Code of Practice for

The Safe Use of Electricity Under Water

International Marine
Contractors Association

www.imca-int.com

IMCA D 045, R 015
October 2010

The International Marine Contractors Association (IMCA) is the international trade association representing offshore, marine and underwater engineering companies.

IMCA promotes improvements in quality, health, safety, environmental and technical standards through the publication of information notes, codes of practice and by other appropriate means.

Members are self-regulating through the adoption of IMCA guidelines as appropriate. They commit to act as responsible members by following relevant guidelines and being willing to be audited against compliance with them by their clients.

There are two core activities that relate to all members:
- Competence & Training
- Safety, Environment & Legislation

The Association is organised through four distinct divisions, each covering a specific area of members' interests: Diving, Marine, Offshore Survey, Remote Systems & ROV.

There are also five regional sections which facilitate work on issues affecting members in their local geographic area – Asia-Pacific, Central & North America, Europe & Africa, Middle East & India and South America.

IMCA D 045, R 015

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This document is a revised and updated version of the AODC document of the same title referred to as AODC 035, published in September 1985.

This new document was prepared by a workgroup made up of the following participants, which met regularly from May 2008 to February 2010. IMCA would like to extend its thanks to these individuals for the efforts they made.

Crawford W Logan	IMCA	Chairman
John Butcher	Bibby Offshore	
Allan Cameron	Subsea 7	
Torquil Crichton	Technip	
George Cooper	Bibby Offshore	
Alexander J Collie	Obsidian Engineering	
Babs Fatogun	Chevron	
Peter Griffiths	Shell	
Ian Murray	Fugro	
Jane Bugler	IMCA	Secretary

It is worth noting that Ian Murray was Chairman of the AODC steering committee that produced the 1985 Code, Crawford Logan acted as secretary to it and Alan Cameron was a member of the committee. This meant that there was considerable continuity in that the members of the 1985 committee were able to provide advice on background issues to the present IMCA working group.

After some introductory meetings of the workgroup, an open workshop was held by IMCA in Aberdeen, UK in August 2008 where a number of invited specialists from both contractors and operators were asked to provide input. Several of these individuals subsequently attended specific meetings of the workgroup to offer specialist advice.

IMCA would also like to express their appreciation to Dr John Ross of Aberdeen University for his input in relation to the human physiology issues involved.

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The Safe Use of Electricity Under Water

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Appendices

1 Scope

This Code deals with the various common hazards which may arise from the use of electricity under water. The most obvious of these is electric shock and the prevention of this is the primary intent of the Code.

In addition, degradation of electrical insulating material by heat can result in the emission of toxic or explosive products, and hot surfaces or electric arcs from faulty equipment or switching devices can ignite some gas mixtures and pollute the diver's breathing gas supplies. Information on the prevention of these hazards is included in the Code.

All other risks associated with the use of electric power under water (mechanical risks, non-electric burns, ionising radiation, and generation of sound, ultra-sound and shock waves) are excluded.

The Code covers all types of electrical equipment used by the diver or employed for his benefit and under his control or that of his support team. In addition, it covers any electrical equipment or supply which the diver may be asked to work on or which is in the vicinity of the diver while he is working or gaining access to the work site.

The Code considers the risks arising from the various environments encountered. It makes recommendations for the selection, installation and maintenance of electrical apparatus used to enable an adequate level of safety to be achieved.

The Code does not address electrical safety above water as this subject is adequately covered in other documents. However, personnel involved in maintenance or modification of surface equipment used in connection with electricity under water should remember that the measures outlined in this Code are designed to protect man under water and may not on their own provide adequate protection for surface crew. The question of surface back-up supplies and levels of redundancy is also not covered.

Published information on insulation materials is normally based on information relating to the decomposition of materials and the physiological effect of the decomposition products at normal atmospheric pressures. The effect of higher pressure on these processes is not fully known and this should be considered by designers and material specifiers.

The recommendations are based on a number of assumptions (see section 6) and anybody using this Code as a means of ensuring the electrical safety of a diver should check that the assumptions used are applicable to the specific situation which they are considering.

2 Introduction

As the commercial diving industry got more involved in offshore oil and gas exploration in the 1960s and 1970s it became obvious that more and more use would be made of electricity as a power source under water.

There were inevitable technical problems associated with making electrical equipment work correctly in such an environment. However, few problems were encountered with diver safety as divers tended to be kept well away from the electrical equipment and if divers had to work in the vicinity then the power was normally turned off.

As oil and gas production increased in the North Sea, both the UK and Norwegian government agencies responsible for diver safety funded research to establish whether these precautions were necessary or indeed if there were possible hazards that were not obvious.

In 1982 the then UK Department of Energy published a *Code of practice for the safe use of electricity under water* as general guidance on the subject. Further research was carried out and the Association of Offshore Diving Contractors (AODC) agreed to re-issue the Code in a more useful format for offshore use and incorporating the most up to date research. The AODC Code was published in September 1985 and was 'Accepted' or 'Recognised' by the relevant government authorities in the UK, Norway, Canada and Ireland.

Since 1985 the AODC Code AODC 035 – *Code of practice for the safe use of electricity under water* – has become accepted by most relevant bodies as providing the most suitable advice and guidance on the safe use of electricity under water in the oil and gas industry.

As further research was published and international standards were revised, AODC (subsequently IMCA) reviewed the Code in 1993 and 1998 at which times it was decided that it did not need to be altered.

However by the mid 2000s it was realised that the increased use of electrical power under water, especially in ways not common in 1985, plus the widespread use of risk assessment as a safety tool, made it necessary that the AODC Code needed to be reviewed and updated.

This document is the result of that review.

3 Physiology

3.1 Introduction

Since electricity was first widely used in the nineteenth century its effects on the human body have been extensively researched and investigated. This has resulted in a level of knowledge at the start of the twenty first century that allows us to say with reasonable certainty what levels are safe and what levels may be unsafe for the vast majority of people.

Individuals exhibit different reactions to electricity (for example men and women react differently), and an electric shock which is only just perceptible to one person can cause pain to another. For this reason researchers have used as large a number of subjects as possible in order to arrive at average values. Most safety levels have been set to allow for the most susceptible people.

This section gives a brief and simplified overview of the physiology involved and the way in which the values used in this document were derived. Some of the reference documents used are listed in Appendix 1 and these can be referred to for more detail. If a greater understanding is required then it is recommended that a search is done on the internet for relevant standards and research papers.

3.2 The Potential Hazards

In relation to this document, a diver may be exposed to electrical hazards that result in three distinct levels of potential hazard. These are further explained below along with brief details of the way in which these levels have been tested and verified.

3.2.1 Awareness/Feeling

An electrical fault under water will result in the creation of an electrical field surrounding the fault. This field is effectively a sphere centred on the fault with the intensity decreasing as it radiates outwards.

At the lowest level, as a diver enters this field he will become aware of a sensation surrounding him and as he gets closer to the source the 'feeling' will get stronger and progressively more uncomfortable. It will normally reach a level alerting the diver to its presence and causing him to stop his approach well before it becomes in any way hazardous to his health. It is thus highly unlikely that a diver will ever stray in to an electrical field under water which is strong enough to offer any potential to be a possible hazard to him.

One possible hazard, however, is a fault developing under water when the diver is already in the vicinity. The likelihood of this situation arising needs to be one of the things considered during any risk assessment.

This whole phenomenon has been extensively researched by various navies with a view to providing protection to ships against stealth attack by divers.

In relation to the offshore situation, tests were carried out in 1985 using a diver wearing normal offshore diving equipment while approaching a known electrical field under water. The diver was instrumented both on his skin and on various parts of the equipment in order to establish exactly how much electrical energy he was being exposed to. These measurements were correlated with the feelings he described as he entered the electrical field from various angles and in different attitudes. This confirmed that he was well aware of the electrical field and its increasing intensity while the level he was being exposed to remained well below that which is strong enough to offer any potential to be a possible hazard to him.

3.2.2 Muscle Contraction

Another effect that may be encountered is where an electrical source applies sufficient power to cause some of the muscles of the human body to contract involuntarily. It is this effect that results in the phenomenon commonly called the 'let go' level. It should more correctly be called the 'can't let go' level as its commonest manifestation on land is where a person catches hold of an item that is electrically live and is unable to let go of it because the muscles in their hand and forearm have been involuntarily contracted.

In times past this effect was invoked to provide amusement and entertainment to the public. The levels of electricity that cause this phenomenon have been established by extensive testing on human volunteers. One series of experiments used a large number of subjects who were motivated by being offered a sum of money if they could remove their hand from the electrical conductor. This testing produced very consistent results.

The inability of a diver to let go of something he was holding under water would often not in itself be hazardous as there would normally be time to switch off the power before the diver was harmed in any way. However it would be extremely serious if the electricity caused involuntary contraction of the muscles used for breathing. For that reason this particular effect has been used as a basis for some of the values in this document.

3.2.3 Fibrillation

The human heart beats as a result of small, naturally occurring, electrical impulses within the body. The application of any external electrical source to the heart muscle can cause disruption to these impulses which may result in an altered heart rate.

The most serious situation is if the ventricles of the heart are caused to 'flutter' (in medical terms fibrillate) with the result that very little, if any, blood is circulated round the body. While this fibrillation can sometimes be resolved by prompt medical treatment, a diver is in such a situation that it is highly unlikely that he would be able to receive such treatment quickly enough. It should therefore be assumed that a diver caused to enter ventricular fibrillation while under water could die.

The amount of electricity required to cause ventricular fibrillation varies from individual to individual and most published experimental information is based on what will cause this to happen in the most susceptible 0.5% of the population. Extensive experimentation on animals (of a type whose hearts are similar to humans) has established these levels with considerable accuracy. Analysis of a large number of fatal and non fatal electrical accidents to humans on land has allowed these values to be confirmed. Safety factors are then added to further reduce the risk before recommended values are set.

The values used in this document are based on these published levels.

3.3 Other Effects

Electricity can have other effects on the human body, such as burning, however these effects are not considered relevant to the diving scenario (due to the diver being surrounded by a large volume of water) and are not considered.

3.4 Effect of Pressure

Relatively little information was available as to whether increased pressure changed the human body's response to electricity and the UK government therefore sponsored research in the 1970s and early 1980s to establish this.

It has been demonstrated that the human body reacts to electricity in a hyperbaric situation in exactly the same way as it reacts at atmospheric pressure.

No changes are therefore required to the safe level figures to allow for depth or pressure changes.

4 Derivation of Values Used

The most widely accepted international standards on the effect of electricity on the human body are Technical Specifications number 60479-1 (2005) and 60479-2 (2007) of the International Electrotechnical Commission (IEC). In the original version of the under water Code (AODC 035) the relevant standard used was an earlier version of these documents known as IEC 479 and published in 1974.

These standards give values for effective resistance of an individual for various contact paths and also values of current which can flow safely through the body in different circumstances. These values are intended for use on land although the standard gives values for skin wet with both fresh and salt water.

IEC 60479 is based on experimental work by many researchers, including Professor Lee in the UK, Professor Dalziel in the USA, and Professor Biegelmeier in Austria. Doctor Green of the Clinical Research Centre in London has shown that many of the values in IEC 60479 can confidently be applied to the under water situation directly without the need to add any safety factors.

This Code takes full account of all the experimental work and its effect on the values of current given in IEC 60479, particularly the fact that the hyperbaric condition does not affect the fibrillation level, and uses IEC 60479 as the basis of the figures given.

Preparation of this Code has involved a number of assumptions, such as 20 milliseconds (ms) being a typical tripping time for actively protected circuits. It is possible to carry out the specific calculations for any given situation using Ohm's Law to calculate the 'safe' voltage in any situation if the current which is acceptable (i.e. 'safe') to flow through the body can be established and the current route resistance (diver's body resistance) is known. These values for divers immersed in salt water are further explained below.

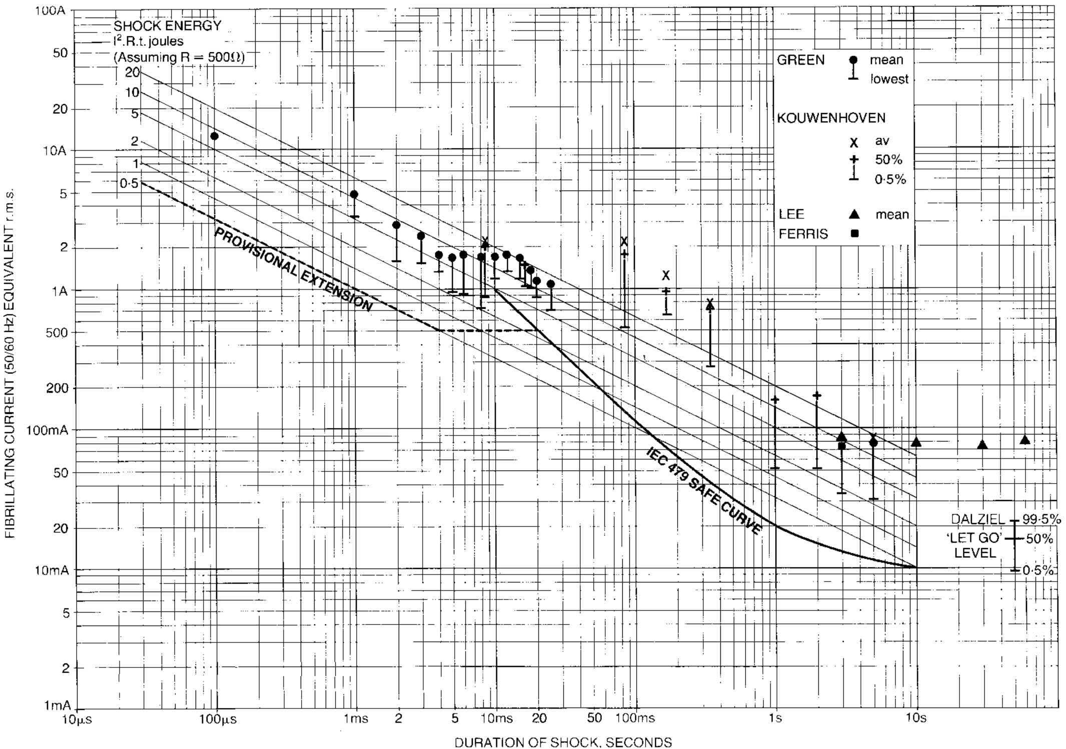
4.1 Safe Body Current

This is the amount of current flowing within the diver's body which will not cause specific unwanted and unsafe effects as described in the previous section on Potential Hazards.

