

Under-currents in Marine IS Earthing!

by Geoff Bottrill
Measurement Technology Ltd (MTL)

Synopsis

Intrinsic safety (IS) is internationally recognised as the most appropriate and safest technique for protecting electrical instrumentation in potentially explosive atmospheres. However, marine applications are sometimes perceived as difficult to implement because of the requirements of electrical distribution systems on ships.

The marine regulations require an approach to electrical earthing which is seen as being in conflict with on-shore codes of practice. Traditionally, when it comes to installing protection against explosions caused by electrical faults, interpreting these regulations leads to much soul-searching. Fortunately, however, newer explosion-protection technologies provide alternative approaches capable of solving these problems. This paper discusses the theory and application of the technique of intrinsic safety in detail and also compares it to other explosion-protection techniques.

Introduction

The blessing of a ship at her launch can properly be extended to all those responsible for her design and fabrication–since these are the people who have the unenviable task of trying to understand and comply with all the rules and regulations devised to make the ship safe to operate. Indeed, there are those who think the champagne at the launch should be drunk to drown misgivings!

For ships designed to carry flammable materials, such as tankers, there are specific regulations covering the use of all types of equipment operated by electricity. Referred to as the 'Explosion Protection of Electrical Equipment' (a term often shortened to just 'Electrical Protection'), it must not be confused with the protection afforded by circuit breakers and fuses. Care must always be taken over the use of terminology when transferring from one facet of engineering to another!

Defining the hazard

The IEE document: *Regulations for the Electrical & Electronic Equipment of Ships with recommended practice for their implementation*: Section 23 gives comprehensive guidance on the specific problem of tankers carrying hazardous cargoes. Lloyd's Register of Shipping: *Rules and Regulations for the Classification of Ships*: Part 6: Chapter 2: Section 13 and *Safety Of Life At Sea* (SOLAS) have similar documents which cross-refer to each other and must therefore be read together.

All the texts agree that an assessment must be made of the areas where ignitable vapours and gases may be present. This assessment is termed 'hazardous area classification', and defines the likelihood of the presence of a hazard and the level of risk. Comparison with the IEC and American systems of classification in Table 1 show differences as yet unreconciled. Lloyds Register adopts similar definitions as IEE's section 23 and also accepts the IEE standards for applying various protection techniques although it does not make use of the classification nomenclature.

Table 1: Hazardous Area Classification:

Equivalents			
IEC Zones	USA Divisions	IEE Section 23 Tankers Definitions	
0	1	A	Areas/spaces in which flammable gas/air mixture is continuously present or present for long periods.
No direct equivalent	No direct equivalent 0	B 1	Cofferdams adjoining oil cargo tanks. Spaces which are separated by a single bulkhead from storage tanks and which have no mechanical ventilation
No direct equivalent	No direct equivalent	C	Cargo pump rooms of oil tankers. Spaces having mechanical ventilation which are separated by a single bulkhead from storage tanks but where the mechanical ventilation may not be in continuous operation whilst the ship is in a non-gas-free condition
1	1	D	Areas/spaces in which flammable gas/air mixture is likely to occur in normal operation
2	2	E	Areas/spaces in which flammable gas/air mixture is not likely to occur in normal operation and if it does occur will exist only for a short time

Within these areas, adequate precautions must be taken to prevent the use of electrical equipment causing ignition of flammable materials. This is achieved by the careful selection of electrical equipment that is certified or approved. The ignition risk can then be reduced to acceptable levels.

Certification

There are nine accepted techniques for the explosion protection of electrical equipment. The certification (or approval, in some countries) of electrical apparatus is part of the design and manufacturing process. Assessment of the equipment to one of many standards must be undertaken by a certifying authority, to ensure that the design and fabrication meet established criteria. Thereafter formal certification is granted.

Of the techniques available, some are regarded as providing better protection than others–a factor which must be taken into account since the user is forced by legislation to assess the likelihood of contact with a hazardous vapour/ air mixture and select a technique which is permitted for use in that risk category. Different industries have their own legislation but the International Electrotechnical Commission (IEC) classification system is now common and will be used as the basis of this discussion, see Table 2.

Acceptance of IEC regulations is regrettably not fully international in its intended form. There are variations and it is appropriate to check what regulations are and are not acceptable to the user for a given application. The cross-referencing of some regulations with others leads to confusion over terminology and application in some instances since there is no full or true harmonisation between the requirements of International, European, Insurance and Engineering bodies.

Techniques of explosion protection

With the specific exception of intrinsic safety, all the other techniques of electrical equipment explosion protection listed in Table 3 rely on mechanical concepts for the prevention of ignition.

