This might seem blasphemous to a power engineer but at low voltage, fault level can often be your friend when it comes to the rapid disconnection of dangerous arcing faults. When the protection fails to clear the fault quickly it is usually because of impedance. You could say, that for low voltage, it is not the fault level that causes the danger, it is the impedance! Apart from that, the energy let through represented by I^2t still holds true. What I have demonstrated so far is that the incident energy depends upon both the current and the time. We must always bear in mind that other destructive consequences of arcing faults, such as ballistic effects, are definitely directly related to the fault level.

Learning Points

- The Prediction step is fundamental to the whole risk assessment approach. To quote Peter Drucker; “if you can’t measure it, you can’t manage it.”
- Arc Flash Hazard prediction is about much more than PPE.
- High prospective short circuit current does not equal a high thermal hazard.

Chapter 5

Prevention & Minimisation



Prevention must be the fundamental safety principle for the management of arc flash hazard. This is embodied in European legislation and cannot be over emphasised. 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. To work dead the electricity supply must be isolated in such a way that it cannot be reconnected, or inadvertently become live again, for the duration of the work. As a minimum, this will include the positive identification of all possible supply sources, the opening and locking of suitable isolation points by personal padlocks and for the proving dead at the point of work. This section is dedicated to the fundamental principle of prevention starting with the elimination of live working but then we go on to describe various practical solutions to help the reader to understand and to embrace the various methods and technologies that are available.

5.1 Elimination of Live Working

To reiterate the earlier point, electrical tasks must be carried out with the equipment made dead and isolated wherever possible. However, the actions required to make safe can expose the person undertaking the isolation. Questions of residual risk and competence of the individual will need to be considered. For instance, the safety considerations and competence of an individual making safe an underground high voltage cable to put others to work is going to be of a much higher order then that of someone isolating a piece of equipment from a local isolation point for themselves. The first example is going to require someone with a high degree of knowledge, training and experience working to strict safety rules, applying circuit main earths, padlocks, issuing permits, discharging a spiking gun and often under the supervision of a control engineer. The second example of an individual isolating for themselves carries fewer processes but the risk assessment approach is the same. I will cover this in a little more detail in Chapter 6: Process, Policies and Procedures.

Designers of electrical systems should consider the need to eliminate live work as part of the overall system design. Some of the elimination measures include the segregation of power and control circuits, safe control voltages and currents, finger safe shrouding of terminals and built-in test points.

Even then, the condition of the electrical equipment must be verified before work commences. It is not uncommon to have accidents occur on equipment that has been rendered dangerous, because electrical workers have not reinstated vital safety components such as door interlocks and insulating shielding after completion of work. I will say much more about this in the chapters on Process and also Myths & Mistakes. (Chapter 6: Process, Policies and Procedures, and Chapter 12: Myths and Mistakes)

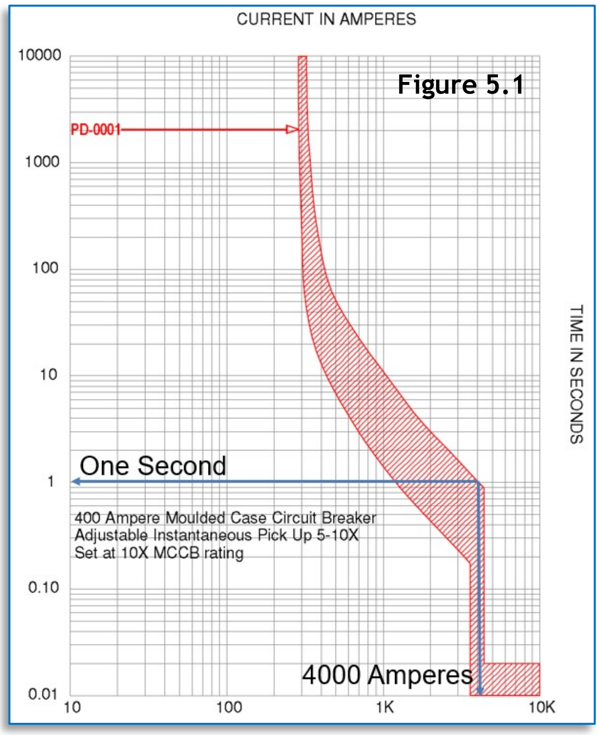
5.2 Protection Settings

The reason why I have written a dedicated section on protection settings rather than a generic approach to protection is born out of my own practical experience in the field of arc flash prevention. Whilst protection systems will not eliminate the arc flash hazard entirely, they can prevent events from causing serious injury and damage. Having undertaken studies in industry, commerce, utilities, power stations and distribution companies, I can boldly state that over 90% of seriously damaging events can be prevented by performing alterations to protection settings.

Since incident energy is a function of short circuit current and the protective device clearing time, a reduction of the arc flash hazard may be achievable by evaluating the protective device sizes, settings and time current curves. Many times, where the incident energy is at dangerous levels, it is because the upstream protective device's instantaneous adjustment is set too high, and the device is operating in the long-time delay region. Lowering the instantaneous setting may allow faster trip times resulting in lower overall incident energy. Caution should be exercised however, because lowering a device's trip setting can create a reliability issue by compromising selective coordination with other devices. This could cause multiple devices to trip during a short circuit and lead to a more widespread outage.

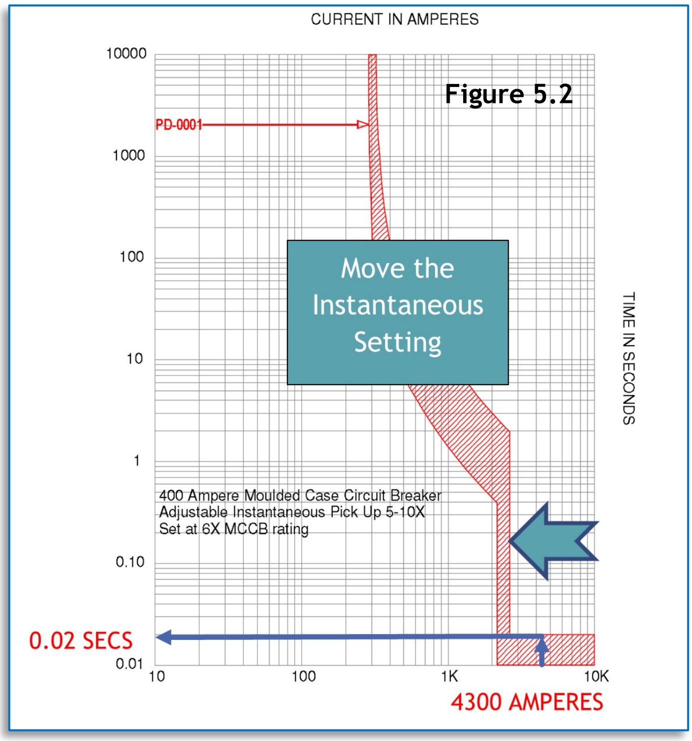
The problem can be solved by changing the device settings only when live work is going to be performed. After the work is completed, the original settings can be restored to maintain existing selective coordination. These types of temporary setting changes are often referred to as "maintenance settings". There are manufacturers who have devised maintenance setting schemes for this purpose and this is described later in more detail.

To consider the point further I am going to use the example of a low voltage circuit protected by a simple 400 ampere moulded case circuit breaker with an adjustable instantaneous pick up of between 5 and 10 times the circuit breaker rating. That is, the instantaneous trip can be set at between 2000 amps and 4000 amps. Illustrated in Figure 5.1 is a time current characteristic curve for the device which has an opening and a clearing characteristic.



We are interested in the clearing characteristic for the purposes of this example which is the line to the right-hand side of the curves. If we predict the arcing current to be 4000 amps and the instantaneous setting of the circuit breaker is at 10 times (4000amps), the time for trip will be of the order of 1 second. Should an arc flash occur and be sustained for this period of time a large amount of thermal energy will be expended in the arc resulting in damage and injury depending upon the design of the equipment. Based upon arc flash calculations for enclosed low voltage equipment this could be in the order of around 11 cal/cm^2. A solution, should protection coordination permit, will be to lower the instantaneous setting to 6 times the circuit breaker rating or 2400 amps.

As you can see from figure 5.2, the resulting time to trip will be in the order of 0.02 seconds or one cycle at 50 Hertz. We have previously discussed the relationship between time and incident energy and this reduction in thermal energy is directly proportional to the reduction in tripping time. So, this simple measure, which can be accomplished by a screwdriver in this case has reduced the incident energy by a factor of 50 (1/.02) to 0.22 cal/cm^2.



My experience is that little effort has been needed to reduce dangerous fault conditions in electrical equipment because of this very simple approach. I remember working on a large technology manufacturing site which had extensive high specification clean room areas. There were 120 panels within the clean room zones that had incident energy levels above 1.2 calories per square centimetre. Working with the Duty Holder, we were able to reduce the incident energy levels below this figure by the adoption of protection alterations. The majority were comparable to the example given above. The other techniques used were to change fuse types or ratings or to reroute the source of supply from a different distribution busbar to reduce the source impedance. Quite simple measures that were inexpensive resulted in an easy to achieve hazard reduction programme for that particular client. Modifying protection settings in order to reduce the risk is what I would term the low hanging fruit of arc flash hazard management.

5.3 Improved Protection Schemes

Protection arrangements should be explored at design stage to prevent or minimise the effects of electrical flashover using schemes such as:

- Fast acting and/or current limiting protection devices
- Maintenance Setting Schemes
- High Impedance Bus Differential
- Low Impedance Bus Differential
- Arc Flash Detection

5.3.1 Current Limiting Protection Devices.

HRC Fuses. High rupturing capacity (HRC) fuses fall into the category of current limiting protection devices. In Europe the NH DIN (Deutsches Institut für Normung or German Institute for Standardization) fuses and the British Standard BS88 fuse are the most popular types of HRC fuses, and both are compliant with IEC 60269-1 standard for low voltage power fuses and both types are current limiting. The fuses are not physically interchangeable, but the characteristic curves are similar. Both NH DIN and BS88 fuses have been around for many years and have a proven reliability record. Indeed, they have remained popular with specifying engineers to this day because of their high fault current handling and minimal energy let-through (I^2t). Indeed "British style BS88 fuses are typically found in equipment manufactured in the United Kingdom or British Commonwealth countries. However, North American manufacturers have begun to specify British style fuses particularly in UPS applications at 240V or less to take advantage of their size, performance, and cost benefits". (Source Cooper Bussmann Fuses)

HRC fuses can minimise the amount of energy let through at high prospective short circuit current and therefore minimise the incident energy. See Figure 5.3. Current limiting fuses can be relied upon to operate in accordance with their operating characteristic. Circuit breakers may not if poorly maintained.

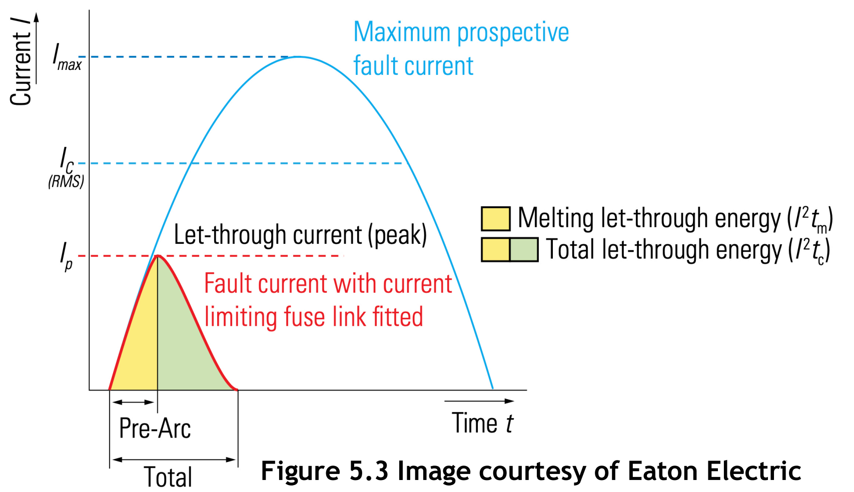


Figure 5.3 Image courtesy of Eaton Electric

A common misconception is that if fuses are current limiting, then the resultant incident energy from their use must always be lower than other overcurrent protection devices. This will only be true if the arcing current is seen by the fuse as short circuit current. As we have seen in the previous chapter, the fuse may see the arcing current as an overload and in which case the time to operate will take longer.

The graph in Figure 5.4 shows the indicative incident energy level for a low voltage system which is protected by an 800 ampere BS88 high rupturing capacity fuse.

As can be seen, the incident energy at a prospective short circuit current of 20 kA or greater is below 5 cal/cm^2. At 80 kA the incident energy is only 2 cal/cm^2. Below 20 kA however, the incident energy level is much higher as the fuse will take longer to operate and as we have seen previously, incident energy is directly proportional to the disconnection time.

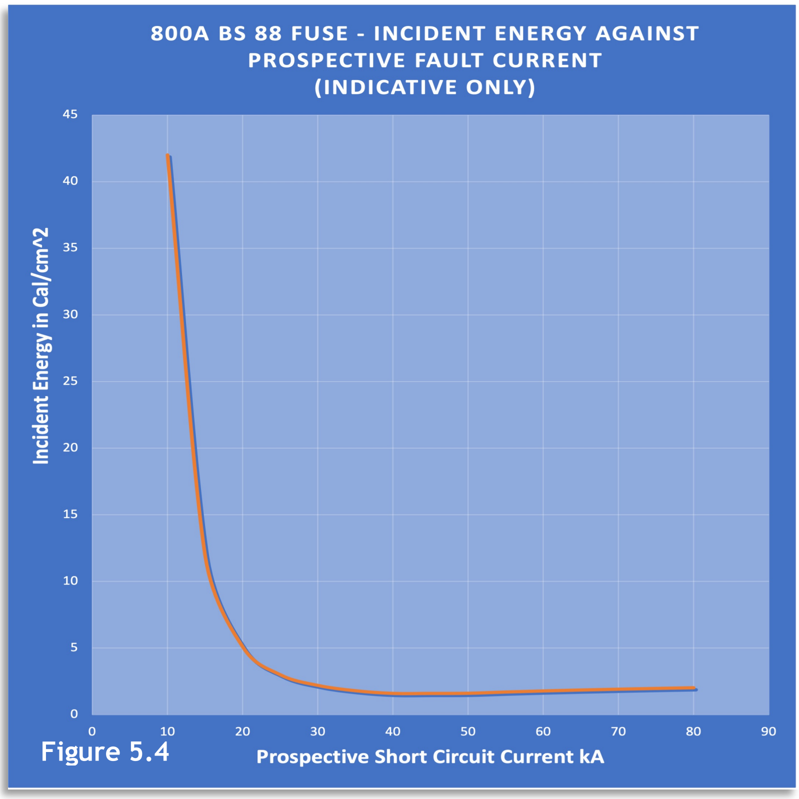


Figure 5.4

Circuit Breakers. There are also current limiting circuit breakers widely available for lower ratings (up to 630 amperes). To qualify as current limiting, they must be capable of restricting the let-through I^2t during a fault to no more than the I^2t available during a half-cycle of prospective symmetrical short-circuit current. This can be shown graphically in figure 5.5.

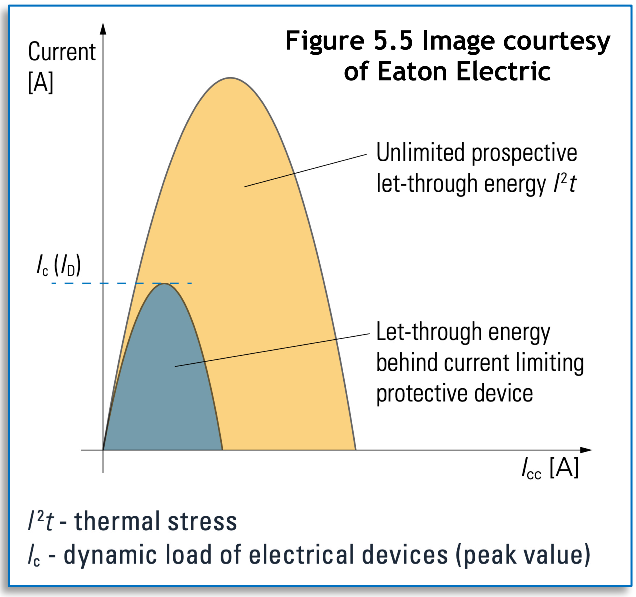


Figure 5.5 Image courtesy of Eaton Electric

Current limiting circuit breakers are identified from the manufacturer's catalogue data of current limiting characteristics for each device. If current limiting characteristics are not available, then the device is usually a non-current limiting circuit breaker. Non-current limiting circuit breakers discharge the full short-circuit current in longer time than a half cycle and their contacts must be capable of withstanding the short-circuit current for a specified time.

Fuses versus circuit breakers. This is one of those debates that exercises the minds of electrical design engineers. Experience shows that preferences are often not based upon sound principles. When it comes to arc flash, there are examples in this guide of where the use of each type of protection may have been a contributory factor in an electrical flashover accident. The first example is in my introduction. I spoke about my experience as a witness for the prosecution against an electrician who had failed to isolate an electrical system prior to his apprentice carrying out work which resulted in him being injured in an arc flash incident. The point of isolation was a 200-ampere moulded case circuit breaker which had opened but the red phase contacts were welded closed due to the earlier fault condition. Therefore, it is a misconception that circuit breakers will always faithfully open all poles of supply whatever type of fault condition. Clearly, the accident could have been avoided by implementing a proper isolation process.

The second example of a contributory factor to an arc flash accident concerned with protection arrangements is apparent in the example that I write about in Chapter 12: Myths and Mistakes (Live Working on Damaged Equipment) In that case it was attributable to the use of fuses. Whilst the fuse carrier and mono block isolator were damaged by an electrician due to negligence, it may serve to highlight that changing large fuses does require a degree of skill and care.

Having opened the debate about fuses versus circuit breakers the following are commonly understood advantages and disadvantages. Fuses are relatively low cost, simple and very reliable in respect of operation, maintenance free and can interrupt high short circuit current with minimal noise or combustion products. In addition, current limiting fuses are available in sizes greater than current limiting circuit breakers. On the other hand, circuit breakers take less time to restore power, where they can be reset following an overload condition and are generally easier to discriminate between upstream and downstream devices. In respect of arc flash protection, circuit breakers give flexibility in that they may have auxiliary devices connected such as arc flash detection and have maintenance settings applied. However, fuses can be relied upon to operate beneath their time current characteristic curve for arcing short circuits whereas poorly maintained circuit breakers may not. Protection arrangements are always a compromise between overload and short circuits, the equipment being protected and coordination requirements. As a result, both fuses and circuit breakers will commonly be used in the same electrical distribution system.

5.3.2 Maintenance Setting Schemes

Interactions with energised equipment of any description will inevitably lead to some risk. These may be inspections, testing, maintenance, operations or perhaps more intrusive tasks that have been properly assessed and stand the test of reasonableness. A solution may be to retrofit circuit breakers with instantaneous trip units or to temporarily alter the instantaneous settings on circuit breakers. Equipment manufacturers are continually developing better methods to reduce or eliminate the arc flash hazard and have come up with their own solutions to incorporate maintenance settings to the circuit breakers. One such system is described below.

Eaton Electric recently patented a system that they call “Arc flash Reduction Maintenance System(TM)” (ARMS technology) for low voltage moulded and air circuit breakers. It allows for a maintenance mode to be set on the circuit breaker which will in effect provide a lower instantaneous pick-up level via a maintenance switch, which is illuminated when activated. When fitted, it operates independently of the main protection unit and is designed to trip with no intentional delay once the instantaneous threshold has been exceeded.

Arc flash Reduction Maintenance System (ARMS)

The following example, Figure 5.6 shows how they ARMS system is deployed and as can be seen in this example this will reduce the time to trip from 250 milliseconds down to 25 milliseconds. As discussed previously, the incident energy is directly proportional to time so in this case the energy reduction is 90%.

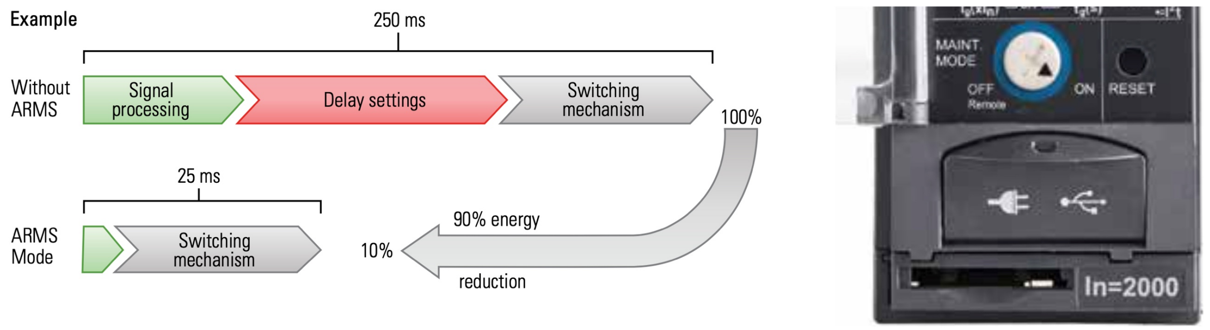


Figure 5.6 Image courtesy of Eaton Electric

A blue ring surrounding the maintenance mode switch is illuminated when ARMS is enabled.

The following time current graph in Figure 5.7 shows the normal circuit breaker settings in blue, and the maintenance setting is in red.

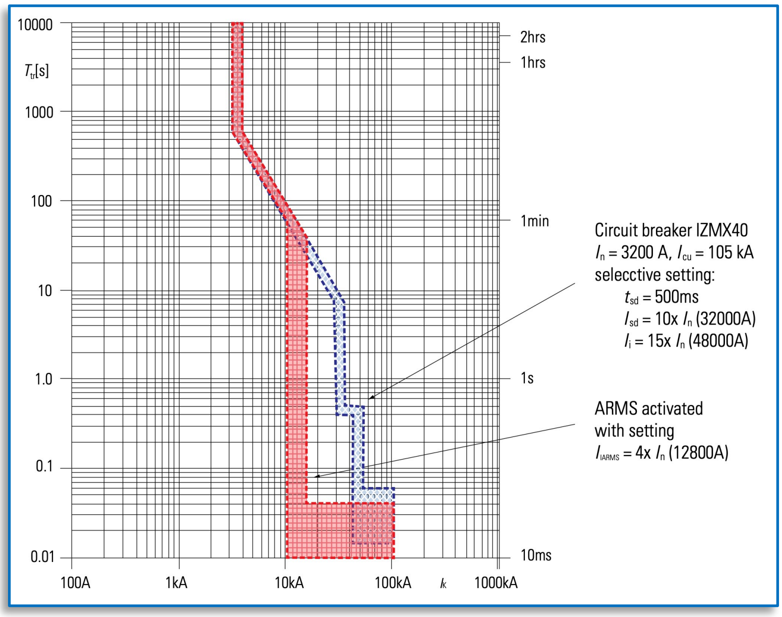


Figure 5.7 Image courtesy of Eaton Electric

As can be seen this effectively reduces the instantaneous pickup level of the circuit breaker in the same way that permanent settings are made to an existing circuit breaker as described in the previous section on protection settings. As with all modifications to protection systems, the selection of one of the reduction settings should be determined and selected by a person who is experienced in power system analysis. I can see that this type of system will grow in popularity but is a solution that is available at design stage only.

5.3.3 High and Low Impedance Bus Differential 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. The principle of operation is based upon Kirchhoff's law which states that the vectoral sum of all currents at a node or bus is equal to zero. Looking at Figure 5.8 the equipment to be protected is the switchboard and associated incoming and outgoing circuit breakers.

