Electrical Arc Flash

Guidance Notes

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The hazards of electric arc faults have been known since the commercial use of electricity began. Only in relatively recent times (circa 1982) have methods to quantify the energy released by an arc fault and mitigate the risk of burns to personnel started to be developed.

In the USA the Occupational Safety and Health Organisation (OSHA) imposes a mandatory requirement for electrical workers to use arc flash Personal Protective Equipment (PPE).

To comply with OSHA requirements it is therefore necessary to calculate the arc incident energy* to arrive at an appropriate Arc Thermal Performance Value** (ATPV) for PPE or alternatively use the tables given in NFPA 70E*** (Table 130.7C (9)).
It is also necessary to calculate the flash protection boundary**** to determine the limit of the zone within which PPE is necessary.

The American Institute of Electrical and Electronic Engineers (IEEE) has published Standard 1584 IEEE Guide for Performing Arc Flash Hazard Calculations.

This document describes the approach used by TAS to complete arc flash hazard studies.

Definitions

* **Incident energy** – The amount of energy impressed on a surface, a certain distance from the source, generated during an electric arc event.

** **Arc Thermal Performance Value (ATPV)** This value represents the maximum capability for arc-flash protection of a particular garment.

Note: both incident energy and ATPV are commonly expressed in calories per centimetre squared or Joules per centimetre squared (1 calorie = 4.186 Joules)

*** **NFPA 70E** US National Fire Protection Association (NFPA) Standard 70E Electrical Safety in the Workplace.

**** **Flash protection boundary:** An approach limit at a distance from live parts that are un-insulated or exposed within which a person could receive second degree burns

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In the UK there is no specific requirement to wear PPE but since a hazard has been identified it is necessary to assess the risk and ensure appropriate mitigation.

It is worth quoting the *Memorandum of Guidance* on the Electricity at Work Regulations:

REGULATION 2

(d) Arcing

Clause 28	Arcing causes a particular type of burn injury which is distinct from other types. Arcing generates ultra violet radiation which causes damage akin to severe sunburn. Molten metal particles from the arc itself can penetrate, burn and lodge in the flesh. These effects are additional to any radiated heat damage caused by the arc.
Clause 29	On its own, ultra violet radiation can cause damage; sensitive skin and eyes are especially vulnerable to arc flash. ('Arc eye' is commonly encountered with electric arc welding if the proper precautions are not adopted.)
Clause 30	Arcing faults can occur if the energy available at a piece of electrical equipment is sufficient to maintain a conductive path through the air or insulation between two conductors which are at different potentials. Under fault flashover conditions, currents many times the nominal rating or setting of a protective device may flow before those devices operate to clear the fault. Much energy is dissipated in the arc and depending on the electrical protection, may continue long enough to inflict very serious arcing burns or to initiate a fire in periods for example as short as 0.25 second, which is not an untypical minimum time for fault clearance. Arc flashovers caused during work on live circuit conductors are likely to be particularly hazardous because the worker is likely to be very near to or even enveloped by the arc. Such cases often lead to very serious, sometimes fatal, burn injuries.

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The TAS Approach

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TAS have been actively involved in arc flash studies since 1995 and our approach has constantly developed to embrace new developments and best practice.

An arc flash hazard study has two elements:

- **Arc flash calculations**
  These provide information on the consequences of an arcing incident, specifically the thermal incident energy at a working distance and the distance at which the arc ceases to present a thermal hazard. The calculations also indicate the PPE required to prevent second degree burns at the working distance.

- **Electrical Safety Review**
  A qualitative assessment of the probability of an arcing incident based many factors including the site operation and maintenance regime together with the physical features of individual items of switchgear.

  A key feature of the Electrical Safety Review is to ensure that the full hierarchy of controls asset out The Health and Safety at Work Act (HSWA) [Ref 1] has been implemented before PPE is recommended.

