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"Having a Blast" - Assessment of Compartment Overpressure following an Arc Fault

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Synopsis

The assessment of arc flash incident energy and the mitigation of the associated hazards in naval platform applications is now well defined and understood, with many previous conference papers having been presented, supported by published guidance notes and standards, such as IEEE1584, NFPA 70E, BR2000(52)-1 and Lloyd's Register Arc Flash guidance document.

However, the assessment of the resultant effects of any arc blast on compartment overpressure and the mitigation of the associated hazards to ships structure and ship's staff are not yet well defined or understood. Literature indicated that considerable damage could be caused to brick built substations and concern was raised about the possible impact on ship structure and personnel safety.

With the above in mind, BAE Systems Naval Ships has developed a modelling tool for assessing the effects of an arc blast on a switchboard room compartment and any personnel that may be within the blast boundary. The toolset uses a spatial representation of the switchboard room being assessed, along with the electrical system fault level data, calculated through the normal power system modelling activities, to calculate the pressure rise resulting from an arcing fault. The developed modelling tool allows engineers the ability to perform calculations of arc blast pressure rise for the purpose of identifying the degree of hazard due to pressure and identifying applicable mitigation activities.

Keywords: Arc Blast, Arc Flash; Pressure; Safety; High Voltage; Electrical

1. Introduction

In response to a growing understanding of arc flash hazards and safety requirements in the electricity supply industry, particular attention is being paid to these hazards in the context of naval vessels. It is apparent that in recent years the focus of attention has been on the release of thermal incident energy, while analysis of the pressure wave released is less understood.

In order to quantify and assess the level of hazard due to arc flash pressure rise, a modelling tool has been developed by BAE Systems based on guidance published in the CIGRE paper *'Tools for the Simulation of Effects of the Internal Arc in Transmission and Distribution Switchgear'* [1]. This tool has been applied by engineers in BAE Systems to provide information to support the safety case of warships in design and in service.

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2. Overpressure Modelling

2.1. Overview

Methods for modelling overpressure in compartments from arc flash events have been examined in [1]. Three main types of model were identified:

Basic models:	Gas pressure is calculated according to general gas equation and mass flow through pressure relief openings. The compartment where the arc is ignited and other connected spaces are described by their effective volumes and openings between them. Gas properties are assumed to be independent of temperature and pressure, and thus the model use is constrained by gas temperature.
Enhanced models:	These models are based on the same basic equations but may also include some additional effects such as temperature and pressure dependent gas properties, exothermic reaction, ablation of material, and mixing of gases.
CFD models:	Gas pressure and temperature is based on the fluid dynamic equations describing conservation of mass, momentum and energy of the gas in finite volume elements.

The basic and enhanced models provide spatial average pressures inside the arc compartment and the connected spaces, while CFD models provide spatially varying pressures and are more appropriate for odd shaped geometries or larger spaces.

The basic model was implemented, using information from [1] and provided good agreement to measured data presented. The model was used to assess arc flash overpressure on naval ships, noting the limitations of electrical supply.

2.2. Basic Model

The basic model describes the overpressure in a succession of spaces from the space in which the arc flash occurs.

The spaces are connected by openings or pressure relief openings. The state of each space is defined by the gas volume (V), the gas temperature (T) and the gas mass (m) which implicitly define the gas pressure (p). The energy input is defined by the input thermal power ($\dot{Q}$). The energy transfer between spaces is characterized by the mass flow ($\dot{m}$) which is dependent on the opening area (A) and the gas state of the adjoining spaces. The opening can be a pressure relief panel that only opens when there is sufficient pressure difference across it.

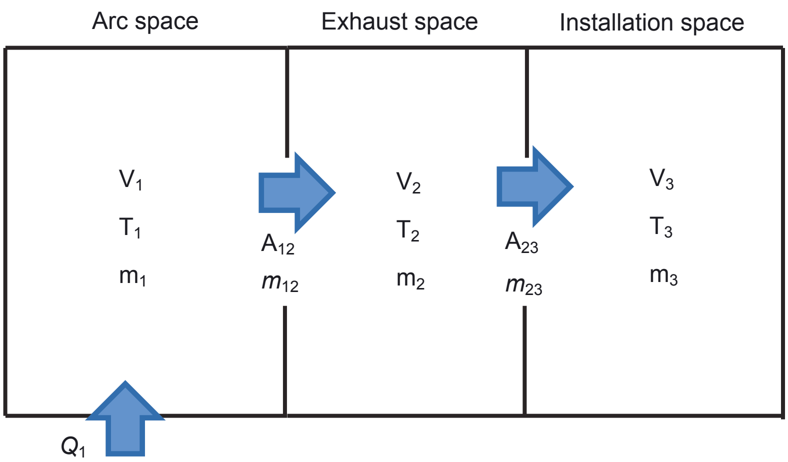

Figure 1 - Three Space Representation of the Basic Model

Differential equations describing the evolution of the pressure, temperature and mass can be derived assuming ideal gas and adiabatic expansion and are described in [1].

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2.1. Equations

The state variables for each space are the gas temperature and the mass of gas in the compartment. The evolution of these quantities is described by a set of differential equations.

