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INTRODUCTION

Arc flash is perhaps the least understood, and yet one of the most dangerous hazards in the workplace. This article sets out to raise awareness about this hazard, its potential consequences, and some of the legal duties of employers. It also discusses some of the factors to be taken into account during risk assessment, and some of the possible measures to mitigate arc flash risks.

Electrical Arc Flash

An electric arc flash is a visible current-carrying plasma discharge between two energised conductors at different voltages or between an energised conductor and earth, which releases energy in the form of heat and light, and in many incidents explosive thermo-acoustic 'blast' waves. The magnitude of the energy released depends upon the magnitude of the current flowing through the arc and the duration of the current. Temperatures can reach a frightening 19,500°C [1] (the surface of the sun is approximately 5,750°C).

Electric arcing is usually caused either by a bolted fault or arcing fault, but may also be drawn by slow separation of energised contacts (e.g. opening of a switch or opening or withdrawal of a circuit breaker).

A bolted fault is a physical low-impedance short-circuit connection between two or more live conductors at different potentials or between a live conductor and earth. The flow of the resultant high fault current causes the overheating and melting of the conductors (e.g. cables or busbars) and ionisation of the interposing gas (typically air), if a protective device does not clear the fault beforehand. Those conditions facilitate the formation of an arc.

An arcing fault, on the other hand, can occur when the voltage between two energised conductors, or between an energised conductor and earth exceeds the dielectric strength of the interposed gas or other insulating material. An arc fault may be caused in turn by an overvoltage or overcurrent.

The effects of an arc flash/ blast can be devastating

Although the statistics published by the Health and Safety Authority (HSA) in Ireland to date do not distinguish between electrocutions and fatal explosive/ burning effects, or between injury resulting from arcing and other electrical fires/explosions, we know that the effects of an arc flash/blast can be devastating. There have been a number of court prosecutions of employers here and in the UK in recent years following fatal and other serious arc flash accidents. There are also many accounts of other arc flash incidents here in Ireland. The National Fire Protection Association (NFPA) in the US tells us that the majority of hospital admissions in the US as a result of electrical accidents are due to arc flash burns, not from electric shock, while each year more than 2000 people are admitted to burn centres with severe arc flash burns.[1]

Unlike other causes of electrical burns, an arc flash emits Ultra Violet radiation which, at a minimum, can cause damage akin to severe sunburn (curable second-degree burn injury). Molten metal particles can also penetrate, burn and lodge in the flesh. It can also result in third degree burns, in which all layers of the skin are permanently destroyed, and can even be fatal.

Inhalation of materials vaporised by the arc (metals and other materials, including insulating materials such as PVC) causes internal burns and intoxication. Additionally, explosive pressure waves can directly cause a range of physical trauma, including potentially permanent hearing loss (ruptured eardrums) and collapse of lungs and other internal organs. They can also cause serious injury indirectly due to flying shrapnel from disintegrated equipment, displacement of any particles in path of the blast, workers being knocked from their standing, collapse of structures etc.

Legal duties of employer

Aside from the obvious moral or social duty on the employer to prevent personal injury to employees and others that may be caused by his or her undertaking, health and safety legislation in Ireland imposes various duties on the employer to the same effect in relation to arc flash. This article does not discuss or even list all of those legal duties, but instead raises some of the more pertinent of those.

The Safety, Health and Welfare at Work (General Application) Regulations 2007, Part 3 – Electricity, imposes the duty on the employer to ensure that all electrical equipment and electrical installations are designed, constructed, installed, maintained, protected and used so as to prevent danger (Reg.76(a)). The interpretation for the Regulations states that 'preventing danger' means preventing, so far as reasonably practicable, risk of personal injury from electrical arcing, among others. This Regulation clearly has very far reaching implications in that it applies to design, construction, installation and use, and also specifically mandates the maintenance and protection of electrical equipment and installations.

Meanwhile, the framework Safety, Health and Welfare at Work Act 2005 imposes the duty on the employer to identify the hazards in the place of work under his or her control, assess the risks presented by those hazards, be in possession of a written risk assessment, and to implement any improvement considered necessary (s.19). Crucially, s.19 states that the employer shall review and, where appropriate, amend a risk assessment where there has been significant change in the matters to which it relates, or there is another reason to believe that it is no longer valid.