Referring to the well-known fire triangle analogy, forms of protection can be basically described as ways of separating the three elements needed to cause ignition, ie, a source

Table 2: IEC classification system

IEC Standard	Protection Type	Protection Name	Permitted Zone of use	CENELEC Standard EN	British Standard BS
IEC 79 – 0	–	General requirements	–	50014	5501: Part 1
IEC79 – 1	Ex d	Flameproof	1 & 2	50018	5501: Part 5
IEC 79 – 2	Ex p	Pressurisation	1 & 2	50016	5501: Part 3
IEC 79 – 5	Ex q	Powder filling	2	50017	5501: Part 4
IEC 79 – 6	Ex o	Oil immersion	1 & 2	50015	5501: Part 2
IEC 79 – 7	Ex e	Increased safety	1 & 2	50019	5501: Part 6
IEC 79 – 11	Ex i	Intrinsic safety	0, 1 & 2	50020	5501: Part 7
IEC 79 – 15	Ex n	Non-incendive	2	50021	6491
IEC 79 – 18	Ex m	Encapsulation	2	50028	5501: Part 8
None	Ex s	Special*	0, 1 & 2	None	SFA3009*

of ignition such as heat or sparks; fuel; and the oxygen in air. 'Segregation' seeks to ensure that there is a physical separation of these constituents. 'Refined mechanical design' refers to a system whereby rules aiming to reduce the risk of ignition are imposed on the design. These include measures like eliminating sparking contacts or using vibration-proof terminals.

The type referred to as 'containment' is known as 'Explosion-proof' in America and as 'Flameproof' in Europe but there is no significant difference between these named

Table 3: Techniques of protection

Type	International Symbol
Segregation	Ex p, o, q & m
Refined mechanical design	Ex n or (N) & e
Containment	Ex d
Intrinsic safety	Ex i
Special	Ex s

techniques. With this technique, electrical equipment which may produce sparks or excessive 'hot spots' capable of igniting flammable atmospheres is housed in enclosures designed to contain an internal explosion without permitting any flames so caused escaping from the enclosure which may be capable of igniting an ambient flammable atmosphere. The belief that flameproof equipment will protect the internal equipment from explosion damage is incorrect but still held by many.

'Special protection' is a British classification (but also used in other countries) awaiting wider adoption for equipment that can be considered adequately safe but which does not conform to any other certifiable technique. Of the remaining techniques the only practical one for marine application is 'intrinsic safety' (IS) which is discussed at length in the main part of this paper. In general these practicable techniques rely on good installation and high quality maintenance. Failure to observe rules can render the techniques unsafe. There are codes of practice providing guidance on how equipment must be installed and maintained to retain the level of safety for which it is certified. These codes are even more diverse and individual countries apply their own peculiar rules. British Standards are accepted in many places where there are no local standards.

Clearly, applying a method of protection has a cost associated with it. This cost is not only concerned with, for example, the purchase of a specially made motor, but manifests itself in the specialist installation and subsequent maintenance and inspection of the equipment. Time must not render the equipment less safe, and so regular and thorough attention must be paid to this. Major consideration should be given at the design stage respecting the cost of subsequent maintenance. Training, good documentation and the correct tools are also necessary. Simple maintenance reduces the cost. It is difficult to compare costs of different techniques because some are not permitted for Zone 0 applications. A technical paper[1] on this subject—but with an onshore bias—is available (TP1110).

Intrinsic safety

Intrinsic safety works by limiting the values of voltage and current in a circuit to levels below those which provide sparks or heat in sufficient quantity to ignite a hazardous gas / air mixture. The limit values are published in the EN 50020 Standard for IS Equipment. Typical maximum values are about 30V (open circuit) and 0.250A (short circuit) with about 1.0W power limit available. One method of achieving this limiting is by incorporating Zener diodes, a resistor and a fuse in the basic circuit reproduced in figure 1. This is known as a 'shunt-diode safety barrier'. These devices are used in each loop that crosses from safe to hazardous area (or vice-versa).

The voltage, current and power permitted in circuits is extremely low compared to that allowed by other protection methods and it therefore cannot be applied to high power systems such as motors or lighting. It is however ideally suited to measurement and instrumentation techniques.

In normal operation, the applied voltage to the safe-area side (input) will be less than the conduction voltage of the Zener diode. If an excessive overvoltage is applied to the barrier as a result of a safe-area electrical fault, the Zener diodes will become conductive–so preventing dangerous levels of voltage and current reaching the hazardous level. The fuse disconnects the circuit when excessive current is conducted through the Zener diodes before any of them can fail.

The standards for the design and construction of IS certified equipment and systems require the inclusion of certain safety factors to enhance the integrity of the system. Consideration must also be given to equipment that is located in the hazardous area and to which the barrier is connected. Such equipment must not be capable of generating or storing energy in an uncontrolled way and will require certification to comply with a system safety approach. This particular aspect is not discussed fully here but is well documented in other publications.

