ARC FAULT
RISK ASSESSMENTS

In electrical safety, the two hazards are shock hazards and arc fault hazards and no electrical safety program is complete unless it addresses both. This article focuses on the hazards associated with arc faults by describing the risk assessment process for an industrial site from hazard identification to the development and implementation of controls.

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In Australia the Workplace Health and Safety Act requires the management of health and safety risks so far as is reasonably practicable. Risk is the possibility that harm might occur when exposed to a hazard. Where risks are identified, control methods need to be developed and implemented, with the hazard and controls reviewed periodically or whenever there are changes to the plant, practices, standards, etc.

The raw risks associated with arc faults are a function of the capacity of the electrical system, the electrical equipment (including protective devices), the tasks being performed on or near the equipment, and the people performing the tasks.

LIVE ELECTRICAL WORK!

Electrical Work requires three general stages, creating a safe working situation, performing the work and restoration. The first and last stages are generally considered operational work, but the tasks required for isolation, earthing and isolation verification as well as the reverse do have associated arc fault hazard exposures that need to be assessed and controlled.

Workplace Health and Safety legislation and codes of practice include testing in the definition of Electrical Work. The legislation also prohibits energised electrical work, but does allow testing by a competent person under certain conditions. Electricians get involved in testing or fault finding as part of their everyday work even if it is just performing the essential "test before you touch" process.

ASSESSING ARC FAULT HAZARDS

Despite the progress in the recent revision of the 2014 Energy Network Association NEN-09 guideline for arc hazards and PPE, there is no prescribed arc flash safety system in Australia that quantifies the arc hazard and the rating of the PPE controls. This leaves the American standard NFPA70E or its Canadian equivalent as the dominant assessment standard, and IEEE 1584 as the main assessment tool. To assist with Arc Hazard assessment NFPA70E includes a task based table outlining when PPE is required and equipment based tables utilising voltage, available fault current, and clearing times to define the levels of PPE required.

In the NFPA 70E task tables, tasks such as reading meters and operating meter selector switches on the front of panels, or accessing control panels via hinged covers with no exposed voltages greater than 120 Vac do not require any arc rated PPE. Likewise, operating equipment without arc rated PPE is permitted providing:

- The equipment is properly installed,
- The equipment is properly maintained,
- All equipment doors are closed and secured,
- All equipment covers are in place and secured, and
- There is no evidence of an impending failure

The use of the equipment tables is limited to the listed clearing times and fault levels and as such still require fault current calculations and protection analysis to establish clearing times. The table groups the protection into the following Arc Flash PPE Categories:

- Category 1 – Minimum 4 cal/cm^2
- Category 2 – Minimum 8 cal/cm^2
- Category 3 – Minimum 25 cal/cm^2
- Category 4 – Minimum 40 cal/cm^2

NFPA 70E also lists the PPE requirements for each category including when to wear arc rated face shields, hoods, gloves and the like.

At this point, if your system falls outside the table limits, or if you prefer, you will need to perform an arc fault hazard analysis to calculate the prospective incident energy. The calculation method utilises IEEE1584 and predicts incident energy as cal/cm^2. If you use the calculation method then you no longer have to define the hazards in terms of the Arc Flash PPE Category, although the tables still provide a useful guide for the PPE controls.

An Arc Fault Hazard Analysis utilises all of your system parameters to predict arc fault currents and the associated incident energy levels based on your protective device characteristics. IEEE1584 is available as an Excel based spreadsheet and is also available in host of electrical system modelling software packages. The benefit of these packages is that you can easily assess the potential impact of any protection changes on predicted incident energy levels and protection co-ordination.

Case Study 1 – Large Port Facility

The following table summarises some of the results from the arc fault hazard analysis at the port. The ports power system is connected to the utility at 22 kV and includes high voltage distribution equipment and drives as well as low voltage distribution boards, motor control centres and drives. The low voltage distribution transformers are rated at 2 MVA.

Table 1 *Case study 1 Initial Arc hazard Analysis Results*

Equipment	Prospective Bolted Fault Current (kA)	Predicted Arc Fault Current (kA)	Max Clearing Time (s)	Distance From Arc (mm)	Min Incident Energy (Cal/cm^2)	Max Incident Energy (Cal/cm^2)	Arc Flash Boundary (m)
22 kV Main HV Substation Indoor Switchgear	7.4 – 8.0	7.4 – 8.0	0.52	1000	23	46	6.1
22 kV HV Substation Indoor Switchgear	5.4 – 7.6	5.4 – 7.6	0.33	700	12	57	4.8
400 V Transformer Fed Main Distribution Boards	40.1 – 50.1	17.9 - 21	2.05	500	13	110	7.9
400 V MCC Sub Boards	5.7 – 32.9	3.1 – 15.2	0.21	500	8	10	1.8

Case Study 2 – Small Factory

This facility was connected to the low voltage terminals of a dedicated 750 kVA distribution transformer owned and operated by the local utility. The facility has a transformer supplied main distribution board, a number of larger sub boards and some local distribution boards.