Arc Flash Calculations

To calculate arc flash energy levels requires knowledge of system fault currents and protection clearance times. TAS use a software package *SKM Power Tools* which is capable of calculating fault currents throughout a system and accepting protection relay characteristics. When the fault and protection information is verified a separate software module completes arc flash energy level calculations in accordance with IEEE 1584.

Key calculation features:

- TAS fully model each system to provide accurate results, we do not employ rules of thumb or short cuts. Any assumptions made are clearly identified and agreed with client. Modelling is a data hungry exercise and a typical data requirement sheet follows.
- The completed model is valuable and can act as a master record of the electrical system as well as aiding the assessment of any proposed system changes
- L.V. circuits with a protective device rated 3-phase 100A and below are excluded from studies as the potential arc energy is low.
- Motor circuits are not usually assessed since it is assumed that motor terminal boxes will contain any arc blast and they will only be opened with the circuit isolated.

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Key calculation features continued

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- The working distance selected for the calculations has a profound effect on the results. As the incident energy is proportional in the inverse square of the distance, TAS use a working distance in accordance with the IEEE 1584 standard. This is typically 457mm (18 inches) for LV switchgear and 910mm (36 inches) for HV switchgear and represents the position of the torso of an operative. It is accepted that the hands may be exposed to much higher incident energy and should be protected accordingly.
- IEEE standard 1584 is valid to 15 kV only, any calculations at higher voltages are indicative only.
- Calculations to IEEE 1584 consider radiant energy only appropriate consideration should be given to the other effects of an arc fault, shrapnel, vaporised/molten metal splatter, explosive noise, blast and noxious fumes.
- TAS experience indicates that the high arc energy levels experienced in LV switchgear are often not recognised; approximately 5% of LV switchboards have incident energy levels in the NFPA 70E "Dangerous" category.
- Following completion of Arc Flash calculations, many operators embark on an engineering programme to reduce energy levels;
  - Switchgear Risk Assessment (tasks undertaken)
  - Electrical protection reviews
  - Switchgear upgrade (e.g. remote operation facility)
  - Installation of arc detection and suppression equipment
  - Revision of operation may also assist
  - Prohibition on live operation of DMO switchgear
  - Isolation of high arc energy 415v switchboard elsewhere, e.g. incomers at 11kV

Arc flash calculation data requirements

Do you have:	
1	An up-to-date Single Line Diagram of the network?
2	The known calculated Fault Level and X/R ratio (R+JX @ 100MVA) for your main power supply sub station / switch house?
3	The calculated Fault Levels at the down-stream points in your network?
4	Details of the High Voltage feeder cables? i.e. types, sizes & lengths
5	Details of the transformers, voltage ratio, KVA ratings, impedance and vector groups?
6	Details of the transformer secondary cables, including type, size, number per phase & length (or Busbars if applicable)?
7	Details of the High Voltage over current protection details - giving relay manufacturer, type, model, CT ratios, setting, etc?
8	Main Low Voltage switchboard details?
	8.1 Incoming circuit breaker / isolator protection details (if fitted)
	8.2 Outgoing Circuit details for all circuits protected at 100 amps and above
	8.3 Main Busbar current rating and fault withstand
9	Details of the Sub-Main distribution boards where incoming / outgoing protection is 100 amps and above?
10	Details of the cables feeding sub-main boards, including size, type and length?
11	Details of the system normal operating configuration - i.e. Bus-section switches / interconnectors usually open / closed?
12	Do you require a site survey to collate / collect the above information?