The great advantage of this approach to the explosion protection of electrical circuits is that it is 'inherently' safe. ie, if the circuit in the hazardous area is shorted out either purposely (as when sensing a switch closure) or inadvertently, (by a cable fault or by equipment failure) then the resulting spark is too weak to

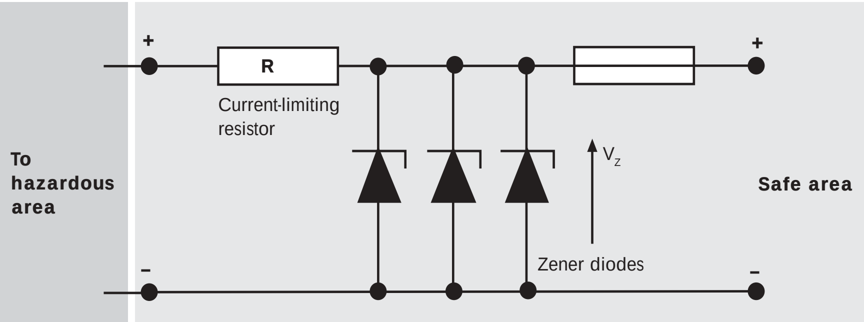

Figure 1: Shunt-diode IS circuit

cause ignition. Some equipment in the hazardous area (such as switches) is considered to be 'simple apparatus' and, according to most IS standards, does not need to be certified or marked. Standard equipment may then often be used in IS loops, whereas other methods require specially certified equipment. It is therefore permissible to carry out live maintenance on IS circuits and equipment. No other method provides this degree of flexibility or safety.

Whilst the safety concept is designed into IS devices, it is necessary to install the interconnected systems in an approved way to maintain the safety integrity. Separate rules are applied—in addition to the design rules—which govern the way systems and equipment are interconnected. For example, although energy is limited to a level which cannot cause ignition in a single loop, when several loops are interconnected then the total power available may reach dangerous levels.

A typical installation for a single loop is shown in figure 2. The star-point neutral-earth bond is shown as it would be for an onshore installation.

The installation regulations must try to anticipate the conditions under which system integrity may be compromised and must, therefore, develop rules to preclude this. It is important that the earthing requirements are understood in order to rationalise the use of IS systems requiring a safety earth. The safety earth for barriers must be interconnected with other earths to assure safety. A typical ship's earthing system must now be examined to explain how this requirement can be met.

Ships' power generation and distribution regulations

In 1880, the IEE proposed general electricity supply regulations. A committee was formed by Lloyds register in 1918 to set up regulations specifically for ships and the IEE regulations were adopted by Lloyds in September, 1919.

These original regulations were designed to cope with 110V dc / ac supplies. Modern vessels usually generate at 3Ø / 440Vac but 6.6kV and even 10kV systems are now permitted and used. The regulations have been slowly upgraded to suit these changes by subsequent editions and amendments.

The IEE Regulations for tankers, section 23.5.2, state that earthed distribution systems should not be used. This statement is qualified by permitting, with provisos, neutral-earthing on supply systems over 3kV. Sections 4.5 and 5.5 (ac and dc systems respectively) do not allow the hull to be used as part of the return circuit (except on vessels other than tankers under 1600 tonnes). This in itself does not preclude the referencing of circuits to the hull of a larger ship. These clauses do permit a 30mA hull current when used with out-of-balance trips. When a fault current flows in the hull it may be said to be using the hull as a return path but this is permitted.

The IEE general regulations (6.10) do require that secondaries of current transformers for ammeters and over-current protection relays be earthed. This therefore suggests that the use of the hull as an electrical reference potential is acceptable. This suggestion is further reinforced by general acceptance of IS requirements in other parts of Section 23. Other documents, such as Lloyds Register, permit IS as a method of protection but are less specific about how it is to be used. SOLAS Regulation II-1 / D,45 4.3.2 expressly permits the use of earthed IS systems on tankers designed after 1st October 1994. IEC 92-502 (1994) Tankers, Special Features discusses area classification, the use of explosion protection methods and the approach to IS in a way that brings together some of the older regulations.

The IEE regulations are comprehensive and specific on the earthing of 'non-current carrying parts' but do not seem to distinguish between bonding and earthing which, if they did, would make some things clearer.

The concern

The earlier regulations were concerned with the possibility of heat or sparks being generated by return currents flowing through the hull of a ship. For tankers, this clearly increases the risk of ignition. The concern dated back to a time when ships were built with riveted plates which implied that a low resistance path through the structure could not be relied upon. It is generally accepted that an all welded construction offers a consistently lower resistance but the standards have not been altered to take this into account.