This subject has been researched for many years and there is a large amount of factual information based on measurements of laboratory animals, experiments on human volunteers, analysis of serious and fatal electrical accidents, etc. It is therefore well established and agreed internationally exactly what values can be tolerated safely by males, females and children. As each person will vary in their susceptibility to electric shock, the published values are based on the most susceptible individuals in the general population. For fibrillation the safe value is based on what would cause 0.5% of the population a problem, for the other 99.5% of the population therefore these values would be higher. Additional safety factors are then added to this 0.5% level.

Experiments were carried out in the 1970s and early 1980s which confirmed that the effect of pressure on the human body did not alter its susceptibility to electrical current and thus it has been established that a diver will have exactly the same susceptibility to current in his body as would a male who was not under water.

Figure 1 coordinates the results of a number of research workers in relation to ac current and can be used to illustrate why certain values have been used in this Code. The IEC 479 curve was published in 1974, before the work of Dr Green on short duration shocks was carried out. His work highlighted a number of possible problems but also allowed an extension of the graph to 0.1 millisecond. It gives rise to the dashed 'provisional extension' line.



(with acknowledgements to R. J. Moulton, MaTSU)

Figure 1 – Allowable ac current in the body

The graph gives a reliable overall view, and shows broadly that shock energy is the main criterion. The shorter shocks are slices of a sine wave and the root mean square (RMS) equivalent has been derived from the energy content in one millisecond samples. Other work (not shown) on electrical discharges supports the short duration shock limit. It should be noted however that, in some work, the shock was synchronised with the vulnerable part of the heart-beat whereas, in other work, it was randomly applied. Apart from the 'let go' level, the work was carried out on animals and there is an unavoidable small doubt in applying the results to humans. A 'let go' level of 0.5% means that only one in 200 volunteers was unable (or unwilling) to release his grasp of the live bar.

The graph is very similar to the relevant graph (Figure 20) in IEC 60479-1 (2005) but is not exactly the same, as the graph in this Code is for adult males only (see section 4.3) and the IEC graph is for a more general population.

It is important to differentiate between fault current and allowable current passing through the body. Based on the maximum fault current the resulting voltage gradient in the surrounding water can be calculated using the conductivity of the sea water, which can in turn be used to estimate the current likely in the diver's body, assuming the worst case. Figure 2 gives the relationship between shock duration and allowable current passing through the body, in the form of two curves, one for 50/60Hz ac current and the other for dc current. These curves start at short duration shocks of less than one second and become constant for shocks lasting more than ten seconds.

(Note: Higher frequencies of ac current are safer on long shock durations but are not in common use. No figures are therefore given for higher frequencies.)

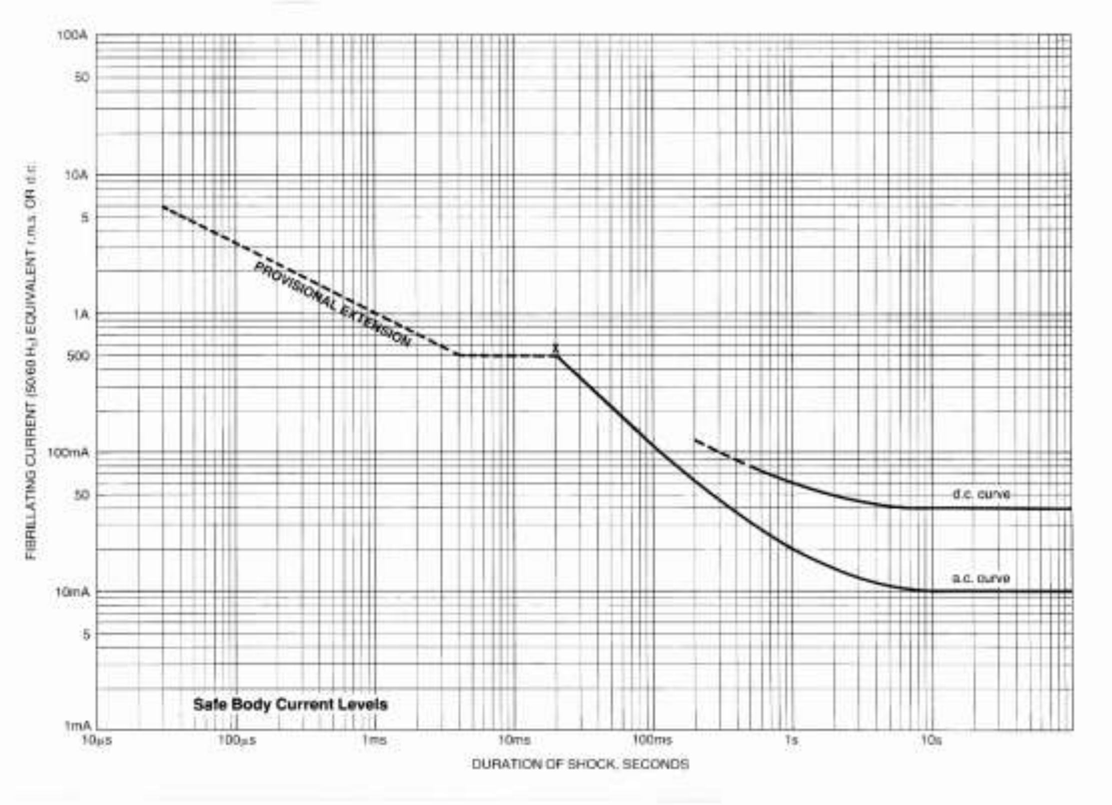


Figure 2 – Allowable ac and dc current in the body

The curves were drawn as a composite of three separate effects. If the shock is short, the only limiting value necessary is the level of current likely to cause heart fibrillation. As the shock duration increases, levels of current, well below that causing fibrillation, may induce involuntary muscle contraction and in particular severe breathing difficulties and the curves use these lower values. When the shock duration exceeds ten seconds, an even lower value of current will produce the phenomenon in which a person cannot let go of an electrical conductor due to localised involuntary muscle contraction in the forearm. At this current level most people suffer no other short term ill effects, as it is less than half that necessary to cause fibrillation or breathing difficulties.

Improved understanding of the ‘safe’ current flowing through the body has allowed these curves to be modified as follows:

4.1.1 dc Current

The dc curve is unaltered for shock durations of 200ms up to the straight line section over ten seconds at a value of 40 milliamps (mA), although the section from 200ms to 500ms is dotted to indicate reservations in fully endorsing it. The curve stops at 200ms as in shorter shocks than this there is little significant difference between ac and dc The single point value of 570mA at 20ms is included and marked with an X as it is a widely used reference value which is considered safe and is only slightly higher than the equivalent ac value.

4.1.2 ac Current

The ac curve has not been altered for durations greater than 20ms. Experimental work subsequent to the publication of the IEC 479 curve, particularly by Dr H Green of the Clinical Research Centre in London, has however shown that at durations less than 20ms the IEC 479 curve comes close to levels which can cause fibrillation (see Figure 1), and thus a horizontal line has been drawn at the value of 500mA. Dr Green’s work has also demonstrated ‘safe’ values for extremely short shock durations and these are shown on the graph as ‘provisional extension’.

4.2 Diver's Body Resistance

For many years a value of 500 ohms has been used for a typical, worst case, limb to limb contact irrespective of voltage. Later research has shown that while this value is safe for medium and high voltages it is overly conservative for low voltages, where resistances of over 1000 ohms have been demonstrated - therefore the value of current route resistance for low voltages (up to 50 volts) was raised to 750 ohms. The value of 500 ohms remains for voltages over 50 volts. Both these values are conservative and are used in this Code.

The only exception to these values is where there is a possibility of a front to back of the chest contact path (such as with an electrically heated diving suit), when a resistance of 100 ohms has been used because of the possible larger area of skin in electrical contact than in the limb to limb case, plus the path is through the area of the heart.

For body resistance, experiments have been carried out over the years and this has included measurements on people who were wet with both fresh and salt water. It was not clear, however, whether total immersion in salt water caused the diver's body resistance to change and a series of experiments was therefore carried out in 1985 in the UK (funded by the UK government) to compare actual measurements of a diver's body resistance with the theoretically predicted values.

Over a number of days, a diver wearing a variety of typical offshore diving equipment was fully instrumented both at various points on his body and on the external surface of his diving equipment. This was repeated using hot water and dry diving suits.

Sensors had also been placed on a non conducting frame which the diver stood inside. This allowed readings to be taken on the amount of electricity that the diver was being exposed to as well as the amounts reaching different parts of his body.

The diver was lowered in to the water with readings being taken at each stage and then once fully immersed the diver was subjected to various levels of electricity.

Figure 3 – Diver being lowered into water during 1985 experiments

The results of these tests confirmed that the body resistance values used in this document are suitable for a diver totally immersed in salt water.

It can therefore be seen that the values used in this document are not simply academic calculations but have been confirmed by practical tests as being correct for diving in salt water while wearing typical offshore diving equipment.

4.3 Sex of the Diver

Within this document the values used as safe have been based on the diver being an adult male.

Males and females have different body characteristics such as fluid levels, body fat percentages, etc. This has a significant effect on the electrical characteristics of the male versus female bodies. As an example, reference to figure 23 in IEC 60479-1 (2005) will show that during experimental work to establish safe ‘can’t let go’ levels, only 1% of the males tested could not let go at 10mA whereas 40% of the females tested could not let go at the same 10mA.

Many published values for electrical safety use a figure which combines the values for males, females and children to give a ‘safe’ figure for the general population. That level is unnecessarily conservative for offshore divers who are almost exclusively adult males.

If the diver involved in any situation is not an adult male then a competent person will need to consider the values used in this document and establish suitable values for the actual situation being encountered.

5 Definitions and Explanations

Active protection	This refers to a system fitted to detect an actual or potential shock condition and respond by actuating a protective device to cut the power. If the protective device can cut the power in a suitably fast time then this will protect the diver. If the response time is not fast enough however the protection will only be to the equipment involved.
Charged	The item has acquired a charge either because it is live or because it has become charged by other means such as by static or induction charging, or has retained or regained a charge due to capacitance effects even though it may be disconnected from the rest of the system.
Conductive coupler	A means of completing an electrical circuit where there is direct contact (normally metal to metal) between the two parts being connected.
Constant-current source	A source of electric power that supplies a current that is independent of the load within a specified working range.
Constant-voltage source	A source of electric power which supplies a voltage that is independent of the load within a specified working range.
Dead (within the context of electrical systems)	Not electrically 'live' or 'charged'.
Differential transformer	A current transformer which delivers an output current proportional to the vector sum of the input current in two or more conductors.
Disconnected	Describes equipment (or part of an electrical system) which is not connected to any source of electrical energy.
Earth leakage circuit breaker (ELCB)	This is the old name for a residual current device (RCD) – see definition below.
Electrical connector	A device used to connect two parts of a circuit such that electricity may flow freely in the circuit.
Electrical equipment	Includes anything used, intended to be used or installed for use, to generate, provide, transmit, transform, rectify, convert, conduct, distribute, control, store, measure or use electrical energy.
Explosive mixture	A mixture of flammable gas or vapour and oxygen in proportions which, after ignition, will lead to very rapid combustion and result in an explosion.
Flammable material	A substance which can react with oxygen and may therefore sustain fire when initiated by a suitable spark, static discharge, hot surface or adiabatic compression.
Fully-protective diving suit	A diving suit which is fully insulating or fully conductive, or may incorporate both insulating and conductive layers, thus providing protection from shock arising from voltage gradients in the water.
High voltage	It is widely accepted internationally that any voltage above 1000V is referred to as high voltage. Within this Code the term 'high voltage' is therefore used to refer to any voltage of 1000V or above.
Inductive coupler	A means of completing an electrical circuit where there is no direct contact between the two parts being connected.
Involuntary contraction	In the context of this Code it refers to the phenomenon whereby an electric shock applied to the hand or forearm causes the muscles of the forearm to contract involuntarily such that the victim cannot let go of the object giving the electric shock. In the diving context it may also apply to the electric shock causing the diaphragm to be contracted thus stopping breathing.