2.1.1. Symbols

A_{ij}	opening area between spaces i and j (m^2)
c_{pi}	specific heat capacity of the gas at constant pressure in space i (J/kg/K)
c_{vi}	specific heat capacity of the gas at constant volume in space i (J/kg/K)
E_i	arc energy in space i (kg)
k_p	thermal transfer coefficient between arc and gas (-)
m_i	mass of gas in space i (kg)
$\frac{dm_{ij}}{dt}$	mass flow of gas from space i to space j (kg/s)
Q_i	the thermal energy input from the arc to space i (J)
R_{si}	the specific gas constant for the gas in space i (J/K/kg)
t	time(s)
T_i	temperature in space i (K)
V_i	gas volume space i (m^3)
w_i	gas velocity in opening between spaces i and j, limited to local sonic maximum (m/s)
α_{ij}	discharge coefficient
κ_i	heat capacity ratio $= c_{pi}/c_{vi}$
ρ_{ij}	gas density in opening between spaces i and j (kg/m^3)
ρ_i	gas density in spaces i (kg/m^3)

2.1.2. Temperature

The temperature is calculated from the heat flow into and out of each space.

$$\frac{dT_1}{dt} = \frac{1}{m_1 c_{v1}}\left(\frac{dQ_1}{dt} - \frac{dm_{12}}{dt}\left(c_{p1} - c_{v1}\right)T_1\right)$$

$$\frac{dT_2}{dt} = \frac{1}{m_2 c_{v2}}\left(\frac{dm_{12}}{dt}\left(c_{p1}T_1 - c_{v2}T_2\right) - \frac{dm_{23}}{dt}\left(c_{p2} - c_{v2}\right)T_2\right)$$

$$\frac{dT_3}{dt} = \frac{1}{m_3 c_{v3}}\left(\frac{dm_{23}}{dt}\left(c_{p2}T_2 - c_{v3}T_3\right)\right)$$

2.1.3. Mass

The mass change in each space is given by

$$\frac{dm_1}{dt} = -\frac{dm_{12}}{dt}$$

$$\frac{dm_2}{dt} = \frac{dm_{12}}{dt} - \frac{dm_{23}}{dt}$$

$$\frac{dm_3}{dt} = \frac{dm_{23}}{dt}$$

2.1.4. Mass Flow Between Spaces

The mass flows are given by

$$\frac{dm_{ij}}{dt} = \alpha_{ij} A_{ij} \rho_{ij} w_{ij}$$

with

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$$\rho_{ij} = \rho_i \left(\frac{p_{ij}}{p_i}\right)^{\frac{1}{\kappa_i}}$$

If $\frac{p_1}{p_2} \geq 1.89$ for air, (or 1.70 for SF6), then there is choked flow and

$$p_{ij} = p_i \left(\frac{2}{\kappa_i+1}\right)^{\frac{\kappa_i}{\kappa_i-1}}$$

else

$$p_{ij} = p_j$$

The gas velocity in the opening is

$$w_{ij} = \sqrt{\frac{2}{\kappa_i+1}\frac{p_i}{\rho_i}\left(1-\left(\frac{p_{ij}}{p_i}\right)^{\frac{\kappa_i}{\kappa_i-1}}\right)}$$

2.1.5. Pressure

The pressure in each space is obtained from the gas volume and mass in the space

$$p_i = \frac{\kappa_i - 1}{V_i} m_i c_{vi} T_i$$

2.1.6. Arc

The thermal power is derived from the arc power by

$$\frac{dQ_i}{dt} = k_p \frac{dE_i}{dt}$$

2.1.7. Initial conditions

The state variables for the each space are the gas temperature and the mass of gas. These need to be specified for each space at the start of the calculation. If the initial state of the spaces is described by temperature and pressure then the mass is obtained from

$$m_i = \frac{p_i V_i}{R_{si} T_i}$$

2.2. Implementation

A simple tool was created to implement the basic model. The inputs required by the tool were:

For each compartment (up to 3):

- the gas volume (compartment volume less the volume of equipment)
- the initial temperature
- the initial pressure
- the gas type (Air/SF6)

For each opening between compartments:

- the area
- the discharge coefficient – ratio of effective opening area to its geometric area to take account of obstructions such as meshes, grills
- the pressure relief threshold

For the arc:

- the thermal transfer coefficient – the fraction of the electrical arc energy which directly results in a pressure rise in the compartment
- the arc power time history

The tool calculates time histories for each compartment for Pressure, Temperature and Gas (relative density).

2.3. Limitations

The basic model and its implementation has a number of limitations

- In many cases – particularly those with long arcing times – the temperature of the gas in the model will become very large, noting that the temperature of the arc itself can be up to 20,000K. As no account is taken of molecular dissociation or ionisation the use of the model should be confined to gas temperatures less than 6,000K (for air).
- When the source compartment is filled with SF6 no account is taken of the change in gas composition of the compartment discharged to.
- No direct account is currently taken of effects such as electrode vaporisation or any exothermic reactions of the electrode with the gas. This influence is negligible as long as the density of the insulating gas (air or SF6) is larger than the density of the vapour, which is true except in the case of long arcing times, where much of the insulating gas has already been exhausted from the arc compartment. These effects can be included in the thermal transfer coefficient but are likely to include a large amount of uncertainty.

2.4. Validation

The tool was validated against the test cases reported in [1]. As an example the predicted pressure levels for Case B are shown in Figure 2, with input data shown in Table 1.

Table 1 - Case B Data used in the model for validation

Compartment data	**Space 1**	**Space 2**	**Space 3**
Volume (m^3)	0.509	1.275	1000
Gas space 1	Air	Air	Air
Initial pressure (kPa)	160	100	100
Area of opening to next space (m^2)	0.00456	0.01	-
Relief pressure (kPa rel)	285	-	-
Discharge coeff 12	1	1	-
Arc data			
Average phase to ground voltage (V)	424		
Current (kA rms)	14.4		
No. of phases	1		
Thermal transfer coefficient	0.55		
Modelled electrical power (kW)	6148		
Arc duration (s)	1		