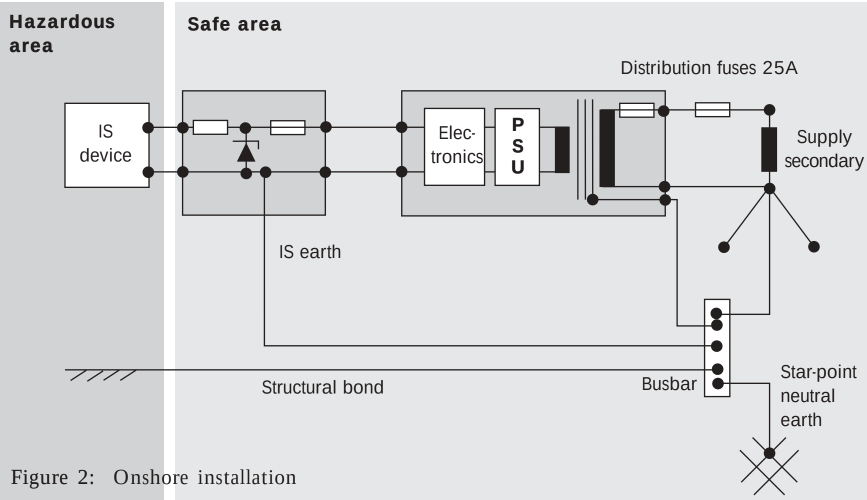

Figure 2: Onshore installation

The other concern is for the maintenance of supplies. If a single phase-to-earth fault on a normally insulated or floating system is experienced then the equipment can still be powered whilst the fault is cleared. However where two faults occur simultaneously, then the overcurrent condition must be sensed and fuses or breakers must operate to ensure that faults are cleared in adequately short times and with the minimum disruption to other systems on the same supply. This is discussed subsequently with further explanation.

Bonding and earthing

The requirement to connect to 'earth' is a commonly used term in electrical engineering documents. In the context of this discussion it is important to define what is meant by 'earth' since electrical safety depends upon its proper use. All seem to agree on the implications of its potential misuse! It is therefore necessary to define and explain the purpose of earthing and bonding before explaining the importance of its integration with IS.

The term 'bonding' is very often confused with 'earthing'. Bonding, however, is generally considered to describe connections made between the metal chassis of two items of electrical equipment in order to eliminate potential differences between them under all circumstances.

The standard for tankers, IEC 92-101 Para 1.3.9, defines 'earthed' as 'metalwork connected to the hull of the ship in such a way as to allow discharge'. This definition is more akin to 'bonding' and appears to take its roots from the lightning or static discharge protection requirements.

A more generally accepted definition of 'earthing' is where a specific path is provided down which fault currents can flow in order to operate any overcurrent protection device during a prescribed fault. The simplest case is shown in Figure 3.

In this diagram, under normal conditions, the currents in the live conductor i_L and in the neutral conductor i_N are the same. A more accurate description is 'equal and opposite'. If a fault occurs, say a short circuit between the live conducter of the supply and the equipment chassis at point A, then the flow of current will be back to the neutral of the supply via the earth path. This may be shared between two routes, one by the armoured cable and the other through the bonding conductors.

The current will reduce in the neutral line but it will increase dramatically in the live line. A fuse in the live conductor should therefore blow and disconnect the fault. A circuit breaker normally set to about 750mA for a motor, should detect an out-of-balance condition in the wires and trip to break the circuit. The amount of current flowing under this fault condition is determined by the voltage divided by the total resistance of the circuit from point A to the neutral-earth point and the source impedance of the fuse / generator. The overcurrent protection system must be designed to distinguish between a full load

