MIKE FRAIN OF ELECTRICAL SAFETY UK LTD DISCUSSES THE ELECTRICAL ARC FLASH HAZARD AND HOW THE DUPONT(TM) ARC-GUIDE HAS BEEN DEVELOPED TO HELP EMPLOYERS COMPLY WITH EUROPEAN LAW THROUGH RISK ASSESSMENT.

INTRODUCTION

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.

The DuPont(TM) Arc-Guide was written by European experts to 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.

ARC FLASH HAZARD EXPLAINED

An arc flash is usually caused by inadvertent contact between an energised conductor such as a bus bar 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. This fault current ionises the air and creates a conducting plasma fireball with arc temperatures that can reach upwards of 20,000 degrees Centigrade. Severe injury and even death can not only occur to persons working on the electrical equipment but also to people located nearby.

Arc flash injury can include external burns to the skin, internal burns from inhaling hot gasses and vaporised metal, hearing damage, eye damage such as 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 which can result in pressures of over 100 kiloPascal (kPa), launching debris as shrapnel at speeds up to 300 metres per second (m/s).

LEGISLATION

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 the level 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.

There has been extensive research in the United States into the arc flash phenomena over many years the result of which has been the prediction of the arc flash hazard severity. Although the hazard is the same in Europe the legislative requirements are different to those in the US. The US model has a direct link from hazard into PPE whereas the EU Directive, 89/391/EEC requires employers to perform risk assessments for all hazards/tasks. The US research however, has resulted in the creation of the IEEE 1584 Guide for Performing Arc Flash Hazard Calculations 2002. The IEEE (Institute of Electrical and Electronics Engineers) is the largest professional electrical engineering body in the world.

The DuPont(TM) Arc-Guide uses IEEE 1584 for carrying out the prediction of the hazard severity and then sets out a clear cycle of prevention, protection and publishing the risk assessment.

HAZARD AND RISK

Before we consider arc flash further we need to be clear about some of the terms that are used. 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. The term risk is the chance (or likelihood), high or low, that someone might be harmed by the hazard.

Although the arc flash hazard may be high, control measures can be adopted to reduce both the hazard, and also the associated risk, to as low as possible. These methodologies are explored within the guide.

ARC FLASH RISK ASSESSMENT

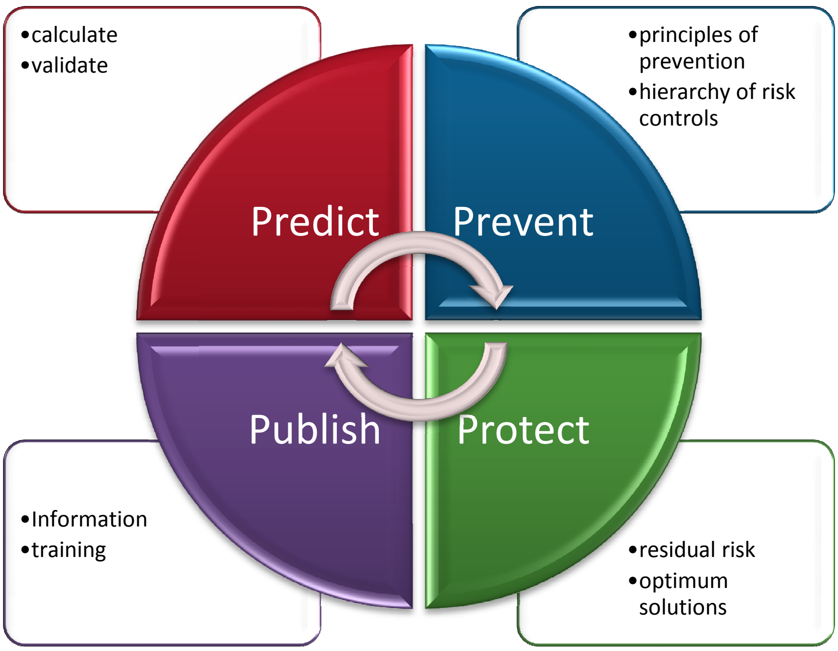
The arc flash hazard needs to be determined by risk assessment out of which, the decision to work live or dead and the required precautions will be derived. The need for risk assessment is embodied in European Law through Directive 89/391 (EU Workplace Health and Safety Directive) and the associated guidance which identifies electrical work as a “high risk” activity.