Isolated	Indicates equipment (or part of an electrical system) which is disconnected and separated by a safe distance (the isolating gap) from all sources of electrical energy in such a way that the disconnection is secure, i.e. it cannot be re-energised accidentally or inadvertently.
Isolating transformer	A transformer, the input and output windings of which are electrically separated. It is used to limit hazards due to accidental contact between earth and live parts (or metal parts which may become live in the event of an insulation fault).
Isolation	In electrical terms this refers to the separation of plant and equipment from every source of energy, in such a manner that the separation is secure.
Isolator: optically coupled	A coupling unit for communications, data or control signals, which incorporates an optical link to provide electrical isolation between the input and output.
Isolator: transformer coupled	A coupling unit, for communications, data or control signals, which incorporates a transformer to provide electrical isolation between the input and output.
Let go effect (more correctly the 'Can't Let Go Effect')	The upper limit of current above which the forearm muscles will contract involuntarily and the diver may be unable to let go of anything he is holding. (See involuntary contraction)
Line insulation monitor (LIM)	A device which continuously monitors the integrity of the insulation between live conductors and an earth return circuit. It normally gives a read out of the insulation value and can be used to trigger an alarm or a cut out device if the insulation value falls below a set level. A LIM can be used to monitor the condition of a cable or umbilical over a period of time prior to diving operations which may indicate if there is a possible developing problem. The primary function of a LIM is to protect equipment (and often production operations) only and, whether fitted with a tripping device or not, it is **not** intended to provide active protection for divers. The response time of such a tripping device will be too slow to provide diver protection and the length of cable or umbilical monitored (often measured in kilometres) results in the possibility of a high charge being stored in the cable/umbilical and therefore potentially harmful to a diver.
Live	Equipment which is energised by being connected to a source of electricity. This implies that, unless otherwise stated, the live parts may be exposed so that they can be touched either directly or indirectly by means of some conducting object.
Low voltage	A figure of 50V is widely used to delineate the upper level regarded as low voltage. Within this Code the term 'low voltage' is therefore used to refer to any voltage up to 50V.
Master control station	Generic name for the topside computer system dedicated to control and monitoring of the entire subsea control and umbilical system.
Medium voltage	Within this Code the term 'medium voltage' is used to refer to any voltage above 50V and below 1000V.
Nominal value	The designed or intended typical value at which an electrical circuit operates. In practice the actual value may be quite different.
Ohm's law	This states that if a voltage of magnitude V is applied across a resistor R then the current I through the resistor is related to V by the equation $V = I \times R$.

<table>
<tr><td>Passive protection</td><td colspan="2">This refers to the situation where aspects of the equipment (insulation, configuration, barriers, etc.) inherently reduce the possibility of a fault causing a shock condition resulting in danger to an individual.</td></tr>
<tr><td>Perception current</td><td colspan="2">The lower limit of current which can be felt.</td></tr>
<tr><td>Residual current device (RCD)
(this device used to be called an Earth Leakage Circuit Breaker (ELCB))</td><td colspan="2">An active protection device which detects earth-leakage current as a difference between the supply and load currents and responds by tripping a circuit breaker which interrupts the supply.
There are different types of RCD:</td></tr>
<tr><td></td><td>Current-operated RCD</td><td>An RCD connected directly, or through a differential transformer, to the supply circuit and responding to leakage current.</td></tr>
<tr><td></td><td>Voltage-operating RCD</td><td>An RCD connected to the screen of a screened and earthed system and responding to voltage on the screen.</td></tr>
<tr><td></td><td>Type 1 RCD</td><td>An RCD which uses a differential transformer to detect the out-of-balance current in the conductors connecting the supply network to the load.</td></tr>
<tr><td></td><td>Type 2 RCD</td><td>An RCD which detects leakage current to earth, being directly connected between supply and earth.</td></tr>
<tr><td></td><td>Current-Sensitive RCD</td><td>A Type 1 or Type 2 RCD which responds to current.</td></tr>
<tr><td></td><td>Voltage-Sensitive RCD</td><td>A Type 1 or Type 2 RCD which responds to voltage</td></tr>
<tr><td></td><td colspan="2">NB: The term RCD, as used in this document, covers all fault operated devices. An RCD on its own does not normally provide any form of over-current protection.</td></tr>
<tr><td>Remotely operated vehicle (ROV)</td><td colspan="2">An under water vehicle controlled from the surface by an operator who has visual control by means of a camera mounted on the ROV. The vehicle is linked to the surface by an umbilical through which electrical power/signals pass.</td></tr>
<tr><td>Ripple</td><td colspan="2">Ripple is the small unwanted residual periodic variation of the direct current (dc) output of a power supply which has been derived from an alternating current (ac) source. This ripple is normally due to incomplete suppression of the alternating waveform within the power supply.</td></tr>
<tr><td>Safe distance</td><td colspan="2">The distance away from an under water fault (or possible fault) beyond which the voltage gradient in the water will present no hazard to the diver.</td></tr>
<tr><td>Safe body current</td><td colspan="2">The maximum current which can be allowed to flow through the diver's body safely which has been derived from international standards. It is **not** the current flowing in the electrical equipment.</td></tr>
<tr><td>Tested</td><td colspan="2">Integrity of the circuit or item has been proven and/or can be monitored.</td></tr>
<tr><td>Trip device</td><td colspan="2">This refers to any device (RCD, LIM with trip facility etc.) which can interrupt the electrical supply on detection of a fault.
For this Code, trip devices that can provide an overall system operating time of 20ms or less have been assumed in deriving the safe values given in the various tables.</td></tr>
</table>

Ultra high voltage	Within this Code the term 'ultra high voltage' is used to refer to any voltage over 30,000V (30kV).
Voltage clipper (or limiter)	A component which prevents the voltage in a circuit from rising above a predetermined level.
Voltage gradient probe	A device that can be used under water to detect (and possibly measure) whether a voltage gradient exists in a particular area. The device can be diver held or ROV mounted.

6 Basic Assumptions

6.1 Background Knowledge

The document is written assuming that the readers and users understand the basic concepts of electricity. It is not assumed that they have detailed knowledge but it is assumed that they are aware what the terms voltage, current, resistance, earthing, insulation, etc. mean.

If any reader or user has any doubt about their level of understanding or their ability to use the information contained in this document then they should consult a person with suitable electrical competence before commencing any work.

6.2 Water

The values given in this document and the safety levels used are all on the basis that the diver is totally immersed in salt water, which is a better conductor of electricity than the human body and therefore provides considerable protection to a diver.

If the diving medium is fresh water, whose conductivity is lower than that of the human body (resulting in a much less safe situation for the diver than exists in salt water), then a separate detailed assessment will need to be made to ensure diver safety. The values given in this document may well not be correct if the medium is fresh water or sea water with a low salinity.

In areas where the salinity of the sea may be diluted (such as a bay with a large river emptying in to it) then an analysis of the salinity/conductivity of the water may be necessary to establish the level of protection needed. (See Appendix 4 for more detailed information on methods of determining salinity and necessary correction calculations.)

6.3 Sex of the Diver

The information contained within this document is based on the assumption that the diver is an adult male. (The bodies of females have different reactions to electricity to that of an adult male – see Physiology section.)

Should there be any possibility that the diver may not be an adult male then a person with the necessary knowledge of electrical safety should be consulted to establish the correct safe values for that particular situation.

6.4 Direct Current (dc)

When dc is referred to in this document it is on the basis that the supply has a ripple content of 5% RMS or less. If a user is not able to guarantee that the ripple content is lower than this, or is unsure of the ripple content, then the safe values for ac should be used in preference to the dc values.

6.5 Frequency

The values given in this document are all based on a system frequency in the 50/60 Hertz (Hz) range, which is the common range of frequencies used offshore.

It is known that different frequencies alter the safe levels and any user who is involved in electrical supplies outside the 50/60Hz range should consult the necessary reference documents (such as IEC 60479 (2005)) as part of their risk assessment to establish the safe levels for their particular situation. It is strongly recommended that a person with the necessary electrical competence is consulted before establishing safe levels under water for electrical supplies with frequencies different from the 50/60Hz range.

6.6 Surface Electrical Supplies

It is not within the scope of this document to identify electrical safety practices for surface electrical supplies as it is concerned only with the use of electricity **under water**. There are adequate guidelines available through national and international standards for the electrical safety standards for surface supplies.

Personnel involved in maintenance or modification of equipment used in connection with electricity under water should remember that the measures outlined in this Code are designed to protect man under water and may not, on their own, provide adequate protection for surface crew.

The questions of surface back-up supplies and levels of redundancy are also not covered.

7 Ensuring Electrical Safety

There are three ways in which the safety of a diver under water can be assured in relation to possible electrical hazards.

7.1 Safe Voltage

Provided the voltage of any item that the diver may come in contact with is less than a ‘safe’ level then work may be carried out in safety. The assumptions made and the basic figures used in the calculations below are explained elsewhere in this document.

The final values are worked out using Ohm’s Law which can be expressed in the equation V = IR. Thus for the following situations the maximum ‘safe’ level is:

Supply	**Safe Body Current mA**		**Body Route Resistance Ω (ohms)**		**Safe Voltage**	
					Maximum V	**Nominal V**
	(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
dc without a suitable trip device	40		750		30	24
ac without a suitable trip device	10		750		7.5	6
dc with a suitable trip device	570		500		285	250
ac with a suitable trip device	500		500		250	220

Note: A suitable trip device is one with a reaction time of 20ms or less.

7.2 Safe Distance

If the voltage involved is above the ‘safe’ limit then it may still be possible to carry out the work if the diver remains a safe distance away from the energised system or equipment.

As part of the risk assessment carried out before the work commences, the minimum safe distance for the energised system or equipment can be calculated (see Appendix 2 for details). Provided the diver, during the work (including his journey to and from the work site) can be physically restricted such that he always remains at least the minimum safe distance away from the energised system or equipment, then the work can probably be carried out safely.

7.3 Isolation/Disconnection of the Power Source

If the voltage involved is above the ‘safe’ level and the diver cannot be guaranteed to stay at least the minimum safe distance away from the energised components then the only way to carry out the dive safely will be to isolate and completely de-energise the power source and the components involved.

This is a complex process that needs to be fully understood and planned in a detailed manner in order to provide the necessary level of safety for the diver.

A detailed treatment of this subject can be found in IMCA D 044 – *Guidelines for isolation and intervention: Diver access to subsea systems.*

See Appendix 8 for further information on methods of protection against shock using passive means.

8 Application Scenarios

In the following section a number of typical scenarios are described along with the factors to consider, an identification of some of the risks and hazards that may be encountered and the relevant steps that can be taken to ensure diver safety.

It should be understood that these are typical situations and that a specific risk assessment should be undertaken for each real situation encountered.

In many cases it will also be beneficial to consult IMCA D 044 – *Guidelines for isolation and intervention: Diver access to subsea systems.*

The typical scenarios listed are:

8.1 Diving on subsea equipment or cables (the generic scenario)

8.2 Electrically heated diving suits

8.3 Impressed current anode systems

8.4 Diver carried or operated equipment

8.5 Wet welding, cutting and burning

8.6 Inside a hyperbaric chamber

8.7 Inside a welding (or other) habitat

8.8 Divers working with ROVs.

8.1 Diving on Subsea Equipment or Cables

8.1.1 Explanation

This application scenario will be the generic scenario for most work being carried out by a diver on or near wellhead and production equipment.

Whether a diver is being asked to work on or around equipment such as manifolds, powered electrical equipment, subsea installations, high power cables, powered umbilicals or similar the hazards and protections will be the same or very similar. In other words the scenario is where there is electrical power or powered systems in the area of the diving operation even if the diver may not be actually carrying out any work directly on the powered systems.

The diver will therefore be exposed to a potential possible hazard if any of such equipment is defective or malfunctions while the diver is in the vicinity or is working directly on it.

8.1.2 Basic Considerations

The diver is considered as being totally immersed in sea water of normal salinity. The surrounding water temperature will be in the range 0°C to 30°C and the pressure in the vicinity will be dependant on the depth.

8.1.3 Technical Considerations

This section covers a vast number of possible situations. The advice given here has therefore to be generic and a detailed risk assessment will need to be carried out for any specific situation before it will be safe to commence a diving operation.

There are a number of possible potential hazards to the diver each of which could result in a potential shock hazard to the diver.

Relevant factors are:

- Will the diver have sufficient visibility to move about the area safely?
- Are there good two way audio communications between diver and diving supervisor?
- Is the diver able to assume a stable and secure working position?
- How is the electrical power supplied to the system and is this supply monitored and controlled?
- Is the voltage of all the electrically powered equipment in the area accurately known?
- Does the voltage exceed the safe level?
- If a trip device is in use, will it respond within the required timescale?
- Is any information available concerning monitoring of any of the systems (for example historical LIM readings)?
- If any of the electrical power supplies are provided through a transformer, does that transformer have the secondary winding isolated?
- Is the type of equipment known (rotating/actuating etc)?
- Is there the possibility of stored energy in the supply cables?
- How accurate is the as-built information?
- Can the equipment be controlled or energised from more than one location or by more than one control system?
- Has anything been modified or retrofitted that may affect the electrical safety of any of the systems?