And so, the employer must identify the hazards, assess the risks associated with all work on or near live electrical equipment, including commissioning, operation and maintenance. He or she must also review and amend risk assessments as appropriate in order to ensure that they remain valid. A critical consideration in the case of arc flash risks is whether or not any proposed alteration or modification of an electrical network would significantly affect the prospective arc incident energy level to which a worker may be exposed.

Additional employer duties are discussed throughout this article.

Arc flash hazard identification and risk assessment

Arc flash hazard is not a single, or to the uninitiated, an easily identifiable hazard. Instead, it comprises a complexity of situations, conditions and/or acts. There are likely too many arc flash hazards in most workplaces. While the occurrence of an arc flash may be considered to be more likely when working on live electrical equipment than in other situations, it can also occur without human intervention, and so is a risk not only to those who work on, but also to those who work near live electrical equipment.

Given the varied and complex nature of arc flash hazards, risk assessors need to be particularly conscious of their competence or lack thereof.

Of the many inputs to an arc flash risk assessment, undoubtedly one of the most important is the calculated prospective arc incident energy at the working distance. The US National Fire Protection Association NFPA 70E Standard for Electrical Safety in the Workplace provides for risk assessment based either on an incident energy analysis or Personal Protective Equipment (PPE) categories method. The latter requires very little field data, and as a result is very limited not only in scope, but also in terms of accuracy, and so is not recommended. NFPA 70E does not provide guidance on incident energy analysis.

The Institute of Electrical and Electronics Engineers (IEEE) IEEE 1584 Guide for Performing Arc-Flash Hazard Calculations (2002 am 2011) provides detailed guidance from collection of field data to final results. However, the application of the IEEE method requires the use of sophisticated computer software, such is the extent of electrical network modelling required, and the complexity of the algorithms used for the subsequent calculation of prospective incident energy.

The influence of working distance

Incident energy analysis produces calculated prospective incident energy values measured in calories/cm^2 (or Joules/cm^2) at nominal typical working distance from the prospective arc source. However, it must be realised when assessing risk that the nominal typical working distance at which the prospective incident energy was calculated is not necessarily representative of the actual working distance of the worker (face, chest or hands). This is a crucially important consideration given that prospective incident energy varies exponentially with distance from the prospective arc source, and so a small variation in distance from the prospective arc source will greatly change the prospective incident energy.

Arc flash protection boundary

Along with the prospective incident energy at typical working distance, an incident energy analysis calculates the arc flash protection boundary. The arc flash protection boundary is the distance from the prospective arc source at which the prospective incident energy is equal to 1.2calories/cm², to which exposure for a duration of 1 second is predicted to cause the onset of second degree burn injury.[2,3] While the arc flash protection boundary is widely assumed to be the safe working distance in the event of an arc flash, this is not necessarily so. The potential blast consequences of higher incident energy events are likely to extend beyond the arc flash boundary.

Hazard identification

When identifying arc flash hazards, among other factors such as work activities, type and condition of equipment used, and work environment, one needs to take account of all foreseeable electrical network configurations which can significantly affect the prospective arc incident energy.

Need for integrated risk assessment

When assessing arc flash risks, one needs to simultaneously assess all other foreseeable risks associated with the operation, use and maintenance of the electrical system, including work near the electrical system (risks relating to electric shock, electric burn, electrical fire, mechanical movement of electrically driven equipment, etc). There is likely to be simultaneous exposure to different risks. Also, a control measure for one risk must not place any person at unacceptable risk.

Combating risks at source

The General Principles of Prevention in the Safety, Health and Welfare at Work Act 2005 tell us that where a risk is unavoidable, an employer must prioritise combat of the risk at source over any other control measure. And in this respect, the employer needs to consider available measures to reduce the likelihood of an arc flash, as well as measures to mitigate consequences of such an event. Where the opportunity for design presents, there is clearly a need for design risk assessment which incorporates proposed network modelling and calculation of prospective short circuit current and prospective arc incident energy, with the aim of designing-out or minimising risk.