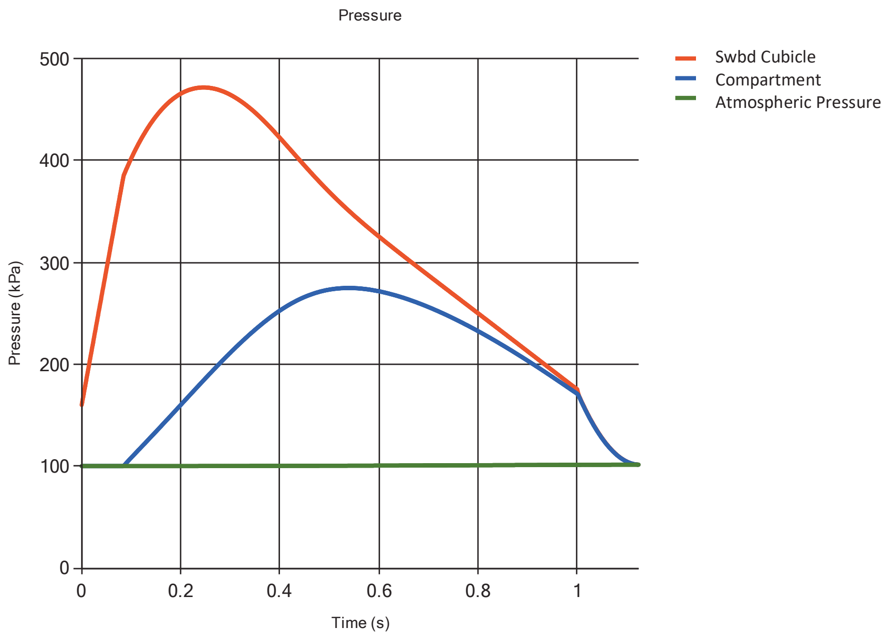

Figure 2 - Predicted Pressure Rise for Validation Case B

2.4.1. Alignment with Predicted Response

The validation case results shown in Figure 2 can be compared with the results in [1] shown in Figure 3 to demonstrate that the calculation as implemented by the tool is close to the paper's simulated response. The results align well enough to validate the tool and the assumptions necessary to implement the tool. Comparison of these two results shows good agreement with transient durations and peak pressures marginally higher at 25kPa higher.

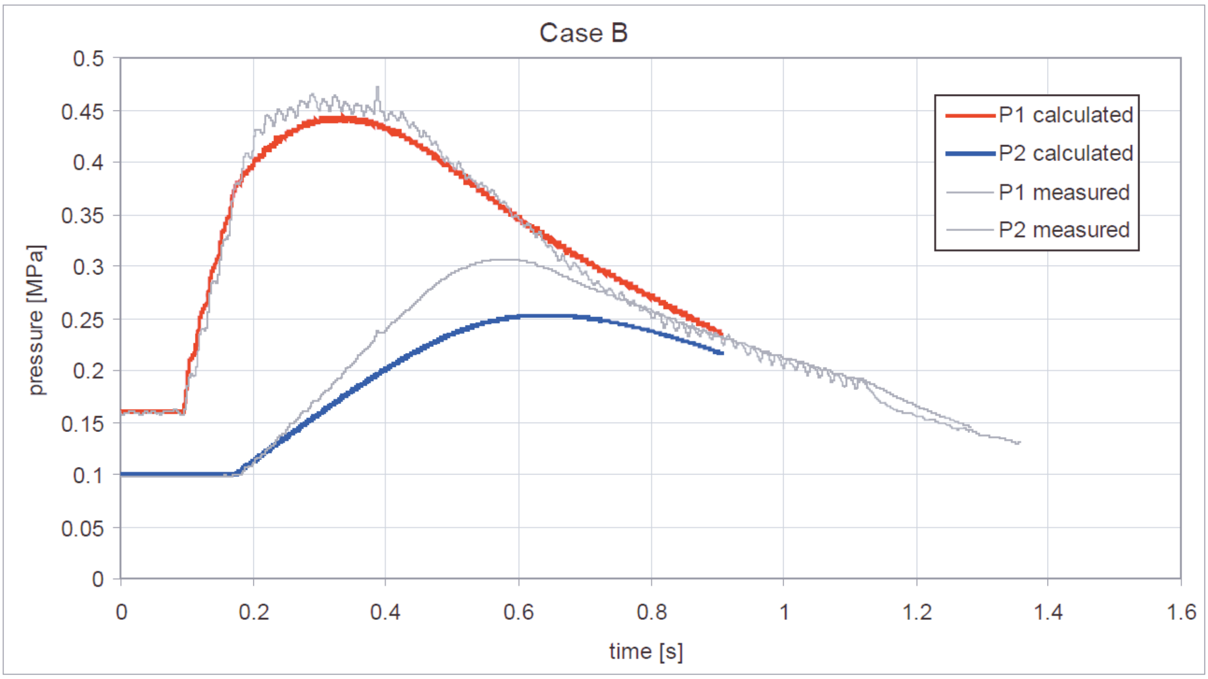

Figure 3 - CIGRE Paper Result for Validation Case B

3. Application to Naval Vessels

3.1. Arc Flash Hazards in Naval Vessel Context

To maintain and improve the awareness of electrical hazards in the marine environment, the MoD has raised concerns at conferences (INEC 2010 [9]) and subsequent seminars, particularly in relation to arc flash. Marine standards have been amended to incorporate guidance on the assessment and management of arc flash hazards, (Lloyds Rules & Regulations for Classification of Naval Ships 2018 [2], BR 2000(52) [3]).

Currently, platform safety cases tend to focus on electrocution hazards, and in recent years have taken greater consideration of the hazards stemming from arc flash (e.g. severe burns) but the hazard of arc blast overpressure is less understood. Emerging research from land based power systems highlights the dangers of arc blast, and can provide additional guidance.

Integration of a high energy electrical power system into a complex warship faces unique challenges due to the constraints of the vessel. Primarily, the available space to construct a switchboard room within a warship is often much smaller than when considering a conventional electrical substation.

