It seems that experience is no protection from the dangers of electrical flashover

By **Jim Phillips** and **Mike Frain**

fear of flashover

MANY YEARS AGO, Mike Frain was called to give evidence in the prosecution of an electrical worker involved in an electrical flashover injury to his apprentice. As he recalls the experience was an extremely unpleasant one, the only comfort being that he was not the one in the dock. Since then it has been his desire to stay clear of such experiences and help other people to do likewise.

You hear many stories of people who have been involved in flashover incidents and very often the age of the victim is 40-plus years old, which shows that experience is not always a solution to this problem. Electrical staff routinely work on live high power equipment, carrying out tasks such as fault finding and diagnostic testing without fully understanding the consequences of what will happen to them should an electrical flashover (arc flash) occur. Frequently there is no risk assessment in place, even though this should always follow the rigorous tests of reasonableness in working live in the first place.

There is a duty on all employers to assess significant risks and although it is valid to describe the outcome of such an event as being potentially serious, there is a lot more that can be done to predict the degree of harm and to implement appropriate workplace precautions. Research has led him to examine how arc flash hazards are addressed in the United States, and he has visited the country to learn more.

Most electrical accidents occur because people are working on or near equipment that is either: thought to be dead when it is in fact still live or thought to be live but those involved do not have the necessary training or equipment or have not taken suitable precautions.

Electrocution is usually the first thing that comes to mind when someone is killed or injured by electricity. The fact is that the blast and thermal energy from an arc flash is equally relevant and is a significant source of long-term injuries and sometimes a slow and painful death. Many hundreds of people in the UK and many thousands in the US receive severe and debilitating burns each year. There is evidence to suggest that, although burns can be caused by electric current passing through the body from direct contact with energised conductors, most burns from electrical accidents actually come from arc flash.

The principle cause of arc flash is inadvertent contact between an energised conductor such as a bus bar with another conductor or an earthed surface. This can be the result of incorrect use of test probes, faulty instruments or dropped tools. The magnetic field from the resultant fault current will cause the conductors to separate or the tool to be blown back producing an arc, which ionises the air, making a conducting plasma fireball. The heat that is generated from the arc flash can be up to 35,000°F. This is four times the surface temperature of the sun, which is enough to immediately vaporise all known materials. This sudden release of thermal energy at the point of the fault is called arc flash and can cause severe burns to the skin, ignition of clothing, blindness from the resulting ultraviolet light and even death. It is not uncommon for the hazard to radiate several metres away from the point of the arc, injuring other people that might be nearby.

When an arc flash occurs, conductors can vaporise, expanding to thousands of times their original volume. The heat from the arc flash also causes the sudden expansion of air. The result can create a pressure wave, called arc blast – literally an explosion. The total force on a worker standing in front of an open enclosure may exceed 2000lbs/ft^2 causing blunt force trauma injuries. During the explosion, molten metal particles, destroyed equipment and related components will be ejected as shrapnel at speeds of up to 700 miles per hour.

It would appear that the severity of the arc flash is proportional to the magnitude of fault current. However, studies in the US indicate that, although higher fault levels will usually lead to larger arc flash events, lower fault currents can cause overcurrent devices to operate more slowly allowing the arc to last longer producing a greater overall amount of arc flash energy.