The current transformers (CTs) monitor the current entering and leaving the switchboard and for healthy conditions a summation of all the currents will equal zero. If there is a fault on the switchboard, or with any of the circuit breakers, then the relay will detect the differential summated current which

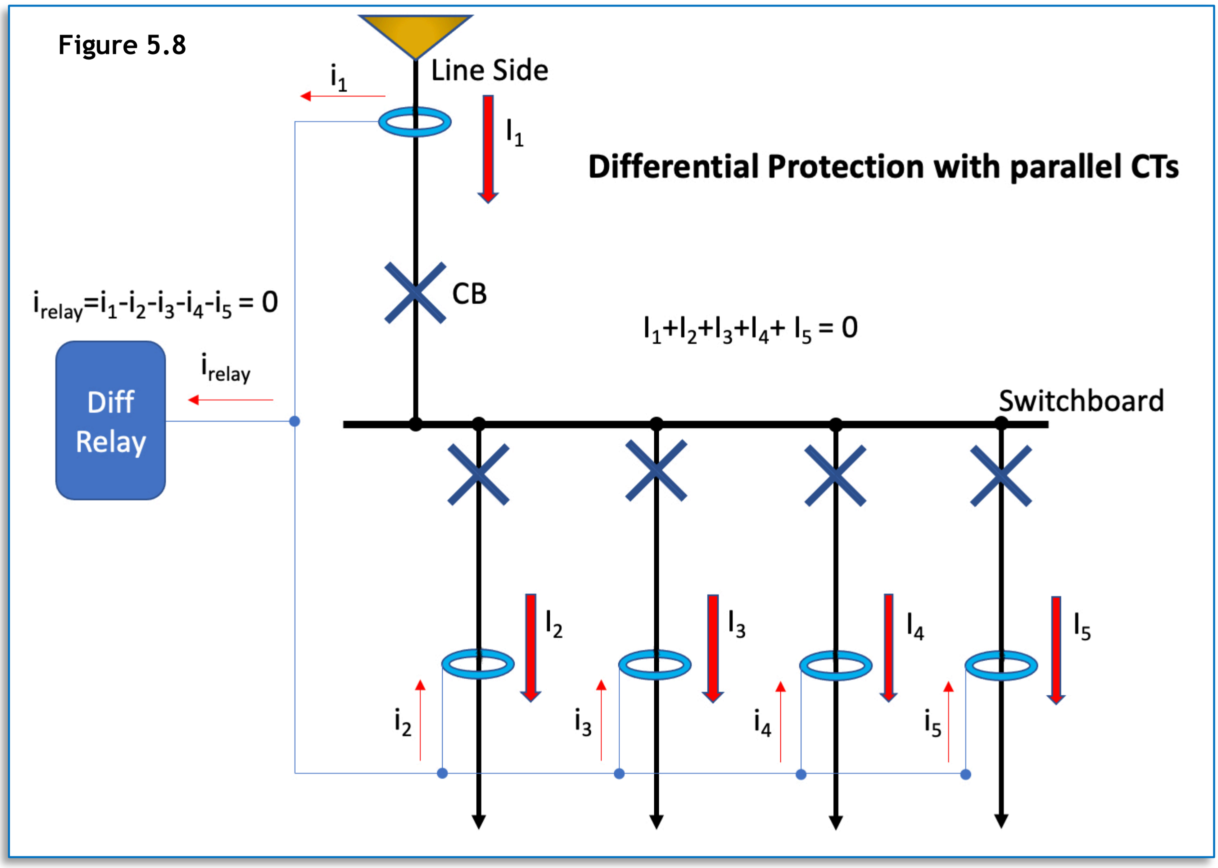


Figure 5.8

will no longer be zero. The relay will quickly trip all of the circuit breakers both incoming and outgoing thus isolating the fault and for arcing faults this can significantly reduce the damage caused. The response time is typically 20 to 30 milliseconds and combined with a typical circuit breaker operating time of 60 milliseconds this will normally give a total clearance time of less than 100 milliseconds. Whilst cost has often put off design engineers from including bus differential schemes in the past, there appears to be a resurgence in the popularity of such schemes in preventing damage from arcing faults in recent years.

There are two types of bus differential schemes, high impedance and low impedance. As the names suggest the high impedance relay presents a high impedance to current flow whereas the low impedance relay does not. The current transformers for the high impedance scheme are simply connected in parallel with the relay. Any difference in current will create a voltage drop across the relay which in turn will trip the circuit breakers included in the scheme. Because of the sensitivity of the relay, it is critical that all the current transformers match by having the same ratios and accuracy. However, one major advantage of the high impedance scheme is scalability. In other words, if another circuit breaker is added, all that is required is a matching current transformer which is simply connected in parallel with the other CTs.

Low impedance relays, on the other hand, have low impedance to current flow from the current transformers. The difference in the installation is that each CT output has to be brought back separately to a discrete input on the relay rather than being connected in parallel with the other CTs. An advantage is that the matching of CTs is no longer critical and it is possible to share the output from CTs for other relays or meters. This makes the low impedance scheme ideal for retrofitting to existing equipment. However, it is not as scalable in that each CT will require its own relay input.

5.3.4 Arc Flash Detection

Another protection method that has been developed uses an optical sensor that detects the ultraviolet light emitted from an arc flash and causes the protective device to instantaneously trip. The method monitors the current into the equipment that is protected by the optical sensors and combined with the ultraviolet light flash from the arc and the abnormal spike in current it will quickly remove the power source and prevent serious damage. Operation time is extremely fast, usually less than 10 milliseconds plus the time for the circuit breaker to clear the fault which is typically around 60 milliseconds. The system has grown in popularity over the last 10 years, and I have seen it retrofitted to very old high voltage switchgear and also to new low voltage factory-built assemblies. The main manufacturers claim tens of thousands of installations worldwide citing the fact that they are a very cost-effective alternative to traditional busbar differential schemes on medium voltage switchgear.

5.3.5 Active Internal Arc Protection

Several manufacturers have produced innovative ways of reacting to an arcing fault by effectively creating a zero-impedance short circuit across the busbars of equipment. Sometimes the energy is

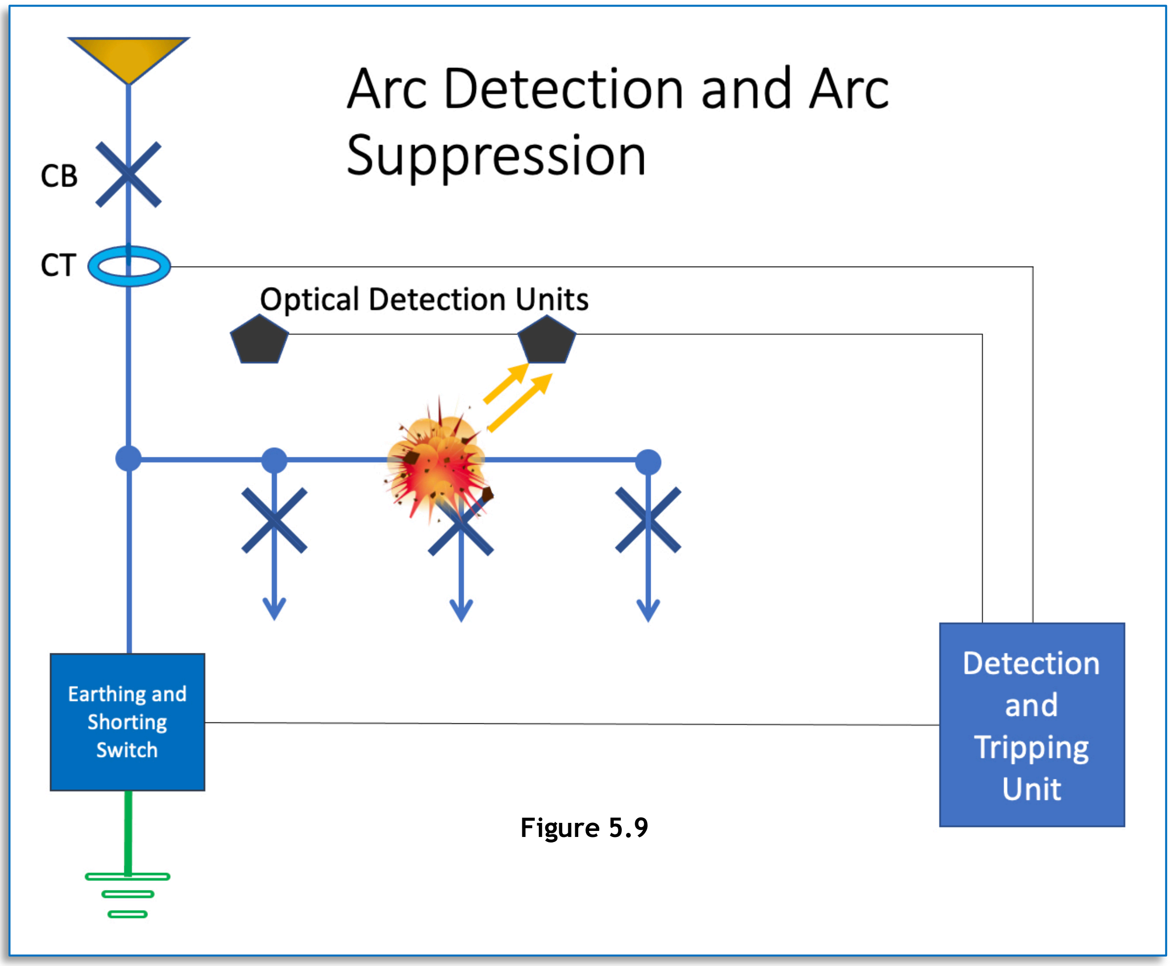


Figure 5.9

dissipated to earth. Depending upon the method used for sensing the development of an arc, they can be incredibly fast and claim disconnection times as low as 4 milliseconds. They are built to withstand voltages above 40 kV and can handle prospective currents of up to 100 kA. In Figure 5.9, there is a diagram of a system that uses arc detection utilising current and optical sensing as described previously. The arcing fault is detected by the current detection unit and simultaneously by the optical sensors which then establishes a three-phase, metallic short-circuit at the earthing switch. The resulting controlled flow of earth fault current is then finally shut down by the feeder circuit-breaker. This all happens almost immediately and whilst there is the expense to consider, the resultant damage from an arcing fault is almost nullified. This means that the equipment can be put back in service quickly resulting in reduced downtime.

5.3.6 Arc Fault Detection Devices

Although Arc Fault Detection Devices (AFDDs), also called Arc-Fault Circuit Interrupter (AFCIs), are primarily aimed at fire safety, the common thread here is that they protect human life from the effects of arcing. The detection and clearance of arcing faults before causing injury or damage is at the heart of much of the beneficial research that has been centred around the arc hazard. Although the technology has been around for over 20 years and required by US and Canadian standards for many years, it has recently been adopted in Europe. In Germany AFDDs are required in hospitals, nurseries and high value buildings. Conventional circuit design has centred upon the clearance of zero impedance short circuits and earth fault current, neither of which will clear all dangerous low-level arcing events. Earth fault protection will pick up line to earth arcing faults but not line to line parallel faults or series faults (i.e., those involving wire breaks) For that reason, AFDDs are worth a mention here to inform of the existence of the technology and possibilities for the future in arc flash detection.

AFDDs work by continuously monitoring the wave form of the current which flows in the protected circuit. Arcing current presents itself as a high frequency and the electronics within the AFDD can differentiate between arcing fault current and those arcs that are produced by switches, contacts, thermostats, carbon brushes, etc.

Currently, the typical cost of an AFDD is in the region of £150 per device which is why they tend to be selected for high-risk situations for instance, premises with sleeping accommodation, risk of fire due to the nature of processed or stored materials, thatched or timber-framed buildings and high value locations such as museums and listed buildings. Most manufacturers provide combined arc fault, over current and earth fault detection.

They are aimed at final circuits at present, up to 63 amperes, so not an option for high incident energy situations. However, one large manufacturer told me that that current capacity will expand in the future.

5.4 Switchgear Design

Designing out the arc flash risk is high ranking on the hierarchy of risk control and above safe working systems, signs & labels and personal protective equipment. It is not however, a silver bullet which will guarantee safety on high power electrical systems. **Things change and people change things**. For example, throughout the lifetime of any piece of equipment, it may be subject to unforeseen environmental changes creating stress or damage to equipment and/or human interventions which will fundamentally undermine the way in which the original design purpose was intended for. The design, however well intentioned, needs to be a part of the safe systems, safe people and safe place's philosophy. This requires a holistic approach taking into account factors which will influence safety over the lifetime of the equipment. It cannot be over emphasised how important communication is in the provision of distribution design philosophy.

5.4.1 Holistic Approach to Design

I often hear Engineers say that they have designed out the arc flash risk but, what they are really referring to is switchgear design. Designs against arc flash require much more than that. Specific factors that need to be considered when designing out or minimising the risk of arcing are as follows.

Distribution System Philosophy

a) Review operating philosophy. For instance, can parallel or very large transformers be avoided?
b) Determine the effects of arcing when designing protective equipment.
c) Can additional protective or arc reduction devices be installed? As described in this section.
d) How is the philosophy for arc prevention communicated? For instance, through design, installation, commissioning and operating manuals.

Switchgear Design

e) How will risk assessments be implemented? Such as the identification of hazards and potential failure mechanisms.
f) Consider arc detection and suppression.
g) Consider internal arc resistance.
h) Improved protection devices set to minimise arc energy.
i) Consider remote operation.
j) Consider dual settings on protective devices.

Operation, Installation and Maintenance

k) Commissioning. The feedback loop to design from final commissioning seems so obvious but sadly often overlooked. Tales of transit packaging left inside protection relays or factory settings on circuit breakers years after installation are all too common. Commissioning processes should be informed by correct procedure and manufacturers recommendations.
l) Operation and Maintenance. What access to switch gear will maintenance teams require? What level of competence do they have and under what safety rules and processes do they operate?

m) Ensure appropriate test, inspection and preventative maintenance processes are in place. These processes should refer to arc flash precautions specifically such as relay setting checks, integrity of insulating shrouding, panels & fastenings and ingress of moisture.

n) How will the major risk of unauthorised modifications be prevented?

In Summary, a holistic approach is much more than designing out the arc flash risk through switchgear design. Minimising of the risk of arcing requires whole life care through distribution philosophy, system design, commissioning, maintenance, auditing, and operation. To achieve this requires clarity of policies through leadership and control. Neglectful dilapidation of equipment such as control panels is a tangible indicator that the policy is not working. The diagram in in Figure 5.10 shows the relationship between the Distribution Philosophy, Switchgear Design and Operations and Maintenance.

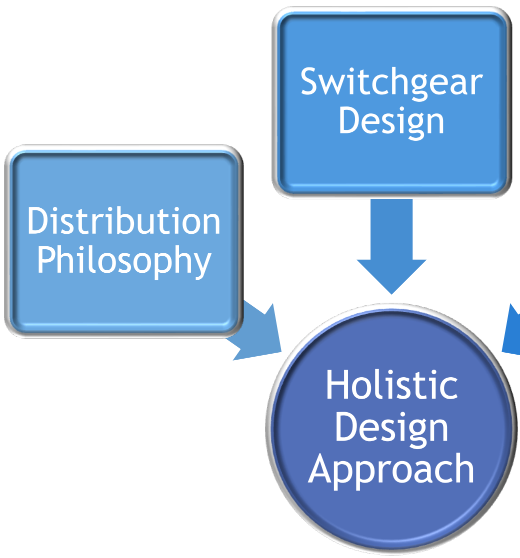


Figure 5.10 The relationship between the Distribution Philosophy, Switchgear Design and Operations and Maintenance.

5.4.2 Design of Low Voltage Switchgear

At low voltage, the design of high-power switchgear is often bespoke in nature and termed as a Power Switchgear and Control Gear Assembly. The standard IEC 61439-2 Power switchgear and control gear assemblies (PSC) applies to such assemblies and stipulates the responsibilities of the end user, the original manufacturer, and the assembly manufacturer.

The assembly manufacturer (manufacturer of the switchgear and control gear assembly) takes responsibility for the completed assembly, but this is often not the original manufacturer of the equipment. They are responsible for the manufacture, conformity to standards, including those of the original manufacturer and routine tests. The user or customer may be represented or assisted by a designer who has, in my view, the greatest responsibility in providing specific design characteristics for the assembly. They will have to provide information such as supply and load characteristics, the environmental conditions and details of operation and maintenance. Dependent upon this data, the final design of the switchgear could vary widely from one assembly to another. There is no specific international standard that covers arc containment in low voltage equipment so it is vitally important that the user (or user's designer) understands how the specification can help prevent the propagation of an internal fault. There was a time when the risk of internal faults was ignored completely and the term "fault free zone" was used to describe an area of a switchboard that had low risk. Experience shows however, that where there is a current carrying conductor, there is the possibility of a flashover. In Figure 5.11 you can see the wide difference in specifications for the insulation of busbar systems.

Figure 5.11 Non-Shrouded and Shrouded Bus Bars

IEC 61439-2 also identifies the four main categories of separation: Forms 1, 2, 3 and 4 within assemblies. I have included references to free publications that describe the forms of separation with some detail and clarity. Put simply, the higher the form number, the higher the degree of separation between terminations, functional units and busbars. So, it follows that the higher the number, then the higher the level of safety and the greater the number of tasks that can be carried out whilst the switchgear is energised.

But we cannot rely solely on the design of equipment for safe working and therefore any activities must be covered with risk assessment and safe systems of work. In arriving at which form of separation will be required, reasons for access whilst the equipment is energised will need to be explored. Some reasons may be as follows, although justification is another matter.

a) Routine maintenance, where applicable.
b) Adjusting settings of overloads and protective devices.
c) Resetting Overload or short circuit protective devices.
d) Changing fuses.
e) Taking instrument readings or measurements
f) Fault finding.
g) Re-configuring control circuits.
h) Replacing components.
i) Terminating power and/or control cables.
j) Changing the configuration of outgoing circuits.

One point of contention is how the forms of separation are interpreted for interactions with energised switchgear. For instance, there are references in some manufacturer's information that state that Form 4 construction is suitable for the connection and disconnection of cables whilst adjacent circuits are live. Whilst the source is named as the BEAMA Guide to Forms of Separation for Low Voltage Switchgear and Control Gear Assemblies to BS EN 61439-2 there is an extremely important caveat given in that document under the section on "Other Considerations Item 7." This states the following. *"Safe working with adjacent equipment energised - Switchboard manufacturers cannot give all embracing assurances for safe working, according to the form of separation with parts of the assembly energised. Specifying a particular form of separation will not guarantee this for any given form number. Effectively this means that where live working is being contemplated, a risk assessment and judgement must be made for every situation by the Duty Holder."*

To illustrate this point, compliance with IEC 61439-2, Power switchgear and control gear assemblies (PSC) requires that the separation between functional units, separate compartments or enclosed protected spaces is attained by either one or more of the following conditions:

- Protection against contact with hazardous parts. The degree of protection shall be at least IPXXB.
- Protection against the passage of solid foreign bodies. The degree of protection shall be at least IP2X.

Both methods are similar and often referred to as "finger safe" although it is just method IPXXB that uses a test finger to prove compliance. In either case, a 12mm gap will be acceptable and this is enough to allow the passage of some tools, fastenings and cable armour wires. The main message here is to be aware that equipment design alone does not ensure safe working on energised equipment. I have referenced forms of separation in my chapter on Myths and Mistakes later and give examples where misinterpretation of design criteria has led to accidents in Form 4 equipment which is the specification for higher forms of separation.

For many of the reasons for access to low voltage power switchgear and control gear assemblies, safety can be enhanced at design stage by reducing the voltage of all controls preferably to 24 volts DC. In addition, by moving them to separate cabinets or enclosures there is a reduced requirement for working on or near energised circuits.

5.4.3 Low Voltage Switchgear and Control Gear Assemblies, Internal Arc Protection

Switchgear that is termed as arc resistant uses various methods to contain or redirect the arc away from the operator or from causing damage to the equipment or surrounding environment. Typically, such equipment will use systems such as venting or containing the arc and international standards are being refined constantly to reflect the progress in this regard.

Internal arcs within switchgear are not common but the severity can be catastrophic. Causes of internal arcs can be the result of incorrect maintenance, vermin, ingress of water or dust, dielectric faults to insulators, terminations, current and voltage transformers. Design issues such as overstressing of functional units and susceptibility to overvoltage and transients are also contributory factors. Not forgetting good old wear and tear and ageing.

I stated previously that there is no specific international standard that covers arc containment in low voltage equipment. There is, however, an IEC document, IEC/TR 61641, Enclosed low-voltage switchgear and control gear assemblies - Guide for testing under conditions of arcing due to internal fault. This is a technical report which provides guidance on testing under conditions of arcing due to arc faults (not an IEC standard) and is the document to consider. Most low voltage switchgear and control gear assemblies achieve compliance by safely exhausting the arc to safety and away from operators. This is by the use of ducts, chimneys or vents and some examples are shown in Figure 5.13.


Figure 5.13 Arc exhaust ducts.

Compliance with IEC/TR 61641 does not afford protection against injury from arcing faults whilst enclosure doors are open and as we have learnt, two thirds of arcing events happen given that scenario.

5.4.4 High Voltage Switchgear and Control Gear Assemblies - Internal Arc Protection

The international standard IEC 62271-200 High-voltage switchgear and control gear applies to equipment above 1000 volts. An option of the standard characterises the ability of the equipment to contain the effects of an internal arc fault whilst reducing the risk of burns to individuals in the vicinity. It provides a rating referred to as internal arc classification, often referred to as arc resistant classification. The concept of internal arc test has been extended to low voltage assemblies by the IEC Technical Report IEC/TR 61641 as mentioned in the previous section. Note that the internal arc type test is an optional test within IEC 62271-200 and conformity is not mandatory. Clearly, the internal arc rating has not prevented the actual arcing event but seeks to prevent injury to operators and in some cases the public who may be in the vicinity of the equipment. The rating is given for switchgear which is operating under normal conditions which means that no doors or panels are open. To achieve the rating, the equipment will be tested in a high-power laboratory where it is subject to an internal arc fault. The switchgear is surrounded by cotton indicators which simulate the presence of a person and one of the criteria to achieve compliance is that the indicators will not ignite under fault conditions.

In addition to protection to individuals from the thermal effects of an internal arc, the standard requires the verification that there are no mechanical injuries. No switchgear panel or door must open, and no dangerous parts may be ejected. The IEC 62271-200 classification concentrates on reducing risk of personal injury and does not provide any criteria for the resulting damage within the enclosure which could be extensive. Also, another effect of internal arc is pressure stress in the switchgear which must be vented away from personnel. For indoor switchgear, consideration must be given to how this pressure is dissipated to avoid damage to the switchgear building perhaps through overpressure relief systems.

To be comprehensive, the following list of criteria must be fulfilled to achieve compliance.

1. Covers and doors remain closed. Limited deformations are accepted.
2. No fragmentation of the enclosure, no projection of small parts above 60 g weight.
3. No holes in the accessible sides up to a height of 2 metres.
4. Horizontal and vertical indicators do not ignite due to the effect of hot gases.
5. The enclosure remains connected to its earthing parts.

5.5 Operations Sequence

Changing the system operating configuration (switching to an alternate feeder or engaging maintenance mode settings) may reduce the arc flash hazard. Care has to be exercised on complex networks however, as switching and paralleling supplies can result in multiple transformers feeding into a possible fault during the switching operations. This can lead to increased fault levels, even though it may be for short durations. I have known of situations where this has resulted in the over stressing of switchgear.