The figure below shows a simplified schematic of a typical piece of subsea equipment such as a subsea control module. It does not show all the complexity associated with instrumentation and control circuits but aims to indicate the main power supply.

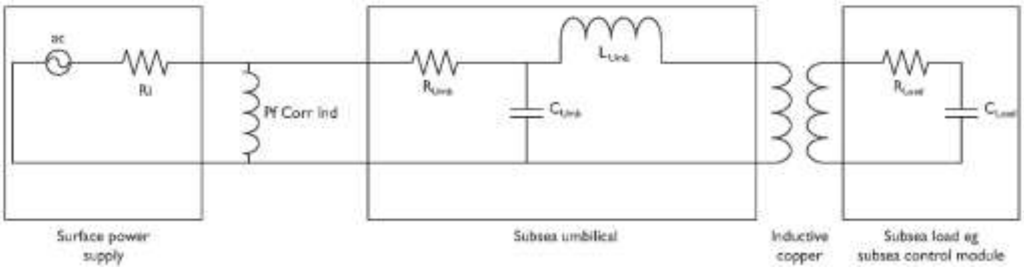


Figure 4 – Schematic of a typical subsea power circuit

8.1.4 Some Potential Hazards

HAZARD	**HAZARD EFFECT**
Voltage gradient in the water	Diver may become disorientated
Failure of equipment	Fault/ possible hazard to diver develops
Isolation fails or is removed	Hazard created for diver
Accidental damage by diver	Possible electrical hazard created
Voltage information wrong	Diver may be exposed to an unsafe voltage
Safe distance wrongly calculated	Diver may come too close to an energised source and enter an unsafe area
Modifications, repairs or changes made to the equipment since originally supplied	The electrical protections included by the designer/ supplier may have been compromised
A trip device being relied on does not operate as required	Diver will be exposed to a voltage higher than is safe for the fault duration.
Other electrical equipment in area which malfunctions	Diver may be exposed to stray voltage
Supply not from isolating transformer	In the event of an electrical fault developing then an easy return path may exist exposing the diver to possible hazard

Other hazards may be present in particular locations and will need to be considered by those carrying out the risk assessment.

8.1.5 Safe Practices

Using the values contained elsewhere within this document, the following have been established as voltage levels for the equipment that the diver is being asked to work on or near that should provide the necessary level of safety.

Supply	Safe Body Current mA		Body Route Resistance Ω (ohms)		Safe Voltage	
					Maximum V	Nominal V
	(I)	x	(R)	=	(V)	(V)
ac with trip device	500		500		250	220
dc with trip device	570		500		285	250
ac without a trip device	10		750		7.5	6
dc without a trip device	40		750		30	24

Based on these values and the other contents of this document, there are at least four ways in which safety can be assured for divers working on or near such equipment.

1. If the operating voltage of the system is under the maximum safe voltage level of 30V dc (7.5V ac)
2. If the operating system is under the maximum safe voltage level of 250V ac (285V dc) and a trip device is fitted with a reaction time less than 20ms.
3. If the diver can be physically restricted such that he can be assured to remain at least the minimum safe distance away from any energised components or cables.
4. If none of these points can be confirmed then it will be necessary to electrically isolate the components and cables until points 1 and 2 can be met. Such isolations may only require isolation of part of a system until point 2 can be met. Any isolations need to be carried out very thoroughly and carefully and detailed information on this subject is contained within IMCA D 044 – *Guidelines for isolation and intervention: Diver access to subsea systems.*

8.1.6 Operational Note

For many subsea projects, the likely method necessary to achieve electrical safety for the diver will be point 4 above – *isolation*.

It is not however intended to limit the provision of electrical safety to only these methods and if another method can be established as providing the necessary level of diver safety then that method can be considered.

8.2 Electrically Heated Diving Suits

8.2.1 Explanation

Offshore divers may be diving in water temperatures where active heating for their bodies is required in order to maintain their thermal balance. This is particularly likely to be the case if their breathing gas contains helium, due to the much higher thermal conductivity of helium than air.

At the present time, virtually all such heating systems do not utilise electrical suits or undersuits to provide the heat. However, such equipment has been used in the past and may well be used again in the future.

Since electrical equipment in direct contact with the diver's body, especially over a large area of contact, could result in a fault path from front to back of the chest (the most unsafe fault path), special care will have to be taken if such equipment is being considered.

8.2.2 Basic Considerations

While electrical heating systems for divers have in the past been designed such that the diver's body and the electrical undersuit remained dry while the diver was in the water, for the purpose of this Code a worst case scenario has been assumed. In this scenario the diver's body and his electric suit are assumed to be wet (due to sweat or water leakage) leading to a large contact area with good electrical contact between the suit and his body.

The diver is considered as being totally immersed in sea water of normal salinity. The surrounding water temperature will be in the range 0°C to 30°C and the pressure in the vicinity will be dependent on the depth.

8.2.3 Technical Considerations

Before deciding to use diver electrical heating as a means of maintaining thermal balance, a risk assessment to consider whether it is safe in all foreseeable circumstances should be carried out. For this risk assessment a number of factors need to be established and considered. The list below is not necessarily comprehensive as there may be other factors peculiar to the particular equipment or operation which need to be considered.

Relevant factors are:

- Is the supply source ac or dc?
- If it is dc, is the ripple factor known to be within acceptable limits?
- How is the electrical power supplied to the system and is this supply monitored and controlled?
- If a trip device is in use, will it respond within the required timescale?
- Is the maximum voltage at the suit known accurately?
- Does the voltage exceed the safe level?
- Has anything been modified that may affect the operation of the suit?

8.2.4 Some Potential Hazards

HAZARD	**HAZARD EFFECT**
Ripple factor too high	Diver may react as if ac current
Voltage higher than intended	Diver may be exposed to hazard
Trip device does not operate as required	Diver will be exposed to a voltage higher than is safe for the fault duration
Failure of equipment	Fault/possible hazard develops

Other hazards may be present in particular locations and will need to be considered by those carrying out the risk assessment.

8.2.5 Safe Practices

Using the figures contained elsewhere within this document, the following have been established as voltage levels for electrically heated suits that should provide the necessary level of safety to a diver wearing one.

This is a unique situation where there is a high possibility that in the event of an electrical fault it could result in a front to back of chest fault path. For this reason the body resistance used is an especially low value. Similarly the normal safe body current limits used elsewhere are divided by 2.5 to reflect the proximity to the heart and diaphragm (which could seriously affect breathing if involuntarily contracted).

Supply	**Safe Body Current mA**		**Body Route Resistance Ω (ohms)**		**Safe Voltage**	
					Maximum V	**Nominal V**
	(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
ac with trip device	200		100		20	18
dc with trip device	228		100		22.8	18
dc without a trip device	70		100		7	6
No figure is given for ac without a trip device as the voltage would be so low as to be impractical						

Based on these figures and the other contents of this document, the only way in which safety can be assured for divers wearing electrically heated suits or undersuits is if the operating voltage of the suit is under the maximum safe voltage level given above for the relevant supply source.

8.2.6 Operational Note

Based on experience from the past, any electrical failure, even a partial failure, is likely to result in extreme discomfort for the diver which will be heard by the diving supervisor over the communications system.

8.3 Impressed Current Anode Systems

8.3.1 Explanation

Impressed current anode systems are installed on vessels or structures and are intended to protect the parent structure from corrosion using electrically supplied anodes under water. When in operation these anodes create an electrically charged field in the water around the parent structure. However, the time this field can take to become fully established in order to provide the protection intended can vary from a number of hours to several weeks. It is for this reason that the electrical power is rarely switched off and thus any intention to carry out diving operations on or in the vicinity of such a protected structure needs to consider the possible risk to the divers from the electrical field or the anodes.

Different anode systems operate on different voltages and power levels. While older systems often operate on relatively low voltages (24V dc being typical) and are thus relatively safe for divers, some suggested systems for future use may operate on much higher voltages.

8.3.2 Basic Considerations

For the purpose of this Code the anodes are considered as being totally immersed in sea water of normal salinity. The surrounding water temperature will be in the range 0°C to 30°C and the pressure in their vicinity will be dependant on their depth.

8.3.3 Technical Considerations

Figure 5 shows a simplified version of a typical impressed current anode system. It shows only one anode but on most installations there will be a number of such anodes (possibly over a hundred) spread over the structure.

Once the system has fully polarised, the actual voltage at the anode tip is likely to be less than when the anode is first energised.

Before commencing a risk assessment to consider whether it is safe to carry out any proposed diving operation, a number of factors need to be established and considered. The list below is not necessarily comprehensive as there may be other factors peculiar to the particular installation that need to be considered.

Relevant factors are:

- Will the diver have sufficient visibility to move about the area safely?
- Are there good two-way audio communications between diver and diving supervisor?
- Is the diver able to assume a stable and secure working position?
- Is the ripple factor in the dc current known to be within acceptable limits?
- How is the electrical power supplied to the system and is this supply monitored and controlled?
- Is the maximum voltage at the anodes known accurately?
- Does the voltage exceed the safe level?
- Has anything been retrofitted or modified since the previous visit or since the system was first installed?

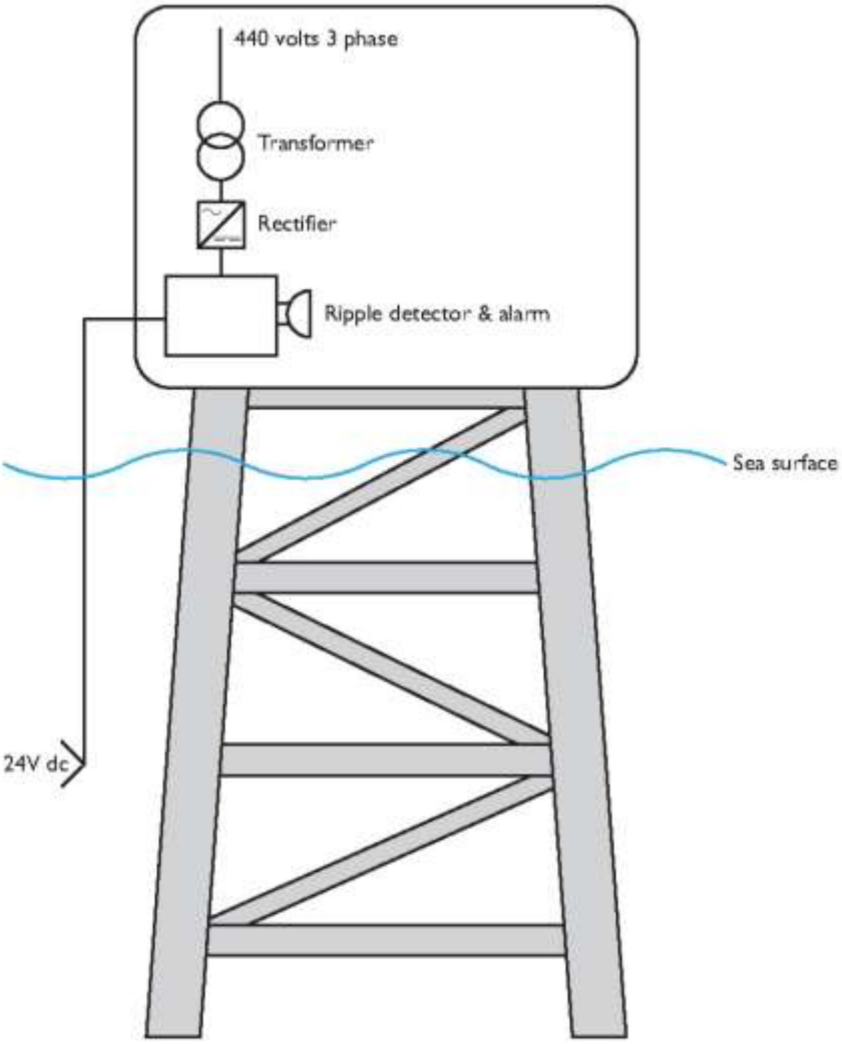


Figure 5 – Schematic of a typical impressed current system

8.3.4 Some Potential Hazards

HAZARD	HAZARD EFFECT
Voltage gradient in the water	Diver may become disorientated
Voltage information wrong	Diver may be exposed to an unsafe voltage
Other electrical equipment in area	Diver may be exposed to stray voltage
Ripple factor too high	Diver may react as if ac current
Supply not from isolating transformer	Platform steel may form a return path thus exposing diver to unsafe voltage
Safe distance wrongly calculated	Divers may come too close to anodes and enter an unsafe area
Failure of equipment	Fault/possible hazard to diver develops
Accidental damage by diver	Possible electrical hazard created

Other hazards may be present in particular locations and will need to be considered by those carrying out the risk assessment.

8.3.5 Safe Practices

Using the figures contained elsewhere within this document, the following have been established as voltage levels for the impressed current system that should provide the necessary level of safety to a diver working in their vicinity.

Supply	**Safe Body Current mA**		**Body Route Resistance Ω (ohms)**		**Safe Voltage**	
					Maximum V	**Nominal V**
	(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
dc without a trip device	40		750		30	24
By definition impressed current anode systems cannot be fitted with trip devices or they would not be able to serve their purpose. Similarly such systems are always dc. For these reasons no other safe values are given.						