In order to identify and implement mitigations to the hazards introduced by electrical arc flash in a warship electrical compartment, power system design must be informed by calculation of arc flash incident energy and the resultant pressure rise in the compartment. For in-service vessels, the safety case should be reviewed and updated based on investigation into arc flash hazards.

3.1.1. Arc Flash Incident Energy

The energy released by an arcing fault introduces a direct hazard to personnel and equipment in the vicinity of the fault. When designing an electrical power system, analysis of fault levels and protection co-ordination must also calculate the level of arc flash incident energy.

The incident energy of an arc is measured in cal/cm^2 at a specified working distance, and is a function of the magnitude of the short circuit current and the duration of an arcing fault. Either of these may be influenced by design, in order to limit the energy of an arcing fault when it occurs. For example, the fault level may be affected by changes to system impedance, and the duration may be reduced by enacting a fast-acting protection scheme such as optical arc flash detection.

Arc flash incident energy presents a burning hazard to personnel in the vicinity of an arcing fault. Safe approach distances and categories of required PPE are defined in terms of the arc flash incident energy by the (NFPA standard).

3.1.2. Arc Blast Pressure Rise

The pressure rise which occurs during an arc fault is governed by the arc power and the properties of the space into which the arc is released. If allowed to propagate, an arc which begins within switchgear will cause a pressure wave which expands outward into the surrounding compartment. This pressure wave presents a safety hazard to personnel and a risk of damage to the compartment and surrounding equipment in the space.

The pressure wave caused by an arc fault is dangerous to humans. Blast waves of 25 kPa to 50 kPa may cause eardrum perforation, and severe risk of harm requiring medical treatment typically results from overpressure between 100 kPa and 340 kPa [6].

3.1.3. Impact of Arc Blast on Naval Vessels

The particular application of electrical power systems to naval vessels amplifies the severity of certain hazards due to spatial constraints and the criticality of equipment to the platform functionality.

The occurrence of an arc fault in an electrical space may damage nearby equipment in the resulting blast. The sudden release of heat and expanding pressure wave may cause severe damage and affect the capability of the vessel after the fault.

- The size of the switchboard rooms is constrained. The room volume available for the expansion of gasses is reduced by the amount of electrical equipment installed, typically by about 50%).
- In situations where the switchboard rooms are located adjacent to other key operational compartments, any blast damage that breaches the switchboard room could have a significant impact on the operation of the ship.

The initial portion of an Arc Flash event is similar to an explosion. The damage effects for an internal explosion can be related to the quasi-static pressure, rising immediately to a value related to the charge weight and room volume and then decaying back to ambient in around 10 to 20 ms.

Typical design guidance for shipbuilders suggests that light internal structure will survive a quasi-static overpressure of around 120 kPa.

3.1.4. Impact of Arc Hazards to Personnel

Electrical arc hazards must be mitigated for any electrical switchgear application to be as low as reasonably practicable (ALARP).

The level of risk to personnel in electrical compartments is determined by;

- The severity of an arcing fault
- The probability of personnel being exposed to that fault

Either of these factors may be influenced by design and by operational decisions. Mitigation actions are described in detail in Section 3.3

The severity of the impact of the fault can be described in terms of the arc flash incident energy (cal/cm^2) and pressure rise (kPa above 1 atmosphere). The severity may be reduced by means of compartment design and reduction of fault clearing time with a fast acting protection scheme.

In order for a fault event to affect a person in the space, a person must be within the compartment at the time a fault occurs. Arc flash only affects individuals within the calculated hazard boundary, but arc blast can impact anyone in the wider compartment through overpressure and dispersion of arc products. The probability of injury or fatality is then determined by the co-incidence of the probability that the person is exposed to the hazard and the probability that an arcing fault occurs.

3.1.5. Hazard due to Low Voltage Arc Faults

Current marine standards ([2], [3]) address arc flash hazards at 1kV and above. Recent research [4] indicates that arc flash can be initiated and sustained at much lower voltages (480v) with large conductor gaps (in excess of 75mm) - see Figure 4.

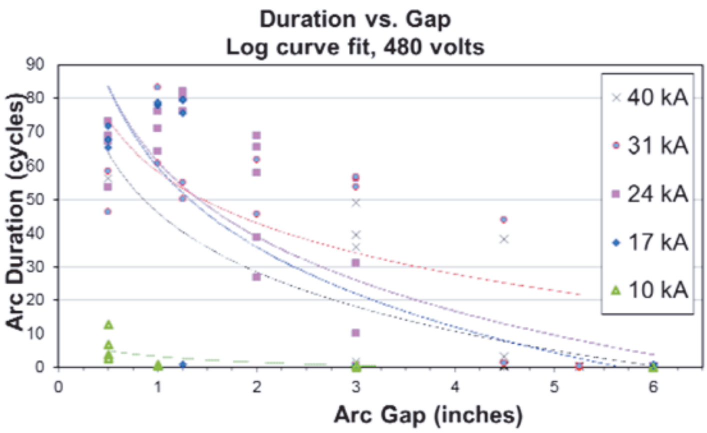

Figure 4 - LV Arc Duration vs. Arc Gap

The severity of an arc flash event is classified by incident energy, measured in calories/cm2, and primarily depends on;

- Available bolted fault current
- Tripping time of upstream protective device

The LV arcs tend to have higher fault currents and thus have severities that are comparable to – or potentially worse than – an HV arc. The effects of arc flash in both HV and LV needs to be reflected in the standards guiding the design of naval vessels.

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3.1.6. Influence of Naval Vessel Characteristics

The industry calculation standard IEEE 1584-2002 [5] assumes that the fault current is supplied from an infinite grid and there is no reduction in current until the protection device trips. On naval vessels, however, the fault current available will be reduced by the characteristics of the generators, in particular their reactance which is a function of time under fault conditions.