A typical ARC Flash warning label

NORTH AMERICAN STUDIES

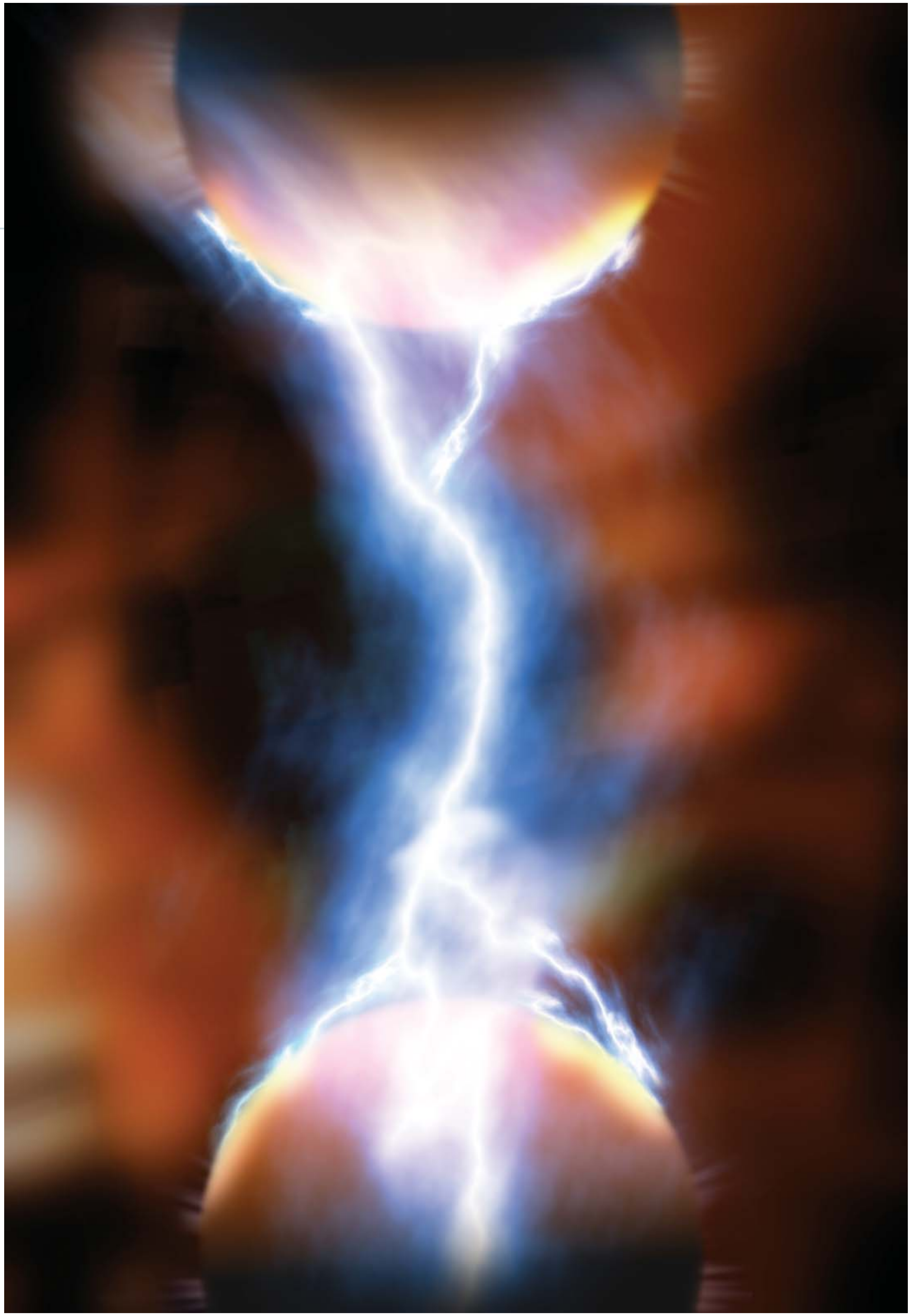
There is a great deal of worldwide research on arc flash phenomena but the results of studies in the US are now incorporated into two standards. NFPA 70E – Standard for Electrical Safety in the Workplace – defines required electrical safety practices and IEEE 1584 – Guide of Performing Arc Flash Hazard Calculations – defines the main method for calculating the degree of the hazard. This effort has been driven by the need to reduce the number of electrical accidents from arc flash. A report compiled by Capelli-Schellpfeffer estimates that five to ten arc flash explosions resulting in hospitalisation happen in the US every day, resulting in one to two deaths per day.

The US is a more litigious society than the UK and there are even legal textbooks written on how to pursue a damage claim brought about by electrical accidents. The research there has been of an empirical nature meaning that calculations have been derived from actual laboratory experiments. An ambitious joint collaborative effort between the NFPA and IEEE has begun which will allow further testing to provide an even better understanding of arc flash. The target budget for this effort will be $6m.