The European Agency for Safety and Health at Work defines risk assessment as the process of evaluating risks to worker's safety and health from workplace hazards. It is a systematic examination of all aspects of work that considers:

a. what could cause injury or harm
b. whether the hazards could be eliminated and, if not,
c. what preventative or protective measures are, or should be, in place to control the risks

PREDICT, PREVENT, PROTECT AND PUBLISH

Users of the guide will know that they have the tools to easily predict incident energy levels at equipment or cables to be worked upon but risk assessment is actually much more than this. The cycle matrix diagram below illustrates how this important step of predict is necessarily followed by prevent, by protect and then finally publish.



Taking each step one by one we will start with Predict.

Predict

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 are most commonly used as this is specified for PPE garment labels according to IEC 61482-2.

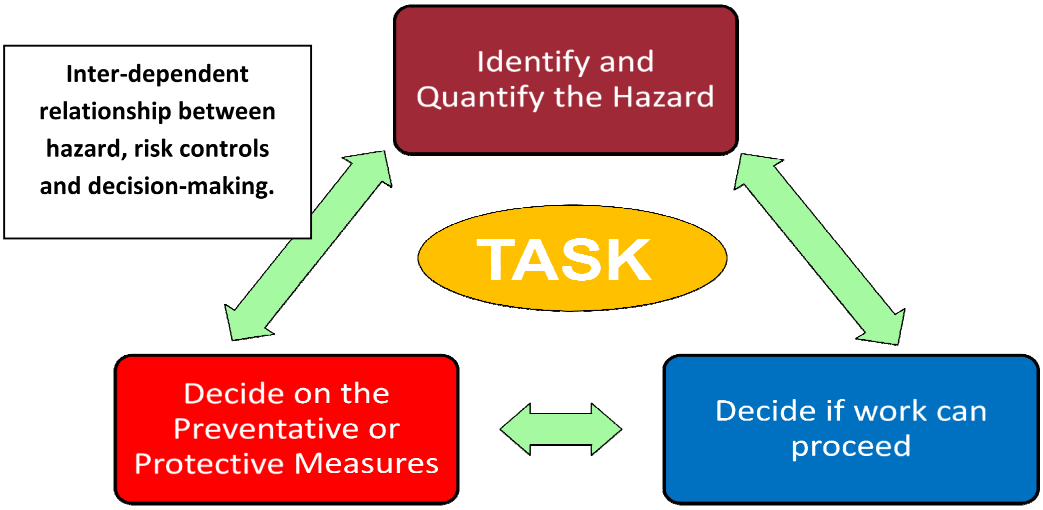
As a frame of reference for incident energy, an exposure to heat flux of 1.2 cal/s.cm^2 during 1 second, i.e exposure to 1.2 cal/cm^2 can produce the onset of second degree burn to the skin. This value is used by many standards as the benchmark that defines protection against the thermal effects of arc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

The calculation methods are taken from the IEEE 1584 Guide for Performing Arc Flash Hazard Calculations 2002 and take into account distance to worker, conductor gap, voltage, prospective fault current and disconnection time. There are accurate calculators to determine prospective fault current; which is always a key element in predicting arcing current and therefore the incident energy levels. There are charts and calculators that will help even when site data is limited such as for circuit breakers and common European style fuses.

Prevent

A fundamental safety principle, which is embodied in European legislation, 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 by personal padlocks and for the proving dead at the point of work.

Where the arc flash hazard cannot be eliminated then suitable risk controls should be in place (preventative or protective measures). The following chart illustrates that the relationship between hazard identification, deciding on suitable risk controls and the decision for work to proceed is an inter-dependent one. Furthermore, the physical task to be carried out on or near energised equipment is a hugely significant factor as it is usually worker activities that initiate a damaging arc flash event.



To further clarify this relationship, a decision for work to proceed where there is a significant arc flash hazard cannot be taken in isolation of other factors. The level of hazard and also the availability and effectiveness of preventative or protective measures will also need to be considered.

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 activities that have the potential to initiate an arc and some of which have been shown to be common causes of electrical flashover. It must be emphasised that the guide discourages live working. Whilst some of the following activities are still common in industry, practices such as connecting cables into live equipment would be very difficult to justify outside the public utilities.

