Maritime and Coastguard Agency

MARINE GUIDANCE NOTE

MGN 452 (M)

ELECTRICAL - Potential Hazards of Arc Flash Associated with High and Low Voltage Equipment

Notice to all Shipowners, Ship Operators, Masters and Officers of Ships, Ship Designers, Shipbuilders and Manufacturers of Marine Electrical Equipment

Summary

This MGN highlights potential hazards of arc flash associated with high and low voltage electrical equipment onboard vessels.

Key Points:

- The best approach for electrical safety to prevent an arc flash incident is to only perform work on de-energised equipment that has been placed into an electrically safe condition.
- After control measures to reduce the risk of an arc flash have been investigated/implemented, protective clothing and PPE requirements should be carefully selected.
- One of the major hazards associated with an arc flash is burn injury from the exposure to the thermal energy from an arc flash.

1. Introduction/Background

1.1 Whilst approaching port a United Kingdom passenger ship suffered a failure of a harmonic filter and the resulting explosion caused extensive damage to the surrounding electrical panels and a total black-out of the vessel.

1.2 The UK Marine Accident Investigation Branch (MAIB) report* identified the explosion in the machinery space was triggered by the failure of a large capacitor within a harmonic filter and the protection system for the harmonic filter did not work.

1.3 The investigation also identified that there is a need to improve the awareness of the potential risks of arc flash associated with high and low voltage equipment.

* MAIB Report No. 28/2011 – RMS Queen Mary 2 – http://www.maib.gov.uk

1.4 Although the Code of Safe Working Practices (COSWP)[1] covers high voltage work permit and sanction-to-test procedures, it currently does not address the hazards of arc flash. Awareness of arc flash hazards needs to improve throughout the marine industry so that designers, builders, owners, operators and engineers understand the problems and the potential risk reduction measures available to reduce the hazard to as low as is reasonably practicable.

1.5 This MGN aims to improve the awareness of the hazards of arc flash and the importance of preventing such an incident by placing equipment into an electrically safe condition before commencing any work.

2. Phenomenon of arc-flash

2.1 When an electric current flows through an air gap between conductors, an arc flash is said to occur. During an arc fault the air is the conductor. An arc can form between phase-to ground (or neutral), or phase-to-phase, and is accompanied by ionisation of the surrounding air.

2.2 An arc fault is similar to the arc obtained during electric welding and the fault has to be manually started by something creating the path of conduction or a failure, such as a breakdown in insulation or contact with a conducting object.

2.3 When the air quality or insulation is degraded with moisture or other impurities, the possibility of an arc striking is increased. The arc column temperature can vary from 5,000ºC to 20,000ºC and the intense heat can vaporise the conductors and surrounding materials.

2.4 The heat of the arc column also heats up the surrounding air, which then moves into the surrounding cooler air with a speed exceeding that of sound, causing a shock wave and explosive noise.

2.5 It can cause severe shock waves, splattering of molten debris, loud explosions due to the rapidly released vapour, as well as shrapnel and serious burn injury to anyone in the vicinity.The arc has a tendency to move away from its source.

2.6 Other potential immobilizing effects on exposed personnel to be considered are blinding from the very intense light, and smoke which may contain toxic vapours.

3. Incident energy

3.1 Incident energy, measured in calories per square centimeter (cal/cm²), is the term used to quantify the severity of an arc flash. It is the amount of thermal energy from an arc flash that reaches a surface, such as a person's skin.

3.2 The greater the incident energy value is, the more severe the burn injury. 1.2 cal/cm² is the energy required to produce the onset of a second degree burn[2], and is the benchmark for personal protection.

3.3 The goal of arc flash protection is to minimise the likelihood of burn injury by providing an adequate thermal barrier that will limit the energy exposure at a person's skin to no more than 1.2 cal/cm².

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[1] Code of Safe Working Practices for Merchant Seamen - ISBN: 9780115532078

[2] Second degree burn – affects both the outer and underlying layer of skin; causes pain, redness, swelling and blistering (National Institutes of Health, 2010)

3.4 It is important to keep in mind that 1.2 cal/cm² is where the onset of a second degree burn can occur, so there is still a possibility of being injured while protected.

4. Arc flash hazard calculation[3]

4.1 An arc flash hazard calculation should be performed in order to determine the magnitude of incident energy that could potentially be available at a specific working distance from each piece of electrical equipment under study.

4.2 It is based on specific system conditions, such as short circuit current and protective device clearing time.

4.3 To mitigate the risk of arc flash, incident energy reduction design measures should be applied, such as maintenance settings, arc flash detection and remote racking.

4.4 Based on the estimated incident energy at each location, (after all incident energy reduction design measures have been considered), appropriate protective clothing and PPE are selected to withstand the incident energy.