There are many examples available in land based installations of the explosive results of an arc flash event in a switchboard, with extreme temperatures accompanied by flames and intense bursts of ultraviolet light; the ejection of vaporised copper; and a blast wave which can destroy brick built structures [7].

Although likely to be of a smaller internal volume, a naval ship switchboard room constructed with steel bulkheads is likely to be better able to withstand a pressure rise than a standard brick building. Oil filled switchgear is not employed on naval vessels, so the additional hazard of oil conflagration is not a factor for arc faults.

3.2. Use of Modelling Tool to Assess Hazard

The calculation of arc blast pressure rise can be applied to the design of electrical spaces for naval vessels to determine the degree of hazard allowing early design decisions to be made, mitigating the hazard.

The calculations may be used as evidence to demonstrate the effect of the mitigation actions proposed to support the platform safety case. Two primary means of reducing the severity of arc blast pressure rise are identified;

- Designing switchboard rooms to be of sufficient internal volume to limit the potential pressure rise
- Reducing the Fault Clearing Time (FCT)

The effect of equipment design measures such as the size and strength of pressure relief flaps may also be investigated using the modelling tool.

3.2.1. Effect of Compartment Size

The size of an electrical compartment determines the internal volume into which the pressure wave can expand. An arcing fault within a small compartment will cause a greater pressure rise than the same fault in a large compartment. This is demonstrated by the example results in Figure 5 and Figure 6.

Maximising the internal volume of the switchboard room compartment has the effect of reducing the severity of the arc flash pressure rise hazard within the space.

For the following two scenarios – a comparatively ‘small’ and ‘large’ switchboard compartment – the following parameters for the arc and switchboard were used:

- Initial conditions of scenarios – a comparatively ‘small’ and ‘large’ internal free space volume of 4.95m^3 for the switchboard, with pressure relief vents configured to open at 50kPa overpressure
- A constant arc power of 8MW triggered at 0s that was extinguished at 0.5s, with a thermal transfer coefficient of 0.6

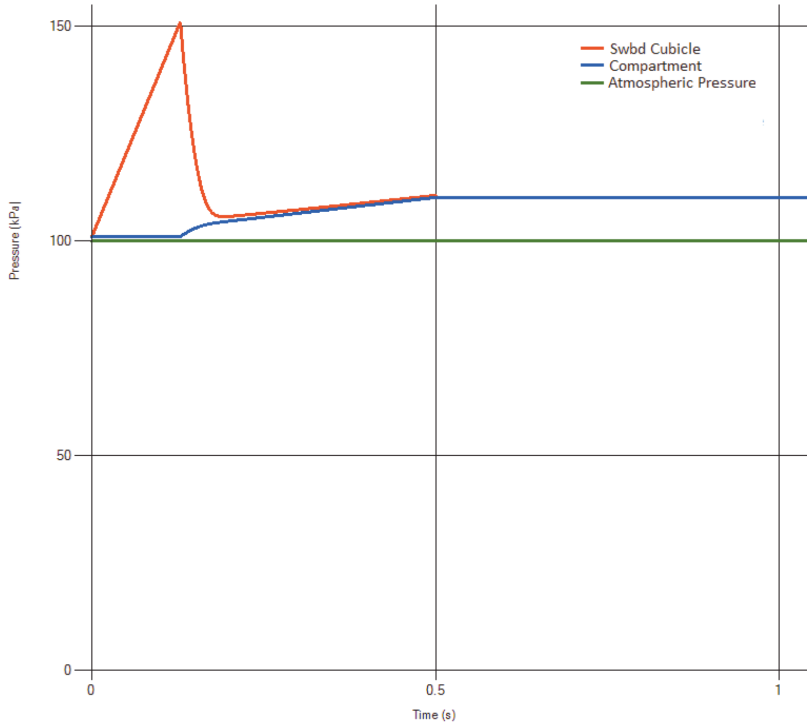

Figure 5 - Arc Overpressure in Comparatively 'Large' Compartment

The free space volume selected for a comparatively ‘large’ compartment in this simulation was 100m^3. The arc vent pressure relief threshold (50kPa) is reached approximately 0.13s after the arc is triggered. The pressure equalises between the switchboard and the compartment, and both experience pressure rise in tandem for the remainder of the arc duration up to a maximum compartment overpressure of 10kPa.