5.6 Remote Operation and Switching

Remote operation and switching of switchgear has been around for many years. As a concept, it is about preventing injury to the individual only, so it is not the complete answer. In other words, it does not prevent the dangerous occurrence at source and in the UK there is an obligation to report such events to the Health and Safety Executive. This obligation is expressed through the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR). That said, the systems are there to prevent personal injury and as we learnt earlier incident energy levels reduce rapidly with distance. As I have already mentioned, some of the systems have been around for many years and were used extensively in power companies and large industry when operating equipment that had been reported as defective elsewhere in the organisation or country. Perhaps there had been a failure detected on a particular make/model of switchgear for instance. It may or may not have been responsible for injury, but the details would have been reported on the National Equipment Defect Reporting System. It would be up to the particular power company to issue a Suspension of Operating Practice which could change the way in which the equipment would be operated. This would often mean that circuit breakers would need to be operated from a remote location or have access restrictions around certain items of plant. The National Equipment Defect Reporting System is administered by the Energy Networks Association on a subscription basis and is open to asset owners and service providers on a worldwide basis.

Various systems of remote switching are shown in the images displayed starting with Figure 5.15 which shows a lanyard system.

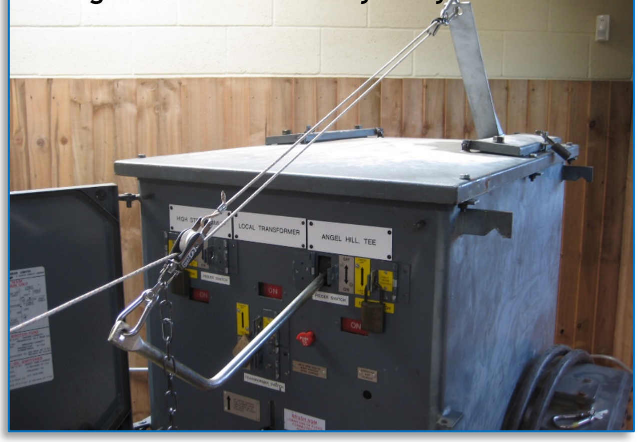


Figure 5.15 Remote lanyard system

As you can see, this looks rather crude, made up of rope and pulleys, but it was very effective at giving good distance between the operator and in this example an 11kV oil filled fused switch. Electrically powered actuators were developed for the operation of manual switchgear which could be retrofitted if necessary. As you can see from Fig 5.16, this is fitted to an outdoor SF6 circuit breaker. The drive was to reduce downtime on electrical distribution systems but would add to safety by removing the individual from the direct operation of the switchgear.

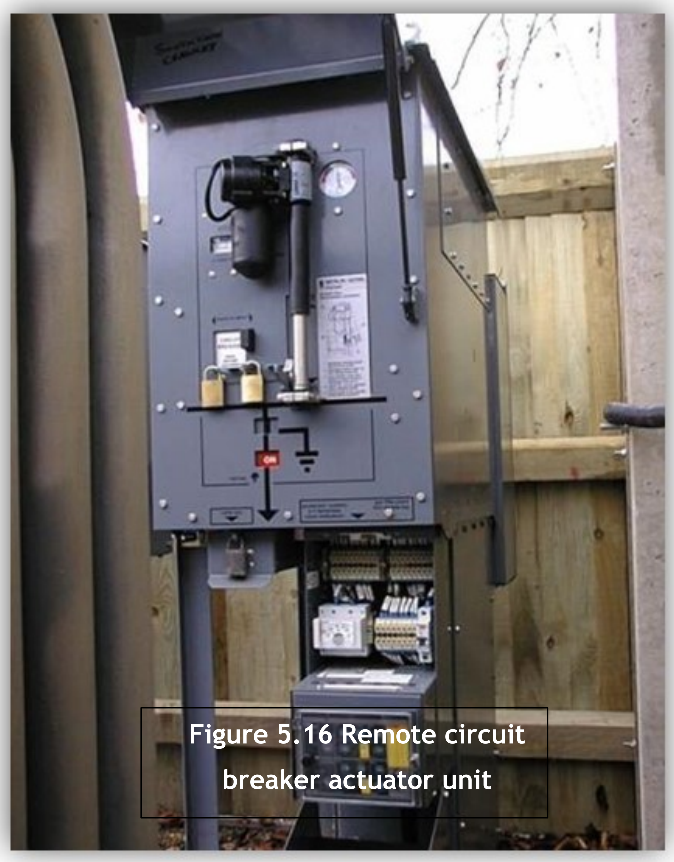


Figure 5.16 Remote circuit breaker actuator unit

There is a growing demand on switchgear manufacturers to provide remote operation at design stage. In Figure 5.17 you can see an example of a low voltage switch board designed and manufactured as a bespoke factory-built assembly which was destined for a European client. The earlier rope and pulleys have been replaced with a remote switching unit with an umbilical cord.

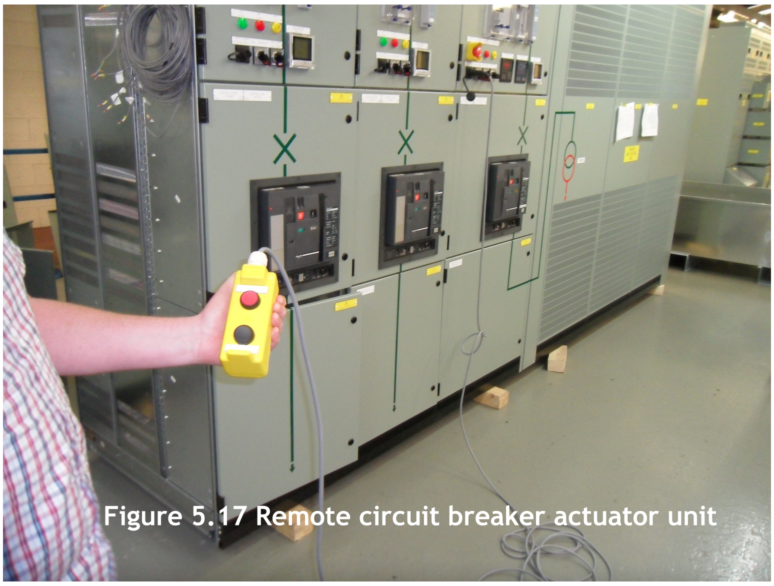


Figure 5.17 Remote circuit breaker actuator unit

The greatest risk to operators of electrical switchgear tends to be in racking operations. This is where a removable circuit breaker is racked out or racked into the fixed portion of switchgear onto busbar spouts. The operation accounts for the deaths of two engineers that I am personally aware of at a power station where I subsequently provided an arc flash study. Most large manufacturers of switchgear are providing remote racking solutions nowadays for new switchgear. There is also demand for remote circuit breaker racking devices and remote switch actuators, operators and kits for older and even obsolete switchgear and independent companies have developed solutions over a number of years. Fig 5.18 shows a rotary remote circuit breaker racking system which is fairly universal and there are fitments that allow for the horizontal or vertical operation of circuit breaker trucks at low and medium voltages.

Figure 5.18 Remote circuit breaker racking units. Image courtesy of CBS ArcSafe

5.7 Partial Discharge Testing

Arc flash events in medium voltage equipment are often preceded by partial discharge. It is defined as a discharge that only bridges part of the space between two conducting elements and is due to voids, cracks and inclusions within the insulation. Partial discharge in electrical switchgear and cables occurs because of ageing from thermal and mechanical stresses sometimes brought on by heat, humidity and other external influences. Left undetected, partial discharge can lead to catastrophic failure and electrical arc flashover. Prevention of a flashover due to partial discharge is therefore a worth looking at as an overall strategy.

Figure 5.19 Image courtesy of Megger Ltd

There is a good deal of research that suggests over 80% of all failures in high voltage electrical equipment is a result of partial discharge, so early detection can prevent injury due to catastrophic events and the consequential losses of power failure. Partial discharge presents as heat at the source of the discharge, ultraviolet and visible corona, electromagnetic radiation, ultrasonic radiation and audible sound.

The following methods can be used to detect partial discharge (PD) and provide condition monitoring of PD levels over time to warn of impending failure in high voltage cables, switchgear, transformers, generators and motors.

5.7.1 Electromagnetic Methods.

Electromagnetic (radio) waves at around 200+ MHz are produced from the site of the discharge which induce small currents in surrounding metalwork. The high frequency voltages that are produced are known as Transient Earth Voltages (TEV) and can be picked up using a capacitive probe and handheld detector or by UHF reception ultrasonic and audio microphones.

5.7.2 Acoustic Methods.

Partial discharge causes sound which is both audible and ultrasound (which is outside the audio range). This will present itself as a fizzing sound and can be picked up using sensitive microphones.

5.7.3 Thermal and Optical Methods

Partial discharge will create heat which can be picked up using thermal imaging. PD will also create ultraviolet light due to the ionisation process which can be picked up by line of sight. However, most industrial indoor enclosed high voltage equipment would not make these methods a viable solution.

5.7.4 Oil Diagnosis

Although increasing amounts of electrical equipment are moving away from using oil as an insulating/cooling or arc quenching medium, there are large amounts out there and will be for some time to come. Oil sampling and dissolved gas analysis will, over time, monitor the condition of insulating oil in equipment and may indicate serious impending breakdown due to internal arcing and or partial discharge activity. Tests on transformers should be carried out annually in my view as results of organic acidity, dielectric strength and moisture content may indicate the conditions in which the equipment will deteriorate more quickly which may lead to partial discharge.

Although partial discharge testing has been used in low voltage systems, detection is generally restricted to equipment operating at voltages greater than 3kV.

5.7.5 Portable PD Testers

Portable partial discharge testers have come on a long way and require much less expertise and technical knowledge to operate. Whilst they will give a traffic light type output, they are very useful as part of dynamic risk assessments and also to signal where further investigation will be required. They are handheld and are capable of picking up the characteristic partial discharge noise, vibrations and RF radiation through a TEV (transient earth voltages) sensor.

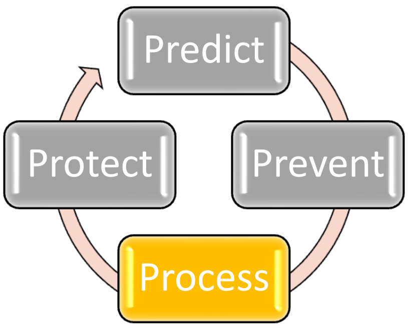
Figure 5.20 Image courtesy of Megger Ltd

Learning Points

- Prevention must be the fundamental safety principle for the management of arc flash hazard.
- It is a legal requirement to design out, eliminate or remove the hazard at its source.
- Simple modifications protection settings can account for 90% of risk reduction techniques.
- New technologies in switchgear design can vastly reduce the risk and prevent injury.
- Reducing disconnection time and increasing distance are key risk control measures.

Chapter 6

Process, Policies & Procedures



Very often electrical workers, management and duty holders do not fully understand the nature of the arc flash hazard and the seriousness of the injuries that can be sustained. As a result, experienced personnel are frequently involved in these types of accidents. Competent electrical workers should be trained in the decision-making process necessary to determine the degree and extent of the hazard and job planning necessary to perform the task safely.

A review of electrical procedures and safe systems of work can substantially raise the profile and understanding of the arc flash hazard and associated control measures. Periodic awareness and refresher training, toolbox talks and specific training in the policy, rules and procedures are essential parts of arc flash risk management.

"Most electrical accidents occur because individuals are working on or near equipment:

a) which is thought to be dead, but which is in fact live;

b) which is known to be live but those involved are without adequate training or appropriate equipment, or they have not taken adequate precautions."

This is a quotation that I have used many times and is taken from the UK HSE guidance booklet Electricity at Work – Safe Working Practices, HSG 85. This defines the key issues that need to be addressed and sets out a starting point for anyone reviewing electrical policies and procedures or maybe writing them for the first time.

6.1 Safe Procedures, Safe People and Safe Places.

Chapter 9: Electrical Duty Holders expands on the concept of the three facets of electrical safety which are safe procedures, safe people, and safe places. Whilst this chapter deals with safe policies and procedures, it also overlaps with safe people in dealing with competence and guidance on maintenance procedures which impact on safe places.

Figure 6.1 Building Blocks of Electrical Safety Management - Theme courtesy of Guardian Electric

Chapter 9, Electrical Duty Holders, breaks down and explains the concept of safe procedures, safe people and safe places in greater detail when applied to arc flash risk management.

6.2 Safety Rules and Procedures

High voltage safety rules and procedures are often straightforward to create and implement because the interactions with equipment and the competence of staff is easier to define. Low voltage rules and procedures can be more difficult because the nature of the work often entails the use of many more staff with different levels of competence. The interactions on or near live equipment is likely to be much higher and those undertaking the work may be contractors as well as staff. It is because of this complexity at low voltage, that rules and procedures need to be very specific to the organisation and environment. As a minimum, a key ingredient should include a robust set of safety rules with the following elements:

a) How the rules address company health and safety policy.
b) Clear responsibilities of stakeholders for implementation, planning, control, authorisations, audit and review. This should identify duty holders in respect of an electrical safety management system encompassing safe people, safe places and safe procedures. See Chapter 9: Electrical Duty Holders.
c) Specific authorisations of the individual for electrical activities which implies a rigorous assessment of competence.

d) Establish dead working as a principal requirement.
e) Specify controlled circumstances for live proximity work such as diagnostic testing, running adjustments and inspections.
f) Have clear instructions on where live working is strictly forbidden such as the removal and replacement of live components.
g) Auditing, monitoring and review.

To supplement the rules there can be separate procedures which can be amended or added to without the need to rewrite the electrical safety rules. They can cover specific equipment on site such as maintenance, working on generators or chiller plant for instance, but the following are some examples of underpinning procedures for the safety rules.

a) Permit to work system for work to be undertaken on the electrical system.
b) Authorisation and assessment process for any electrical work by staff and contractors.
c) Approval of electrical test equipment, tools and PPE.
d) Live testing risk assessment procedure.
e) Audit process for switchgear and control panels.
f) Signs and labels for switchgear.
g) Emergency procedures and first aid.
h) Information, instruction, and training.
i) Minor works and alterations.

There should also be local guidance written into the rules and procedures to help with interpretation and avoid ambiguity. The following flow chart Figure 6.2 shows the relationship between company policy, rules, procedures, and guidance.

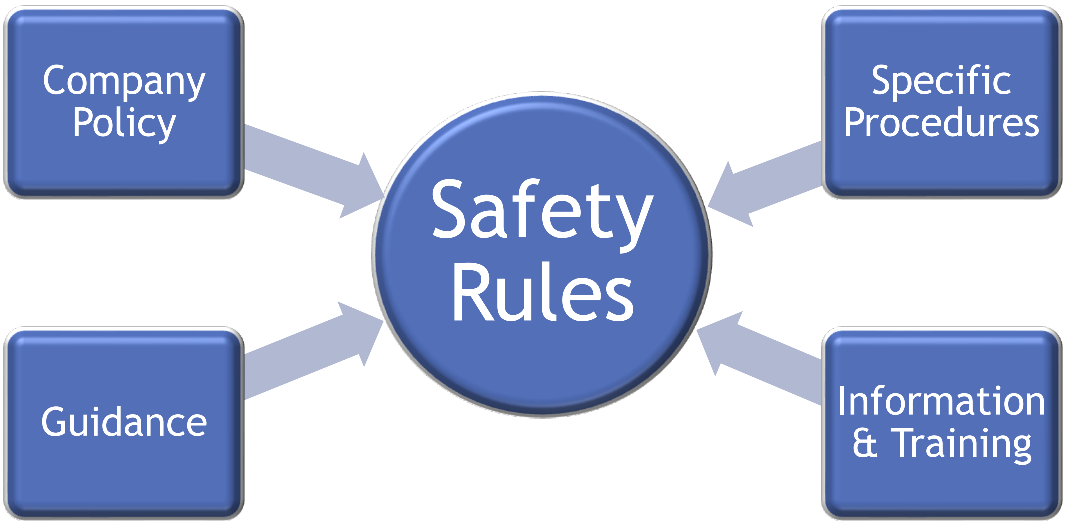


Figure 6.2

Safety rules and procedures with clear responsibilities are essential parts of a safe system of work. They should deal with properly assessing and authorising only competent people and should have systems for risk assessment. Where live working cannot be avoided, then the safe working systems should stipulate the use of the correct equipment and instruments. Electrical flashover accidents are very often caused by the operator dropping uninsulated tools or metal parts or by using incorrectly specified instruments. There should be a rule that no live work will be allowed on equipment that is damaged even for the reasons of proving dead. There have been many incidents involving damaged cables where an approach has been made to prove dead when the damaged cable was in fact still live.

6.3 Electrical Maintenance Program.

The main objective of an electrical maintenance program is to keep electrical equipment in good working condition so that it can reliably and safely operate within its design criteria. This includes testing and maintenance of circuit breakers, protective relaying and associated equipment on a regular basis. Improper maintenance of equipment can contribute to the severity of an arc flash. When a protective device such as a circuit breaker or relay is not properly maintained, the likelihood of it operating slower (or not at all) increases, which would also increase the duration of exposure to the arc flash. Although not technically part of an arc flash calculation study, a proper equipment maintenance program is vital in making sure the protective devices will operate correctly.

Maintenance inspections in particular can substantially impact on the control of arc flash risk with minimal additional effort in most cases. Visual inspections by competent individuals can pick up many defects that raise their own awareness of the hazard and reduce the likelihood of future accidents. In addition, good intelligence on vital assets can inform maintenance and replacement strategies.

In the case of control panels in industry, individuals interact with the equipment on a regular basis for production and breakdown purposes. Sometimes, it is these individuals who are responsible for the accumulation of defects that could lead to fatal electrical shocks and arc flash incidents. Issues such as forgetting to replace vital shrouds or fastenings or possibly allowing unauthorised temporary lash ups to become permanent can have fatal consequences for their colleagues at a later date. It is not just the individuals who are working inside the panels that create safety critical defects. I have worked extensively as an electrical safety consultant in the food industry with many household brands as well as presenting to the Institute of Occupational Safety and Health on the subject. Hygiene standards and electrical safety standards in the industry can sometimes conflict with one another. The need to ensure that production equipment is kept clean means routinely employing aggressive cleaning techniques using water jets and chemicals that often leading to water ingress into electrical equipment. To quote a food industry electrician “if a jumbo jet landed in our car park and we were asked to clean it – it would never fly again.”

The environmental conditions that commonly prevail in industrial production facilities means that design standards governing water/dust ingress and earthing/bonding must be of a high order. But, the first question a designer should ask is, does the electrical equipment (such as control panels) need to be in the high-risk production environment or can it be installed remotely?

All that said, duty holders must take a pragmatic view and for existing production lines it is not going to be possible to undertake any serious redesign of electrical systems. This is where routine inspections really come into their own. An audit process for switchgear and control panels, which is part of the electrical safety rules and procedures will have the effect of highlighting serious defects/omissions.

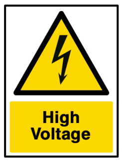
This can help inform risk assessments for future interactions and at one extreme, this may be to ban certain operations until improvements or replacements have been made.

6.4 Signs, Labelling and Field Marking of Equipment in Europe

Risk Assessments must be recorded and field marking of equipment may be required which is produced following survey and inspections. Safe systems of work, safety rules and procedures as discussed previously will be required and disseminated to all affected persons. It should be noted that arc flash labelling is not a mandatory requirement unless the company concerned is working to consensus standards such as the US NFPA 70E Standard for Electrical Safety in the Workplace. The European approach is one where labelling is less prescriptive but there is a general requirement that employers must provide safety signs where there is residual risk. The regulations require employers to ensure that safety signs are provided (or are in place) and maintained in circumstances where there is a significant risk to health and safety that has not been removed or controlled by other methods. The Health and Safety (Safety Signs and Signals) Regulations 1996 is the relevant legislation in the UK and is based upon the European Directive 92/58/EEC. The legislation lays down the minimum requirements for provision and use of safety signs at work the purpose of which is to encourage the standardisation of safety signs throughout the member states of the European Union such that safety signs, wherever they are seen, have the same meaning. Signs are only appropriate where use of a sign can further reduce the risk.

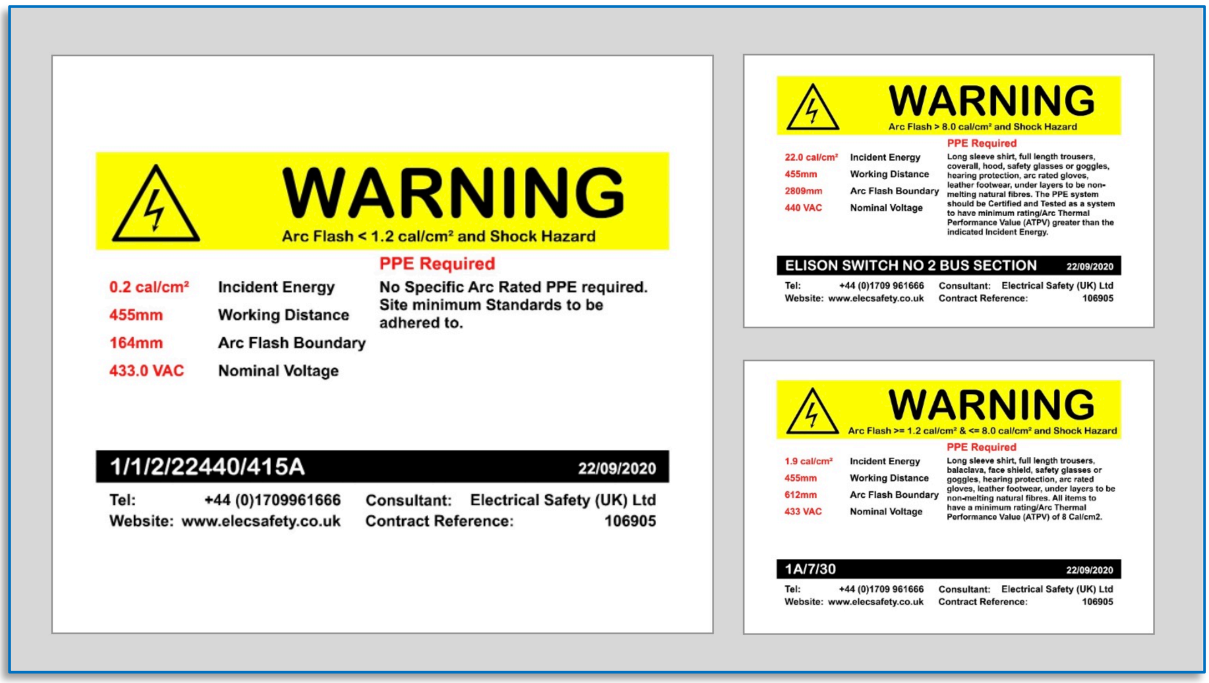
Warning signs must be standardized across Europe in a way which will minimize the potential problem that may arise from linguistic and cultural differences between workers. U.S style labels based on ANSI Z535 are not acceptable in Europe as the colours and symbols do not conform to the European legislation. When designing labels, the requirements of this legislation for warning and prohibition signs will need to be in accordance with this directive. Warning signs for instance must be yellow (or amber), they must be triangular, and the yellow must take up at least 50% of the sign. Information from arc flash studies can be included such as the incident energy level, PPE and various approach boundaries. The table in Figure 6.3 gives the meaning of each colour.

Figure 6.3 European Safety Signs and Symbology (excluding Fire Signs)

MEANING OR PURPOSE	INSTRUCTION AND INFORMATION	EXAMPLES
RED Prohibition Sign or Danger Alarm	Prohibiting dangerous behaviour, STOP such as no access to unauthorised persons.	
YELLOW or AMBER Warning Sign	Warning of Hazards such as electric shock or arc flash.	
BLUE Mandatory Sign	Specific behaviour required such as wear PPE or carry out a risk assessment.	
GREEN Emergency Escape or First Aid Sign	Shows doors, exits, escape routes, first aid equipment and facilities.	