Based on these figures and the other contents of this document, there are a number of ways in which safety can be assured for divers working in the vicinity of impressed current systems.

1. If the operating voltage of the system is under the maximum safe voltage level of 30V dc.
2. If the divers are going to be far enough away from any anodes that they can be guaranteed to be outside the safe distance for the operating voltage of that system. The safe distance can be established for any particular location and voltage (see Appendix 2).
3. If neither of the points above can be confirmed then it may be possible to switch off the anode (or anodes) in the area that the divers will be working or transiting through without the need to switch off the complete system.
4. If none of the above are possible then it may be necessary to switch off and isolate the entire system before diving commences.

Additional information on possible safe practices may be found in IMCA D 044 – *Guidelines for isolation and intervention: Diver access to subsea systems.*

8.3.6 Operational Note

If divers operate in the vicinity of energised impressed current anodes then they may well ‘feel’ the electrical field in the water as they move about (see section 3.2.1). This is not necessarily unsafe, however it can be disconcerting to a diver if they have not been pre-warned about the possibility. The use of a voltage gradient probe at the commencement of each dive will provide confirmation that the calculated electrical field in the area is as expected while also giving the divers confidence regarding their safety.

8.4 Diver Carried or Operated Equipment

Note: This category includes any electrical equipment carried by or mounted on the diver (such as cameras and lights) as well as hand held tools, non-destructive testing (NDT) equipment etc.

8.4.1 Explanation

Divers are required to use a variety of electrically powered items as part of their routine activities. Examples would be head mounted cameras and lights, portable non-destructive testing (NDT) equipment, electrically powered hand tools etc.

Such equipment obviously needs to present no possible electrical hazard to the diver and, since he will be in very close proximity to it, care needs to be taken to ensure that it is safe.

8.4.2 Basic Considerations

For the purpose of this Code both the diver and the equipment are considered as being totally immersed in sea water of normal salinity. The surrounding water temperature will be in the range 0°C to 30°C and the pressure in the vicinity will be dependant on the depth.

Some of this equipment may also be taken in to the inside of a closed diving bell where the atmosphere will be gaseous but with a very high humidity level.

8.4.3 Technical Considerations

Figure 6 shows a simplified version of a typical tool powered by an electrical supply from the surface. There are of course many variations with electrical supplies from the surface, from a diving bell or built in to the equipment.

Before commencing a risk assessment to consider whether it is safe to carry out any proposed diving operation, a number of factors need to be established and considered. The list below is not necessarily comprehensive as there may be other factors peculiar to the particular installation or equipment that need to be considered.

Relevant factors are:

- Are there good two-way audio communications between diver and diving supervisor?
- Is the installation ac or dc?
- If it is dc, is the ripple factor known to be within acceptable limits?
- How is the electrical power supplied to the system and is this supply monitored and controlled?
- If a trip device is in use, will it respond within the required timescale?
- Is the maximum voltage at the tool/equipment known accurately?
- Does the voltage exceed the safe level?
- If using a surface supply, is this being fed from a transformer with the secondary winding isolated such that there is not an obvious return path if a fault develops?
- Has anything been modified or changed since the tool/equipment was originally supplied?

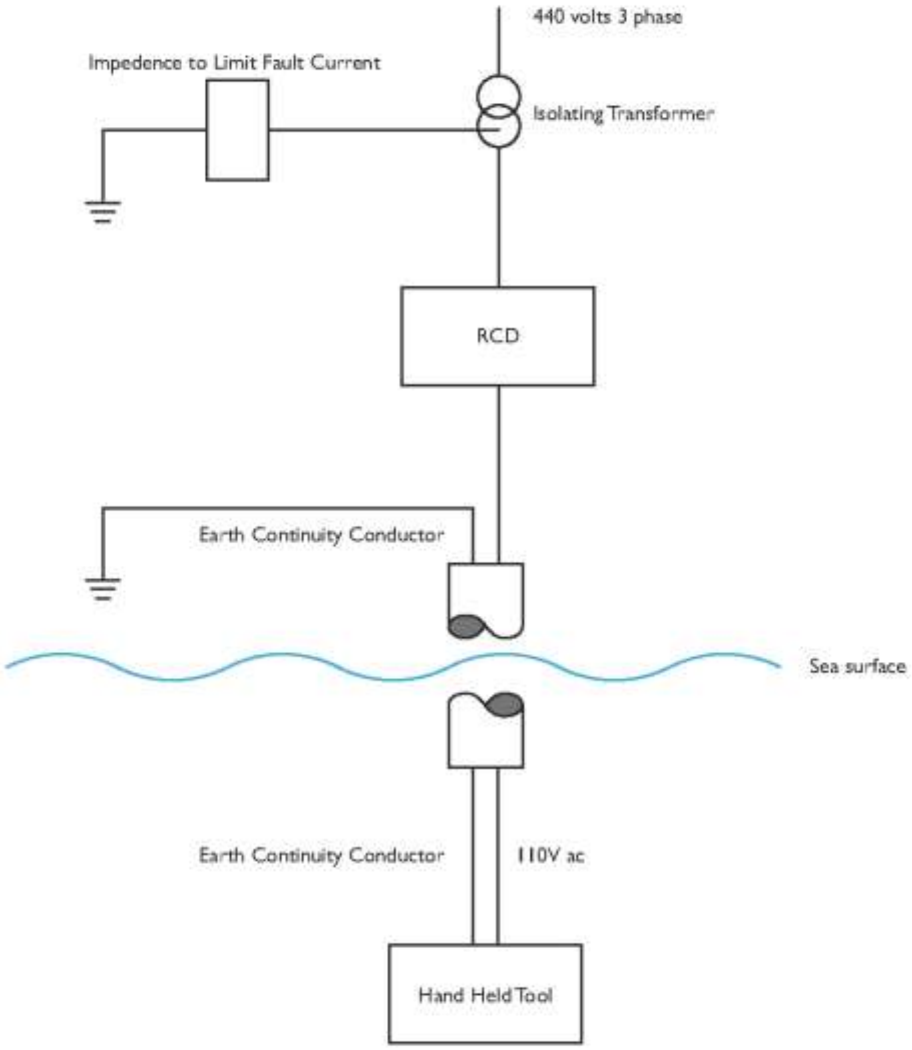


Figure 6 – Schematic of a typical hand held tool

8.4.4 Some Potential Hazards

HAZARD	**HAZARD EFFECT**
Ripple factor too high	Diver may react as if ac current
Voltage information wrong	Diver may be exposed to an unsafe voltage
Trip device does not operate as required	Diver will be exposed to a voltage higher than is safe for the fault duration
Voltage higher than intended	Diver may be exposed to hazard
Supply not from isolating transformer	In the event of an electrical fault developing then an easy return path may exist exposing the diver to possible hazard
Modifications, repairs or changes made to the tool/equipment since originally supplied	The electrical protections included by the designer/supplier may have been compromised
Failure of equipment	Fault/possible hazard to diver develops
Accidental damage by diver	Possible hazard to diver created

Other hazards may be present in particular locations or work situations and these will need to be considered by those carrying out the risk assessment.

8.4.5 Safe Practices

Using the figures contained elsewhere within this document, the following have been established as voltage levels for diver carried or operated equipment that should provide the necessary level of safety to a diver working in their vicinity.

Supply	**Safe Body Current mA**		**Body Route Resistance Ω (ohms)**		**Safe Voltage**	
					Maximum V	**Nominal V**
	(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
ac with trip device	500		500		250	220
dc with trip device	570		500		285	250
ac without a trip device	10		750		7.5	6
dc without a trip device	40		750		30	24

Based on these figures and the other contents of this document, there are at least two ways in which safety can be assured for divers working with diver carried or operated equipment.

1. If the operating voltage of the system is under the maximum safe voltage level of 30V dc (7.5V ac).
2. If the operating voltage is under the maximum safe voltage level of 250V ac (285V dc) and a trip device is fitted with a reaction time less than 20ms.

8.4.6 Operational Note

The normal method of ensuring diver safety from electrical hazard when using, or close to, diver carried or operated equipment is to adopt one of the two methods outlined above.

It is not intended to limit the use of this type of equipment to only these two methods and if another method can be established as providing the necessary level of diver safety then that method can be considered.

8.5 Wet Welding, Cutting and Burning

8.5.1 Explanation

Divers are often required to hot cut or burn items under water. It is also becoming common for divers offshore to be asked to weld items together while totally immersed (known as wet welding). This section covers any welding, burning or cutting operation where both the diver and the workpiece are totally immersed in salt water.

Since the cutting, burning and welding processes require the use of electrical energy, it is necessary to take precautions to ensure the safety of the diver carrying out the work, in relation to any possible hazard from the electricity.

Note: Further information on this topic can be found in IMCA D 003 – *Oxy-arc cutting operations underwater.*

8.5.2 Basic Considerations

Both the diver and the workpiece are considered as being totally immersed in sea water of normal salinity. The surrounding water temperature will be in the range 0°C to 30°C and the pressure in the vicinity will be dependent on the depth.

The diver will normally be wearing heavy rubber gloves, over a pair of light rubber gloves. The gloves will give a measure of electrical protection where the voltage gradient is highest.

8.5.3 Technical Considerations

Figure 7 shows a simplified version of a typical wet welding/cutting setup used offshore and powered by an electrical supply from the surface.

As electrical energy in excess of the voltage that is inherently safe for a diver is required at the tip of the rod for this technique to operate properly, electrical safety for the diver is obtained not by normal electrical means but by good operational practice and rigid adherence to the agreed procedures.

Before commencing a risk assessment to consider whether it is safe to carry out any proposed under water cutting, burning or wet welding operation, a number of factors need to be established and considered. The list below is not necessarily comprehensive as there may be other factors peculiar to the particular installation or equipment that need to be considered.

Relevant factors are:

- Is there good access to the worksite for the diver and his equipment?
- Will the diver have sufficient visibility to carry out the work safely?
- Are there good two-way audio communications between diver and diving supervisor?
- Is the diver able to assume a stable and secure working position?
- How is the electrical power supplied to the system and is this supply monitored and controlled?
- Has anything been modified or changed since the cutting, burning or welding equipment was originally supplied?

Note: These factors refer to considerations of diver safety in relation to possible electrical hazard only. Other factors of an operational nature, such as the possible presence of hydrocarbons, enclosed space trapping waste gas in the vicinity etc., will also need to be considered.

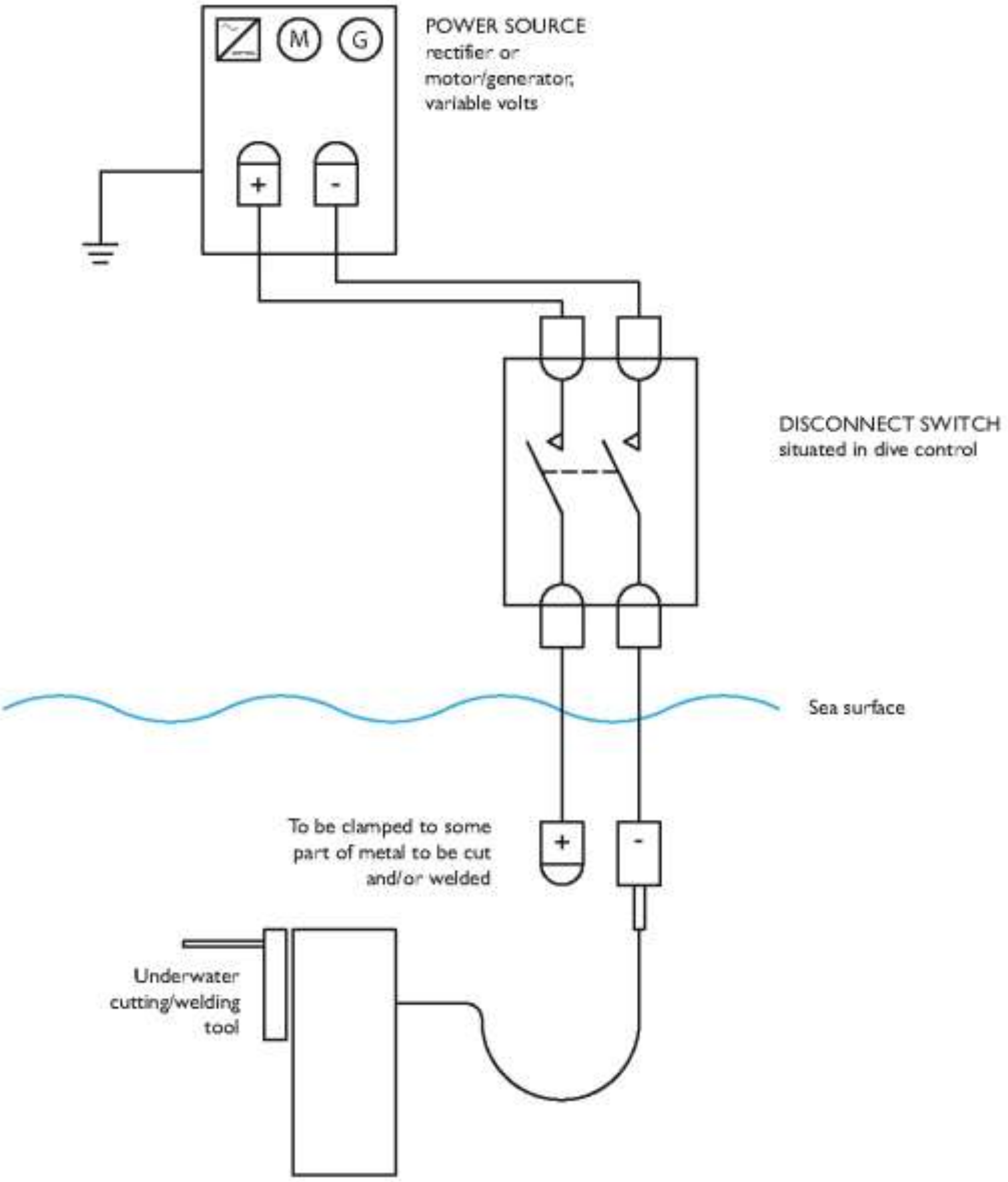


Figure 7 – Schematic of wet welding/cutting

8.5.4 Some Potential Hazards:

HAZARD	HAZARD EFFECT
Modifications, repairs or changes made to the equipment since originally supplied	The electrical protections included by the designer/supplier may have been compromised
Failure of equipment	Fault/possible hazard to diver develops
Accidental damage by diver	Possible hazard to diver created

Other hazards may be present in particular locations or work situations and these will need to be considered by those carrying out the risk assessment.