Switchgear and controlgear assemblies

The design and construction of switchgear and controlgear assemblies greatly influence arc flash risks, both in terms of the likelihood of internal arcing and the consequences of arcing for workers. And so, it is essential when selecting switchgear and controlgear to be in possession of all necessary information relating to the electrical installation, including prospective load and short circuit currents, environmental conditions etc.

Switchgear and controlgear may, by agreement between the user and manufacturer, be tested under conditions of arcing due to internal fault, in order to give a high degree of assurance as to the withstand capability of the assembly both in terms of personal and assembly protection, but a pre-requisite for internal arc testing is the calculation of the prospective arc fault current.

Detection systems may be installed in switchgear and controlgear which detect light emitted during arc initiation, and which operate a circuit breaker instantaneously to rapidly extinguish the arc and reduce its energy.

Chutes may also be incorporated in switchgear and controlgear which relieve excessive pressure during an arc event and channel gases safely out of building.

Another option is remote switching and racking, which removes the operator from the immediate danger zone.

Other measures to reduce prospective arc incident energy

Measures either to permanently reduce the prospective incident energy should not only be considered in the context of major design or redesign.

The level of available arc energy is influenced by the potential bolted short circuit current (or short circuit power), each of the prospective short circuit sources at a location, the distance between busbars, the tripping times of upstream protective devices, etc. Protective device settings can only be determined by undertaking a protection coordination study. Of course, full system grading generally involves a number of compromises between operational reliability on the one hand and equipment and personnel protection on the other.

In this context, optimum settings for protection coordination must be determined on the basis of an assessment of the risks to workers and plant, taking account of the criticality of loads. Settings are often influenced by the fact that the settings at the highest point (utility connection or point of common coupling) are determined by the utility and, full grading by time and/or current down to final load point may not be possible, so a compromise solution may be required.

There are various strategies to reduce the potential incident arc energy which may be feasible, such as:

- The protection device may be changed or an additional device introduced.
- Change of the network arrangement to reduce prospective short circuit current.
- Protection device settings may be temporarily changed during work on a particular piece of equipment.
- In some circumstances it may be possible to temporarily supply equipment from a standby generator which has a lower short circuit power than the utility supply.

Arc rated PPE

Aside from the inherent limitations of PPE in general, arc rated PPE has its own particular limitations. Correctly selected and used, arc rated PPE affords protection against external burn injury only. It does not afford any protection against other possible effects of arc events, such as physical trauma injury caused directly or indirectly by explosive pressure waves (which includes hearing damage or loss), or internal burns and intoxication caused by the inhalation of hot, toxic gases and mists. And so, even though necessary in many work situations, PPE is only ever to be used as 'a last line of defence'.

Arc rating, as it relates to PPE, is the value attributed to materials or material systems that describes their performance on exposure to an electrical arc discharge. The arc rating is expressed in calories/cm², and is derived from the determined value of ATPV or break open Threshold Energy (EBT50) should a material or garment exhibit a break open response below the ATPV value.

Training

The Safety, Health and Welfare at Work Act 2005 requires the employer to provide the information, instruction, training and supervision necessary to ensure, so far as reasonably practicable, the safety, health and welfare at work of his or her employees (s.8(2)(g)).

The Act also requires that information specifically relating to hazards, risks and the preventive and protective measures to be taken arising from risk assessment, shall be provided not only to employees, but also to any other employer whose employee(s) is engaged (s.9(1)(b) and 9(2)).

Therefore, an employer needs to ensure that employees and contractors have the knowledge and understanding necessary to be able to recognise arc flash hazards which can arise during work, the associated risks and the precautions to be observed. They need to know how arcing might be initiated, the potential consequences, and the measures to be taken to prevent arcing and to mitigate the consequences in the event of a flashover.

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[1] NFPA 70E 2015 Standard for Electrical Safety in the Workplace

[2] A.M.Stoll, M.A.Chianta, "Method and Rating System for Evaluation of Thermal Protection", Aerospace Medicine, Vol.40, No.11, Nov 1969.

[3] A.M.Stoll, M.A.Chianta, "Burn Production and Prevention in Convective and Radiant Heat Transfer", Aerospace Medicine, Vol.39, No.10, Oct 1968.