What both case studies show is that transformer fed main boards and sub boards with protective devices rated higher than 400 A present a significantly larger hazard than the high voltage equipment or the sub boards with lower rated protective devices. Remember here that the threshold for 2nd degree burns is 1.2 cal/cm^2. One can only imagine the devastation at greater than 100 cal/cm^2 and yet prior to the completion of the analysis for Case Study 1 the electricians were taking off their flash suits when performing operating tasks on the low voltage boards.

Once you have the results of the analysis you need to review the likelihood of any of your known tasks exposing your electricians to the prospective arc fault level on each type of equipment and develop some controls.

Table 2 *Case study 2 Initial Arc hazard Analysis Results*
** Clearing time limited to 2 seconds - actual clearing duration is longer*

Equipment	Upstream Protective Device	Prospective Bolted Fault Current (kA)	Predicted Arc Fault Current (kA)	Max Clearing Time (s)	Incident Energy (Cal/cm^2) at 457mm	Arc Flash Boundary (m)
22 kV Transformer HV Terminals	Utility HV Fuse	4.6	4.6	0.01	0.62	0.658
415 V Main Incomer Switch Board	Utility HV Fuse	15.8	8.7	2*	55	4.7
415 V Switch Board 1	630 A MCCB	14.7	6.9	2	45	4.1
415 V Sub Board 1	400 A CFS	13.7	6.5	0.122	2.6	0.73
415 V Sub Board 2	200 A CFS	10.2	6.0	0.01	0.19	0.15
415 V Sub Board 3	100 A CFS	14.1	7.9	0.01	0.26	0.18

DEVELOPING ARC FAULT MITIGATION CONTROLS

To manage arc fault hazards onsite you will generally need to layer a number of controls on top of each other to reduce the likelihood of initiation, the frequency of exposure, the prospective level of the hazard and the likely consequences for the worker and the equipment. Using the Hierarchy of Controls as described in AS/NZS 4836 Safe working on or near low-voltage electrical installation and equipment, you can develop controls to minimise the hazards.

ELIMINATE THE HAZARD

Elimination is always the ultimate control. AS/NZS 4836 includes isolation in the elimination category as a means of creating an electrical safe situation. As stated previously there are hazards associated with the isolation and isolation verification steps in creating the safe electrical situation. With arc fault hazards, you also need to consider the boundaries of the isolation against the tasks being performed. It is fair to argue that administrative controls such as policies, procedures and training are required to safely eliminate the hazard via isolation, further reinforcing the need for layered hazard controls. Work involving tasks such as those listed below should only be performed under full (remote end) isolation:

- The removal of busbar covers
- Any work on the incoming side busbar system or anything directly connected to it
- The removal or insertion of bolts or screws that enter blind holes in back plates, equipment mounting plates, etc.
- All drilling except on an open door where both sides can be seen
- Metal work modifications where both sides of the panel cannot be seen
- Pulling- in and termination of cables in compartments with exposed conductors or terminals
- Disconnecting and re-terminating of cables in compartments with exposed conductors or terminals
- Blowing out or vacuuming any of this equipment
- Any activity (except operating work) on any isolating device where the incoming side is still live
- Working on top of or above switchgear

Workplaces should also consider the process of operating work with respect to eliminating the hazard. In Case Study 1 the High Voltage switchgear was already fitted with remote operation. For the vast majority of the low voltage switchboards, remote isolation via the high voltage breaker enabled the low voltage breaker to be switched and racked without any arc flash hazard exposure. This small change in philosophy recommended as part of the Engineering Safety arc hazard assessment cost the client nothing to implement and eliminated high frequency task exposures of up to 110 Cal/cm^2.

SUBSTITUTION

At an equipment level, substitution of high fault level equipment required for commercial and industrial processes is not practicable. At a task level, you can substitute high arc hazard exposures to low ones for tasks such as isolation. Retrofitting or specifying suitably protected low fault level test points for distribution boards and MCC's can enable the electrician to complete isolation verification and some fault finding tests without any arc hazard exposure.