8.5.5 Safe Practices

Using the figures contained elsewhere within this document, the following have been established as voltage levels for burning, cutting or wet welding that should provide the necessary level of safety to a diver carrying out such work.

Supply	Safe Body Current mA		Body Route Resistance Ω (ohms)		Safe Voltage	
					Maximum V	Nominal V
	(I)	x	(R)	=	(V)	(V)
dc without a trip device	40		750		30	24

It is recognised that 30V dc is not a high enough voltage to be practical in many circumstances. In such cases it is recognised that it would be difficult to provide active protection to ensure that the diver is safe from electric shock at all times.

In the past a device known as an open circuit voltage reducer has been used to reduce to a safe level the voltage on the electrode when there is no arc. When used under water there have been many problems with these units and they should **not** be used as the primary means of ensuring safety.

Since electrical safety of the diver cannot therefore always be guaranteed by electrical protection alone it is necessary to use good quality equipment which is correctly installed and set up plus rigid adherence to pre-arranged operational safety procedures.

Equipment points to be noted and considered include:

- The welding unit should be grounded to the vessel and the ground lead should be securely grounded to the work (not simply to a nearby point);
- No part of the torch or the submerged sections of the power cables should be left un-insulated;
- The power source for welding under water is a dc welding generator or rectifier of at least 300A capacity;
- Rubber gloves should be worn by the diver to provide additional protection;
- The return connection from the workpiece should be made as close to the work area as possible;
- A high-quality two-pole knife switch or a contactor, rated for breaking dc, should be included in the welding circuit as a means of positive disconnection in order to safeguard the diver. It is important that the switch:
  - can be seen to be open. If a contactor is used, a visual indication of the contact position should be provided
  - should be fixed so as to be readily to hand of the person controlling the welding equipment
  - cannot be knocked or vibrated to the ‘on’ position (it should fall to the ‘off’ position) and that a slotted cover is used to prevent accidental contact with the fixed live terminals;
- Welding cables of adequate cross section should be used, connected in parallel if necessary, particularly with longer lengths, to avoid excessive voltage drop in the cable (guidance is contained in a number of international standards which give specifications for welding cables);
- Lengths of cable should be kept to a minimum, consistent with operational requirements, to limit circuit inductance;
- Cables should be arranged with positive and negative close together and tied at intervals to reduce the inductive effect;
- Cables connected in parallel should be arranged with leads of the same polarity diagonally opposite to reduce the inductive effect;
- Welding cable should have a protective sleeve at the point of entry to connectors to reduce flexing and prevent cable damage;
- The welding cable should comprise two fully-insulated conductors, one of which connects the negative terminal of the welding (or cutting) set to the torch, while the other bonds the positive terminal of the set to the workpiece.
- All joints in the welding cable should be fully insulated;

- The electrode holder for an oxy-arc cutting system should be so designed that the oxygen valve is at all times insulated from the electrode;
- The electrode should have an electrically insulating coating which is as resistant as possible to chipping and to deterioration caused by prolonged immersion in sea water.

Operational procedure points to be noted and considered include:

- Since the tip of the welding or cutting electrode cannot be insulated from the water, it should be at a safe distance from the diver's hand. The electrode should not be consumed beyond a safe minimum length such that the distance from the hand to the tip of the electrode is at least 100 mm;
- All welding and cutting equipment (including cables and connectors) should be checked by a competent person before use to ensure that it is in a serviceable condition;
- A clear command system with return confirmation should be established for switching supplies on and off;
- Before lowering or raising of the workpiece, clamp or welding torch, a check should be made to ensure that the welding circuit is dead and that there is no welding rod in the welding torch;
- An electrode with an unchipped insulating coating should be used. Electrodes which have been in the water for a long time should be rejected in case the coating has absorbed water;
- Before welding or cutting begins, it is essential to check that there are no combustible solids, liquids or gases adjacent to, on or within the workpiece;
- A check should be made that there are no gas entrapment spaces above the work area. Cutting or welding operations should never be carried out directly underneath a closed diving bell;
- The welding circuit should only be switched on when:
  - the diver is in position to start welding or cutting: this position needs to be as stable as possible
  - the workpiece clamp is securely fastened
  - the welding rod is fitted securely into the welding torch, is pointing away from the diver, and is as near to the workpiece as practicable
  - neither the diver nor any of the diver's equipment is between the welding torch and the workpiece
  - the diver confirms that he is ready;
- Care should be taken with large loose metallic items carried by a diver (e.g. wrenches and backpacks) to prevent electrical contact with a live electrode;
- Electrodes should not be changed with the supply switched on;
- The welding torch should not be put down or carried with the power on;
- Welding or cutting equipment should never be taken into a closed diving bell or lock-out submersible. If any problem occurs with the welding/cutting gear, it should be returned to the surface for attention;
- Whenever practical, a second diver, or the person controlling the diving operation, should be able to observe the diver carrying out the welding/cutting operation, either directly or via video;
- The electrode should be inserted into the head of the torch so that it is seated firmly against the rubber seal within the torch head;
- An additional coating of wax or tape should not be added to electrodes if welding in a habitat, as toxic or flammable gases may be produced;
- A properly designed and maintained electrode holder should be used.

8.5.6 Operational Note

This is one of the few operations where a diver is using electrical equipment that does not inherently provide built in safety. A live welding torch could very easily provide an unwanted possible hazard if the above protective procedures and equipment points are not followed.

8.6 Inside a Hyperbaric Chamber

8.6.1 Explanation

Whilst it is not strictly under water, the electrical safety of a diver inside a chamber is very similar to under water in that the inside of most such chambers (closed diving bells, deck decompression chambers (DDC), hyperbaric rescue chambers etc.) is an extremely damp environment. The electrical safety parameters in a physiological sense are the same and the only difference is that the diver will be surrounded by a gaseous rather than aqueous environment.

8.6.2 Basic Considerations

For the purpose of this Code, internal pressure can vary between 0 and 50 bar but is commonly in the range 0 to 25 bar and can change at various rates. Externally a closed diving bell will be subject to sea water pressure according to the depth, which will be in the range of 0 to 50 bar, but normally 0 to 25 bar.

The atmosphere is either compressed air at a pressure of 0 to 5 bar, or an oxygen/helium mix at a pressure of 0 to 50 bar. The oxygen concentration will normally be the lower of 25% by volume or 0.5 bar ppO_2.

The internal temperature range is normally 25°C to 35°C in a saturation chamber (but could drop to 10°C in exceptional circumstances) and 5°C to 25°C in an air chamber. External temperatures will vary from 0°C to 30°C but will normally be between 5°C and 15°C.

There will always be a high humidity internally and equipment mounted inside transfer chambers and closed diving bells will be subject to exposure to sea water splash, and possible total immersion in the case of diving bells.

Divers in closed diving bells will normally wear divers' rubber suits, but in other chambers they could be lightly clad with no electrical protection from their clothing.

Closed diving bells may be subjected to rough handling during launch and recovery and will also be immersed for a long time in sea water.

8.6.3 Technical Considerations

Figures 8 and 9 show a simplified version of a typical deck decompression chamber and a closed diving bell.

The typical DDC electrical installation includes a wide range of chamber equipment. In this particular installation the supplies used in the chamber are derived from a 440V 3 phase supply which is stepped down, isolated and rectified to give the protected 24V dc for use within the chamber.

Instrumentation operates from a basic 220V ac supply. The excitation voltages for the various sensors are never greater than 10V dc at low currents, typically 15mA. Regulation within the instrument associated with the sensor provides protection for these supplies.

In the electrical arrangement of a typical mixed gas closed diving bell all primary power is supplied via a main isolating transformer on the surface. The centre point of the secondary winding of this transformer is earthed through a suitable impedance to limit the fault current to a maximum of 1A. An RCD is fitted to the circuit with an overall response time of 20ms.

Power inside the diving bell is entirely 24V dc with no active protection, and is supplied by transforming and rectifying the power supplied from the surface inside a pressure proof container mounted on the outside of the bell.

The 220V ac supply which is used externally to power the under water lights is protected by being fed from the isolating transformer with the fault current limited and active protection provided by the RCD.

There are of course many variations possible and a detailed risk assessment will be required for the initial set up of the electrical equipment as well as for any subsequent modifications.

Relevant factors are:

- Is the installation ac or dc?
- If it is dc, is the ripple factor known to be within acceptable limits?
- How is the electrical power supplied to the system and is this supply monitored and controlled?
- If a trip device is in use, will it respond within the required timescale?
- Is the maximum voltage at the equipment known accurately?
- Does the voltage exceed the safe level?
- If using a surface supply, is this being fed from a transformer with the secondary winding isolated such that there is not an obvious return path if a fault develops?
- Has anything been modified or changed since the equipment was originally supplied?