The following are typical arc flash labels that have been produced to comply with the colours and symbology used in Europe and are based upon the European Directive 92/58/EEC.

Figure 6.4 Images courtesy of Electrical Safety UK Ltd



6.5 Competence

A competent person can be described as a person who has the skill, knowledge, attitude, training, possess the experience to undertake the work and has the ability to recognise the extent of their own competence and leading them to take appropriate action. Regulation 16 of the UK Electricity at Work Regulations 1989 and the Republic of Ireland Guide to the Safety, Health and Welfare at Work (General Application) Regulations 2007 Part 3 Electricity, states that "No person shall be engaged in any work activity where technical knowledge or experience is necessary to prevent danger or, where appropriate, injury, unless he possesses such knowledge or experience, or is under such degree of supervision as may be appropriate having regard to the nature of the work". The guidance on the above goes on to say "The scope of technical knowledge or experience may include:

a) Adequate knowledge of electricity;
b) Adequate experience of electrical work;
c) Adequate understanding of the system to be worked on and practical experience of that class of system;
d) Understanding of the hazards which may arise during the work and the precautions which need to be taken;
e) Ability to recognise at all times whether it is safe for work to continue."

The very important guidance clauses c), d), and e) are greatly enhanced by risk assessments that includes the prediction of the arc flash hazard. It is not enough to say that a person is competent because he or she is a time served electrician or engineer. Indeed, my experience is that enforcing authorities expect that duty holders can demonstrate that individuals are competent for the work that they are expected to do.

6.5.1 Competence Assessment

To be authorised and deemed competent to work on or adjacent to electrical systems, employees must demonstrate the required combination of knowledge, training and experience. The rules ought to stipulate that the authorisation be carried out in writing using a certificate of competence. In that way, there are no doubts about what the individual is authorised to do as well as what they are not allowed to do.

So, where do we start in assessing competence? For existing direct employees, it is probably best to start with a framework for competence followed by an appraisal comprising an interview and a short technical competence test. Managers are often mistaken in the belief that this will be somehow demoralising; when in fact, experience shows that it can be motivating to find that one's skills are being formally recorded and recognised in such a way. Indeed, there is good evidence to show that the human brain is wired for competence. To quote the author and neuroscientist Dean Burnett, "Our brains desire a sense of competence and when we feel that we're competent, we're more likely to be happy". In 2015, the Guardian newspaper looked at several surveys to try and find the happiest occupations and concluded that the job of engineer came out on top. Being an engineer, that is no surprise to me. I have been so fortunate to have enjoyed a degree of control, competence and being fairly well paid which is often associated with the role. In conclusion, if competence assessments are followed up by formal periodic reviews and built into personal development plans, this can have a beneficial effect on morale.

6.5.2 Competence of Contractors

The competence of contractors also needs to be addressed which is exemplified in Chapter 12: Myths and Mistakes where a contractor was killed on a manufacturing plant. The company ordering the work was prosecuted for (i) not ensuring that the subcontractor was sufficiently competent to perform such work and (ii) not ensuring a safe system of work was in place. The authorisation and assessment procedure mentioned under safety rules previously, should be implemented for any electrical work by employees and contractors. I have on several occasions found engineers working on energised high-power electrical equipment with no formal electrical qualifications at all. Large refrigeration control equipment regularly contains high current busbar systems in excess of 800 amperes at low voltage. However, electrical training is purely supplemental to some refrigeration engineers or perhaps a skill that has just been acquired over time.

For contracting companies and agencies, it is suggested that their employees must satisfy the requirements of the company safety rules and procedures in a similar way to direct employees. Temporary certificates of competence can be issued to contract employees for specific construction, maintenance or repair projects. There needs to be some recognition of emergency situations but there needs to be dialogue in anticipation of unplanned events.

6.5.3 Competence of Accompanying Persons

It is very important to consider the competence of an accompanying person when live working is involved. It is necessary to consider the role of this person in the achievement of safe working, in other words: why are they there? And what are they to do? The usual role is to be able to electrically isolate the installation, system or equipment without endangering himself or herself when something goes wrong and to render help to the worker carrying out the live work activity. They can also play a significant part in securing and managing the work area. The usual training, assessment and authorisation of such persons is necessary and appropriate criteria must be applied.

6.5.4 Competence Matrix

The creation of a competence matrix which will detail the minimum or preferred attainment in each area of competence is essential. Firstly, define a list of work categories for which the employee will receive an authorisation. For instance, the employee may be given an authorisation as a competent person carrying out dead work only. Another example is as a competent person testing and commissioning or perhaps as a competent person supervising others. Against each competence will be the minimum or preferred attainments. A list of these attainments could be as follows but clearly there could be many others depending upon the complexity of the work.

a) **Professional or craft qualifications.** Maybe these can be grouped for simplicity so one group could be Professional Qualification, Degree, relevant professional body or National Vocational

Qualification Level 5 (NVQ5). The second group could have a relevant Engineering at HNC or NVQ level 4, the third a recognised apprenticeship, NVQ level 3 and so on.

b) **Formal Training in Health and Safety**. This can be carried out in house, but I can recommend the Institution of Occupational Safety and Health (IOSH) courses that can be delivered by accredited trainers on site. There is IOSH Working Safely which is a one-day course for people at any level in the organisation. For those in a supervisory or managerial capacity, I would recommend the IOSH Managing Safely which is usually four days in duration plus a day practical assessment. A need for a higher qualification may be thought appropriate so there may be another attainment level on the competence matrix for a qualification at NEBOSH (National Examination Board in Occupational Safety and Health) National General Certificate in Occupational Health and Safety or higher.

c) **Experience**. A requirement for appropriate experience in years.

d) **Externally Assessed Competence Cards**. For electrical contracting workers in the United Kingdom the requirements of the Electro-technical Certification Scheme (ECS) is a very good start. The scheme is administered by the Joint Industry Board (JIB) for the Electrical Contracting Industry. It not only covers the traditional electrical contracting electrician but other electro-technical disciplines such as Electrical Fitters, Instruments Technicians, Maintenance Electricians, Wireman/Panel Builder, Building Controls, Emergency & Security Fitters, Cable Jointers and Telecommunications Fitters. Before a card can be issued the individual will have to prove technical and vocational qualifications, age and minimum experience and health & safety awareness. It is externally assessed and good value requiring very little administrative work on behalf of the company.

e) **Specific Vocational Training**. This classification could include formal training on particular pieces of equipment or perhaps electrical installation wiring regulations.

f) **Continuing Professional Development (CPD)**. A requirement could be to highlight ongoing enhancement of skills. This could be important where the competence of an individual may be dependent upon upskilling and keeping up to date with latest developments in a particular field or piece of equipment.

g) **Review and Audit Requirements**. There may be a formal review and or audit procedure out of which a particular classification could be highlighted on the matrix.

6.5.5 Comparison of International Qualifications.

Sometimes, there is a requirement for technicians and engineers from abroad to work in the UK or Ireland or vice versa. Although it is not practical to assess knowledge based on examinations passed or qualifications gained in other countries, a baseline can be established onto which a competence matrix can be populated. It is possible to set criteria for the minimum content for any knowledge-based learning. There are various organisations that can help in comparing the qualifications of individuals across Europe which are listed as follows.

UK NARIC – The National Agency responsible for information, advice, data and informed opinion on qualifications from outside the UK.

ECVET – The National Contact Point for England improving the mobility of those holding vocational qualifications across Europe.

ReferNet – The European Network offering comparable information on Vocational Education and Training across Europe.

Europass – The UK's National Europass Centre – removing barriers to work and study in Europe.

CPQ – The Centre for Professional Qualifications which provides advice and guidance on professional qualifications and their recognition in the UK, EU and globally.

All these organisations can be found on UK NARIC, website https://www.ecctis.com/.

6.5.6 Competence – Human Factors

Whenever we introduce people into risk management processes, we first have to consider that they sometimes will not behave in the way that we would want them to. We all make mistakes, but sometimes human failure can be deliberate which leads to non-compliance, or it can be inadvertent which leads to errors. Whilst human factors are a huge topic on its own, I have devised some suggestions that may help when managing arc flash risk as follows.

Non-compliance is sometimes a cultural issue, or it can be an individual refusal to follow rules and procedures. In either case, it is a problem that must be faced head on and the reality has to be taken into account when devising risk control measures. Cultural issues are sometimes difficult to change as they inevitably come from the leadership within the organisation. It is at management level where we need to start in changing culture and to get agreement at the highest level through awareness and policy changes. It is then important that the workforce is involved in any changes to procedures which includes any risk control measures for arc flash. This is where awareness of the arcing hazard will be most effective. When and if it gets to protection by PPE, Chapter 7: Protection gives further advice on the involvement of the workforce in the provision of workwear, etc... We can also encourage reporting of non-compliance (violations) to make it unacceptable, akin to drink driving for instance. Where we know that there could be deliberate non-compliance, then targeted audits and raising the likelihood of sanctions must be considered.

In the case of inadvertent errors, we need to be aware of the need for ongoing training and competency assessment. Other factors that may lead to inadvertent errors are distractions and this is where control of the working environment is important, this is dealt with later.

Time pressure and tiredness particularly towards the end of a shift can be a vulnerable time. Another surprising common factor that I have come across on more than one occasion, is carrying out high risk activities out of hours that are on normal days off. Allow me to paint a picture of a non-shift working team who have been brought into work on a Saturday morning. Not wishing to stereotype, maybe Friday night is their usual night out and they will not be as bright on a Saturday morning. Maybe it is the football game on a Saturday afternoon, so the time pressure is self-generated. Their performance would definitely be affected in contrast to if these factors were not in play.

Finally, I think that we also need to always be vigilant about the possibility of morning after intoxication through alcohol or drugs. Not a good mix when working near energised conductors.

6.5.7 Competence - Further Reading

Clearly, the competence of persons involved in live work will vary widely between industries and organisations. For instance, the requirements for someone involved in the manipulation of energised conductors by hot stick or live jointing is hugely different from a maintenance electrician undertaking diagnostic testing on a production line. It is not possible to cover all levels of work and supervision, but I can recommend the following comprehensive guide which was written by experts in live working across Europe. It is available to download free of charge from the International Social Security Association (ISSA) website. Guideline for Assessing the Competence of Persons involved in Live Working published by the International Social Security Association (ISBN-Nr. 3-9807576-6-8).

6.6 New Work and Alterations

There needs to be control over new work and alterations to electrical systems. It is often the case that the design of new installations or additions are left to the discretion of contractors even in medium to large facilities. Paperwork such as test sheets and minor works certificates are often not being handed over or even completed for modified electrical installations. This results in electrical installations that are a mixture of design specifications.

There needs to be a procedure that will ensure that any installation work is properly specified, designed, approved and installed to ensure consistency across the facility. The process will also deal with the inspection and testing, some of which may be on energised equipment and also the completion and handover.

6.7 Approval of Electrical Test Equipment & Tools

There needs to be control via a formal approvals process for all electrical test equipment, insulated tools, locks, labels, insulating tools, matting, shrouding and electrical PPE. This will require control over all such equipment on site and also equipment used by contractors. Incorrect test equipment is frequently used by the incorrect individuals and/or incorrect circumstances. For instance, there are often concerns as to the suitability of instruments to verify that circuits are dead. Engineers (including multi-skilled engineers who may or may not have electrical qualifications) use the voltage setting of digital multi-meters for testing for dead. The leads are often unfused, and this does not comply with the expectations of the enforcing authorities or guidance. Many times, multi-meters and leads that I inspect are not rated correctly for over voltage protection and had excessive visible tips on the probes. A very good reference on the subject is available as a free download from https://www.hse.gov.uk/ called Guidance Note GS38 (Fourth edition) on electrical test equipment for use on low voltage electrical systems. A suggested structure for the approval of tools and equipment is as follows.

Generic List. Create a generic approval list which will give standards to which all equipment shall be built. A generic list provides a specification for equipment where external contractors will be able to check their own equipment to ensure compliance with company standards.

Specific List. The next stage is to formulate a data base of specific list for equipment which is purchased by the company. Specific lists will describe the equipment, model number, manufacturer/supplier and other relevant information.

New Equipment. Next, create a process for the approval of new equipment so that items not listed on the specific list can be properly considered and control of equipment coming onto site is assured.

Specialised and Hired in Equipment. Finally, a process for specialised or hired in equipment, for example highly specialised for a particular task, such as harmonics monitoring equipment can be given a temporary approval by the site duty holder.

Maintenance and Calibration. Users must ensure that all specialist equipment is in good condition and correctly maintained and where necessary calibrated in accordance with the manufacturer's requirements.

PPE, Safety signs and Labels. Specialist electrical personal protective equipment such as shock and arc flash protection, approved safety signs and labels such as danger & caution notices and field marking labels should have a record kept in the specific list. The labels should include an image and approximate dimensions.

Audits. All equipment covered under the approval of tools and equipment should be audited on a regular basis, to ensure that it complies with the approved list of equipment. Any equipment that does not comply should be removed and destroyed.

6.8 Thermography and Partial Discharge Testing

Thermal imaging and partial discharge testing are classed as condition monitoring to detect impending failure in components and connections. This necessitates that the equipment is monitored in service and energised. Both techniques require some specialism particularly in the interpretation of results. Insurance companies sometimes provide discounts for companies that undertake thermal imaging mainly to reduce the risk of losses through electrical fires. Other insurance companies will insist on measures such as thermography. In addition, discovery of faulty joints or contacts could prevent overheating/arcing that could lead to a dangerous arc flash.

Can the procedures be carried out safely? The answer is yes, providing that a risk assessment which explores the alternatives has been properly implemented. As far as arc flash risk is concerned, this necessitates the predictive techniques always with a goal of prevention as first choice.

Thermal imaging requires that panel doors need to be opened in order to get accurate measurements. Sometimes internal shrouding may interfere with the thermographic images and I have come across situations where individuals may resort to the removal of shrouding. This obviously gives an extra order of risk to the operation and needs very careful consideration by the electrical duty holder. Among the alternatives to the opening of panel doors onto energised equipment there are:

a) Viewing windows which are mounted in the panel doors. These allow thermal imaging to occur without opening doors onto energised conductors.
b) Ductor testing which uses a high current digital micro-ohmmeter to measure very low resistances in circuit breakers contact resistance and joints in switchgear and busbar systems.
c) Joint inspection and tightening regimes as part of routine maintenance.

6.9 Risk Assessments – Practical Approach

Risk Assessments were spoken about in general terms in Chapter 3: Risk Assessment and the Four P Guide. What follows is some practical guidance on how risk assessments may be carried out on low voltage equipment which is where the majority of interactions with energised equipment occur.

Risk Assessments need to document the hazard severity and the risk control measures. Wherever possible, these should be dynamically produced, and task based. In other words, be available to the person carrying out the work who will reassess such things as environmental conditions and equipment state.

6.9.1 Can the normal policy of dead working be carried out?

Work on energised circuits must always be subject to a suitable and sufficient risk assessment. A key part of the risk assessment is the decision to proceed with live work rather than to have equipment dead and isolated for the duration of the work. To help with that decision, I have reproduced guidance from the excellent document, Electricity at Work – Safe Working Practices HSG 85 published by the UK Health and Safety Executive under Open Government Licence v3.0. I can thoroughly recommend the document which can now be obtained free of charge from https://www.hse.gov.uk. I have used the guidance as a framework not only to methodically breakdown the decision but establish the precautions that should be in place particularly in respect of arc flash but also for other electrical hazards. The following illustration, Figure 6.5, describes the process of decision making in greater detail.

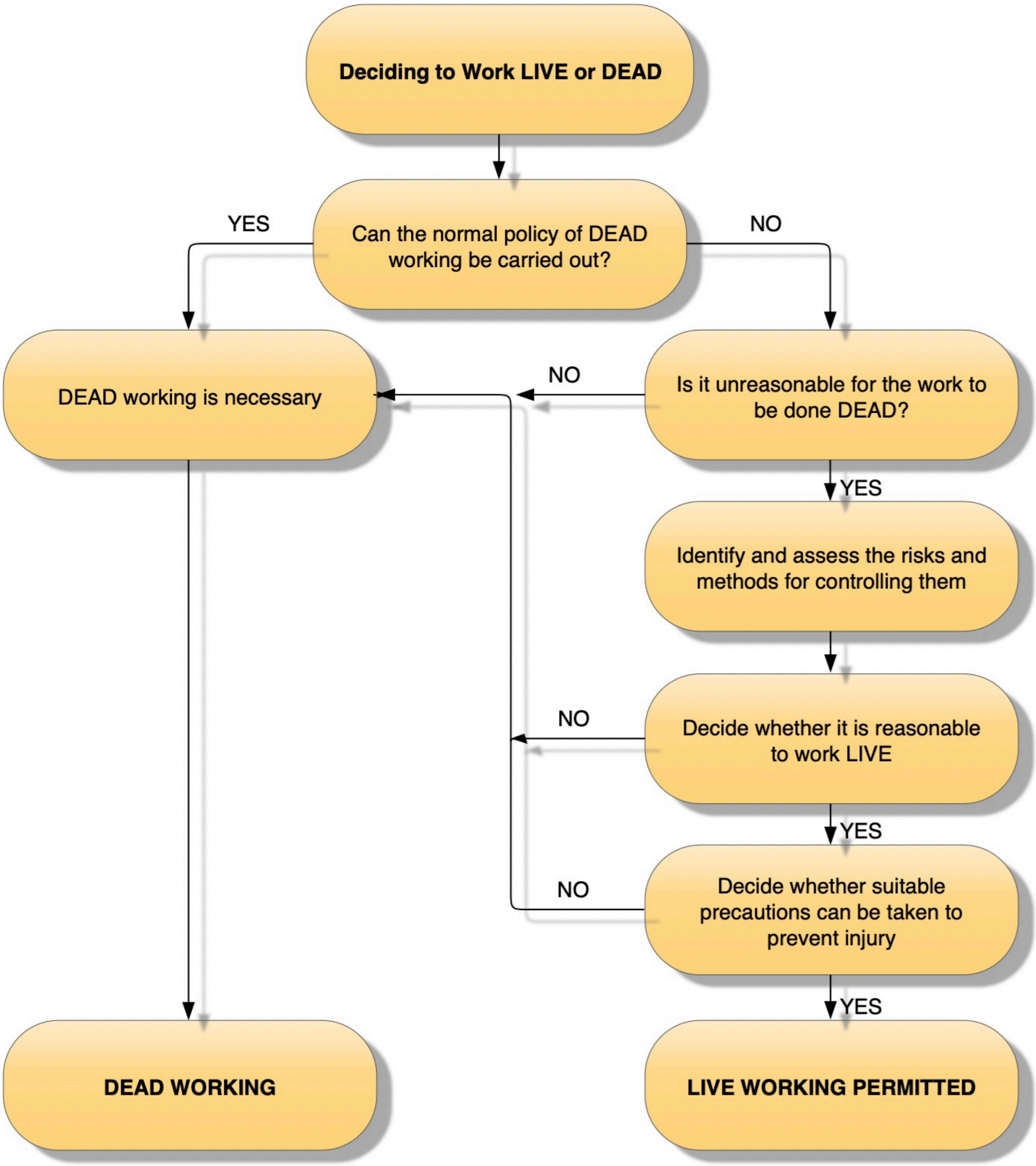


Figure 6.5

Work on or near live exposed conductors should rarely be permitted. Many accidents to electricians, fitters, technicians and engineers occur when they are working on equipment that could have been isolated. You should plan and programme the work to allow all jobs to be carried out where possible with the equipment dead. Three conditions must be met for live working to be permitted where danger may arise. If just one of these conditions cannot be met, live working must not be permitted, and dead working is essential. The assessment procedure illustrates this. The conditions are:

a) it is unreasonable in all the circumstances for the conductor to be dead; and
b) it is reasonable in all the circumstances for the person to be at work on or near that conductor while it is live; and
c) suitable precautions (including, where necessary, the provision of personal protective equipment) have been taken to prevent injury.

6.9.2 Is it unreasonable for the work to be done DEAD?

The following examples are taken from HSG 85 to illustrate some circumstances where it is unreasonable to make equipment dead because of the difficulties it would cause:

- It may be difficult, if not impossible, to commission a complex control cabinet without having it energised at some time with parts live (but not exposed so that they may be easily touched);
- It may not be technically feasible to monitor the operation and performance of a control system or to trace a malfunction of such equipment with it dead, i.e., fault-finding;
- A distribution network operator (DNO) needs to connect a new low-voltage service to an existing main, but it might be unreasonable to disconnect many customers. In recognition of the dangers associated with live working, the DNO must have a very strict code of safety rules and procedures to prevent injury;
- Switching off a system, such as the supply to an electric railway track, to carry out maintenance or repair work may cause disproportionate disruption and cost.
- Identify, assess and evaluate the risks and methods for controlling them.

If you have decided that it is unreasonable for the work to be done dead, a risk assessment is necessary. The risk assessment must cover the work on or near the specific equipment and it must be carried out by someone with comprehensive knowledge and experience of the type of work and the means of controlling the risks. If live working can be justified through a rigorous test of reasonableness in conditions a) and b), judgements must be made about suitable precautions against electric shock and the effects of electrical flashover to satisfy the requirements of condition c). Work (which is not confined to just electrical work but includes any work activity) is permitted only if conditions a) and b) and c) are satisfied.

6.9.3 Identify and assess the risks & methods for controlling them.

The first stage of the risk assessment is to identify the hazards, and although not exhaustive, the following highlights some of the more common ones.

- Electrical shock from passage of current through the body, leading to death or injury due to cardiac arrest, shutting down of the respiratory system and heart fibrillation at extremely small currents. This is typically greater than 30mA on alternating current systems. Muscle contraction can occur.
- Internal burns where the current involved is in the order of amperes. The destruction of body tissue and internal organs can occur with the passage of current at around one ampere.
- Arc flash injury can include external burns (i.e., severe burns to the skin), internal burns and intoxication from inhaling hot gases and vaporised metal, hearing damage, eye damage and

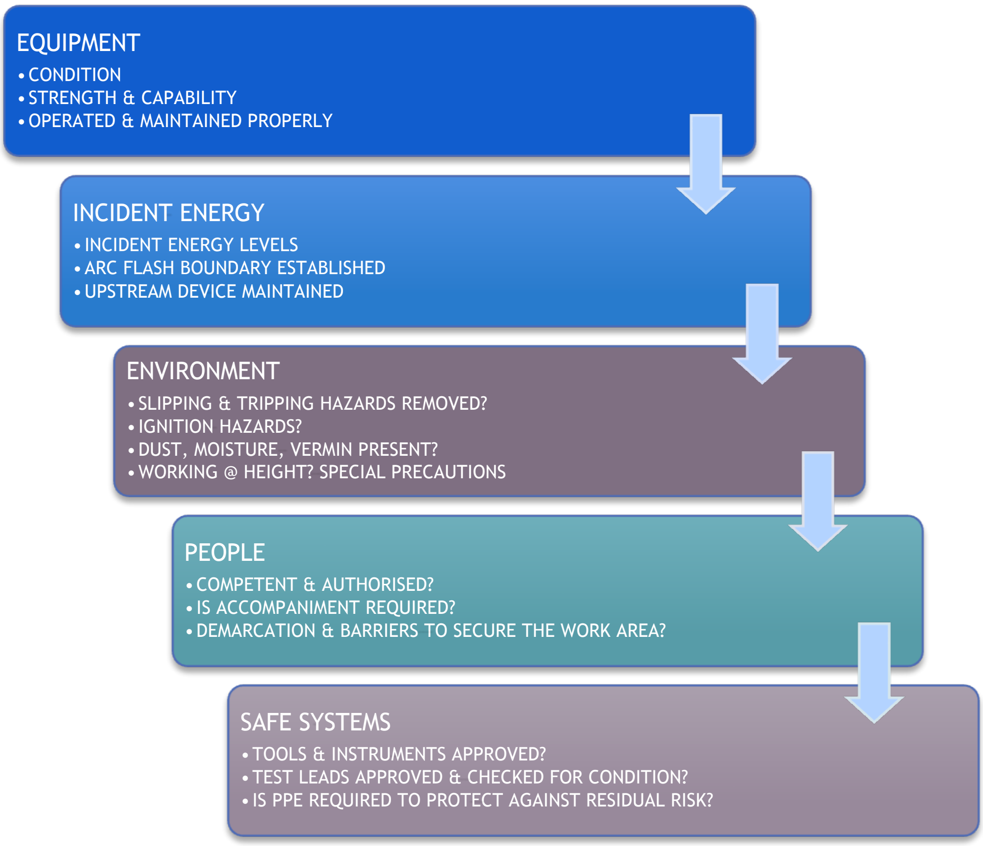
blindness from the ultraviolet light of the flash as well as many other devastating injuries. Depending on the severity of the arc flash, an explosive force known as an arc blast may also occur and could cause the propulsion of molten metal, equipment parts and other debris.