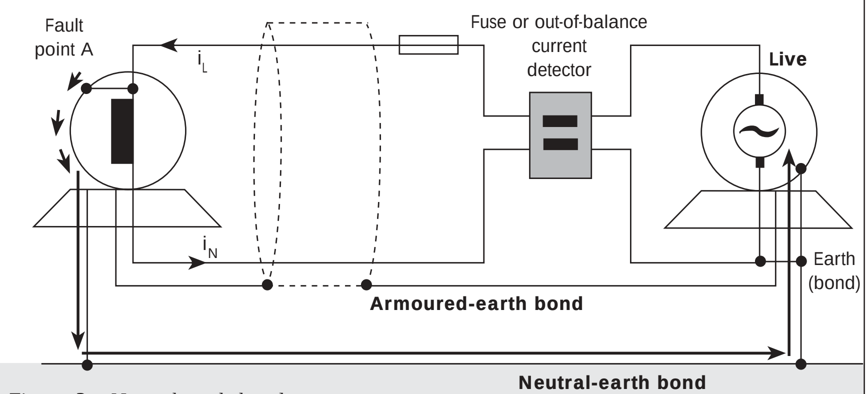

Figure 3: Neutral-earth bond

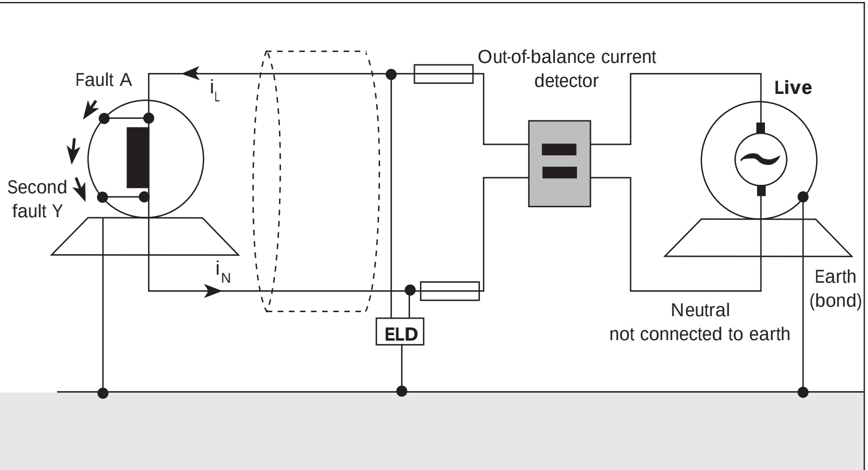

Figure 4: Neutral not connected to earth

current and a fault current. If a fault current flows undetected, it could cause a dangerous situation.

If, however, no connection between the neutral of the generator and the earth plane is made (as in figure 4), fault detection in the circuit must be done from two points of view. The live-to-frame connection in this case will not cause excess current to flow in any part of the circuit and so—although it may be a matter of concern—it presents no urgent problem. The circuit will continue to operate and will become referenced to the load's frame. If the resistance of the load becomes too low, ie, a short-circuit condition arises, then an overcurrent circuit-breaker or fuse must operate to disconnect the circuit. However, a second fault to the frame, at Y, would cause the overcurrent condition and so would blow a fuse or a breaker.

In this mode, then, the detection of the first earth fault via an earth leakage detection system gives advance warning of a future and more disastrous failure. The second advantage is that the supply will remain powering the load without disconnection and this may be preferable where essential equipment must continue to operate under some level of fault condition. The earth fault may be correctable without disconnection of the supply in some cases.

A typical arrangement of generation and primary distribution is shown in figure 5 where there is no neutral connection to the generator. The neutral is available for test purposes and so is normally available at the terminal housing but insulated.

Under these conditions, earth leakage detection is applied to monitor any earth fault in each isolated segment of the distribution chain.

It is interesting to note that the 1992 second edition IEE Recommendations for fixed and mobile offshore installations imply that the structure of these can be considered to be of adequately low resistance where earth fault currents are unlimited. Section 23 on hazardous installations refers only to BS 5345.

Applying intrinsic safety

A clear distinction must be drawn between normal operation and fault conditions. It is under these fault conditions that IS circuits perform their protection function. Analysis of the fault conditions will explain how the IS requirements can be accommodated under the regulations imposed on ships' systems.

A simple barrier circuit

A shunt-diode safety barrier is shown in a typical onshore application with the star-point neutral of the supply earthed and a conventional intrinsic safety earth connected in accordance with BS 5345: Part 4. The barrier is introduced into an instrument loop between the safe and hazardous areas. The modes of failure of the system involving the safety of the barrier are concerned with two aspects. First, should the mains transformer fail or some wiring fault occur within the instrument, then the supply voltage may become connected to the secondary of the transformer. The full fault voltage to the hazardous area is limited by the barrier to prescribed levels of voltage and also current by the series resistance to assure safety in the hazardous area. This is shown in figure 6 The weakest link in the chain is the barrier fuse at about 50 or 100mA. This may be referred to a loop-confined or internal fault. However if an external fault is applied, as in figure 7, then the IS earth can be clearly seen as an essential conduction path for the fault current.

Where some external fault touches the earth conductor, the distribution fuse will be the weakest link in the chain and will therefore permit a considerably higher current to flow in this circuit, possibly of the order of 100A.

The IS Codes of Practice that operate in the UK (BS 5345: Part 4) and other European documents require a neutral-earth bond to which the IS earth is connected (with an impedance of 1Ω or less). Such a fault current cannot be permitted to flow into the hazardous area. The IS circuit in the hazardous area will normally withstand a 500V insulation test to prevent such a current path. Barriers are then inextricably linked to the power supply and distribution system because of this necessity to provide a return path directly to the return of the source of supply.

The conflict

The shipping regulations do not permit a ship's hull to be used as an earth return by insulating the distribution system, while IS codes of practice state that connection to the point where the hull and distribution system are linked is mandatory. Herein lies the conflict. At first sight it seems that the regulations preclude the use of barriers. However examination of the regulations has shown that IS systems are acceptable, hence it is necessary to rationalise the differing earthing requirements.

Figure 8 illustrates a solution. The distribution system feeds a local isolating transformer to power the IS instrument system. The sub-distribution system for the instrument system is configured in the normal way. A localised neutral-earth busbar is created to which the neutral of the isolating transformer secondary and the hull of the ship are connected. In this way, both the requirements of IS and the intent of ship's earthing regulations are preserved. The quality of the insulating tranformer must be acceptable for this.