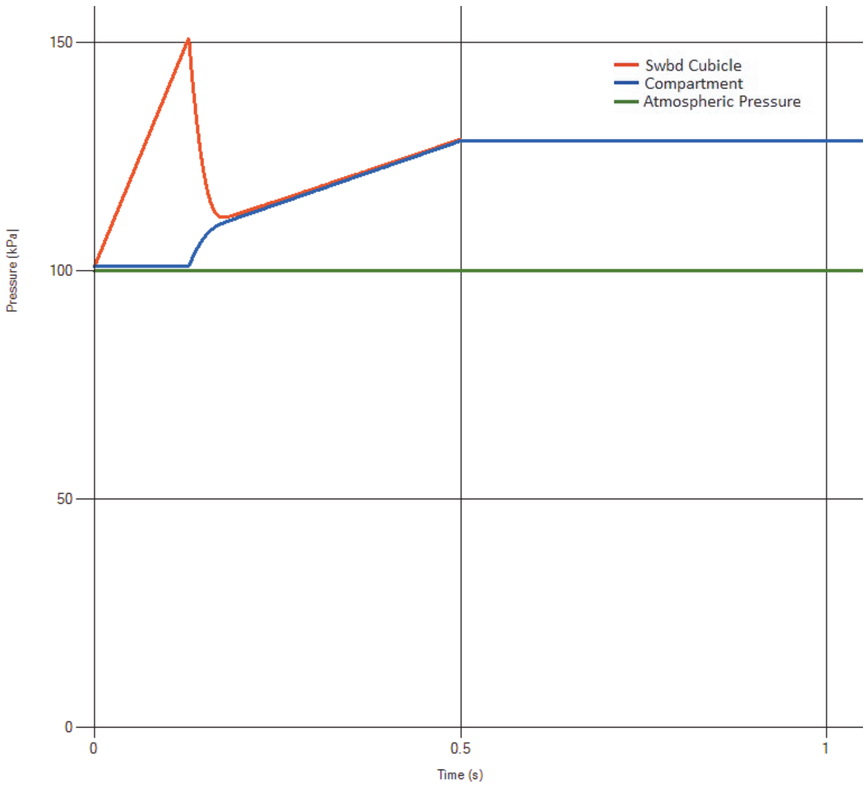

Figure 6 - Arc Overpressure in Comparatively 'Small' Compartment

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The free space volume selected for the comparatively 'small' compartment in this simulation was 30m^3, a 70% reduction in available gas volume. The arc vent pressure relief threshold is again reached approximately 0.13s after the arc is triggered. Due to the reduced compartment volume the equalisation profile is much steeper, converging at 12kPa overpressure, and then rising to a final value of 29kPa overpressure.

Table 2 below illustrates results for more values of compartment free space volume. It can be seen that resultant overpressure is essentially linearly dependent on the amount of free space volume in the compartment.

Table 2 - Compartment Free Volume vs Overpressure

Compartment Free Space Volume (m^3)	Resultant Compartment Overpressure (kPa)
150	6
100	10
75	12
50	18
30	29

3.2.2. Effect of Fault Clearing Time

When the Fault Clearing Time is reduced by means of the protection scheme, the let-through energy is minimised. Consequently, the pressure rise due to the arcing fault is limited. This is demonstrated by the example results in Figure 7Figure 5.

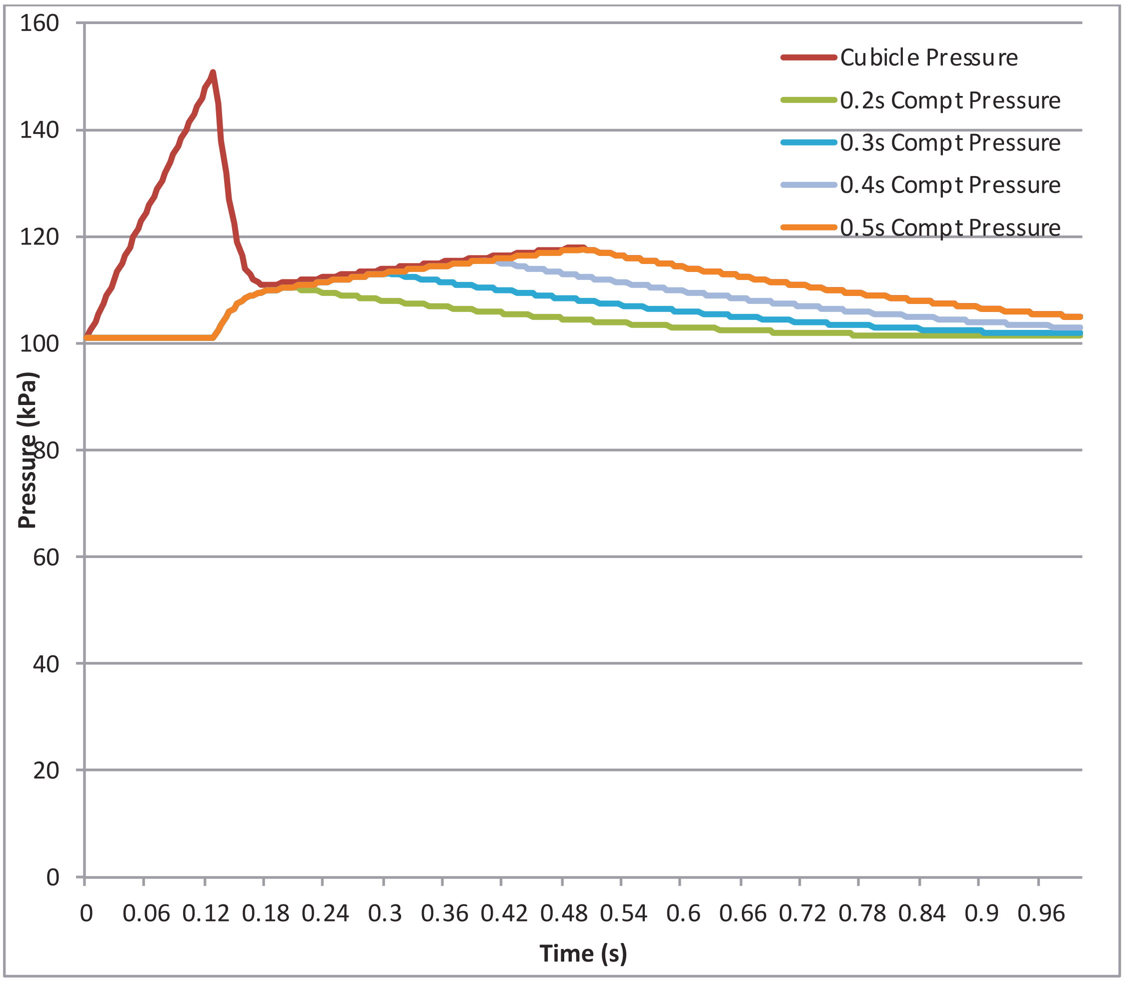

Figure 7 - Fault Clearing Time vs Compartment Pressure

Note: the settings for these simulations were as described in Section 3.2.1 for the 'small' compartment case. The only alteration is the addition of a small exhaust route to the wider atmosphere from the compartment. The protective device clearing time for the fault was varied from 0.2s to 0.5s.