- Ignition of flammable materials from electrical arcing which could be the clothing that an electrical worker is wearing. Serious third-degree burns have occurred to workers wearing flammable clothing which could become a hazard irrespective of PPE considerations.

6.10 Dynamic Risk Assessment Checklist

Having identified the hazards arising from the live work, you then must decide how likely it is that harm will occur and the severity of injury that might occur. The following is a check list, Figure 6.6, of issues to consider that may impact on the likelihood of the hazards causing harm.

Figure 6.6 Risk Assessment Checklist



6.10.1 Equipment

ALWAYS ASSUME THAT EQUIPMENT OR CONDUCTORS ARE LIVE UNLESS PROVEN DEAD!

Has the equipment been checked and is it in a safe condition? Check whether the equipment to be worked upon has been examined and in a safe condition for work. Live work should never be permitted where there are any doubts about the safety of cables and electrical equipment being worked upon or adjacent to those being worked upon. The examination can be visual but also using other senses. Smell and hearing can detect burning or electrical discharge. Signs of vermin, birds or organic growths inside switchgear or water ingress is a definite prompt to stop and investigate when the switchgear can be made dead and isolated. Approaches should never be made to damaged cables. Check that the equipment doors, panels and covers are closed and secured and there is there is no evidence of impending failure.

For new equipment, the person undertaking the risk assessment should be confident that the equipment has been professionally installed in accordance with the design specification and manufacturer's instructions. For existing equipment, in addition, a judgement should be made that it is being maintained and is operating in accordance with the design parameters. Is the equipment over stressed? An arc flash study if properly conducted will provide a single line diagram, a protection coordination study and assure that the strength and capability of the equipment is adequate.

If the equipment is in a safe condition the next step is to consider whether the equipment is finger safe. If the equipment is not finger safe, can measures to prevent contact with live parts be implemented? The term "Finger Safe" is defined as no exposed live parts that can be accessed by solid objects greater than 12.5mm as given by IP rating IP2X.

Do not rely purely on the original specification of the equipment. Insulation is often removed and not replaced. If it is not finger safe, or other measures cannot be introduced to prevent contact with live parts then proceed no further.

If a maintenance program has been implemented as suggested earlier in this chapter, there may be established risk control measures to be adopted when working on a particular piece of equipment. These controls may be displayed in the form of labelling on the equipment which should be taken into account in this risk assessment process.

6.10.2 Arc Flash

A major objective of this guide is to provide the predictive tools to determine the arc flash hazard and the means to prevent it causing harm. As part of the risk assessment, the degree of harm may be predicted and quantified in terms of incident energy and distance. This is very useful, particularly on low voltage equipment where interactions with energised equipment and cables are countless and the relative severity of the hazard has little to do with nominal current ratings or available prospective short circuit current. (See Chapter 12: Myths and Mistakes)

By using this guide and the tools for determining the incident energy, a quantitative analysis can be made about the severity of a possible arc flash which will have a bearing on this decision-making process and also provide the specification data on any protection requirements. The conclusion may be that the incident energy levels are too high and cannot be suitably controlled but experience shows that preventative measures can be formulated in the majority of cases at low voltage.

Using the IEEE 1584 Guide for Performing Arc Flash Calculations, the incident energy level at a distance to the worker is determined. The distance is normally to the head and torso but the calculators with this guide can easily be used to determine the incident energy to other parts of the body and particularly the hands. Where the arc flash hazard is dependent upon tripping time for the upstream protective device, there needs to be confidence that this has been adequately maintained?

Boundaries

It should be ensured that adequate clearances are established and maintained when working on or near to live equipment. Annex A of BS EN 50110-1:2013, Operation of Electrical Systems, gives guidance for shock protection distances in air for working procedures. As we are speaking about low voltage systems here, any contact either by the worker or tools/instruments is classed as live working. Any encroachment below 300mm from the live part below 1000 volts, is classed as "work in the vicinity".

Using the IEEE 1584 Guide for Performing Arc Flash Calculations, the arc flash boundary can be determined. This is defined as a distance from a prospective arc source at which the incident energy is calculated to be 5.0J/cm^2 (1.2 cal/cm^2) The significance of this figure, is that this amount of thermal energy is calculated to have a 50% chance of a second degree burn to bare skin if sustained for 1 second. This value is used by many standards as the benchmark that defines protection against the thermal effects of arc flash and the threshold of a zone. For instance, working on or near energised equipment within the arc flash boundary will require the wearing of arc flash PPE. The calculation of the arc flash boundary is very useful regardless of whether prescriptive standards may be applicable in determining the level of harm from the arc flash hazard at a determined distance. For further information, See Chapter 14: Hazard and Severity Calculators.

6.10.3 Environment

Is access and space adequate? Establish whether the access and space in front of the equipment is adequate to allow the worker to pull back from the conductors without hazard. Refer also to the earlier arc flash section on the shock and arc flash boundaries.

The work area should be clearly defined, with no tripping & slipping hazards and with good means of escape and illumination. Simple barriers and signs can be erected for the demarcation of work areas to keep unauthorised staff away and also to protect electrical workers from interruptions at times when they need to concentrate.

Is lighting adequate? Also, it is important to check whether lighting levels are adequate for work. Use of additional lighting is essential where required. Further details on lighting at work can be found in HSG38 Lighting at work which is free to download on https://www.hse.gov.uk/.

Are hazardous conditions present? Check to ensure that the immediate environment is free from water or dust. A hostile or wet environment will significantly increase the risk and severity of electric shock and should therefore be subject of special consideration to control the risks.

Ensuring there is no possibility of an ignition hazard due to sparks is crucial. If there are signs that there is a possibility of an ignition hazard, take precautions to remove the hazard before proceeding with the working in accordance with company procedures.

6.10.4 People and Safe Systems of Work

As described previously, it is essential to check whether the workers are competent for the task. In the context of live work, technical knowledge or experience means that the person should be properly trained and assessed in the techniques being employed but the person must also understand the hazards from the system and be able to recognise whether it is safe for the work to continue. The person should, as a minimum, have a specific authorisation to carry out live working tasks under any electrical safety rules.

Is the work to be carried out at height? Working at height whilst carrying out live work is always a special case for consideration for two reasons:

a) Electric shock or arc flash to a worker at height can bring about a fall with obvious consequences.
b) An arc flash incident whilst working at height may mean that the worker cannot move out of the way because of the limited working space on access equipment. This may be the work platform of a scaffold or a mobile elevated work platform.

If the work is to be carried out at height can risk control measures to prevent shock, burns and falls be put in place?

Consider the use of protective screens or insulation to prevent simultaneous contact with live parts at different potentials. These are commercially available and an example of temporary insulation together with insulating fasteners is given in Figure 6.7.

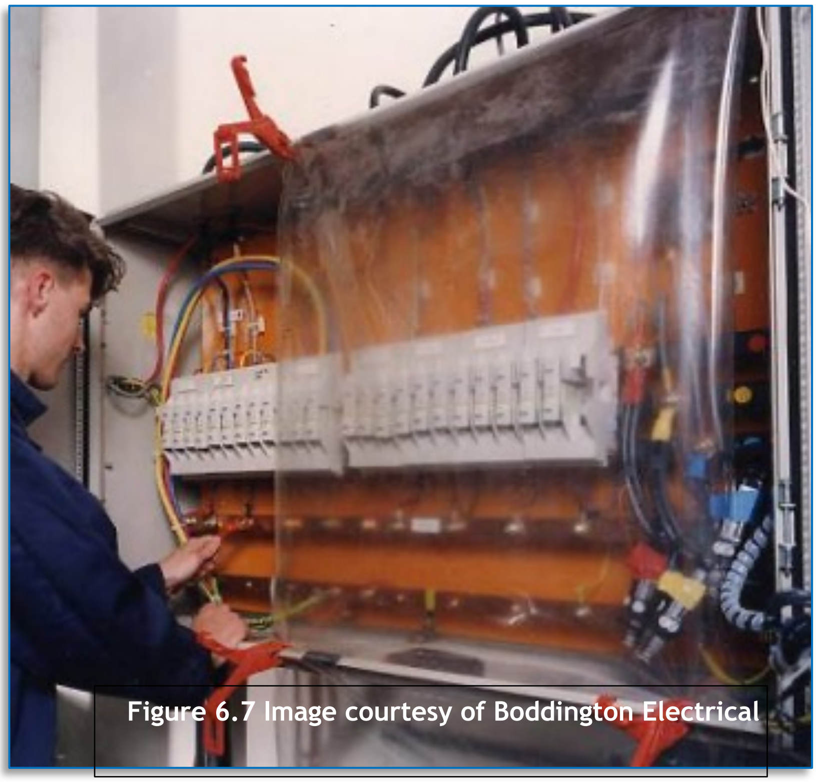


Figure 6.7 Image courtesy of Boddington Electrical

Establish whether accompaniment is required. Anyone undertaking work on or near energised electrical conductors will nearly always require some form of accompaniment by someone who can give assistance in an emergency. The emergency backup may be for the accompanying person to be able to make the system safe and to provide a medical response as may be necessary. This implies a degree of competence such that the accompanying person can assist without danger to themselves or others. A requirement for a second person is to implement and maintain safe working procedures such as by preventing distractions and encroachment from non-authorised personnel into the working area.

Provide and use the correct personal protective equipment (PPE) to reduce the risk of contact with live parts or earth through insulating gloves and matting. If there is a risk of burns from arc flash that cannot be eliminated by other means, use adequately rated, thermally insulating, flame-resistant PPE. Personal protective equipment (PPE) is dealt with separately in Chapter 7: Protection.

If measures to prevent contact with live parts can be implemented, are tools, instruments and leads checked fit for purpose? Tools and instruments must be of the correct duty rating and their condition must be checked especially test leads. It is important that correct instruments and leads should be selected and in particular the correct over voltage installation category. The wrong meter and leads can increase the chances of electric shock or the instigation of an arc flash due to transient over voltage. Only approved test equipment and leads should be used, and the leads should be fused and have insulated probes.

I have come across many organisations who adopt a permit to work for live work. Indeed, the Standard for Electrical Safety in the Workplace NFPA 70E in the USA mandates the use of an Energized Electrical Work Permit. BEWARE! It should be noted that the use of an energized electrical work permit would not be acceptable in the UK as electrical permits are restricted to dead working only. To quote HSG 85 Electricity at Work – Safe Working Practices “An electrical permit-to-work is primarily a statement that a circuit or item of equipment is safe to work on, 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.”

However, all the information for non-routine work should be documented as special circumstances in the risk assessment and if necessary, a sanction for testing/live work can act as a supplement to give greater authority.

6.10.5 Decide whether it is reasonable to work live!

“The risk assessment should inform managers and supervisors whether it is reasonable in all the circumstances to work live. The decision should not be taken lightly. At this stage the economic and operational factors should be evaluated against the risks involved before making a decision, bearing in mind that the risks associated with working live can be very serious. Minor inconveniences arising from working with the equipment dead, sometimes arising from commercial and time pressures, will very rarely outweigh the risks associated with live work”. (Source: HSG 85 Electricity at Work – Safe Working Practices)

6.10.6 Decide whether suitable precautions can be taken to prevent injury!

Once the above requirements have been met, the third condition for the justification of live working must be met which is: suitable precautions (including, where necessary, the provision of personal protective equipment) have been taken to prevent injury. At this stage, the hazards and the precautions to prevent injury should all have been identified and recorded in the risk assessment as detailed in previous paragraphs.

6.10.7 FINALLY - Proceeding with Work

After all the above steps are satisfied, implement safe working and ensure adequate monitoring and supervision. Things change in workplaces, and risk assessments need to be reviewed on an ongoing basis. Consider a “toolbox talk” to run through the requirements of the risk assessment and ensure that these are understood by those undertaking the work.

In addition, the worker must:

- Make sure that any special equipment and PPE is properly used and maintained.
- Pay attention to housekeeping and ensure that the work area is organised and tidy.
- Keep the duration of any live work to a minimum.
- Store tools correctly – horizontal surfaces and projections inside control cabinets should not be used – and ensure that objects such as tools and bolts cannot fall onto exposed live parts.
- Maintain tools and test equipment in good condition and replace them if damaged.
- Avoid lone live working at any stage and make sure that any accompanying person is competent.

6.11 Testing for DEAD

A core principle of most electrical safety programmes is dead working and to always try to avoid live working. Why I emphasise the avoidance of live working, is that sometimes, there can be danger in making equipment dead, or putting equipment in an electrically safe condition.

I recall, many years ago, a utility company repairs electrician being called out to look at a low voltage cable which had been severed by excavation in the street. The current carrying conductors in the severed armoured cable were clearly visible and the electrician jumped into the trench to see if they were still live. The conductors were still live, but the act of prodding them with a test lamp initiated an arc flash incident in which he received some burns. A footnote to this incident is that the same electrician did a very similar thing some years later, but this time was very severely burnt from the resulting fireball and was hospitalised.

Remember!

TREAT ALL ELECTRICAL EQUIPMENT AND CONDUCTORS AS LIVE UNLESS PROVEN DEAD.

So, with that in mind, how shall we safely test for dead. Whilst the following is not meant to be a definitive guide to isolation practices or lock out tag out procedures, it is a practical approach to ensure that the process of testing at low voltage will not create danger from arc flash. This is to be taken as a whole and no one measure should be taken in isolation.

STEP 1. COMPETENCE - Designate the person who will have responsibility for the isolation. We will call him/her the designated person here, but that term can be changed as long as it is clear, written into the safety rules and does not clash or be confused with any other terms in use. Make sure that the designated person possesses the competence required to undertake the isolation. By that I mean a person who has the skill, knowledge, attitude, training, possess the experience to undertake the work and has the ability to recognise the extent of their own competence and leading them to take appropriate action. Specific requirements over and above general electrotechnical knowledge are that he/she will have an adequate understanding of the system to be worked on and practical experience of that class of system, an understanding of the hazards which may arise and the precautions which need to be taken and an ability to recognise at all times whether it is safe for work to continue. Sadly, the repairs electrician that I spoke about earlier failed on all three counts.

STEP 2. IDENTIFY. The designated person must correctly identify and make dead and Isolated from ALL points of supply. This will include alternative feeders and emergency standby arrangements such as generators and uninterruptible power supply systems. Correctly identifying circuits will take away the trial-and-error approach and reduce the risk.

Do the detective work. Reference to current drawings (taking care to allow for inaccuracies) and records alongside circuit and equipment labelling is a good start. Consult the electrical system owner or experienced maintenance crews whenever possible. Use physical inspection such as tracing out circuits to determine the correct isolation points relating to the work required. If the equipment is a distribution board, identify an outgoing load that is non-essential such as a lighting circuit. When switching and verifying it can be another step in positively identifying the points of isolation by observing simultaneous extinguishing of lighting circuits through the switching operation. A similar approach can be made with panel control lamps if the piece of equipment is a power switchgear and control gear assembly. This may sound like stating the blindingly obvious, but believe me, having audited individuals whilst they are undertaking isolation procedures, it surprises me how often these simple steps are omitted.

Testing because of inadequate records. Where testing is carried out to locate circuits due to inadequate records or circuit labelling then this should be considered as live working.

Unauthorised modifications or circuits. Finally, always be open to the possibility that there may be unauthorised feeders and/or modification that are not detailed in circuit diagrams and records.

STEP 3. DISCONNECT.

The usual means of disconnection of circuits at low voltage are:

a) the withdrawal of fuses and/or links
b) operation of miniature and moulded circuit breakers
c) opening and isolation of air circuit breakers
d) opening of switch fuses
e) opening of isolators
f) physical disconnection of conductors
g) withdrawal of a plug from the socket outlet
h) third party isolation via a utility company

Notes.

Reduce connected load. Before operating isolators or removing fuses reduce as much of the connected load as possible.

Physical disconnection of conductors. This can only to be carried out dead, but this may be the only option in certain circumstances. For instance, if the disconnection device is not rated as an isolator or that the point of isolation cannot be secured with a padlock or other device.

Visual inspection of isolator blades. Make sure, wherever possible and visible, to check and to ensure that all the blades have opened in switch fuses and isolators. I have seen it first-hand where the operating bar has broken leaving a blade in place and energised. I also remember a recall notice for a popular brand of devices for that same fault.

Circuit Breakers in the tripped position. Miniature and moulded circuit breakers can never be used for isolation in the "tripped" only position. This is one of the mistakes that led to the incident mentioned in my introduction to the guide.

Storage Devices. Ensure that storage devices such as capacitors are fully discharged. Capacitors can store huge amounts of energy that can cause a serious blast hazard. If you have concerns about the capacitors, I can recommend the 2021 version of NFPA 70E which has the subject covered in some detail in Informative Index R. It is free to view, and I have given details of the document including caveats in Chapter 16: Rules, Codes and Legislation.

STEP 4. VERIFY INCLUDING TESTING.

The whole point of steps one, two and three is that verification will be on dead conductors. We have already reduced the risk from arc flash if these steps have been carried out diligently. But should there still be a residual risk the following will serve to reduce it to as close to zero as possible. Know what the incident energy level is and take a decision on how to proceed. Decisions should be based upon risk assessment especially in respect of whether to deploy PPE or not. There is a good deal of guidance on this elsewhere in the guide especially in Chapter 4: Prediction and Chapter 7: Protection but what I would suggest is a minimum of hand protection regardless of the incident energy levels for low voltage testing. So, in other words, insulating gloves and leather over gloves.

Figure 6.8 Image courtesy of Martindale Electric

In Chapter 12: Myths and Mistakes, I give an example of an electrician who was hospitalised after suffering burns to his hand. I put objections to wearing gloves for testing in the same category as not wearing a mask. There may be some inconvenience, but loss of dexterity is in my view, overblown.

Figure 6.9 Courtesy of Martindale Electric

Use the correct equipment. I would suggest that multi-meters should not be used for testing for dead. Correctly calibrated proprietary voltage indicators, with fused leads and matching test units (Figure 6.9) should be used to check for the absence of voltage.

Non-contact voltage indicators (Figure 6.10) are a good idea providing that they are <u>NOT</u> relied upon for the final proof of dead conductors. Look for devices that have self-proving circuits and can give an indication if they are faulty. They may obviate the need for PPE for instance as used as part of the risk assessment given earlier. In addition, they can be used to look for rogue circuits. For example, in a control panel or composite switchboard, cables may have been drawn in that are supplied from another source. The panel may have been used as a trunking so there may be insulated but live cables in the working area. Make sure that you fully understand what the non-contact voltage indicators are capable of from the manufacturer's data and instructions especially voltage ranges.

Figure 6.10 Image courtesy of Martindale Electric

Test ALL Poles of Supply. The arc flash incident mentioned in the introduction was a classic case of not testing all poles of supply between current carrying conductors and then each current carrying conductor and earth including neutrals. There was a failure to test to earth which would have detected that the red phase contact on the controlling moulded case circuit breaker was welded closed whilst the other two phases were open.

Test the lowest rated circuits first. For instance, if the piece of equipment is a power switchgear and control gear assembly then test at the control fuses or an outgoing protective device.

Lower upstream device settings. If the incident energy levels are still very high, consider lowering the upstream protection settings. This does need care to make sure that appropriate settings are reapplied upon completion.

STEP 5. SECURE.

ALL practical steps to prevent re-energisation should be taken with the goal that there is no risk that circuit conductors and electrical equipment can be made live, whilst work is in progress. Some measures can include:

a) The retention of fuses, links and withdrawable circuit breakers and application of lockable blanks and retention of keys.
b) Disconnection of circuit conductors.
c) Locking off points of isolation such as circuit breakers, isolators and the retention of keys.
d) Removal and retention of castell keys where these mechanically interlock with switches or circuit breakers ensuring that spare keys are not available.
e) Specially designed locked facilities, e.g., lockout boxes.
f) Use of properly designed earthing devices.

g) **Earthing.** Applying circuit main earths where they are available is mandatory. For other situations this is an option for the designated person to consider bearing in mind that control needs to be exercised in their application and removal.

Lock and Label Points of Isolation. Secure all points isolation using a lock and unique key. Post caution notices at all points of isolation and also on any earths that have been applied. Make sure that all notices are removed on completion.

Labelling adjacent equipment. If there is live equipment in the vicinity that could be mistaken for the equipment to be worked upon, then apply a label. A “danger live” notice will usually suffice, the presence of which should be noted on any permits that are in use and they must be removed on completion.

Third Party Isolations. An isolation from a third party such as a utility company, needs to be thought through carefully as the designated person for securing the isolation should always have control. There are various ways in which this is achieved, and this is how I have gone about it in the past. Firstly, try to accompany the person from the third party who is undertaking the isolation and be assured from discussion and observation that this is the correct point of isolation. Secondly, ask that person to accept a means of securing that point of isolation such as a lockout box with your lock on it or a multi hasp device. Finally, ask for a written statement of the isolation. This will not be a permit to work as the third party is not responsible for your working party (there could be other sources of supply outside his/her control), and it is likely to be an isolation and earthing certificate. Most utility engineers that I have worked with will cooperate in assisting and assuring you in order to help you to fulfil your responsibility to set up a safe system of work.

Generators. Work on generating and motor driven plant is not to be carried out unless the machine concerned has been securely isolated from all possible rotational driving forces. Particular attention is to be given to the isolation of the auxiliary circuits, controlling the automatic start sequence of any prime mover associated with a generator.

Distance. Finally, putting any distance between the test site and the person is beneficial because of the exponential reduction of incident energy as discussed previously.

STEP 6. AUTHORISE.

Even though we are speaking here about low voltage isolations, an electrical permit to work system is beneficial for any complex commercial or industrial site. The following is meant as a brief overview only, but a permit system should be carefully considered and be drafted into electrical safety rules. A permit to work should always be issued where the designated person undertaking the isolation is not the one who is going to do the work and self-permitting is to be discouraged. The specific circumstances where a low voltage permit to work can be issued are:

a) Where the designated person is isolating for others.
b) For multiple working parties.
c) For complex isolations where there may be more than one point of supply.
d) Where third parties such as a utility company are involved in isolating their equipment to provide you with a point of isolation.
e) Switchgear with automatic changeover or remote-control switchgear and equipment controlled by phase failure relays.

f) Extensions to switchboards or control panels.
g) Isolations from Generators and UPS equipment.
h) Stored energy systems (either mechanical or electrical).
i) Isolations lasting more than one shift.