In normal operation there are no heavy currents flowing in the earth circuit, the connection to the hull merely serves as a reference. Should a fault occur, as in figure 7, then the route for the high current will not impinge on the hull. If a short circuit occurs in the hazardous area, the maximum current is limited to that permitted by the safety resistance of the barrier and cannot, by design, provide an incendive spark. Fault tolerance is implicit in IS systems.

The connection of the IS earth to the hull forces the referencing of associated instrument circuits to the same point. The reference potential can be used in the control of unwanted noise on the instrument system. The hull acts as an earth plane for lightning and cathodic protection systems which do not change the IS installation approach.

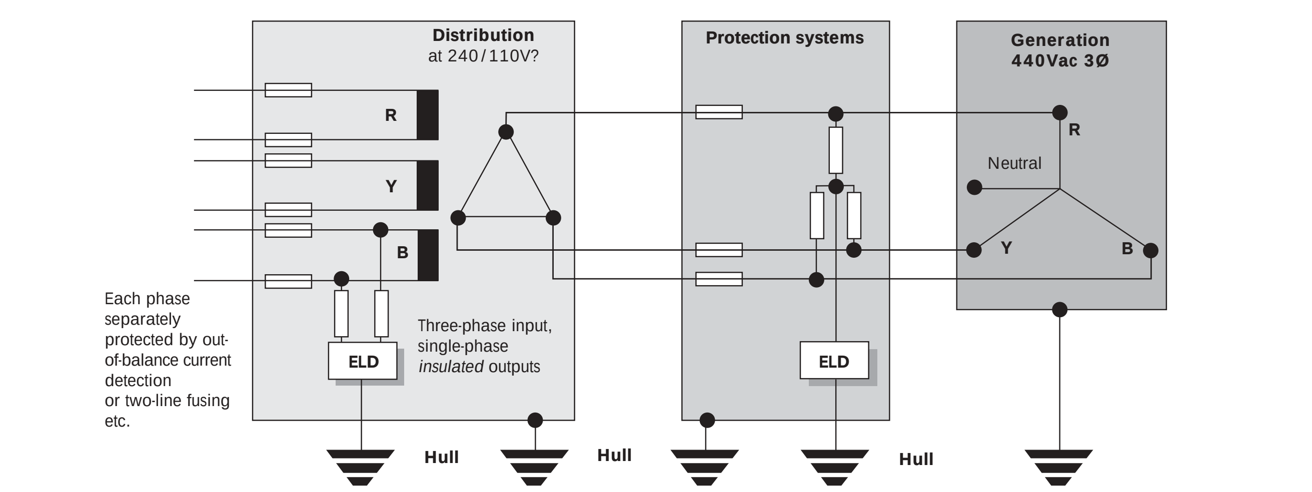

Figure 5: Typical arrangement of generation and primary distribution

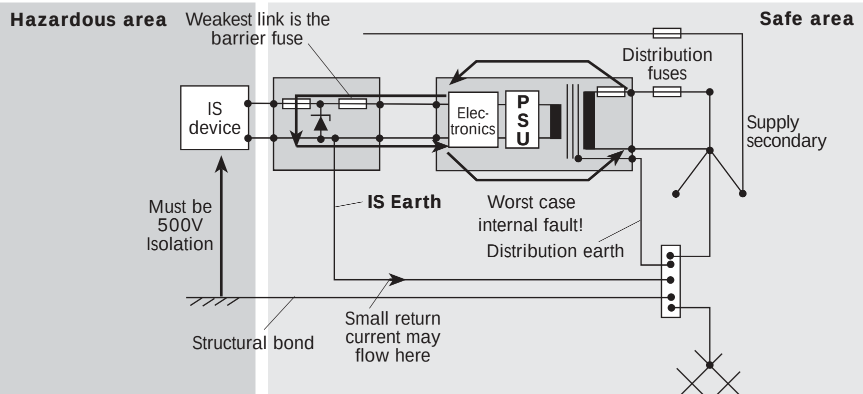

Figure 6: Fault in power supply unit

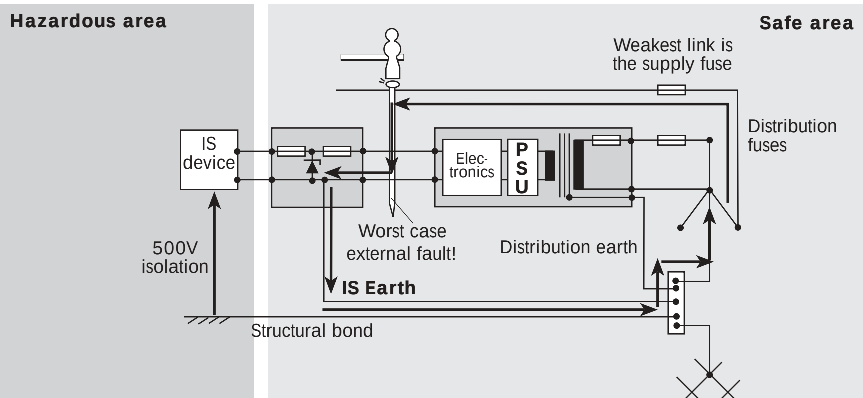

Figure 7: External fault

One point to be made is that all methods of explosion protection assume that the supply system is of the earthed-neutral type and where installations are fully insulated from earth an assessment of the effect of faults on safety is required.