There are similarities between US and UK legislation and in broad terms parallels can be drawn between the US Occupational Safety and Health Act and the UK Health and Safety at Work Act and NFPA 70E to the UK Electricity at Work Regulations. The IEEE is of course, similar to our own IET.

ARC FLASH STUDY

Incident energy is the term used to define the severity of an arc ▶



CORBIS

APPROACH BOUNDARIES

THERE ARE FOUR approach boundaries that need to be considered – prohibited, restricted, limited and flash protection – as described below.

- Prohibited Approach Boundary is defined as "An approach limit at distance from an exposed live part within which work is considered the same as making contact with the live part."

- Restricted Approach Boundary is defined as "An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the live part."

- Limited Approach Boundary is defined as "An approach limit at a distance from an exposed live part within which a shock hazard exists."

- Flash Protection Boundary is defined as "An approach limit at a distance from exposed live parts within which a person could receive a second degree burn if an electrical arc flash were to occur.

The effects of ARC flash can be devastating

flash. Measured in calories per square centimetre (cal/cm^2), it is the amount of thermal energy from the arc that reaches a surface such as a person's skin. The figure of 1.2cal/cm^2 is considered to be the energy required to produce the onset of a second-degree burn and used as the benchmark for personal protection. An arc flash study is conducted to determine the potential incident energy exposure that personnel working on or near energised equipment could receive if an arc flash occurs.

This value is used to determine the appropriate level of Personal Protective Equipment (PPE) for the workers and the Flash Protection Boundary (FPB). This boundary is the distance from the potential arc source where the incident energy drops off to 1.2cal/cm^2.

People working within the flash protection boundary are required to wear the appropriate Personal Protective Equipment whereas unprotected people are required to stay beyond the FPB.

NFPA 70E Standard for Electrical Safety in the Workplace defines a series of boundaries when working on energised equipment. Identifying the Limited, Restricted, Prohibited Approach boundaries that are used for shock protection and calculating the Flash Protection Boundaries are all a part of the detailed arc flash hazard study. Proper signage can be used to list these boundaries as well as the class of PPE based on the calculated incident energy. The classifications of PPE range from Class 0, which is untreated cotton to Class 4, which includes a complete flash suit rated a minimum of 40 cal/cm^2.

The heat from an arc flash causes the sudden expansion of air

Personal protection equipment for defence from arc flash

PERSONAL PROTECTIVE EQUIPMENT (PPE)

PPE is designed to provide a thermal barrier between the extreme heat of an arc flash and a person's skin. Depending on how much heat the skin receives and how long it lasts, a person can experience anything from pain and redness to total destruction of the tissue. Research dating back to the 1960s by Alice Stoll led to the development of the 'Stoll Curve', which is essentially a plot of thermal energy and time predicted to cause a pain sensation or a second degree burn in human tissue. It is still used today in many tests for predicting thermal protective performance of materials for flame-resistant (FR) clothing.

Since 1.2cal/cm^2 is considered to be the energy required to produce the onset of a second-degree burn, it is considered the minimum protection goal of PPE. When the screwdriver slips and an arc-flash occurs, the incident energy can be large enough to cause severe burn injury and even death. However, providing a thermal barrier in the form of PPE limits this to no more than 1.2cal/cm^2 at the person's skin and greatly improves the probability of survival and less debilitating injury. It should be noted however, that the correct use of PPE can still allow the onset of a second degree burn meaning a person can still receive some injury.

'An arc flash study is conducted to determine the potential incident energy exposure that personnel working on or near energised equipment could receive if an arc flash occurs'

PPE happens to be last resort in the UK risk control hierarchy behind removing and avoiding the hazard altogether. There is evidence that some UK companies adopt a comfort/protection balance argument such that it is better to allow a lower level of arc protection PPE rather than to insist on better protection that will be difficult to enforce because workers will not wear it for comfort reasons.

In the US however, the mandatory wearing of appropriate PPE is likened to the introduction of seats belts in automobiles, which were originally met with resistance, but over time, have become routine. In addition, this mandatory approach has forced managers and workers to think further up the risk control hierarchy and adopt measures that remove or avoid the hazard altogether rather than be forced into wearing uncomfortable PPE.