The list is not exhaustive and there may be other situations requiring the use of permits.

6.12 Live Testing, Fault Finding and Diagnostics

Testing for fault finding, diagnostic or commissioning purposes on live equipment, is live work and precautions should be taken to reduce the risk of arc flash (and electric shock of course) to as low as is reasonably practicable. If workers are routinely testing on very high incident energy circuits, I would suggest that Chapter 5: Prevention should be revisited as a matter of urgency. The use of extra low voltage and/or segregation of control circuits from power circuits is always the desired option and if that is not possible because of legacy equipment design then the following checklist may help to prevent accidents.

6.12.1 Live Testing Risk Assessment Checklist for Low Voltage Equipment

Planning for Safety. If the live testing is for diagnostics or fault finding, I would suggest that an equipment audit will be a good start. There is an example of a control panel audit form which can be used as one part of the audit step in Chapter 9: Electrical Duty Holders. It will be an opportunity to not only deal with the arc flash risk but also very effectively take stock of equipment which is likely to have the greatest number of interactions and therefore risk in terms of likelihood of electrical incidents.

	Example Control Panel Audit	YES	NO
Panel Reference	Location		
	Working environment		
1	Is the access/space adequate to allow the worker to pull back without hazard?		
2	Can access doors/panels be opened with no obstructions to access safely?		
3	Are the lighting levels adequate?		
4	Is the immediate area free from dust, water or other substances?		
5	Is there NO risk of ignition hazards?		
	Equipment and Shock Hazard		
6	Are warning labels and panel reference are in place?		
7	Can the panel be secured against unauthorised entry?		
8	Is the isolator functioning correctly?		
9	Can the isolator be securely locked in the off position?		
10	Are external connecting cables in good condition with glands and shrouds secured?		
11	Are earth connections for outgoing armoured sound?		
12	Are earth bonds on extraneous metal work in place?		
13	Is containment such as conduits, basket and trunking lids free from damage?		
15	Are components including cables free of any signs of damage?		
16	Is the panel free of any exposed cores, corrosion or signs of burning or discoloration?		
17	Is the panel free from signs of water/dust ingress		
18	Are the door seals intact?		
19	Are ventilation fans clean, operational and fitted with a serviceable filter where appropriate?		
20	Is the condition of equipment cables, lamps, bulbs, conduit glands and local switches in good order?		
21	Is the panel IP2X Finger safe?		
22	Is the panel free of holes or unused cable entries?		
23	Is the house keeping inside the panel in good order?		
	Design & Utilisation		
24	Has the panel been properly installed and maintained?		
25	Has the panel been used in accordance with manufacturer's instructions?		
26	There are no modifications to the original equipment specification		
27	Are equipment doors and covers closed and secured?		
28	Is it verified that there is no evidence of impending failure?		
	Arc Flash		
29	What is the fault level at the panel?		
30	What is the upstream device and settings?		
31	What is the incident energy at the panel @ 450mm working distance?		

Figure 6.11 Example of a Control Panel Audit Form

Incident Energy Level. As described earlier, knowledge of what the incident energy level is will allow for a decision on how to proceed. Decisions should be based upon risk assessment especially in respect of whether to deploy PPE or not. As I stated under testing for dead, I would suggest a minimum of hand protection regardless of the incident energy levels for low voltage testing comprising of insulating gloves and leather over gloves. Consider also the routine wearing of face and eye protection for live testing.

Competence. A high degree of competence is required for live testing and although I have said it previously under dead testing, it is worth repeating. Competence means that the worker must have the skill, knowledge, attitude, training, possess the experience to undertake the work and has the ability to recognise the extent of their own competence and leading them to take appropriate action. Specific requirements over and above general electrotechnical knowledge are that he/she will have an adequate understanding of the system to be worked on and practical experience of that class of system, an understanding of the hazards which may arise and the precautions which need to be taken and an ability to recognise at all times whether it is safe for work to continue. What I would add here is that multi-skilled "technicians" are often used for fault finding on electrical equipment whose first calling may not be electrical. I can relate many experiences of this approach which are quite uncomfortable, and this is a route that needs skill and care that such individuals have the necessary electrotechnical knowledge to avoid endangering themselves or others.

Secure the work area. Sufficient space should be provided and maintained around the equipment to permit safe testing. Make sure that tripping and slipping hazards are removed and the work area is under the complete control of the person undertaking the tests. This could be by accompaniment and/or the area is demarcated or defined with barriers.

Work at height. Both the arc flash and electrical shock hazards could be made much more deadly when testing or carrying out any other work on or near live equipment at high level. Special consideration should be given to working at height in the risk assessment with a view to avoidance. Even minor arc flash incidents at height can cause falls or in one case that I know about, injury by jumping from a mobile elevated work platform.

Keep the work to a minimum. The work should be kept to a minimum and the panel doors and access should be secured at breaks or at the end of a shift.

Illumination of work area. Lighting levels should be adequate for the person carrying out the work. Natural light is preferable but permanent artificial lighting improvements should be implemented. Handheld torches are not recommended and should be avoided.

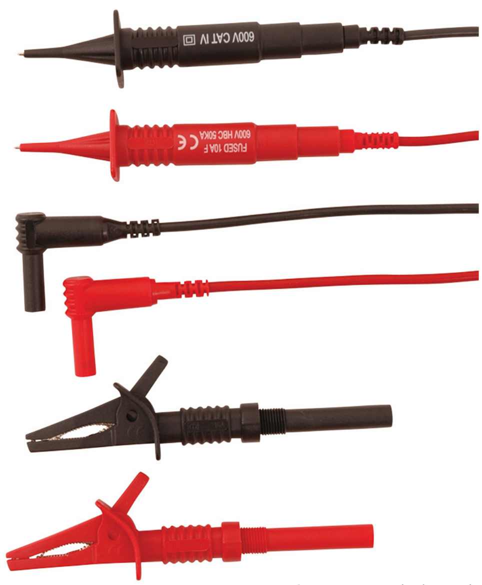


Figure 6.12 Image courtesy of Martindale Electric

Correct test equipment. The standard IEC 61010-1 Safety requirements for electrical equipment for measurement, control, and laboratory use gives categories of hazardous transient impulse overvoltage protection in four categories. The closer to the source the higher the degree of protection is required. I would suggest that testing on anything that has the potential to cause serious injury from arc flash ought to be nothing less than

Cat IV impulse voltage protection for industrial and commercial applications. I would also recommend good quality fused leads which are pictured in Figure 6.12.

Accompaniment. In high-risk situations accompaniment ought to be a consideration. An example may be where there may be difficulty in keeping people away from the work area. The person providing the accompaniment must be trained to be able to recognise danger and give assistance in the event of an emergency.

Prohibit removal of components. Removal of live components and the disconnection of live components should always be prohibited and made clear in the electrical safety rules.

Insulated Tools. At the age of 16 years as an apprentice electrician, I was given my first tool bag. It was full of brand-new high quality, fully insulated tools. It was not a signal to me that I would be carrying out live work but I did recognise the potential risk of using uninsulated tools anywhere near energised equipment. Even routine testing may include the use of tools for access and running adjustments. The standard IEC 60900 is applicable for hand tools for use up to 1000 volts AC and 1500 volts DC.

Remove jewellery. Metal jewellery such as watches, rings, bracelets, piercings, and neck chains should be removed before commencement of work.

6.12.2 Battery Testing

Work on large battery systems, even at extra low voltage can be hazardous and common injuries are arc flash burns from electrical melting of metallic objects inadvertently shorted across the battery terminals and also electrically ignited hydrogen/oxygen explosions. Consider the following non exhaustive options for work on or near batteries.

Incident Energy Level. Awareness of the arc flash hazard level is important and there is a hazard calculator provided for the assessment of the incident energy level at direct current. As always this should be taken into account in the risk assessment process in terms of overall risk and is not a direct route into PPE. This all depends on the task and the state of the equipment.

Competence. Workers who are engaged in the connection, disconnection and testing of secondary battery systems should be competent in all the ways previously expressed. In addition to the competence requirements outlined in live testing above, they will be persons who are considered to have the necessary experience, personal qualities and training to work safely and recognise the risk involved when working on secondary batteries. The training will include, where necessary, the precautions for non-electrical hazards such as the handling of electrolyte.

Personal Protective Equipment. Face protection and insulating gloves are worn regardless of incident energy. This is where care needs to be taken in the selection of PPE that cover all hazards and do not create a hazard. This is where manufacturer's handling instructions need to be taken into account especially where contact with liquid electrolyte may be encountered.

The work area is well ventilated. There may be a requirement for specialist aprons for the chemical hazards as an example, and as pointed out in the next Chapter 7: Protection, all personal protective equipment must be appropriate for the risks involved, without itself leading to any increased risk.

Other precautions. As described in live testing above; the extent of live working should be kept to a minimum, metal jewellery such as watches, rings, bracelets and neck chains should be removed before commencement of work and correctly selected insulated tools and instruments should be used.

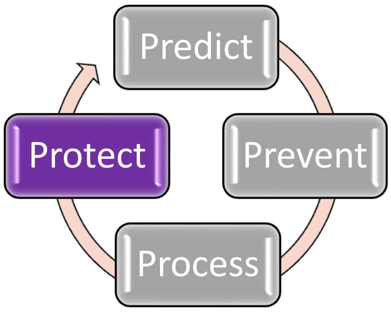
There is an excellent free resource available on the Great Britain Health and Safety Executive site called "Using Electric Storage Batteries Safely". It can be downloaded via the link; https://www.hse.gov.uk/pubns/indg139.pdf

Learning Points

- The competence of the individual is of paramount importance whether they are making dead or working anywhere near energised conductors.
- Having safe procedures, safe people and safe places will provide the building blocks to arc flash risk management and electrical safety.
- The legal requirement for safety signs is different in Europe. Safety signs are where there is a significant risk to health and safety that has not been removed or controlled by other methods. Also, the colours are totally different to the US.
- Live working permits are not a good idea in the UK.
- Treat all electrical equipment and conductors as live unless proven dead.

Chapter 7

Protection



Where the risk cannot be 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. In Chapter 3: Risk Assessments and the Four P Guide, there was a hierarchy of risk controls for electrical flashover and the final risk control measure in the hierarchy is Personal Protective Equipment. It is fairly obvious that PPE is not mentioned in the principles of prevention given in Chapter 3: Risk Assessments and the Four P Guide as PPE alone will not prevent the accident. It is therefore seen as a last line of defence but where used properly, there is evidence that it has prevented injury to individuals. In this chapter, the main focus is on the selection of PPE for protection against arc flash and it will look at how this aligns with the risk assessment process. Although the intention is to inform about how arc flash PPE is selected and used, one objective is to simplify the selection process. In most situations, flame resistant PPE is surprisingly comfortable nowadays and can be worn as everyday workwear. If we follow the steps laid out in this guide so far, the residual risk should now be much less severe and hopefully minimised to a great extent. That means that should PPE be required as a final risk control measure, then this will be much lighter and less cumbersome. The wearing of PPE should be much more acceptable, not only in terms of user agreement but also in expense. Heavy duty PPE is expensive!

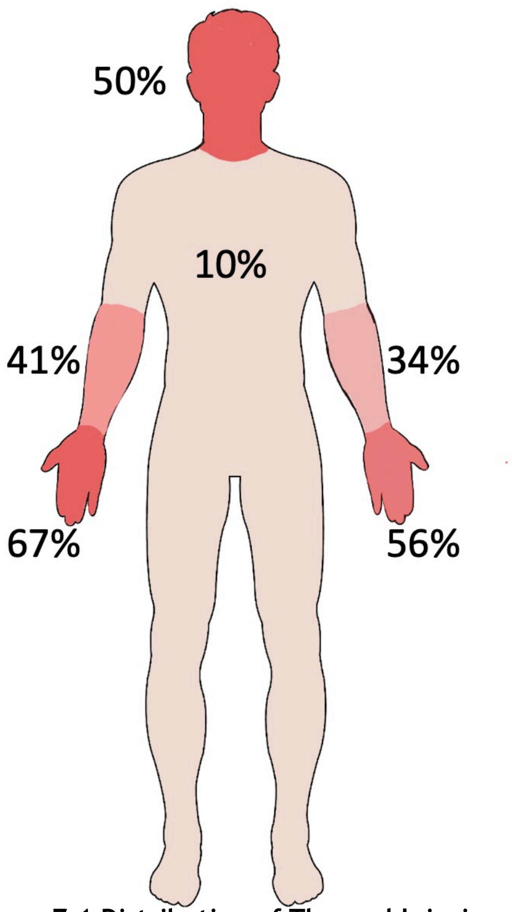


Figure 7.1 Distribution of Thermal Injuries

Non-flame-resistant clothing may ignite or melt at low incident energy values and once ignited will continue to burn after the electrical arc has been extinguished. Three seconds of burning material next to the flesh can result in serious full thickness burns. This means that ordinary clothing could actually become a hazard and for this reason it is well worth considering a policy of comfortable Flame Resistant (FR) clothing. There is research that shows that the hands, arms and face are the most commonly affected parts of the body in an arc flash incident. See Figure 7.1 (Source: Guideline for selection of personnel protective clothing when exposed to the thermal effects of an electric arc, International Social Security Association- Section Electricity, Koln, 2002) This is not surprising as these parts of the body are often exposed and are also much closer to the arc, special emphasis should be given to face and hand protection.

7.1 Standards for PPE in Europe

European Council Directive 89/656/EEC Use of Personal Protective Equipment covers the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace. Laws in EU countries on the use of personal protective equipment (PPE) in the workplace are all based upon this directive. You can find the specific legislation in Chapter 16: Rules, Codes and Legislation for the UK and Ireland. Priority must be given to collective safety measures. PPE can only be used where the existing risks cannot be sufficiently limited by technical means or collective protection or work organization procedures. The employer must also provide the appropriate equipment free of charge and ensure that it is in good working order and hygienic condition.

PPE can only be prescribed after the employer has analysed and assessed the risks which cannot be avoided by other means. For arc flash this means an employer must consider other means of achieving safety prior to considering the use of PPE, such as the elimination of hazard, engineering controls and safe systems of work.

Issues of use, which must be part of the risk assessment process, must include ergonomics, sensory deprivation of user, continuing integrity of PPE and other injury mechanisms, including loss of hearing and sight. Heat stress is a particular concern with arc flash PPE as it may lead to fatigue at best and could lead to poor decision making, not a good thing when working near live conductors. This is one more reason to ensure that the risk assessment process is followed rigorously with the avoidance of over specified PPE. In addition, the health of the worker must be considered, bearing in mind that arc flash PPE will usually result in some restriction of the face. There could therefore be some physical and even psychological issues to take into account.

In addition to the above is the Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on Personal Protective Equipment, repealing Council Directive 89/686/EEC. The regulation lays down requirements for the design and manufacture of personal protective equipment (PPE), which is to be made available on the market, in order to ensure protection of the health and safety of users and establish rules on the free movement of PPE in the European Union.

7.2 Selection of PPE

Article 5 of Directive 89/656/EEC clarifies that assessment of personal protective equipment shall involve an analysis and assessment of risks which cannot be avoided by other means. In respect of arc flash, to start off with a quantitative assessment based on incident energy will go some way to satisfying this requirement. Before choosing personal protective equipment, Article 5 asks us to assess whether the PPE that we intend to use will satisfy the following requirements.

(1) Personal protective equipment must comply with the relevant community provisions on design and manufacture with respect to safety and health. All personal protective equipment must:

- Be appropriate for the risks involved, without itself leading to any increased risk.
- Correspond to existing conditions at the workplace.
- 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 personal protective equipment, such equipment must be compatible and continue to be effective against the risk or risks in question.

The assessment to meet the above requirements involves a three-step process as follows: *(Note, that the italics are guidance on how that step can be implemented)*

(A) an ANALYSIS AND ASSESSMENT of risks which cannot be avoided by other means.

HOW? *By predicting the severity of the arc. See Chapter 14: Hazard and Severity Calculations. If the risk assessment has been carried out in accordance with four P's 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. At this stage we will have a numerical value for the incident energy at a working distance and also an arc flash boundary which will give a distance at which no PPE is necessary. It has to be remembered that different parts of the body will be affected in different ways. If you use the tools available with this guide, you will be able to instantly determine the incident energy at any part of the body in a dynamic way. For instance, the hands may be closer to an arc and have a much greater magnitude of incident energy. (Alternatively, if undertaking an assessment under the IEC64182-1-2 Box test method we will arrive at either an arc protection class (APC) 1 or 2)*

(B) the DEFINITION OF THE CHARACTERISTICS which PPE must have in order to be effective against the risks referred to in (A), taking into account any risks which this equipment itself may create.

HOW? *Whilst the arc flash attributes can be established by straightforward calculation 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, or where there may be a biological hazard or outdoors or perhaps a very dirty area which may degrade or compromise the type of FR materials available. This needs to be identified as environmental considerations. Finally, the characteristics need to include all the other risks that have been identified previously such as ergonomics, compatibility with other protection and fit.*

(C) COMPARISON OF THE CHARACTERISTICS of the PPE available with the characteristics referred to in (B).

HOW? *CE marking is essential so should be the starting point when making comparisons in the marketplace. There have been great developments in the design of PPE systems in recent years and systems are available for parts of the body of environmental conditions. However, depending upon the environmental considerations and other risks, there may have to be compromises when considering the available choices. One of the issues that will crop up 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 all this is dealt with in a later section as will CE marking.*

In summary, the following diagram Figure 7.2 shows the above three step process.

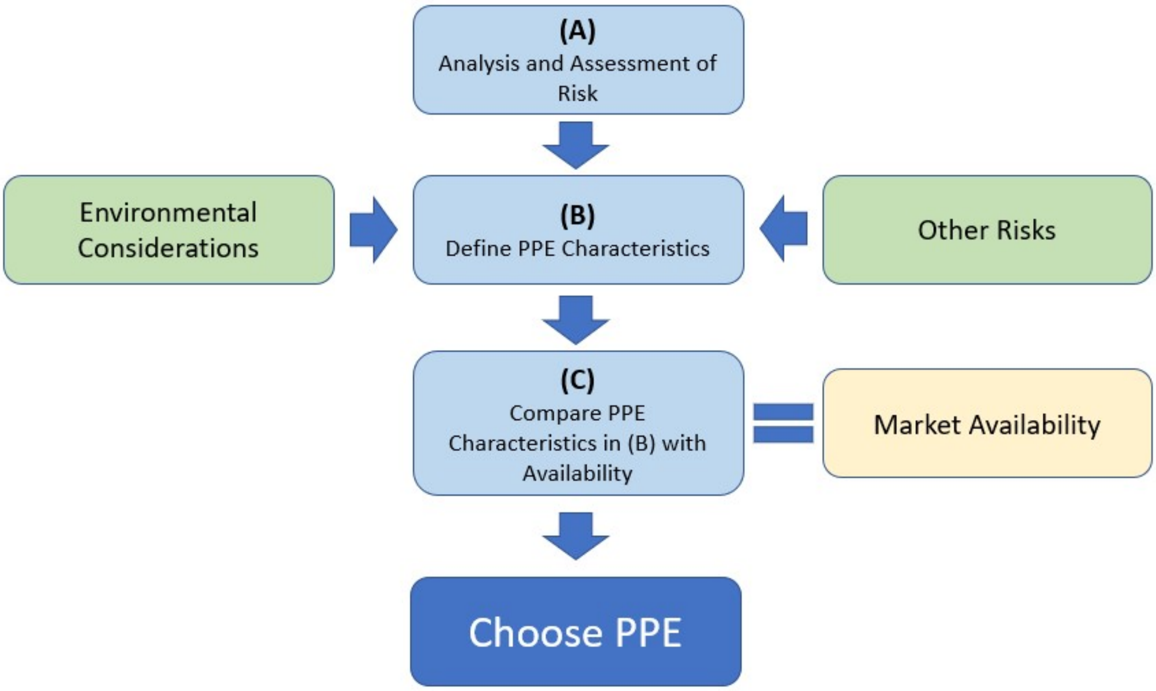


Figure 7.2 PPE assessment flowchart

The following table is reproduced from Article 5 of the 89/656/EEC Use of Personal Protective Equipment Directive. This will aid the aid in the identification of all hazards.

		RISKS																				
		PHYSICAL											CHEMICAL						BIOLOGICAL			
		MECHANICAL					THERMAL		ELECTRICAL	RADIATION		NOISE	AEROSOLS			LIQUIDS		GASES, VAPOURS	HARMFUL BACTERIA	HARMFUL VIRUSES	MYOCOTIC FUNGI	NON MICROBE BIOLOGICAL ANTIGENS
PARTS OF THE BODY		FALS FROM HEIGHT	BLOWS CUTS IMPACT CRUSHING	STABS CUTS GRAZES	VIBRATION	SLIPPING FALLING OVER	HEAT FIRE	COLD		NON IONISING	IONISING		DUST FIBRES	FUMES	VAPOURS	IMERSION	SPLASHES	GASES VAPOURS				
HEAD	CRANIUM																					
	EARS																					
	EYES																					
	RESPIRATORY TRACT																					
	FACE																					
	WHOLE HEAD																					
UPPER LIMBS	HANDS																					
	ARMS																					
LOWER LIMBS	FOOT																					
	LEGS																					
VARIOUS	SKIN																					
	TRUNK ABDOMEN																					
	PARENTAREL PASSAGES																					
	WHOLE BODY																					

Figure 7.2b Risks table

Personal protective equipment is, in principle, intended for personal use although the PPE directive gives the possibility for it to be worn by more than one person by ensuring that this does not create any health or hygiene problem. I would very much doubt if that would be acceptable nowadays.

In addition, the employer must consult the workforce every step of the way. I cannot stress how important that this is when choosing arc flash protection and when carried out correctly, it has a positive effect on morale and eradicates misuse and non-compliance. There is a good example of how this can be done in Chapter 11: Electrical Utilities. It describes the journey taken to equip the entire workforce at Northern Powergrid with new FR uniforms and where worker involvement was a study in how it can be done well. Notwithstanding the case for worker involvement from a sensible management perspective, the “Framework Directive” (European Council Directory 89/391/EEC (EU Workplace Health and Safety Directive)) states that workers shall be informed of all measures to be taken with regard to the health and safety of workers when PPE is used by workers at work. The “Framework Directive” also mandates that there shall be consultation of workers and participation by them in all matters relating to the provision of PPE. As a minimum, the employer must first inform the worker of the risks against which the wearing of the personal protective equipment protects him. The employer shall then arrange for training and shall, if appropriate, organize demonstrations in the wearing of personal protective equipment.

7.3 CE Marking

Employers should ensure that any PPE they buy bears a ‘CE’ mark and complies with Regulation (EU) 2016/425 on personal protective equipment. (The full title is Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on Personal Protective Equipment, repealing Council Directive 89/686/EEC). Not to be confused with the Use of Personal Protective Equipment Directive

(89/656/EEC) covered previously, the regulation lays down requirements for the design and manufacture of PPE, which is to be made available on the market, in order to ensure protection of the health and safety of users and establish rules on the free movement of PPE in the European Union. It requires manufacturers to CE mark their products to show compliance. If you use PPE for providing protection against arc flash hazards, you should ask for confirmation, from the supplier, that the PPE certified satisfies the requirements of the PPE Directive.

Following Brexit, things are different in the United Kingdom. The UKCA (UK Conformity Assessed) marking is a new UK product marking that is used for goods being placed on the market in Great Britain (England, Wales and Scotland). It covers most goods which previously required the CE marking. The UKCA mark will not be recognised for products being placed on the EU market.