SEPARATION

Arc hazards are proportional to the square of the distance. Any mechanism that can be safely installed or utilised to separate the worker from the hazard will have a positive effect on reducing arc hazard exposure levels for the given task. Improved separation is achievable by the installation/utilisation of remote operation panels and devices, remote racking devices, earth switches instead of hand-applied earths etc. These could be as elaborate as a SCADA system or as simple as a piece of string.

Many ACB manufacturers have developed remote racking devices to complement their products, and other engineering firms have developed racking devices for a range of breakers. The arc flash boundary is a factor when considering separation, as boundaries in excess of 5m are possible meaning that in smaller substations there may not be a safe zone. Keeping the door closed also acts as a form of separation that can reduce the arc hazard exposure.

A range of manufacturers offer infrared viewing portals and panels that can eliminate the need for removal of switchgear panels for thermography inspection.

ENGINEERING CONTROLS

Engineering controls through design can assist with the controls described above as well as act to limit the hazard levels. The largest impact for engineered controls aside from assisting with the controls described above in reducing arc fault hazards is through reduced arc fault clearing times. Protective devices are generally sized to protect the equipment from damage by ensuring the device clears the prospective bolted fault level within a specified time. The reduced arc fault currents at low voltage levels means that arc faults can take many seconds to clear resulting in a hazardous situation for workers and equipment damage.

Completing a protection study as part of an arc hazard assessment will identify possible protection setting changes to reduce arc hazard exposure levels. Depending on

your electrical system, correctly sized fuses and specialist designed fuse systems such as the Australian developed SafeARC system can be utilised to reduce durations and limit the fault current.

Improvements to low voltage circuit breaker tripping units have resulted in zoned interlocking and maintenance setting functionality previously only available on high voltage protection relays. Zoned interlocking operates in a similar way to differential / bus bar protection schemes and enable instantaneous tripping on switchgear faults whilst still maintaining protection grading. Maintenance settings functionality allows switchable protection settings that can be utilised to reduce instantaneous protection settings to below arc current thresholds while operational tasks are carried out without compromising protection grading during normal operation.

Arc fault detectors with or without current check can also be fitted to switchgear to trip breakers in the event of a fault within the detection zone.

In Case Study 1 recommendations were made regarding the implementation of engineering controls to reduce arc fault hazard exposure levels. The table below details the reduction in arc fault hazard levels due to the protection setting changes. In this Case Study the available fault level and the nature of the loads meant that instantaneous protection could be set below that arc current threshold on the main low voltage boards without compromising on grading. Changes were not able to be made at the sub boards without introducing grading issues.

With respect to Case Study 2 the hazard levels at the main board were not able to be changed. The utility declined an engineered request to change the HV incomer fuse rating, as it did not did not fit within their fuse standard. Even allowing for a high voltage fuse change, high levels of PPE were still required for operational tasks on the board due to its construction and lack of maintenance.

With no isolation device between the transformer and the board it was recommended that isolation for maintenance and repairs be via the utility HV drop out fuse links.

Table 3 *Case study 1 Reduced Incident Energy after implementation of recommended risk assessment controls*

Equipment	Protection Change	Previous Incident Energy (cal/cm^2)	Modified Max Incident Energy (Cal/cm^2)
22 kV Main HV Substation Indoor Switchgear	Install Maintenance Mode	46 Outside Bus Bar Diff Zone	25 Inside and outside Bus Bar Diff Zone
22 kV HV Substation Indoor Switchgear	Install Maintenance Mode	57	21
400 V Transformer Fed Main Distribution Boards	Modify Protection Settings	110	6.2
400 V MCC Sub Boards	No protection changes	10	10

ADMINISTRATIVE CONTROLS

Administrative controls include policies and procedures, signage and training. Administrative controls act to assist implementation and reinforcement of task related changes. Training also provides an opportunity to improve workers understanding of arc hazards and the necessity for changes to equipment and behaviour. Training should focus on the hazard in general as well as the site-specific equipment and task related exposures and controls.

Labelling of the equipment highlighting the level of arc hazard exposure and required PPE is called for under NFPA 70E and provides the workers with enough information to make informed choices about how to safely plan and execute their work.

PERSONAL PROTECTIVE EQUIPMENT

Regardless of the output of the study wherever there is a potential for exposures above 1.2 cal/cm^2 workplaces should be implementing a PPE policy at least in line with ENA NENS 09 2014 National Guideline for the Selection, Use and Maintenance of Personal Protective Equipment for Electrical Arc Hazards. ENA recommends a minimum of 4 cal/cm^2 for everyday wear. Higher exposure levels may be required for certain tasks on certain equipment as per the results of the arc flash risk assessment. As it stands non arc rated synthetic or cotton work wear can melt or ignite increasing the severity of the injuries to the workers they were purchased to protect.

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