Minimising the fault clearing time has the effect of reducing the severity of both the arc flash incident energy and arc pressure rise hazards within the space.

3.2.3. Effect of Generator Decrement

The calculation of Arc Flash energy and Arc Blast overpressure generally assume an 'infinite bus bar' at a distance from a fault with a constant impedance between the source and the fault. As a result the fault current remains constant for the duration of the fault. On Ships the characteristics of the generators introduce a varying fault current profile. The current reduces quickly as the fault progresses. In 1 cycle (17ms) the current reduces to 80% of its peak and in 100ms it is below 50%. The exact shape of the decrement curve depends on generator characteristics and the recovery from the dip is determined by AVR action. Figure 8 shows a typical current decrement curve with AVR action.

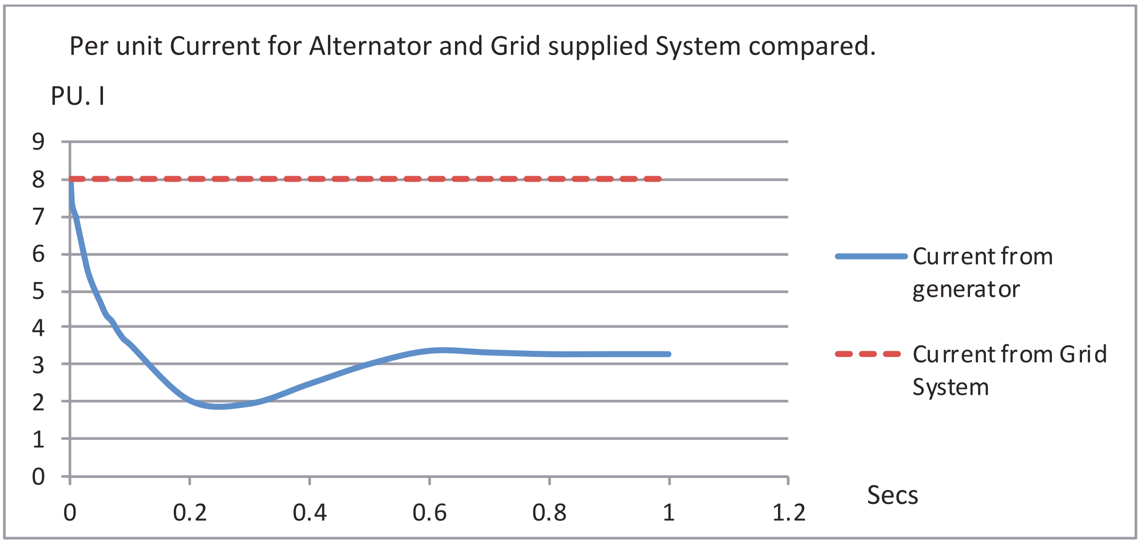

Figure 8 - Comparison between Alternator and Grid supplied system

Arc Faults are generally considered to be resistive [8] with an increasing ohmic value as the current reduces. The arc resistance will have two effects it will reduce the current and reduce the time the current takes to decay. It can be shown that the maximum power delivered to a resistance happens when the Ohmic value of the inductance of the source equals the ohmic value of resistance of the load. Thus to deliver maximum power to the arc its resistance would have to rise in tandem with the inductance of the generator.

The power delivered to the arc is proportional to the current (assuming) a constant voltage across the arc. However if the arc has a constant resistance the power in the arc will be proportional to the square of the current.

Pressure generated by the arc is directly related to the power of the arc. The initial pressure spike within the switchboard cubicle during the sub-transient period is partially mitigated by elongating the duration; however the largest difference is experienced at the latter stage of the arc where compartment overpressure can be drastically reduced. Figure 9 illustrates this, using the simulation scenario described in Section 3.2.1 with a 30m3 compartment.

The arc pressure relief panel operation (with threshold 50kPa overpressure) is delayed approximately twice as long, until 0.25s, when generator decrement is accounted for. At this point, the generator is in the transient reactance period so available fault current is lower, thus pressure rise is reduced. Overpressures experienced in the compartment at the extinguishing of the arc are 75% lower than the infinite bus case.

Given this, intelligent selection of the arc vent pressure relief threshold allows the cubicle to absorb the majority of the pressure, and minimises the risks to personnel and other equipment in the compartment.

In either case comparing the energy delivered by grid fed fault to the energy delivered from generator, the energy in the generator fed arc may reduce to such a level that the arc self-extinguishes. In a ships systems much less Arc Flash and Arc Blast energy will be produced compared to the land based system of the same fault level.