5. Arc flash and shock protection boundaries

NFPA 70E (National Fire Protection Association) has developed boundary requirements to reduce the risk of injury to workers due to arc flash and shock hazards:

5.1 *Arc Flash Boundary (AFB)*: is the distance from a prospective arc flash where the incident energy falls to 1.2 cal/cm^2. This represents the minimum distance at which PPE must be worn to minimise burn injury in the event of an arc flash.
Unqualified persons may cross the AFB only when accompanied by a qualified worker.
Any persons crossing the AFB must wear appropriate PPE.

5.2 *Limited Approach Boundary*: is the distance from a live part to which unqualified persons may approach unaccompanied. To cross the Limited Approach Boundary, unqualified persons must be accompanied by a qualified worker wearing the appropriate PPE and trained on the task to be performed.

5.3 *Restricted Approach Boundary*: may only be crossed by qualified workers with appropriate PPE and training on the task to be performed. In addition, the worker must have an approved work permit and written plan for the task. The plan should include shock prevention procedures designed to keep all portions of the worker's body from crossing the Prohibited Approach Boundary at any time.

5.4 *Prohibited Approach Boundary*: is the distance from a live part which is equivalent to direct contact. Crossing this boundary with unprotected (conductive) body parts or tools risks an electrical arc. Any body part which crosses this boundary must be protected with PPE rated appropriately for direct contact with the part. A risk assessment must be performed and a written work plan approved before crossing the Prohibited Approach Boundary.

5.5 A key feature of managing exclusion distances is the presence of a “safety buddy” for any risk situation, and that the buddy is <u>outside</u> the flash protection boundary so that they are not also incapacitated in the event of an incident.

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[3] One widely accepted means of calculation is IEEE Standard 1584-2002 - *IEEE Guide for Performing Arc Flash Hazard Calculations*
The Institution of Electrical and Electronic Engineers (IEEE): http://standards.ieee.org/

6. Control measures to be considered to reduce the risk of an arc flash

6.1 In so far as practical, switchboard compartments should be designated unmanned spaces.

6.2 Wherever possible, remote breaker switching should be utilised.

6.3 All metal fittings and phase conductors are to be secured to prevent any unintentional short circuit.

6.4 Electrical equipment enclosures can be designed and tested in accordance with international standards that contain or direct arc-flash products away from an operator, however, this is not a mandatory requirement for LV equipment.

6.5 Arc flash energy can be reduced by faster protection. There are products available that provide high speed initiation of switchgear on physical detection of an arc flash (e.g. by sensing light or pressure) which will override the normal delays associated with discriminative short circuit protection.

7. Protective clothing and personal protective equipment (PPE)

7.1 When all other control measures to reduce the risk of an arc flash have been investigated/implemented, protective clothing and PPE requirements should be considered.

7.2 Protective clothing and PPE is required to limit workers exposure to incident energy should an arc flash occur. Incident energy causes burns, which is the major hazard to individuals from an arc flash.

7.3 Some examples of where protective clothing and PPE may be required are:

- during load interruption;
- during the visual inspection that verifies that all disconnecting devices are open; and
- during the equipment lock out/tag out procedures.

Appropriate protective clothing and PPE is also required during the tests to verify the absence of voltage after the circuits are de-energized and properly locked out/tagged out.

7.4 When used, protective clothing and PPE should be worn as a last form of defense, but it should never be considered as providing an alternative to the other safety measures in this notice. The protection is not intended to prevent all injuries but to mitigate the impact of an arc flash upon the individual, should it occur. In many cases, the use of protective clothing and PPE has saved lives or prevented injury.

8. Arc flash and electrical safety training

8.1 Once the results of the completed arc flash hazard calculation study have been incorporated into the electrical safety programme, personnel must be trained to understand the results and requirements.

8.2 Every person that works on or near energised conductors should be trained to understand the hazards associated with arc flash, as well as the arc flash and shock protection boundaries, the use of arc flash warning labels, and the selection and use of personal protective equipment.

8.3 In addition, health and safety personnel, managers and supervisors responsible for those working where these hazards could exist, should receive similar training.

8.4 Training should always be conducted by persons with experience and a thorough understanding of arc flash safety practices, as well as relevant codes and standards.

9. Electrically safe working condition

9.1 The best approach for electrical safety is to only perform work on de-energised equipment that has been placed into an electrically safe condition. This should always be considered the ultimate safe work practice for electrical systems, when possible.

9.2 With only a few exceptions, such as testing and start-up, or where de-energising a system produces an increased hazard or is infeasible, performing work on energized electrical equipment should *only* be carried out as a last resort.

10. Definitions

Capacitor	A device that stores energy in the form of an electric field.
Harmonic filter	Variable speed motors for electric propulsion or other machinery are supplied by power converters. Switching devices used in power converters result in voltage distortion. Harmonic filters mitigate the effects of excessive voltage distortion.

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