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Typical abbreviated calculation results

LV Equipment

Bus Name	Protective Device name	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (cal/cm²)	Required Protective FR Clothing Category
025A LTG & SP	P1E-SWBD FAD02	835	457	3.2	Category 1 (*N3)
107A-TCA-001 SW.BD	FTC-SWBD-INC1-OC	5800	457	77	Dangerous! (*N3)
108B SWBD	108-SWDB-INC OC	6017	457	82	Dangerous! (*N3) (*N9)
108B-TGA-001	108FAB02	1237	457	6.1	Category 2
108B-TGA-002	108FAC02	1237	457	6.1	Category 2
108C SWBD	108C-INC-OC	538	457	1.6	Category 1
110 SWBD-LHS	110 SWBD INC2 O/C	928	457	3.8	Category 1
110-SWBD-RHS	110-FAB-10 E/F	1183	457	5.7	Category 2

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Electrical Safety Review

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A typical risk assessment scoring matrix is shown herewith.

Residual Risk Score	Action Required	Interpretation
3e ,4e, 5e, 4d, 5d	Stop work, improve or increase controls immediately	Prohibition notice
2e, 3c, 3d ,4c, 5c	**Improve** or increase control measures as a **matter of urgency**	Improvement notice
1e, 2d, 4b, 2c, 3b, 5b	Improve or increase control measures	Need to demonstrate good progress against an improvement plan
1c, 2b, 4a, 1d, 3a, 5a	Monitor existing control measures for continued effectiveness	Keep good control. Don't slip backwards!
1a, 1b, 2a	No action required. Monitor situation	Keep under review

Severity		***Residual risk rating***				
5	Multiple Fatalities	5a	5b	5c	5d	5e
4	Single Fatality	4a	4b	4c	4d	4e
3	Very harmful *(amputations, loss of eyesight)*	3a	3b	3c	3d	3e
2	Harmful *(fractures, burns. L.T.A.)*	2a	2b	2c	2d	2e
1	Slightly harmful *(cuts, bruises, bumps, etc.)*	1a	1b	1c	1d	1e
Risk Assessment Matrix		**Highly Improbable** (extremely unlikely to occur)	**Improbable** (small chance of occurring)	**Possible** (could occur at some time)	**Probable** (not be surprised if it happened)	**Highly probable** (bound to happen at some point)
Likelihood						

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Electrical Safety Review

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This risk assessment considers the severity of an event together with the probability of an event to arrive at an estimated residual risk rating.

The catastrophic effects of an arc flash incident score highly on the severity scale with even switchgear falling in NFPA Category 0 capable of scoring “Harmful” (2) and switchgear in categories 1 and above capable of scoring “Very harmful” (3) or even fatalities (4 or 5)

The severity score leads to the only acceptable likelihood score for an arc flash incident being “highly improbable” with constant monitoring of controls.

Core TAS Assumptions

- Properly specified and installed switchgear, which is within its reasonable working life (circa 30 years) with no known defects, correctly operated and maintained with safe systems of work in place for all of its activities has a highly improbable likelihood of an arc flash fault.
- Arc flash PPE should only be recommended when the hierarchy of controls has been applied fully and no other practical mitigation is possible.
- The Switchgear Risk Assessment must actively engage site personnel as they are experts on their system and the TAS role is principally that of training and facilitation.

The purpose of the Electrical Safety Review is to establish if there any factors with increase the probability that an arc flash incident may occur above the lowest “highly improbable” level, and where possible, how to mitigate the risk.

Where there is an increased risk of an arc fault, recommendations for risk mitigation are made and where appropriate, levels of PPE are recommended.

There are two elements within the electrical safety review, the first element is to assess site wide arrangements for electrical safety and the second is to assess individual items of switchgear.

Following the review, a report will be prepared summarising the processes and outcomes of the review and giving recommendations.

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References

1. Health and Safety at Work Act 1974
2. Electricity at Work Regulations 1989
3. Memorandum of Guidance on the Electricity at Work Regulations 1989, Guidance on Regulations HSR 25
4. Health and Safety Executive HSG 85 Electricity at Work – Safe Working Practices
5. Health and Safety Executive HSG 230 Keeping Electrical Switchgear Safe
6. IEEE 1584 IEEE Guide for performing Arc Flash Calculations
7. NFPA 70E Electrical Safety Code

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