The UKCA marking alone cannot however, be used for goods placed on the Northern Ireland market, which require the CE marking or UKNI marking. There is a separate Northern Ireland Protocol which, for as long as it is in force, Northern Ireland will align with all relevant EU rules relating to the placing on the market of manufactured goods.

7.4 Types of Arc Flash PPE

When considering protecting persons against the arc flash hazard, much of the focus seems to have been on providing clothing made from FR fabrics in the form of shirts, polo tops, trousers coveralls and so on. However, as I mentioned earlier, it has been shown that the parts of the body which have been most frequently affected by arc flash have been the hands, arms and face. Some years ago, when researching the subject, I remember being told by a HSE Specialist Electrical Inspector about an horrific injury to a young man injured in an arc flash accident. He suffered permanent and debilitating injuries to his respiratory system due to the inhalation of toxic and super-heated gases. I have been very fortunate to have made the acquaintance of experts in hand and face protection with whom I have used this observation on several occasions. Fortunately, the standards for face and hand protection have caught up in recent years and details of the different types of arc flash protection and related standards are detailed as follows.

7.4.1 FR Protective Clothing

Compliance is required with Standard IEC (EN) 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. The subjects covered are; tear resistance, tensile strength, burst strength, shrinkage and other effects of cleaning, arc thermal performance, marking/labelling, user instructions specification and flame resistance. There are also inspections of construction and workmanship, size designation and ergonomics, ageing and threads and closures.

All flame-resistant garments are made from fabrics which are in turn, made from fibres which are woven together to form the fabric. The term “Inherently Flame Resistant” means that the fibres are naturally flame resistant and when woven into a fabric require no further treatment and can be made into garments to withstand levels of the thermal hazard from an arc flash event. The flame resistance is an inherent property of the polymer chemistry and will not diminish during the lifetime of the garment.

Then there are those garments made from “Permanently Treated Fabrics”. They tend to be made from cotton fibres which acquire their flame resistance from a treatment received after it is woven into fabrics. Permanently treated fabrics were often characterised by the treatment washing out over a period of time which is determined by the frequency of washes that the fabric was exposed to. This is less of a problem nowadays although the life expectancy of inherently flame-resistant fabric appears to be longer through anecdotal evidence and published data. Those manufacturing FR garments from permanently treated fabrics would say that they are more likely to naturally wear out before losing flame resistance.

Whether inherent or treated, sewing thread used in the construction of FR garments have to be inherently FR fibre except for where threads in seams that have no influence on protection, such as hems and pocket seams.

My own preference is for garments made from inherently flame-resistant fibres and my reason is supported by my house building analogy. A house may be built out of several different materials. I love to see a house made out of kiln fired bricks, but I have to accept that a house made out of concrete blocks will probably be cheaper and perform just as well. The fact is, that the cost of the bricks or the concrete blocks, will be a fraction of the total building costs and the manufacturer of the materials will not be the company that builds the house. This is the same for PPE where the weavers will mostly be separated from the manufacturers of the fibres. So, for larger bespoke procurement of PPE it is preferable, in my view, to specify the type and even the producer of the fibre and drive the value for money through the weaving and manufacturing of the garments. For smaller, off the shelf procurement exercises, the comparison of apples with pears starts with being aware of the performance of the various fibres that go into the garments. The following information will help with the comparison.

7.4.2 User acceptability

Comfort

If the garment is to be worn as part of everyday workwear, then it needs to be comfortable. In addition to the thermal performance per weight of fabric, it has to feel comfortable as well as be lightweight. This is often termed as the hand of a fabric and is assessed by the reaction obtained from your sense of touch. The challenge with measuring fabric hand is that everyone perceives things differently. The air-permeability of the fabric and a good garment design are parameters, which determine the comfort of protective clothing. Comfort is not only another key aspect for acceptance of the clothing by workers, but if the garments are very uncomfortable then this may even increase the risk of an electrical accident or even trip, slips and falls.

Colour

In addition to being comfortable, if the garment is to be worn as part of everyday workwear, then it needs to look good, and colour could be important to gain user acceptability. The problem is that inherently flame-resistant fibres may be limited in colour ranges so this is where compromises may be required. Durable appearance and colour fastness are also a key element for acceptance of clothing by workers and evidence should be available from the supplier.

Life Expectancy

There needs to be a discussion about the life expectancy of any garment and which factors will affect it. From the data that I have seen, it is likely that inherently flame resistant fabrics will last longer than permanently treated fabrics, but purveyors of the latter type may be able to give a contrary viewpoint. The life cycle cost could vary widely and an inability to provide evidence could result in a much greater expense for an inferior product.

Laundering

The standard allows for both washing and dry cleaning, but it is down to the manufacture to make clear how the garments have to be cleaned in their instructions. This could have a significant effect on life cycle cost. The manufacturer may state a maximum number of cleaning cycles, in which case the requirements for limited flame spread have to be met after the stated cleaning cycles. Otherwise, if no maximum number of cleaning cycles is specified, the flame test has to be carried out after five cleaning cycles.

Underwear

Arc rated under garments are available and their provision does ensure that workers are equipped with non-flammable clothing throughout. Another advantage is that higher levels of protection can be obtained when used as part of a layered solution as described above. In Europe however, the provision of undergarments as part of a PPE system has some drawbacks. The employer must provide it free of charge and they also have an audit inspection role to ensure that it is being worn. The complications such an audit will bring, I will just leave to your imagination. From a practical perspective, it may be better to mandate that the worker must not wear undergarments or clothing made of materials that would add to the hazard of possible burns. This is where the specifier may find that the open arc Incident Energy Limit (ELIM) rating has a part to play, insomuch that there is a zero chance of burn injury. It follows that undergarments cannot ignite for properly rated FR PPE in an arc flash incident. See section 7.5.2 for further information about ELIM.

Labels

Every arc resistant garment has to be labelled which should show the manufacturer, type of product, size, and care requirements. In addition, the garment will have the IEC arc flash symbol shown in Figure 7.4 which denotes protection against the thermal effect of the electric arc. It should also show the level of arc thermal protection in the form of an arc rating ELIM and/or arc protection class (APC 1 or APC 2). In addition to ELIM the lower value of either ATPV or EBT (Energy Breakopen Threshold) can also be added. All basic essential guidance with respect to cleaning should be given by labels or other marking of an item of PPE. More detailed additional information will be given on instruction for use/manufacturer's leaflets.

Figure 7.3
IEC Garment Symbol

Layering

The layering of arc rated garments can have a beneficial effect on the final arc rating as well as comfort. For instance, if an arc rated jacket of 8 cal/cm^2 is worn over an arc rated shirt of 8 cal/cm^2 it would suggest that the final Arc Thermal Protection Value (ATPV) will be of the order of 16 cal/cm^2. The fact is that the final ATPV if the garments were to be used together would be considerably higher than that. This is often used by suppliers to produce higher comfort levels from higher rated garment systems. It should be stressed that layering has to be tested as a system together to assure their protection level. The following diagram (Figure 7.4) shows how two layers of 9.4 cal/cm^2 results in a final tested ATPV of 33 cal/cm^2. See section 7.5.2 for further information about ATPV.

Figure 7.4 Layering of Protection Example

7.4.3 Use and Maintenance of PPE

Personal protective equipment 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 obligation 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.

When choosing PPE, it is at the bottom of the hierarchy of risk control measures. As such, all lower order risk control measures need to have a much greater level of monitoring and review. The goals of the monitoring and review process should be:

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

7.4.4 Training

The usual training, assessment and authorisation of persons is necessary and appropriate criteria must be applied, see Chapter 6: Process, Policies and Procedures. 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:

- Information concerning limitations and capabilities of the PPE.
- How the PPE works and what the PPE will and will not protect.
- How to follow the risk assessment of which PPE is a part.
- Issues of sensory deprivation and how these issues can be mitigated.
- How to read and correctly interpret the information which is given on label or other instructions.
- How to use, wear and inspect the PPE.
- How to store the PPE when not in use.
- Information concerning arrangements for handling, cleaning and decontamination.
- How to determine when the PPE is no longer fit for purpose.
- How to obtain replacements.
- The dangers of using PPE which is contaminated by inflammable liquids or substances.

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.

7.4.5 Record keeping

The keeping of records 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.

7.4.6 Routine examination

PPE should be examined preferably by the user before and after use. The overall risk assessment should detail the examination which should also be to match the thermal protective performance to the item of 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.

7.4.7 Cleaning and Ageing

Cleaning should be strictly in accordance with the manufacturer information including care instructions. Based on this information, the duty holder 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.

7.5 PPE Test Methods for the Electric Arc Hazard

In Europe, for protective clothing, there are two tests that are used to determine the level of protection against the thermal effects of electrical arcs. The two tests are referred to colloquially as the “Open Arc Test” and the “Box Test”. Their full reference is given below.

Open Arc Test - IEC 61482-1-1:2019, 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.

Box Test - IEC 61482-1-2:2014, 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)

Both the box test and the open arc test 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. Depending on the needs, either or both standards can be specified.

The most commonly used output from the open arc test is an arc thermal performance value (ATPV) which 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 12 $cal/cm^{2,}$ 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 1.2 cal/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 main output from the box test is an Arc Protection Class. The box test method defines two arc thermal protection classes APC 1 and APC 2. 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).

7.5.1 Open Arc Test Setup.

The open arc test set up uses two stainless steel electrodes at a distance of 30mm to 300mm using a decoupled source giving a prospective short circuit current between 1 kA and 20 kA. The test voltage needs to be sufficient to sustain an electric arc across the electrodes which is typically between 400 V and 700 V. It is the duration of the arc that 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.

In the case of PPE, the specimen garments or samples of material are placed around the arc electrodes spaced at 120 degrees at a distance of 300 mm. Calorimeters are placed behind the materials to be tested to measure the energy let through the sample. At the same distance, further calorimeters are placed that are exposed to the electric arcs. These calorimeters directly exposed to the electric arcs measure the actual effective energy to which the garments or sample materials are being subjected.

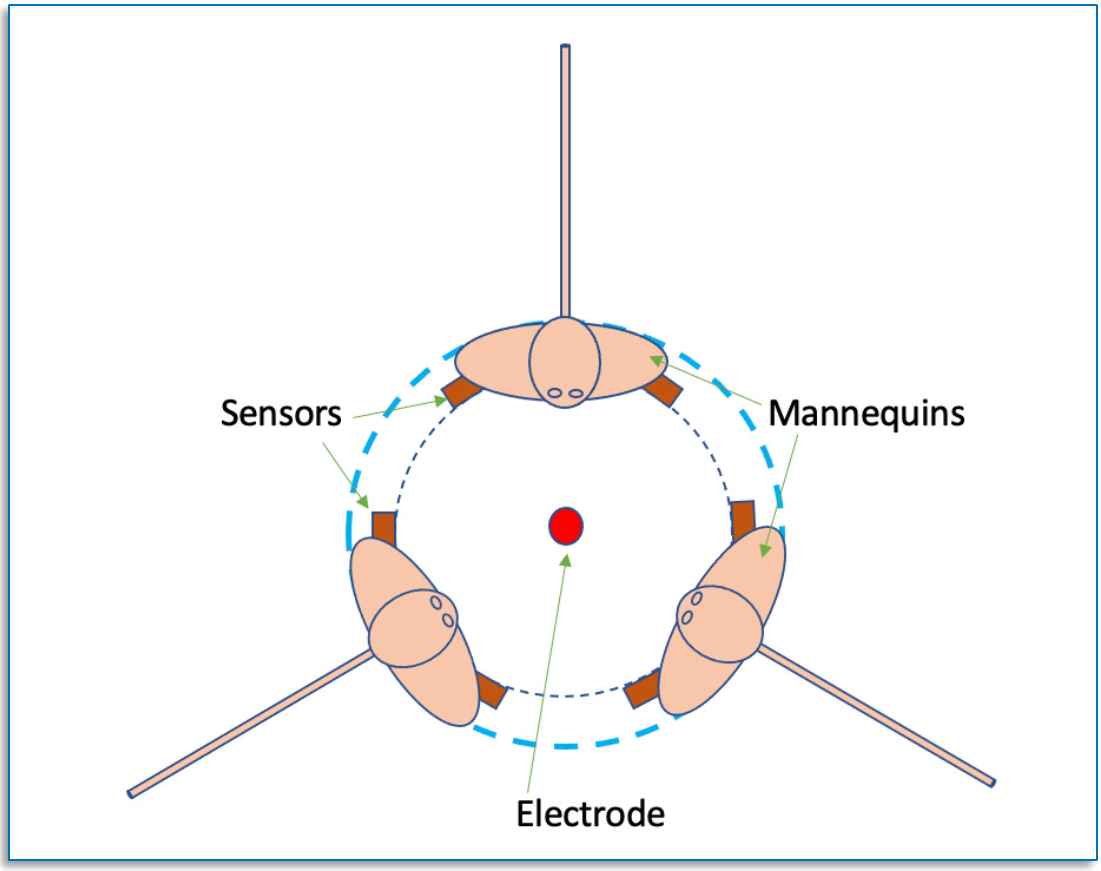


Figure 7.5 Open Arc Test Setup

The above diagram shows the mounting of three mannequins at 120 degrees around the central electrode. These could be materials or a mixture of mannequins and materials. The additional calorimeters are placed as shown at a predetermined distance from the arc and the sternum is held centrally to the arc.

7.5.2 Open Arc Output Values

The Arc Thermal Performance Value (ATPV), as mentioned previously, is the main output for the open arc testing that is required to match PPE to the site calculated incident energy levels. In order to determine the ATPV, the electric arc current will be 8 kA, the distance between the electrodes 300mm and the distance from the arc 300 mm. A calculation of ATPV is made from the measured calorimetric values of the directly exposed calorimeters and the calorimeters covered by material samples. Tests are performed using different arcing durations to give the resultant variable energy exposure.

I mentioned a value of 1.2 cal/cm^2 as a “safer” level and this 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 the 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 cross the Stoll Curve is identified as the point at which a human would feel pain and be at risk of second-degree burns. The ATPV gives the incident energy of a material that results in a 50% probability that sufficient heat transfer through the specimen to cause the onset of second-degree burn injury based on the Stoll Curve. In other words, half the points measured would be above the curve and half below.

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, I understand that this additional safety factor will usually result in a derating of about 10%. It is sometimes regarded as a purely academic measure. This is because the ATPV would have to be exactly equal to the actual arc flash to create the conditions of a 50% chance of a minor burn. In my practical experience of thousands of arc flash calculations in the field, I cannot recall a single occasion when these conditions have existed. If used as part of a risk assessment, it will be usually an additional safety factor on top of how the incident energy calculations are applied.

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 1.6 cm^2 hole formation. Various fibre types act in different ways but each one can breakopen before the burn prediction level is reached. Workers are assumed safe if the arc rating of their clothing (or ATPV value) exceeds the electric arc incident energy as calculated in the worst-case scenario of a risk assessment.

7.5.3 Open Arc Test - Further Discussion

PPE tested to the open arc method can be linked directly to quantitative risk assessments on site and calculations through the IEEE 1584 Guide for Performing Arc Flash Calculations. The calculations will provide incident energy and an arc flash boundary and, although discussed elsewhere in this guide, some additional care is required due to the interpretation of the outputs from the open arc test according to IEC 61482-1-1.

Exposure to heat flux of 1.2 cal/cm^2 for the duration of 1 second, i.e., exposure to incident energy of 1.2 cal/cm^2, can produce the onset of second-degree burn or partial thickness burn of the bare skin. Limiting the incident energy exposure at the skin surface to no more than 1.2cal/cm^2 means that you can still receive some burn injury, however the primary objective of arc flash protection has been to minimise the injury and probability of death. In general, if the prospective incident energy exposure at a given location is below 1.2cal/cm^2, no additional thermal protection is required for the worker. This is achieved by the determination of a boundary beyond which the incident energy is less than 1.2cal/cm^2, or through shielding or application of properly designed specialist PPE capable of withstanding the thermal effects of the arc. Where protection against the thermal effects becomes necessary it must be emphasised that PPE does not prevent the accident happening in the first place.

Personal Protective Equipment (PPE) used for arc flash protection includes garments made from FR fabric. When tested to the open arc test IEC 61482-1-1, the fabric is designed to provide a thermal barrier and limit the incident energy exposure at the skin surface to no greater than 1.2 cal/cm^2. Although FR fabric may burn when exposed to a flame, it is designed to stop burning when the flame is removed. It also must not break or burn open and expose the skin directly to the flame. As discussed previously, the ATPV represents the incident thermal energy that results in a 50% probability that sufficient heat transfer through the clothing is predicted to cause the onset of a second-degree burn injury, or - more colloquially - the ATPV is the incident thermal energy that the clothing can support before the wearer would suffer second-degree burns.

As described above, when carrying out open arc testing according to IEC 61482-1-1, an ELIM is obtained which similar to the ATPV in that it is derived by statistical means from the test data but is slightly more conservative. Whereas the ATPV is based on the 50% probability of crossing the Stoll curve, the ELIM is based on no points crossing the Stoll curve. The reason that the ELIM was introduced was because of disagreement in Europe over the concept of a 50% chance of a burn, albeit a minor one. This was based upon the European PPE Directive. So, the ELIM was introduced which made sure that there would be a zero chance of a burn where the ELIM rating of the garment is greater than the prospective incident energy level. An advantage of using ELIM instead of ATPV is that the prescribing of specific undergarments is less of an issue. See the earlier section on undergarments. In other words, if properly prescribed, there is zero probability of the ignition of garments worn beneath ELIM rated PPE.

It might be worth pointing out that having spoken with various people in the industry, the ATPV model is valid and there are no injuries reported where the ATPV was greater than or equal to the actual incident energy level in an arc flash accident.

The introduction of ELIM creates a dilemma for the duty holder when determining the arc flash protection and how to match the site calculated data. For instance, the IEEE 1584 Guide for Performing Arc Flash Calculations will produce an arc flash boundary which is the distance from a prospective arc source at which the incident energy is calculated to be 1.2 cal/cm^2. This is the boundary, outside which, no FR PPE is required according to US and Canadian consensus standards. In addition, working on any equipment where the incident energy level was calculated to be less than 1.2 cal/cm^2 at the working distance would not require FR PPE. Theoretically, there could be a 50% chance of a burn at both these distances where the incident energy level was 1.2cal/cm^2. These are the various options that the duty holder could adopt to accommodate ELIM principles.

- **Options for the arc flash boundary (AFB)** – Either stick to the 1.2 cal/cm^2 limit for the arc flash boundary or build in an additional safety factor on top of the IEEE 1584 calculations. For instance, if the arc flash boundary was 1 metre add 10% safety factor making the AFB = 1.1 metre. A better solution would be for a site wide standard arc flash boundary to be adopted. Say if the arc flash boundary varies from between 0.5 and 1.8 metres, then round it up to 2 metres. It is easier to apply and easier to understand.
- **Options for incident energy levels requiring no PPE** – Either stick to the requirement of 1.2 cal/cm^2 above which FR PPE would be required or reduce this incident energy level at the working distance by a factor of approximately 10%. For instance, FR PPE will be required in all case where the incident energy level at the working distance was above 1.08 cal/cm^2. A better solution would be that FR PPE should be worn for any interactions with energised equipment.

7.5.4 Further Requirements for Protective Clothing

When tested according to the open arc test, the protective clothing made of the tested material has to have an arc rating as described below in order to meet with the requirements of IEC 61482-2:2018 - Live working protective clothing against the thermal hazards of an electric arc.

Arc Rating is the numerical value attributed to a product, that describes its protective performance when tested in accordance with the open arc test. The arc rating can be the arc thermal performance value (ATPV), the breakopen threshold energy (EBT) or the incident energy limit (ELIM). A manufacturer may assign a lower arc rating value to a material or protective clothing than the value resulting from testing.

Protective clothing needs to meet a minimum arc thermal protection value, where the ELIM is at least 130 kJ/m^2 (3.2 cal/cm^2). In addition, it can have a minimum arc thermal protection, where the lower value of ATPV and EBT is at least 167 kJ/m^2 (4 cal/cm^2). In case only either ATPV or EBT can be determined, this value will be at least 167 kJ/m2 (4 cal/cm^2).

Due to the limitations of test apparatus at very high energy arcs, no arc rating above 4186 kJ/m^2 (100 cal/cm^2) shall be assigned to garments.

7.5.5 Box Test Setup.

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. See Figure 7.6.

The open circuit voltage is 400 V (50 Hz) and the arc gap is fixed at 30mm, with an aluminium upper electrode and a copper lower electrode. The duration of the arc is also fixed for a period of 500ms. The arc emission is focused outwards and corresponds to extreme effects under the relevant conditions. The test takes account not only of the directed effect of heat, but also the effect of hot metal particles and splashes that accompany actual electric arc faults. The box test will test a sample of fabric up to a maximum of five samples and then a specimen of the garment. It is a very simple test not requiring decoupled power supplies and the only variability is the prospective short circuit current which is either 4 kA or 7 kA. The result is either pass or fail resulting in either thermal protection classes Arc Protection Class (APC) 1 (at 4kA) or Class 2 (at 7kA).

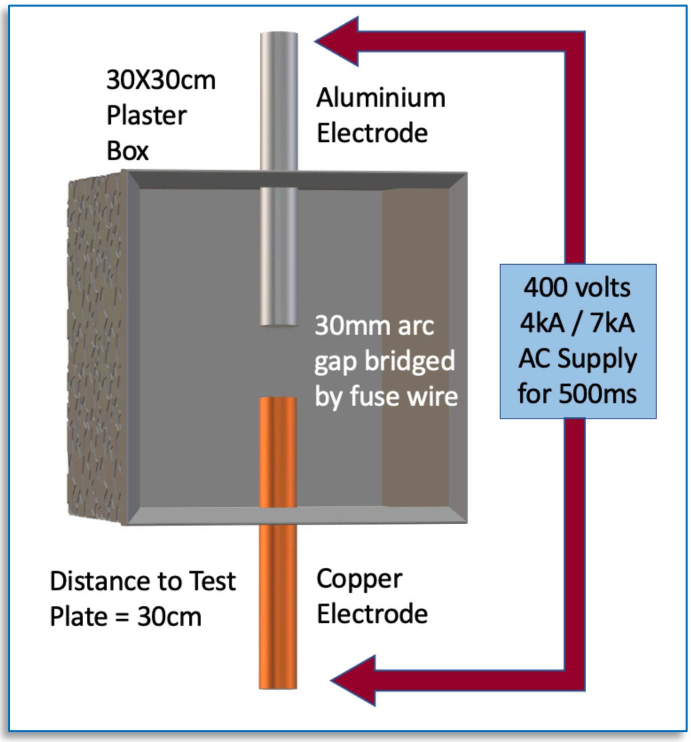


Figure 7.6 Box Test Setup

Figure 7.7 The Author observing the box test at Ilmenau University in Germany

The materials to be evaluated are fixed onto a plate at a horizontal distance of 300mm from the electrodes. There are two calorimeters are set in this plate which determine the heat flow densities and are used to judge whether the wearer of clothing made from this material would have suffered second-degree burns. A further requirement is that there is no afterburn lasting for more than 5 seconds and that holes are no bigger than 5mm in any direction. Attention is paid to the total behaviour of the clothing, whether for example the clothing can be opened easily after testing and that fasteners are still functional.