ARC FLASH CALCULATIONS

The most comprehensive approach for conducting an arc flash study is to perform calculations based on IEEE 1584. The results are used to determine the incident energy, appropriate level of PPE as well as the flash protection boundary. Commercially available software can be used to perform the calculations and produce labels to place on equipment that detail the boundaries and PPE requirements.

It should always be remembered that the accuracy of any study is only as good as the input data and system studies should always take account of variables due to changes in system configuration for example.

For this reason only trained individuals should undertake arc flash calculations. Since the more detailed IEEE calculations can be quite laborious, as a simpler alternative, NFPA 70E provides generalised tables based on the task, hazard and associated risk that can be used for the selection of PPE.

Although there is ongoing research into predicting the associated blast energy or pressure this is not yet covered in either NFPA70E or IEEE 1584. This can, as described earlier, be significant and can even lead to injuries that are more severe than the resulting burns such as through falls from height. This should be taken into account when carrying out a risk assessment.

Whilst it is possible to acquire the time/current curves for most circuit protective devices, even obsolete ones; account should be taken of the accuracy of the device characteristics.

UK engineers and managers who are responsible for putting people to work on high power electrical systems can learn a great deal from the US research on arc flash.

There are differences in the way in which we approach the subject of electrical safety as described above but an arc flash study will give a rigorous and qualitative approach to determine; the hazard, who might be harmed and how, an evaluation of the risks and work place precautions. ■

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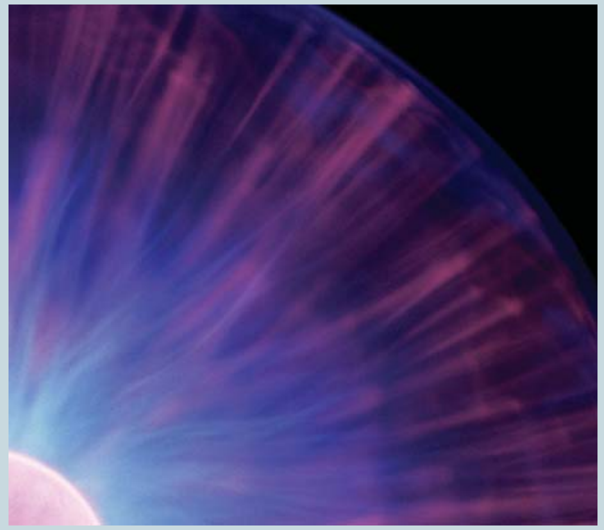

US STANDARDS

In the US, three major organisations define the requirements for electrical safety and arc flash protection. OSHA is the primary organisation that sets the general directives while the National Fire Protection Association's NFPA 70E Standard defines the specific details for electrical safety. The Institute of Electrical and Electronics Engineers' IEEE 1584 Standard defines the calculation methods used to determine the level of incident energy, Personal Protective Equipment requirements and Flash Protection Boundary.There are three main US standards as described below.

OSHA – In 1970 the US Congress created the Occupational Safety and Health Act, which led to the formation of the Occupational Safety and Health Administration. Its purpose is to; encourage employees and employers to reduce workplace hazards, create and enforce mandatory OSHA standards, maintain job related injuries and sickness statistics and approve State OSHA programs. Within the OSHA regulations is a general duty clause which states that "each employer shall furnish to each of his employees, employment and a place of employment which are free from recognised hazards that are causing or are likely to cause death or serious physical harm to employees".

The phrase 'recognised hazards' generally refers to hazards defined by industry consensus standards which are standards developed, approved and used by persons in the industry.

NFPA 70E – Published by the National Fire Protection Association, NFPA 70E Standard for Electrical Safety in the Workplace is the main standard that defines the details for electrical safety. This standard was developed at the request of OSHA and first published in 1979.

Although OSHA is Federal Law, it sets more general requirements while NFPA 70E defines the specific details for electrical safety.

IEEE 1584 – A detailed arc flash study requires calculating the potential arc flash incident energy and flash protection boundary at the electrical equipment's location.

These calculations are frequently based on formulas published in the IEEE 1584 Guide for Arc Flash Hazard Analysis. This IEEE working group is responsible for much of the testing and research associated with arc flash.