- Connecting cables into live equipment
- Testing; especially with substandard instruments and test methods
- Testing on damaged cables and equipment. There are several known cases of arc flash due to using voltage indicators on faulted cables.
- Inspections or any interactions which involves the exposure of live low voltage conductors.
- Work on or adjacent to live low voltage conductors that are insulated but where the work may adversely affect the integrity of that insulation. Examples are drilling into panels and drawing cables into cable management systems
- Custom and practice activities such as Installing or repairing equipment which is adjacent to exposed live low voltage conductors.
- Removal and replacement/insertion of live components such as circuit breakers in panel boards and large power bus bar tap off units

- Live underground cable jointing
- Switching and racking out poorly maintained or legacy LV switchgear
- Replacement of fuses and links especially onto faults

The likelihood of an incident is greatly enhanced by poor worker competence and ignorance of the hazards. Common to this is the dropping of uninsulated tools or fastenings, sometimes out of breast pockets in clothing. Even for competent workers the loss of concentration, distraction and human error may be factors which lead to arc flash events.

ARC FLASH PROTECTION - PREVENTION

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. *(The author's interpretation of each principle of prevention when applied to the arc flash hazard is shown in blue italics)*

1. Avoiding the Risk – *which means Dead working, Not energised = No electrical danger*

2. Evaluation 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 by 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 (eg test equipment) and tools (eg insulated)*

7. Developing a coherent overall prevention policy – *create a safe systems approach which is specific to structure environment, workforce & 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 on the individual's choice.*

9. Giving appropriate instruction to employees – *create a safe person 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.

1. Elimination of the arc flash hazard
2. Minimisation/engineering controls
3. Safe Systems of Work
4. Information and Training
5. PPE

All these measures should be properly monitored and reviewed and this is particularly important when considering the lower order risk controls.

Protect

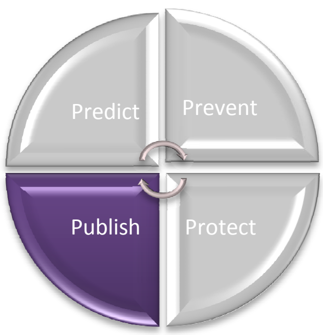
Where the risk cannot be controlled by prevention or where there is a residual risk of injury then it may be necessary to consider mitigation to prevent injury to the worker. The requirement for and suitability of mitigation techniques must form an essential element of any risk assessment. Many different forms of protection arrangements are discussed in the guide such as remote operations, reduction in arcing time through arc detection & rapid disconnection and through training in operational techniques such as body positioning when operating equipment.

As described previously, exposure to heat flux of 1.2 cal/cm^2.s 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 is 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 Flame Resistant (FR) fabric. This 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. FR clothing is rated based on its Arc Thermal Performance Value (ATPV) in cal/cm^2 or Breakopen Threshhold Energy (EBTI in cal/cm^2 according to IEC 61482-1-1 and/or on its Class 1 or 2 performance according to IEC 61482-1-2, with the arc rating certified according to IEC 61482-2.. 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 2nd degree burn injury, or - more colloquially - the ATPV is the incident thermal energy that the clothing can support before that the wearer will suffer 2nd degree burns.

To properly protect a worker, the ATPV value – or the EBT value in case that no ATPV can be determined - of the FR clothing must exceed the prospective incident energy available at a given location at a given distance from the electric arc event. Class 1 or Class 2 rating 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 Class 1 or Class 2 testing according to IEC 61482-1-2.

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. Burning material next to the flesh can result in serious 3rd degree burns even for very short durations. This actually means that ordinary clothing could actually become a hazard and for this reason it is should be considered within the risk assessment.



Publish

The European Council Directive 92/58/EEC stipulates the minimum requirements for the provision of safety and/or health signs at work. It states that safety and/or health signs must be provided where hazards cannot be adequately reduced by techniques for collective protection or by measures, methods or procedures used in the organization of work. In other words, as required by a risk assessment in circumstances where risks to health and safety have not been avoided by other means, for example engineering controls or safe systems of work. Signs must be standardised across Europe in a way in which will reduce the hazards which may arise from linguistic and cultural differences between workers.

Safety signs are to warn of any remaining significant risk or to instruct employees of the measures they must take in relation to these risks. It is very important that employees fully understand the meaning of such safety signs and are aware of the consequences of not following the warning or instruction given by the sign. The publishing tool in the guide allows the user to produce EU compliant labels to warn of the arc flash hazard and to give vital information about the severity of the arc flash hazard to electrical workers.

Typical EU compliant field marking signs

SUMMARY

The arc flash hazard is a serious electrical risk that needs to be managed in many industrial environments. Arc flash risk assessment for workers who operate in proximity to, or on, energised electrical equipment and cables is essential to ensure safety and compliance with the law. This assessment needs to include Predict, Prevent, Protect and Publish and the DuPont(TM) Arc-Guide gives all the tools necessary to fulfil all these steps as well as give access to expert advice to ensure compliance.

THE AUTHOR

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