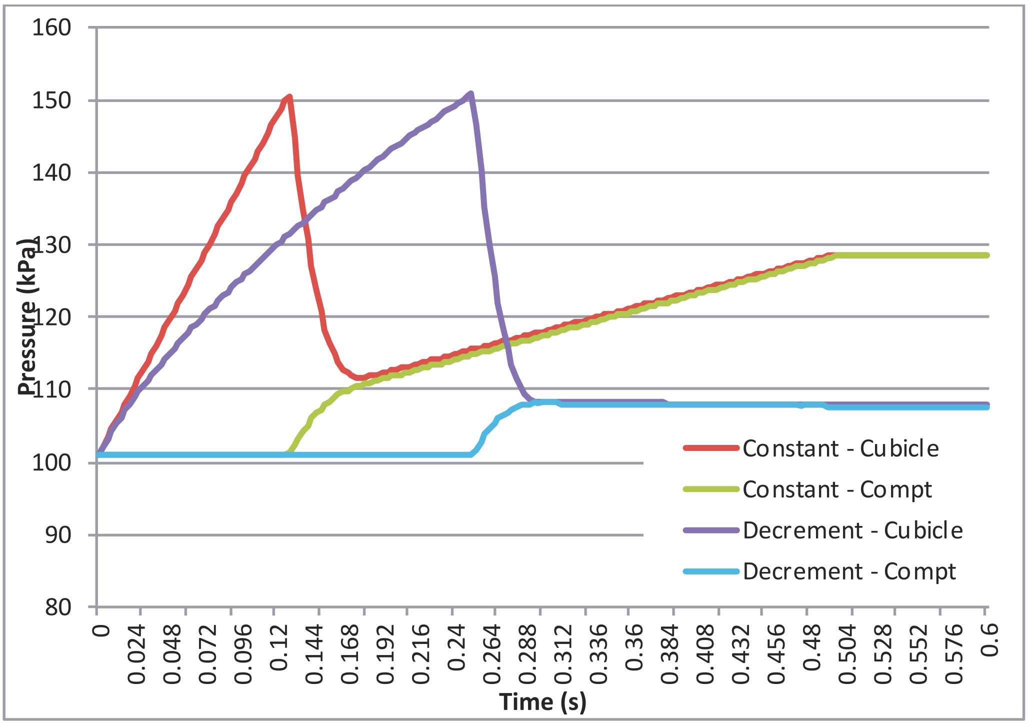

Figure 9 - Infinite Bus vs Generator Decrement Overpressure

3.3. Hazard Mitigation

3.3.1. Reduction of Hazard to Personnel

To reduce the hazard to personnel working in electrical compartments, the following mitigation actions may be employed;

- Reduce the severity of the hazard
  - Reduction of Fault Clearing Time (FCT) through fast-acting protection;
  - Reduction of fault level by design – influence system impedance;
  - Design of electrical compartments to maximise internal volume;
  - Design and type testing of switchgear to be I_{AC} rated.
- Reduce the frequency of faults
  - Root cause analysis to identify and prevent causes of failures;
  - Design for reliability - physical protection of equipment.
- Reduce the frequency of exposure of personnel to the hazard
  - Implement access controls to electrical spaces;
  - Minimise the need for operators to access the switchboard room by situating local operating panels away from switchboards;
  - Improved awareness through electrical safety training.

3.3.2. Mitigation by Design of Compartments and Equipment

When designing a naval vessel, the level of arc blast pressure rise must be considered for candidate electrical compartments. System designers must be cognisant of the hazards introduced by designing small electrical spaces with limited volume to allow the pressure wave to expand. Measures to modify the compartment and equipment to allow venting of arc pressure should also be considered. Examples of such measures include arc chutes from switchgear and pressure relief ducting for the compartment.

Substation design typically features physical barriers between major equipment to limit the potential for cascading equipment failures. Measures to limit the impact of an arc blast in new naval vessel electrical compartments should be implemented within the space constraints available to achieve an ALARP position.

Consequently, assessments of system wide functional criticality, choices of system architecture, and equipment housing design should all take into account the effect of the loss of the equipment due to an arc blast event.

3.3.3. Mitigation by Reduction of Fault Clearing Time

Introducing additional functions to the protection scheme such as optical arc flash protection will reduce the fault clearing time and hence reduce the level of hazard due to arc flash incident energy and pressure rise. This form of mitigation is the most practical means of reducing the hazard severity for in-service systems as it is the least intrusive means of affecting the pressure rise.

3.3.4. Reduction of Personnel Exposure to Hazard

An improved understanding of arc induced overpressure in the design and operations communities reduces the likelihood that the hazard will be encountered by personnel on the vessel. This may be achieved through training of operations staff to increase hazard awareness, through imposing access controls on switchboard rooms through the vessel Standard Operating Procedures (SOP), and design actions which minimise the requirement to access the switchboards directly while live. Primarily, all switching should be done remotely by the control room operator without personnel within the switchboard room. For situations where local operation is required, the operating panel should be separated from the switchboard by a barrier and a safe distance. This should be achieved by design for any new switchboard room to minimise the level of hazard to operators.

3.3.5. Input to Platform Safety Case

The platform safety case must describe the severity and probability of hazards and provide supporting evidence of the expected performance of the ships systems in response to those hazards. The results of analyses conducted with the modelling tool may be used to support design decisions by informing the design on the level of hazard and the expected efficacy of proposed mitigation actions.

3.3.6. Project Benefit through Technical Risk Mitigation

Arc induced overpressure is a hazard to the safety of personnel, to equipment near the arc, and to the structure of the compartment. This hazard presents a risk that an electrical space may not be sufficiently rated for the pressure wave. Should this risk be realised during a design programme, it will require re-work while technical mitigations are pursued such as altering the size and layout of a proposed switchboard room, and consideration of overpressure venting. Employing a calculation tool to calculate arc induced overpressure has the distinct advantage of allowing candidate switchboard rooms to be assessed for the likely overpressure and required mitigations to be identified early in the design programme. This minimises the risk of re-work later in the design programme.

4. Conclusions

The phenomenon of arc blast pressure rise must be considered when designing electrical spaces in order to support a satisfactory platform safety case. The developed modelling tool allows engineers the ability to perform calculations of arc blast pressure rise for the purpose of identifying the degree of hazard due to pressure and identifying applicable mitigation activities.

These calculations indicate that compartment overpressure is unlikely to cause structural damage. Injury to personnel from arc blast overpressure is unlikely except in the smallest compartments.

Most published work in this area assumes a constant impedance throughout the fault. In ships the fault impedance increases as the fault proceeds resulting in the current decrement. Calculations indicate that this considerably reduces the hazard associated with Arc Flash and Arc Blast.

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6. References

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