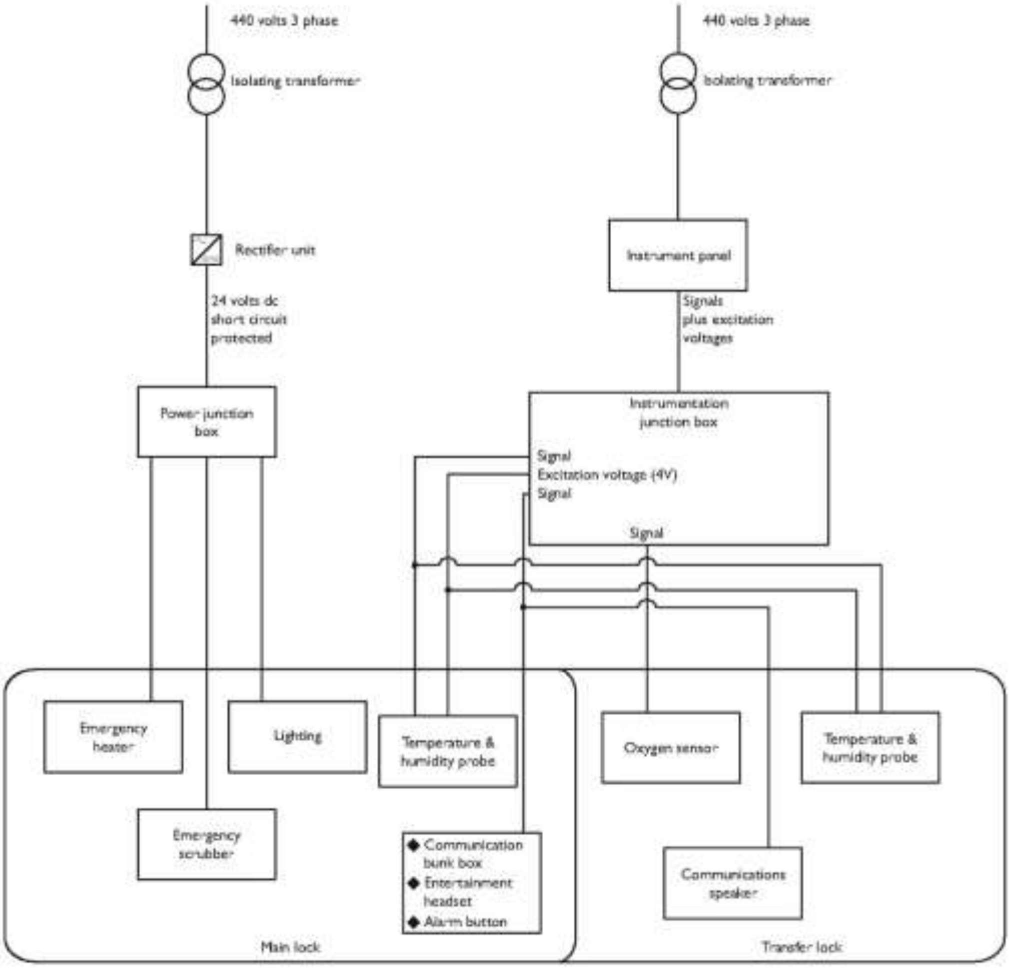


Figure 8 – Schematic of typical DDC electrical installation

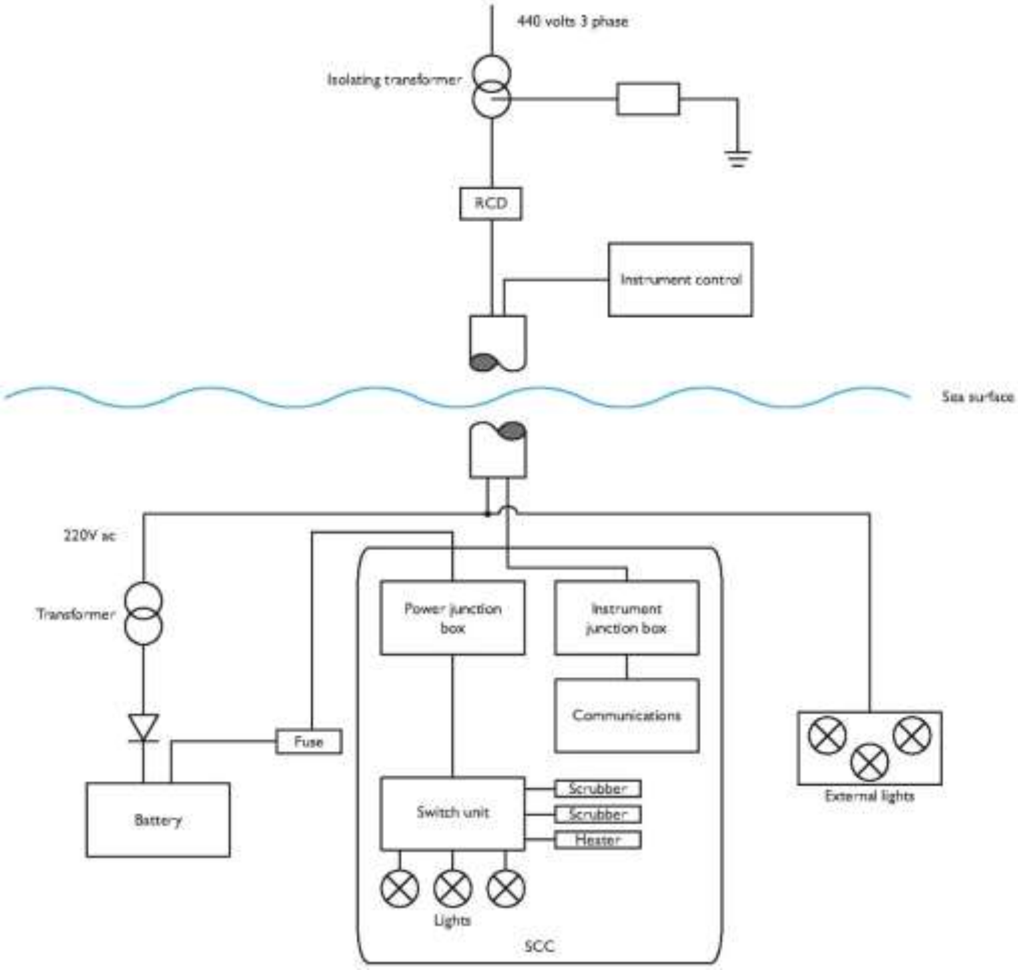


Figure 9 – Schematic of typical diving bell electrical installation

8.6.4 Some Potential Hazards

HAZARD	**HAZARD EFFECT**
Ripple factor too high	Diver may react as if ac current
Voltage information wrong	Diver may be exposed to an unsafe voltage
Trip device does not operate as required	Diver will be exposed to a voltage higher than is safe for the fault duration
Voltage higher than intended	Diver may be exposed to hazard
Supply not from isolating transformer	In the event of an electrical fault developing then an easy return path may exist exposing the diver to possible hazard
Modifications, repairs or changes made to the equipment since originally supplied	The electrical protections included by the designer/supplier may have been compromised
Failure of equipment	Fault/possible hazard to diver develops
Accidental damage to equipment	Possible hazard to diver created

Other hazards may be present in particular work situations and these will need to be considered by those carrying out the risk assessment.

8.6.5 Safe Practices

Using the figures contained elsewhere within this document, the following have been established as voltage levels for use inside a hyperbaric chamber that should provide the necessary level of safety to an occupant.

Supply	**Safe Body Current mA**		**Body Route Resistance Ω (ohms)**		**Safe Voltage**	
					Maximum V	**Nominal V**
	(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
ac with trip device (see note below)	500		500		250	220
dc with trip device	570		500		285	250
ac without a trip device	10		750		7.5	6
dc without a trip device	40		750		30	24

Note: If a trip device (such as an RCD) is used then it should be able to be reset by the diving supervisor after necessary safety checks. They should have an override facility which may only subsequently be operated by the diving supervisor if he considers the danger to the diver as a result of loss of power to be greater than the possible electrical hazard.

Based on these figures and the other contents of this document, there are at least two ways in which safety can be assured for divers inside a hyperbaric chamber:

1. If the operating voltage of the equipment is under the maximum safe voltage level of 30V dc (7.5V ac).
2. If the operating voltage is under the maximum safe voltage level of 250V ac (285V dc) and a trip device is fitted with a reaction time less than 20ms.

8.6.6 Operational Note

The normal method of ensuring diver/occupant safety from electrical hazard when inside a hyperbaric chamber is to adopt one of the two methods outlined above.

It is not intended to limit the electrical safety protections of this type of equipment to only these two methods and if another method can be established as providing the necessary level of diver/occupant safety then that method can be considered.

8.7 Inside a Welding (or Other) Habitat

8.7.1 Explanation

This refers to a structure which is located around or over the area to be worked on and inside which there is a substantially dry but humid gaseous atmosphere at ambient sea water pressure. The commonest use of such items is to provide facilities for hyperbaric welding.

Whilst it is not strictly under water, the electrical safety of a diver inside a habitat is very similar in that it is an extremely damp environment. The electrical safety parameters in a physiological sense are the same and the only difference is that the diver will be surrounded by a gaseous rather than aqueous environment.

8.7.2 Basic Considerations

Habitats are by their very nature subject to wide extremes of environment.

During operations, equipment within a habitat will be subject to internal pressure varying between 0 to 50 bar but normally in the range of 0 to 25 bar. This pressure could be subject to rapid change. Externally a habitat will be subject to sea water pressure according to the depth, which will be in the range of 0 to 50 bar, but normally 0 to 25 bar.

The atmosphere is either compressed air at a pressure of 0 to 5 bar or an oxygen and helium mix at a pressure of 0 to 50 bar. The oxygen concentration will normally be the lower of 25% by volume or 0.5 bar ppO_2.

The internal temperature will vary from 5°C up to 40°C and exceptionally, particularly in very small habitats, could rise to 60°C. External temperatures will vary from 0°C to 30°C but will normally be between 5°C and 15°C.

During operations the humidity level will vary from 70-100%.

Occupants' clothing will be divers' rubber suits, conventional welding clothing or even fire resistant boiler suits.

During the deployment phase, the habitat may be flooded and any electrical equipment needs to be capable of withstanding total immersion in salt water at ambient pressure. The habitat may also be subjected to rough handling during launch and recovery and will remain immersed for a long time in sea water.

8.7.3 Technical Considerations

The figure below shows the electrical arrangement of a typical welding habitat.

All primary power is supplied via a main isolating transformer on the surface. All voltages in the habitat are derived from additional isolating transformers on the habitat.

Umbilical lines from the surface are continuously monitored for insulation breakdown using line insulation monitors. Critical power supplies within the habitat, such as pre-heat power and power for hand-held tools, are also monitored continuously using line insulation monitors (LIMs). The LIMs monitor leakage resistance by a dc injection method and can be arranged to provide shut-down of an affected circuit at any pre-set level of leakage. They also provide a continuous read-out to monitor progressive deterioration of circuit insulation.

There are of course many variations possible and a detailed risk assessment will be required for the initial set up of the electrical equipment as well as for any subsequent modifications.

Relevant factors are:

- Is the equipment ac or dc?
- If it is dc, is the ripple factor known to be within acceptable limits?
- How is the electrical power supplied to the system and is this supply monitored and controlled?
- If a trip device is in use, will it respond within the required timescale?

- Are the LIMs working and are the circuit breakers set to operate at the correct level?
- Is the maximum voltage at the equipment known accurately?
- Does the voltage exceed the safe level?
- If using a surface supply, is this being fed from a transformer with the secondary winding isolated such that there is not an obvious return path if a fault develops?
- Has anything been modified or changed since the equipment was originally supplied?

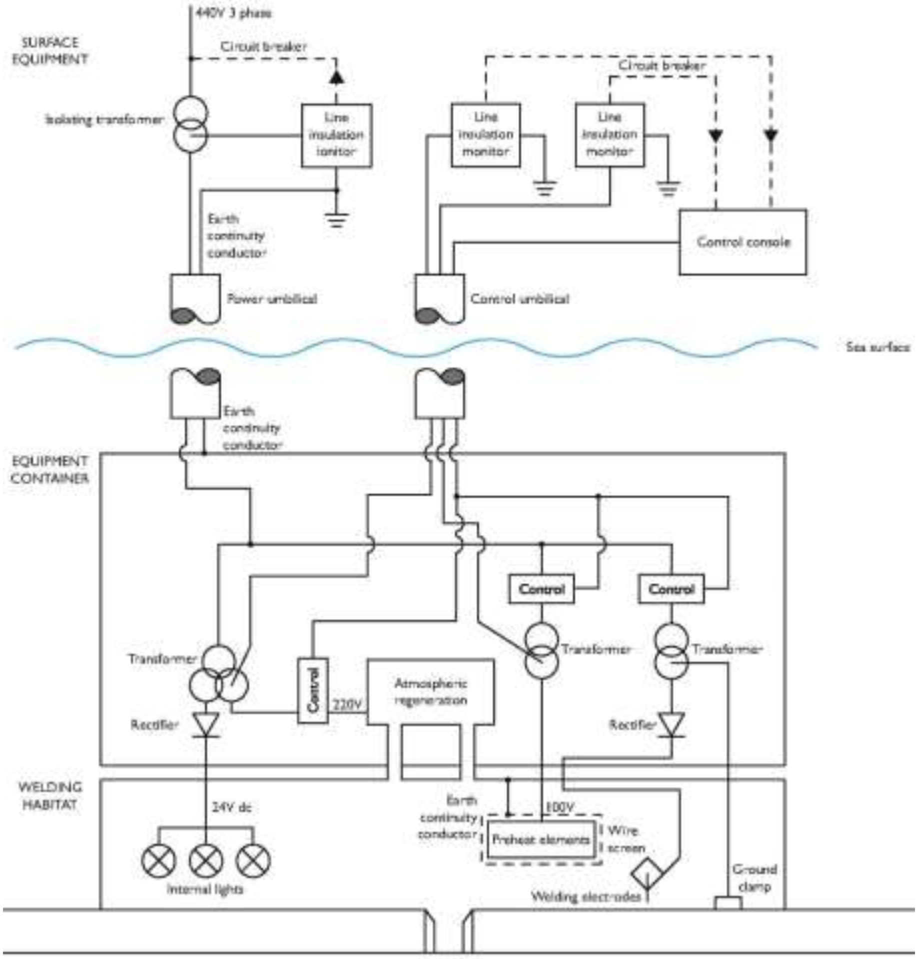


Figure 10 – Schematic of welding habitat power supply

8.7.4 Some Potential Hazards

HAZARD	HAZARD EFFECT
Ripple factor too high	Diver may react as if ac current
Voltage information wrong	Diver may be exposed to an unsafe voltage
Trip device does not operate as required	Diver will be exposed to a voltage higher than is safe for the fault duration
LIM not operating correctly	An insulation fault may have developed that exposes the diver to a possible hazard
Circuit breaker may not function	An insulation fault may expose the diver to a possible hazard
Voltage higher than intended	Diver may be exposed to hazard

Supply not from isolating transformer	In the event of an electrical fault developing then an easy return path may exist exposing the diver to possible hazard
Modifications, repairs or changes made to the equipment since originally supplied	The electrical protections included by the designer/supplier may have been compromised
Failure of equipment	Fault/possible hazard to diver develops
Accidental damage to equipment	Possible hazard to diver created

Other hazards may be present in particular work situations and these will need to be considered by those carrying out the risk assessment.

8.7.5 Safe Practices

Using the figures contained elsewhere within this document, the following have been established as voltage levels for use inside a habitat that should provide the necessary level of safety to an occupant.

Supply	**Safe Body Current mA**		**Body Route Resistance Ω (ohms)**		**Safe Voltage**	
					Maximum V	**Nominal V**
	(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
ac with trip device (see note below)	500		500		250	220
dc with trip device	570		500		285	250
ac without a trip device	10		750		7.5	6
dc without a trip device	40		750		30	24
A supply fed from an ac isolating transformer with non-earthed secondary, using a line insulation monitor with circuit breaker	n/a		n/a		In this case, a single fault does not present a hazard and thus no maximum voltage need be stipulated provided the protective devices are able to prevent the occurrence of a second fault from constituting a hazard	
A supply fed from an ac isolating transformer with the secondary earthed through an impedance to limit fault current to 1A, and trip device	n/a		n/a		No voltage limit is stated as the diver is protected by the fault current limit and the associated trip device	

Note: If a trip device (such as an RCD) is used then it should be able to be reset by the diving supervisor after necessary safety checks. They should have an override facility which may only subsequently be operated by the diving supervisor if he considers the danger to the diver as a result of loss of power to be greater than the possible electrical hazard.