7.5.6 Box Test Output Values

To comply with IEC 61482-2:2018 Live working — Protective clothing against the thermal hazards of an electric arc a material and the clothes made from it must at least pass Class 1 of the "Box Test" in order for clothing from this material to be termed "clothing for protection against thermal effects of electric arcing". (Alternatively, the material must at least have an ATPV of 4 cal/cm^2 and the clothing made from it must pass the "Open Arc Test" as described earlier)

7.5.7 Arc protection classes

When tested according to Box Test, the protective clothing made of the tested material is assigned one of two arc protection classes (APC) This will either be APC 1 is subjected to a prospective short circuit current of 4 kA for 500ms or APC 2 at a prospective short circuit current of 7 kA for 500ms. Protective clothing has to demonstrate a minimum arc thermal protection of APC 1 in order to be given an arc rating according to the standard. A fabric will pass the test:

- If the heat transferred behind the fabric cannot cause a second-degree burn. (In box testing, no crossings of the Stoll Curve are permitted)
- If the fabric passes a visual assessment covering:
    - No after-flame time is below 5 seconds.
    - No melting to the inner side of the fabric.
    - No holes larger than 5mm.

Future visual assessment requirements for head, face and eye protection will probably not allow breakopen, dripping or molten matter inside the protector.

NOTE: The necessary arc protection class is determined by risk analysis. Guidance for the appropriate selection of the arc protection class is provided in other separate guidelines, such as the ISSA Guide and DGUV-I 203-078, Thermal hazards for electric fault arcs – Guide to the selection of personal protective equipment for electric work. There is a calculator which is available through this guide on ea-guide.com. In addition, some further assistance in predicting arc severity for Box Test PPE can be found in Chapter 14: Hazard and Severity Calculations. My opinion is that APC 1 or 2 ratings may be the basis for the selection of PPE, as long as the actual expected exposure situation can be considered to be less severe than the specific exposure condition simulated during the box testing according to IEC 61482-1-2.

7.6 Summary of Minimum Arc Thermal Performance for Protective Clothing from IEC 61482 -2

In summary the following diagram, Figure 7.8, shows the minimum requirements that protective clothing will need in order to meet EN 61482 -2.

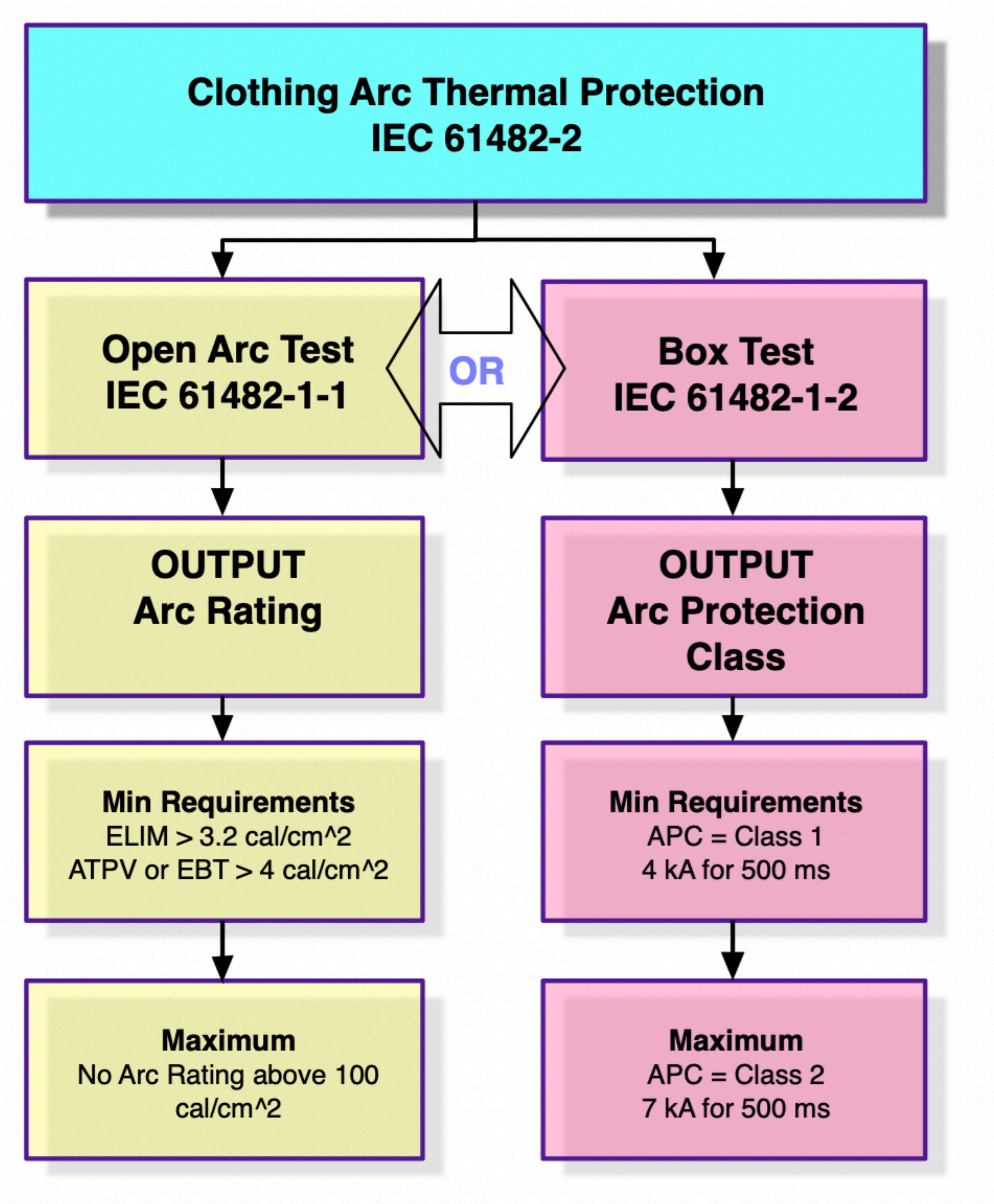


Figure 7.8

7.6.1 Box Test versus Open Arc

There has been considerable argument over the relative advantages and disadvantages between the box test and open out test methods. This has even manifested itself in comments made in International standards and official guidance on the subject of protection against the thermal effects of electrical arcs. The following are examples of such comments.

The following comment is a quotation from the National Foreword to the box test standard – EN 61482-1-2:2007 from the UK technical committee PEL/78. "It is the opinion of UK technical committee PEL/78 that the "box test" does not provide the user with a realistic and reliable test. A premise of this test is that the fault currents will not exceed 4000A or 7000A and the worker will not be closer than the specified distance from the arc (in reality this cannot be guaranteed)". "The UK technical committee PEL/78 believes that the open arc test IEC 61482-1-1 will provide the best way to determine whether a particular material will provide the best protection for the worker for any given job".

The following comment came from the *DGUV 5188 Thermal Hazards from Electric Fault Arc -Guide to The Selection of Personal Protective Equipment for Electrical Work. "On the other hand, Arc-Man test results lead to the so- called Arc Thermal Performance Value, or ATPV. In this context, the incident energy is determined according to a statistical methodology, by which a 50% probability exists of suffering second-degree skin burns behind the PPE. Even if an electric fault accident is relatively improbable, the EU directive regarding PPE allows no interpretation of PPE that would tolerate such injury. For this reason, as a matter of principle, such test methods should not be used within the EU". This is very clear but as I have said previously, to be wearing PPE which had an ATPV at the exact level of the actual arcing incident energy in a real-life situation would be improbable. It is also the case that there are safety factors built into how the incident energy calculations are applied. This is where the new test parameter the Incident Energy Limit (ELIM) has been introduced. ELIM differs from the ATPV in that there is 0% chance of a second-degree burn rather than a 50% probability.

*Note - DGUV is the German Social Accident Insurance which is the national, compulsory program that insures workers for injuries or illness incurred through their employment.

Both methods are not perfect because how could they be? Electrical arcs are violent and often unpredictable events, so the research has served well to provide two methods of meeting international standards. I have therefore provided information on both standards and also calculator tools for determining the ATPV/ELIM associated with the open arc method as well as the (APC) box test. In this case you have the tools to do some comparisons. The following are my thoughts on the relative merits and drawbacks to each method.

The setup of the box test closely resembles low voltage utility termination equipment or cut out, the similarities being copper and aluminium electrodes, the voltage and the prospective current. The closeness of the sample to the arc is also plausible for this type of equipment which is often installed in enclosed areas. Lots of low voltage cut outs are still mounted in cupboards under stairs for instance and service cupboards are notoriously tight on space. Indeed, "the (box test) conditions are intended to represent the practical situation in low-voltage installations and low-voltage networks. The qualitative results (re-burning, melting, hole formation etc), derived at either 4 kA/500ms or at 7 kA/500ms, may be used to assess whether any given test system (fabric or protective clothing) would be appropriate under exactly the same real working conditions". (ISSA Guideline for the selection of personal protective clothing when exposed to the thermal effects of an electric arc) However, these conditions are dissimilar to conditions outside electrical utilities. For instance, very few modern industrial installations have a mixture of copper and aluminium and in most situations the working distances are greater. In addition, the fault currents within industrial facilities are much greater so the box test is unlike "the same real working conditions."

The box test is much harder to correlate to quantitative risk evaluation via arc flash calculations such as IEEE 1584. In addition, the arcing current and time to clear are two variables that are essential to obtain an accurate estimate of arc power/incident energy. Perhaps one could use IEEE 1584 and then apply that to obtain a disconnection time to determine the box test APC.

The electrical source for the open arc test is a large generator setup which has to be decoupled from the mains supply. The cost of these facilities is high which explains the reason why there are so few of them in the world. The electrical source for the box test is a directly coupled mains transformer making it much easier and cheaper to perform the test.

The open arc test is carried out on the garment whereas the open arc test only needs the fabric. In addition, there are only 4 exposures required for the box test making it cheaper. The drawback is that the box test does not subject the whole garment to the thermal effects of the arc and therefore, the open arc test could be seen as giving a truer prediction of the garment performance in an actual arc event.

Advocates of the box test would point out that the open arc method can only capture the radiated thermal effects of an arc whereas the box test specimens will be more effected by splashes of vaporised and molten materials.

The box test has, as previously explained, got just two exposure levels which are a prospective short circuit current of 4 kA for 500ms (APC1) and 7 kA for 500ms (APC2) The material must pass either to be given an arc protection class (APC) as well as fulfil the qualitative criteria in the standard. Having just two levels means exposures higher than APC2 cannot be evaluated which could mean that exposures above 12 to 20 cal/cm^2 cannot be protected. APC1 can return an approximate ATPV of 4-8 cal/cm^2 and Class 2 is from 12-20 cal/cm^2. However, it can be argued that pass/fail makes interpretation more straightforward as no statistical analysis is required to determine classification levels. The downside of a pass/fail result is that repeatability for fabrics that only just pass is not as easy to identify compared with specific values given for ATPV or ELIM.

I have seen evidence of where a major utility company who were using box test garments in the knowledge that the supplied PPE may be underrated for certain site conditions. This was based upon what the perceived level of acceptance to protection would be and the phrases used were "comfort/risk balance" and "some protection was better than none at all". I am sure that a better strategy would be to do the field studies first and then determine the PPE requirements in terms of ATPV based upon the task, distance, fault levels, protection arrangement as well as the prevention techniques detailed in Chapter 5: Prevention.

My recommendation would be for the box test rated PPE to be used for utility type low voltage systems only for instance to replicate potential hazards in; service entrance boxes, cable distribution, street lighting cut-outs, cabinets, distribution substations or comparable installations and/or where the arc is directed to the front of a worker at the height of the breastbone. For all HV and LV industrial and commercial situations, utilities, power stations and transport infrastructure I would strongly recommend the use of open arc rated PPE.

7.7 Head, Face and Eyes Protection

At present, there is no IEC standard for arc protection for the head, face and eyes and IEC 61482-2 is only for garments. There is, however, a standard being written with the probable title of "Live Working – Eye, Face and Head Protectors against the Effects of Electrical Arc – Performance Requirements and Test Methods".

In the meantime, there are a choice of products available that may give the protection that you need. The advice is that you must use a face shield with a reputable arc rating. Where fabric forms part of a head assembly as shown in the following image Figure 7.9, then the fabric can be tested to either the box test or the open arc test and given either an arc protection class (APC) or an arc rating. There are also many products on the market that are tested to ASTM standards (American Society for Testing and Materials) such as the ASTM F2178 / F2178M - 20 Standard Specification for Arc Rated Eye or Face Protective Products. If it tested to that ASTM standard, then an ATPV is available but not an ELIM. There are German standards available that require testing to box test to BG-Prüfzert GS-ET-29:2010-02: Supplementary requirements for the testing and certification of face shields for electrical works and suppliers will often quote both an ATPV as well as a box test APC 1 or 2. A face shield which is tested to American standards will be valid as they are similar to the IEC open arc test.

The face shields are often made from energy absorbing formulations that can provide higher levels of protection from the radiant energy. The shields are tinted so advice should be sought from the manufacturer in respect of light transmission class, as they may compromise colour perception visual acuity. This is obviously an important issue and supplementary illumination of the work area might be necessary when these types of arc protective face shields are used.

There may be a requirement for the protectors to cover not only eyes and face, but also further the entire head, including the neck. This needs to be addressed in the risk assessment. If necessary, this can be provided by a hood to cover all the areas simultaneously.

The images below (Figure 7.9) show typical face shields mounted with a fabric chin and neck guard on a helmet or a brow guard and often come with an open arc test ATPV of around 12 cal/cm^2 and typically box test APC2.

Figure 7.9

Face Protection images courtesy of J K Ross

These examples can be supplemented by an FR balaclava to give 360-degree protection.

7.8 Hand Protection

Hand protection comprising rubber insulating gloves and leather over protectors have been worn for electric shock protection for many years. The good news is that the same combination provides fairly good protection against arc flash as well. There are, however, arc flash protection gloves that have been tested to both box and open arc test methods and they are readily available in Europe. Furthermore, products are available with high level of cut resistance and chemical protection. Care must be exercised if choosing leather over protectors to ensure that they are unlined or lined with non-flammable, non-melting fabrics. Heavy-duty leather gloves with minimum thickness of 0.7mm meeting this requirement have been shown to have ATPV values in excess of 10 cal/cm^2. (Source - NFPA 70E:2015 Standard for Electrical Safety in the Workplace) The specialist arc flash protection gloves are available with an ATPV of > 50 cal/cm^2 and/or ARC 1 or 2 classification.

The standard for insulating gloves is IEC 60903 Electrical Insulating Gloves. There are insulating gloves on the market in Europe that claim that over protectors are not required although care is always required that the dielectric properties are not compromised through heavy use. From personal experience, leather or specialist over protectors do not reduce dexterity if sized properly and paradoxically can sometimes improve the grip of small components. To determine the size, measure the distance around the palm of the hand, just behind the knuckles and choose the next available size up.

7.9 Foot Protection.

I am not aware of any standards but normal industrial heavy-duty leather footwear provides a degree of arc flash protection. You may think that the feet will be the body part furthest away from an arc flash incident and usually you would be right. There are situations however, when they are the closest to a possible arc such as phasing out a pavement mounted link box for an electrical utility for instance.

7.10 Hearing

Although hearing protection for arc flash protection is much debated, there are no specific standards requiring arc rated hearing protection. Future standards may deal with the need for testing FR ratings if part of an overall head and face protector.

The general consensus of opinion appears to be that standard canal inserts to reduce sound pressure exposure above 100 dB will be adequate. In this way the inserts (and the person's ears) will be protected by a shield, hood or balaclava. Canal inserts typically give a SNR (Single Number Rating) of 30 and most large suppliers have SNR 33 canal inserts which will give the desired protection. Canal caps are not favoured they tend to be held in place with plastic that can melt and tend to be less efficient.

7.11 Pragmatic Approaches to PPE Selection

At this stage, if you have followed the 4P approach, any PPE that is prescribed will be as a last resort and for the residual risk only. Where an ATPV is used, it is likely that the majority of calculated incident energy levels at control panels and switchgear will now be below 1.2 cal/cm^2, or the threshold of a second-degree burn. Furthermore, the vast majority of incident energy levels in industrial and commercial environments will be in single figures. The remainder may be quite high in magnitude. This fact will allow the duty holder to think about protection in terms of categories based upon the risk assessments on a local basis. So, if the majority of levels are below 8 cal/cm^2 for instance, then a simple approach will be to have a standardised level of 8 cal/cm^2. At this level, there are many options available giving a very comfortable single layer solution. This has been called “basic protection” and every situation above this level as “enhanced protection”. (reference Jim Phillips – Arc Flash Hazard Calculation Studies) For those enhanced protection situations there may be a simple solution involving layering which is covered in my earlier section on layering.

Learning Points

- PPE can only be prescribed in Europe after the employer has analysed and assessed the risks which cannot be avoided by other means.
- Follow the assessment of PPE which shall involve an analysis and assessment of risks which cannot be avoided by other means.
- Involve the users at an early stage to get acceptability and compliance.
- Try to follow a simplified pragmatic approach to PPE Selection.

Chapters 8 to 16

Chapters 8 to 16 may be obtained through the purchase of online calculators and tools on www.ea-guide.com or by paperback through most mainstream booksellers including Amazon, W H Smith, Book Depository, Waterstones, and Blackwell's or by contacting the publisher:

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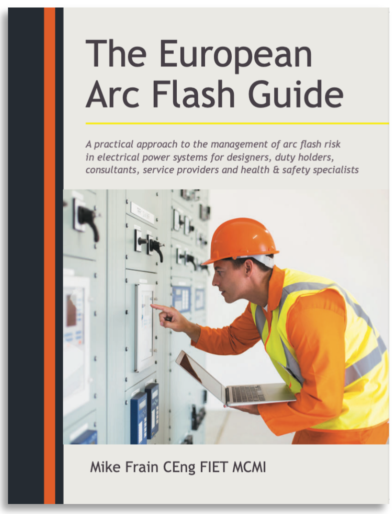

Bibliography

Please see also Chapter 16 for Rules Codes and Legislation that are not referenced directly in the guide but are relevant to arc flash hazard measurement and management.

1. Introduction to Health and Safety at Work by Phil Hughes and Ed Ferrett (NEBOSH National General Certificate textbook).
2. European View of Arc Flash Hazards and Electrical Safety by Mike Frain and Jim Phillips paper presented to the IEEE Electrical Safety Workshop 2012 Daytona Beach Florida.
3. National Fire Protection Association Standard for Electrical Safety in the Workplace NFPA70E.
4. IEEE 1584 Guide for Performing Arc Flash Calculations. The Institute of Electrical and Electronics Engineers.
5. European Council Directive 89/391/EEC. (EU Workplace Health and Safety Directive)
6. European Council Directive 89/656/EEC (Use of Personal Protective Equipment)
7. The Other Electrical Hazard: Electrical Arc Blast Burns– Ralph H Lee IEEE Transactions 1982.
8. Pressures developed by Arcs – Ralph H Lee IEEE Transactions 1987.
9. German guide DGUV-I 203-078 Thermal Hazards from Electric Fault Arc
10. IEC 61482-1-2:2014, 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)
11. IEC 61482-1-1:2019, 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.
12. IEC 60269-1 Low voltage fuses
13. IEC 61439-2 Power switchgear and control gear assemblies (PSC)
14. Considerations for Using High-Impedance or Low-Impedance Relays for Bus Differential Protection -Ken Behrendt, David Costello, and Stanley E. Zocholl
15. GAMBICA Technical Guide low-voltage power switchgear and control gear assemblies Edition 2: 2013 A guide to the requirements of: BS EN 61439-1:2011 BS EN 61439-2:2011
16. Technical report IEC/TR 61641 - Enclosed low-voltage switchgear and control gear assemblies – Guide for testing under conditions of arcing due to internal fault.
17. A GAMBICA Technical guide internal arc fault capability of assemblies in accordance with IEC/TR 61641
18. Regulation (EU) 2016/425 of the European Parliament and of the Council of 9 March 2016 on Personal Protective Equipment
19. European Council Directive 89/656/EEC Use of Personal Protective Equipment
20. ASTM F2178 / F2178M - 20 Standard Specification for Arc Rated Eye or Face Protective Products.

21. The BEAMA (British Electrotechnical and Allied Manufacturers' Association) Guide to Forms of Separation.
22. Forms of Separation - a time for change - Schneider Electric 2017
23. IEC 62271-200 High-voltage switchgear and control gear
24. The Health and Safety (Safety Signs and Signals) Regulations 1996
25. European Directive 92/58/EEC Safety and/or Health Signs
26. The Republic of Ireland Guide to the Safety, Health and Welfare at Work (General Application) Regulations 2007 (Part 3 Electricity)
27. Guideline for Assessing the Competence of Persons involved in Live Working published by the International Social Security Association (ISBN-Nr. 3-9807576-6-8).
28. Guidance Note GS38 (Fourth edition) on electrical test equipment for use on low voltage electrical systems.
29. Code of Practice for Electrical Safety Management – Institution of Engineering and Technology ISBN 9781849196697
30. EN 50110-1:2013 Operation of Electrical Installations.
31. Observations on the procedures for testing the protective effect of Personal Safety equipment against the effect of arcing – Dr Dirk Borneburg, Dr Frank Wachholz, Jurgen Volger and Dr Helmut Eichinger 2007.
32. Arc Flash Forum on www.arcflashforum.com.
33. Mitigating Personnel Exposure to The Arc Flash Hazard. White paper written by Catherine Irwin, Udo Kerssebaum, Helmut Eichinger, Daniel Doan June 2009.
34. Fear of Flashover - article written for the Institute of Engineering and Technology Power Engineer magazine by Mike Frain and Jim Phillips July 2007.
35. Electrical Flashover-Live Proximity Work in Industry-Magazine article written for the Electrical review by Mike Frain, September 2007.
36. Arc Flash-not just electrocution hazard, parts 1,2 &3 – A trilogy of magazine articles by Mike Frain and Jim Phillips written for the Electrical Review September, October & November 2009.
37. Guidance for Assessing the Competence of Persons involved in Live Working Issue by the International Social Security Association.
38. HSR25 Memorandum of Guidance on the Electricity at Work Regulations 1989 (HSE books www.hse.gov.uk)
39. HSG85 Electricity at Work - Safe Working Practices (HSE books www.hse.gov.uk)
40. HSG230 Keeping Electrical switchgear Safe (HSE books www.hse.gov.uk)
41. INDG372 Electrical Switchgear and Safety (HSE books www.hse.gov.uk)
42. INDG163REV2 Five Steps to Risk Assessment (HSE books www.hse.gov.uk)
43. INDG 354 Safety in Electrical Testing at Work (HSE books www.hse.gov.uk)
44. GS38 Electrical Test Equipment for use by Electricians (HSE books www.hse.gov.uk)
45. Comprehensive Overview and Comparison of ANSI vs. IEC Short Circuit Calculations: Using IEC Short Circuit Results in IEEE 1584 Arc Flash Calculations". A. Majd, R. Lou, M. Devadass, J. Phillips, IEEE PCIC Conference proceedings, Cincinnati, OH Sept. 2018.
46. Understanding Short Circuit Motor Contribution by Darrell Broussard, GE Industrial Solutions.
47. Complete Guide to Arc Flash Hazard Calculation Studies by Jim Phillips P.E – Brainfiller Inc. 2010.
48. DC Arc Flash Calculations by Jim Phillips – Posted on Brainfiller.com, November 20, 2019.
49. Arc Flash Calculations for Exposures to DC Systems by D.R. Doan – IEEE Transactions on Industry Applications, Vol.46 No 5.

50. 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.
51. Electric Arcs in open Air by A.D.Stokes and W.T.Oppenlander – Journal of Physics D: Applied Physics 1991.
52. Simple Improved Equations for Arc Flash Analysis by R. Wilkins – IEEE Electrical Safety Forum, August 30, 2004.
53. Schneider Electric Cahier technique no. 158 - Calculation of short-circuit currents by Metz-Noblat, Dumas and Poulain.
54. Method and Rating System for the Evaluation of Thermal Protection, Stoll,A.M. and M.A. Chianta