There is little discussion of the handling of cathodic protection in the various parts of the standards mentioned here but lightning is covered in the IEE document.

Galvanically isolating interfaces

An alternative preferred solution is to use a form of interface with isolation built in that does not allow the direct physical connection of the hazardous and safe areas through each loop. The hazardous-area signal circuits are coupled electronically by some device which will withstand high voltages across it. The loops in the safe and hazardous areas may then adopt their own separate potentials. Such a technique is referred to as 'galvanic isolation' and is becoming popular in many applications because of the removal of the requirements for a safety earth. Figure 9 shows the principles of IS isolators designed according to these principles.

In operation, IS isolators are designed specifically for each signal type and direction but the safety aspects are the same as for barriers and it should be noted that the

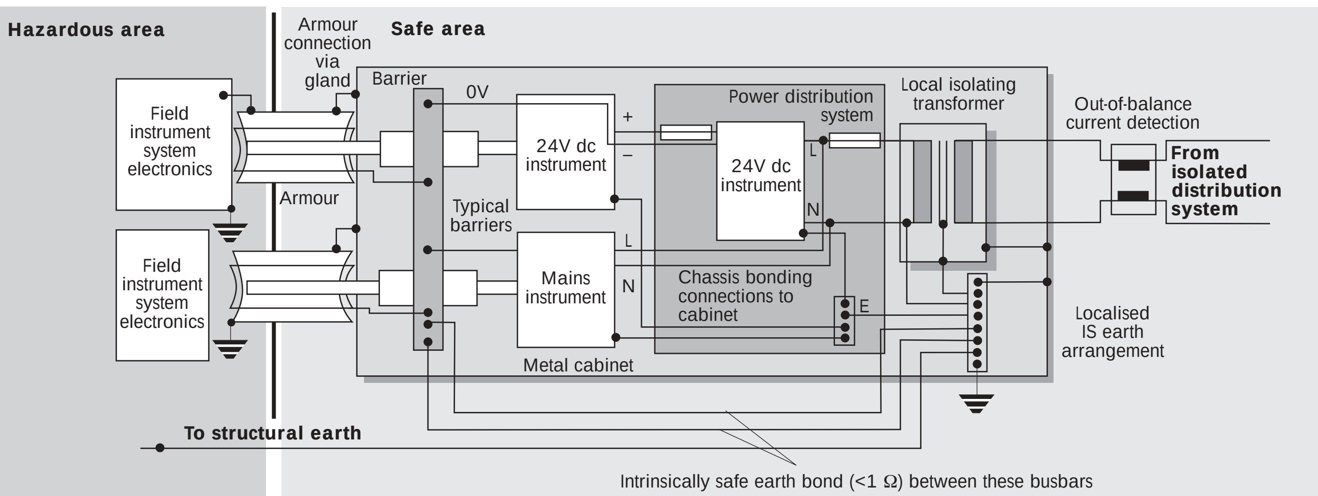

Figure 8: IS earth configuration on ships with no neutral-earth bond

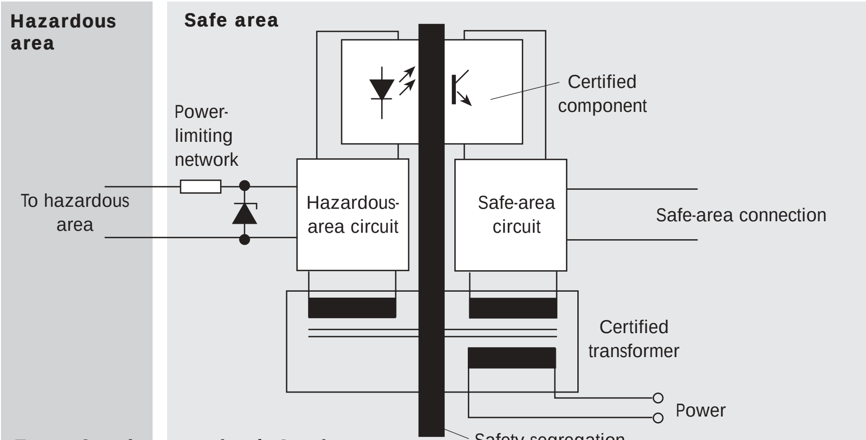

Figure 9: The principle of IS isolation

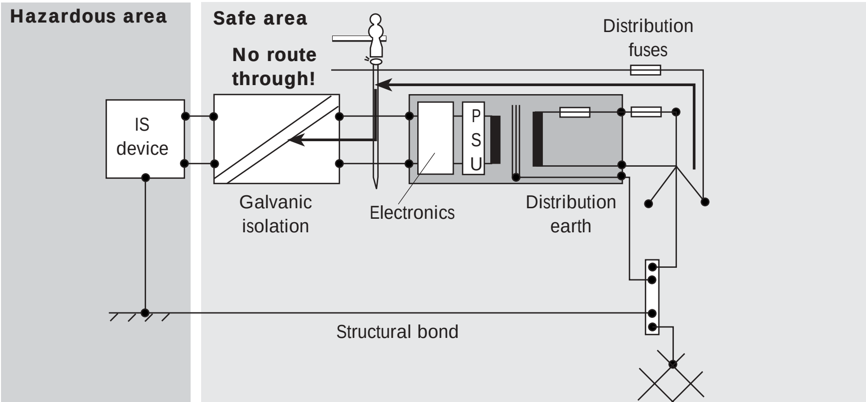

Figure 10: A typical application for an IS isolator

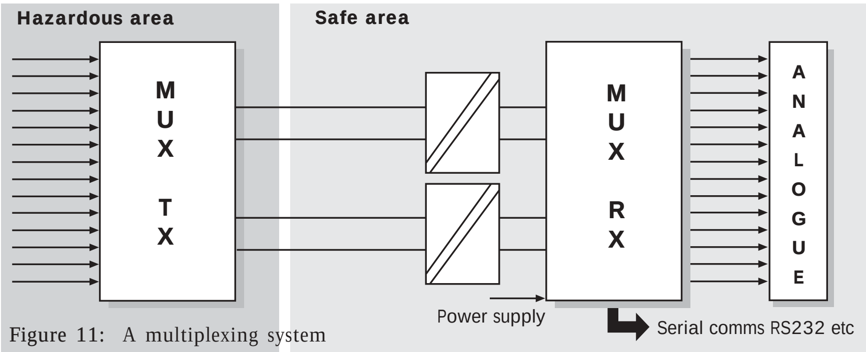

Figure 11: A multiplexing system

hazardous-area circuit contains the same energy-limiting components as barriers. Isolation in a typical application is shown in figure 10.

The cost of isolating interfaces is dramatically reducing as their popularity increases. There are, however, certain measurements that can only be performed through barriers. More detailed information is available from suppliers concerning the comparison and selection criteria of IS interfaces[2](TP1113).

New technology

Advances in technology permit the use of more sophisticated low-power electronics systems for multi-point measurement collection. Each time an instrument loop is added to an installation then a further pair of copper wires is added to the cost. A multiplexing system shown in figure 11 reduces the cable core count between safe and hazardous areas by compressing a number of measurements into twisted-pair cable serial communication. This technology has been available for some ten years in a certified IS form but has only recently been more acceptable in an understandably conservative marketplace.

The technique utilises the safety advantages of IS isolation but also offers many other features such as direct digital processing of signals that can be accepted directly by computer control and monitoring systems via a communications port. Diagnostics can be included to enhance signal integrity so that failure of highways, for example, are annunciated. Accuracy, resolution and speed of response can surpass that required for many monitoring situations.

Conclusions

There are two ways of reconciling the use of IS systems on ships. The solution using safety barriers requires a more thought-out approach in overall system design but is by no means in conflict with any earthing requirements. The use of isolators may well be preferred simply for the ease with which they can be integrated into accepted practice.

Reference material

"Blue Book": IEE Regulations for electrical & electronic equipment of ships: 1990 Sixth Edition & 1994 Supplement.

"Green Book": IEE Recommendations for the use of electrical & electronic equipment of mobile & fixed offshore installations: 1992 Second Edition & 1995 Supplement.

Lloyd's Register of Shipping: Rules and Regulations for the Classification of Ships: Part 6: Chapter 2: Section 13.

BS 5345:1989: Code of practice for the selection, installation and maintenance of electrical apparatus on potentially explosive atmospheres.

EN 50020: 1977 & 1995: Electrical apparatus for potentially explosive atmospheres - intrinsic safety 'i'.

IEC92 Series (Ships)-101: definitions 502: Tankers: Special Features

SOLAS: International Convention for Safety Of Life At Sea, 1974.

Other references

1) TP 1110: Cost comparison of methods of explosion protection (June 1995)

2) TP 1113: Barriers and Isolators ... A comparison. (July 1995)

TPs are reprints of published Technical Papers available from Measurement Technology Limited, Power Court, Luton, Bedfordshire, LU1 3JJ.

Measurement Technology Limited
Power Court, Luton, Bedfordshire, LU1 3JJ, England.
Tel:+44 (0)1582 23633 Fax: +44 (0)1582 422283
E-mail enquiry@mtluk.tcom.co.uk Internet home page http://www.mtl-inst.com/

A member of The MTL Instruments Group

2/97 Printed in the EU