Based on the above and the other contents of this document, there are at least three ways in which safety can be assured for divers working in or around a habitat.

1. If the operating voltage of the system is under the maximum safe voltage level of 30V dc (7.5V ac).
2. If the operating voltage is under the maximum safe voltage level of 250V ac (285V dc) and a trip device is fitted with a reaction time less than 20ms.
3. Feeding the ROV main electrical supply from an isolating transformer set up in one of the ways detailed above.

8.7.6 Operational Note

The normal method of ensuring diver/occupant safety from electrical hazard when inside a hyperbaric chamber is to adopt one of the methods outlined above.

It is not intended to limit the electrical safety protections of this type of equipment to only these three methods and if another method can be established as providing the necessary level of diver/occupant safety then that method can be considered.

8.8 Divers Working with ROVs

8.8.1 Explanation

There are a number of scenarios where a diver may be expected to work on or in the close vicinity of an ROV. These will vary from the situation where a small ROV is being used to monitor the diver's task (or to provide a view to the surface personnel from a different angle to that seen on the diver's head mounted camera) to situations where an (possibly large and high powered) ROV has suffered a failure or become entangled and a diver is asked to assist in its recovery.

The diver will be exposed to a potential possible hazard if any of the electrical equipment on or forming part of the ROV is defective or malfunctions while the diver is in the vicinity or is working directly on it.

This section only covers the possible hazard to the diver from the electrical power supplied to the ROV. It does not address any possible electrical hazard to personnel above water. It also does not address other possible hazards to the diver such as entrapment, hydraulic power, rotating thrusters etc.

Specific guidance on divers working in the vicinity of ROVs is contained in IMCA publication AODC 032 – *Remotely operated vehicle intervention during diving operations*

8.8.2 Basic Considerations

The diver is considered as being totally immersed in sea water of normal salinity. The surrounding water temperature will be in the range 0°C to 30°C and the pressure in the vicinity will be dependant on the depth.

8.8.3 Technical Considerations

Figure 11 shows a simplified electrical circuit for a typical ROV.

Primary power is derived from the vessel's 440v 3 phase system stepped up to 1100V through an isolating transformer to provide 1000V via the umbilical to the hydraulic pump motor mounted on the vehicle. This supply is monitored by an LIM connected to an alarm.

Lights and controls are also fed in a similar manner and monitored by a second LIM.

There are many different types of ROV thus the advice given here has to be generic and a detailed risk assessment will need to be carried out for any specific situation before it will be safe to commence a diving operation.

Before commencing a risk assessment to consider whether it is safe to carry out any proposed diving operation, a number of factors need to be established and considered. The list below is not necessarily comprehensive as there may be other factors peculiar to the particular ROV or job site that need to be considered.

Relevant factors are:

- Will the diver have sufficient visibility to see the ROV properly?
- Will the ROV pilot have sufficient visibility to see the diver?
- Are there good two-way audio communications between diver and diving supervisor?
- Are there good two-way audio communications between the ROV pilot and the diving supervisor?
- Is the diver able to assume a stable and secure working position?
- Is the ROV under sufficient control that the pilot can ensure its correct positioning?
- How is the electrical power supplied to the ROV and is this supply monitored and controlled?
- Is the maximum voltage of all the electrically powered equipment accurately known?
- Does the voltage exceed the safe level?

- If a trip device is in use, will it respond within the required timescale?
- If any of the electrical power supplies are provided through a transformer, does that transformer have the secondary winding isolated such that there is not an obvious return path if a fault develops?
- Is there the possibility of stored energy in the supply umbilical?
- If there is any dc supply, is the ripple factor known to be within acceptable limits?
- Has anything been modified or retrofitted that may affect the electrical safety of any of the systems?

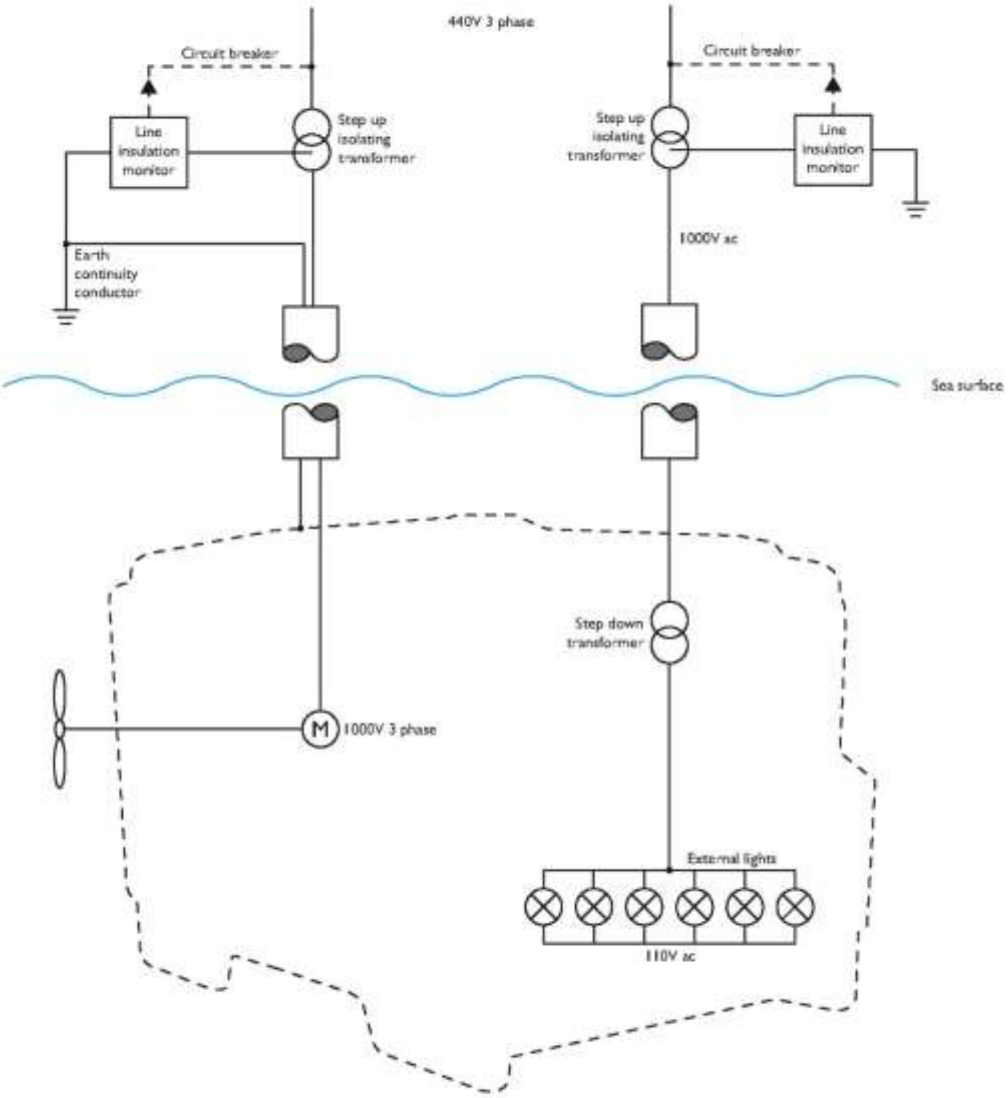


Figure 11 – Schematic of a typical ROV

8.8.4 Some Potential Hazards

HAZARD	**HAZARD EFFECT**
Voltage gradient in the water	Diver may become disorientated
Failure of equipment	Fault/possible hazard to diver develops
Accidental damage by diver	Possible electrical hazard created
If dc used, ripple factor too high	Diver may react as if ac current

Voltage information wrong	Diver may be exposed to an unsafe voltage
Safe distance wrongly calculated	Diver may come too close to an energised source and enter an unsafe area
Modifications, repairs or changes made to the equipment since originally supplied	The electrical protections included by the designer/supplier may have been compromised
A trip device being relied on does not operate as required	Diver will be exposed to a voltage higher than is safe for the fault duration
Other electrical equipment in area which malfunctions	Diver may be exposed to stray voltage
Supply not from isolating transformer	In the event of an electrical fault developing then an easy return path may exist exposing the diver to possible hazard

Other hazards may be present on particular ROVs and will need to be considered by those carrying out the risk assessment.

8.8.5 Safe Practices

Using the values contained elsewhere within this document, the following have been established as voltage levels for the equipment that the diver is being asked to work on or near that should provide the necessary level of safety.

	Safe Body Current mA		**Body Route Resistance Ω (ohms)**		**Safe Voltage**	
					Maximum V	**Nominal V**
	(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
ac with drip device	500		500		250	220
A supply fed from an ac isolating transformer with non-earthed secondary. Using a LIM with circuit breaker	n/a		n/a		In this case a single fault does not present a hazard and thus no maximum voltage needs to be stipulated provided the protective devices are able to prevent the occurrence of a second fault constituting a hazard	
A supply fed from an ac isolating transformer with the secondary earthed through an impedance to limit fault current to 1A and trip device	n/a		n/a		No voltage limit is stated as the diver is protected by the fault current limit and the associated trip device	

Based on the above and the other contents of this document, there are at least four ways in which safety can be assured for divers working on or near ROVs.

1. If the operating voltage of the ROV is under the maximum safe voltage level of 250V ac and a trip device is fitted with a reaction time less than 20ms.
2. Feeding the ROV main electrical supply from an isolating transformer set up in one of the ways detailed above.
3. If the diver can be physically restricted such that he can be assured to remain at least the minimum safe distance away from the ROV at all times.

4. Note: As both diver and ROV will be changing position during the dive, this method should only be used if there is an absolute guarantee that the safe distance can be maintained in all foreseeable circumstances.
5. If the ROV malfunctions such that normal control is lost by the ROV pilot (control problems; partial or total power loss; physical damage; entanglement of vehicle etc) and a diver is asked to intervene, then it will normally be necessary to electrically isolate the ROV before the diver approaches it unless there are other ways in which diver safety can be guaranteed. Any isolations need to be carried out very thoroughly and carefully and detailed information on this subject is contained within IMCA D 044 *– Guidelines for isolation and intervention: Diver access to subsea systems.*

8.8.6 Operational Note

The normal method of ensuring diver safety from electrical hazard when near an ROV is to adopt one of the methods outlined above.

It is not, however, intended to limit the provision of electrical safety to only these methods and if another method can be established as providing the necessary level of diver safety then that method can be considered.

Bibliography

If it is required to investigate in detail any of the values or concepts used in this Code, then it is recommended that a search is done using the internet for any relevant or helpful research or source documents.

Further details on IMCA/AODC publications and their latest revisions are available from IMCA (www.imca-int.com).

Listed below are the main documents that the workgroup referred to when revising this Code.

CEI/IEC/TS 60479-1:2005 – Technical Specification TS 60479-1 Fourth Edition 2005-07 – *Effects of current on human beings and livestock part 1: General aspects*

IEC/CEI/TS 60479-2:2007 – Technical Specification TS 60479-2 Third Edition 2007-05 – *Effects of current on human beings and livestock part 2: Special aspects*

British Hyperbaric Association – *Guide to electrical safety standards for hyperbaric treatment centres*, July 2006, ISBN 0952762307

GKSS 91/E/30 – *Safety of wet welding with increased open circuit voltages up to 150V dc*, April 1991

IMCA D 044 – *Guidelines for isolation and intervention: Diver access to subsea systems*, October 2009

OT-R-8273 – *Shock risk to swimmers and divers from an electrical field*, September 1980

OT-R-8274 – *Calculation of safe distance from an electrically live object in water*, January 1981

IMCA D 003 – *Oxy-arc cutting operations underwater*, December 1995

IMCA D 002 – *Battery packs in pressure housings*, January 1996

IMCA D 041 – *Use of battery-operated equipment in hyperbaric conditions*, October 2006

AODC 032 Rev. 1 – *Remotely operated vehicle intervention during diving operations*, September 1992

IMCA D 018 – *Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment*, February 1999

Calculation of 'Safe Distance'

In certain instances involving diver intervention in the vicinity of a subsea electrical component or system, it may be a requirement to consider the possibility of the component becoming, or remaining, live during the work. Possible reasons for this could be:

- There may be equipment near to the worksite (but not involved in the actual work) which needs to remain energised;
- The increasing complexity of electrical power applications subsea may result in circumstances for which it is not possible to obtain a confirmed isolation;
- Systems which have been installed for many years (in some cases more than 20 years) have a potential for component failure;
- Divers (rather than an ROV) may be required to approach a worksite for initial non-intrusive investigation purposes whilst the (possibly faulty) electrical system remains live, or is subjected to a series of topside fault-finding/diagnostic tests.

Electrical safety for the diver can be ensured in such situations if the diver can be prevented from coming closer to any possible electrical fault than a specified safe distance. (See section 7.2).

Thus, for safe intervention to take place in any of the above (or similar instances), the risk-assessment process associated with the work should establish and specify in advance, by calculation, the approximate minimum safe distance to which a diver can approach the subsea system component or system which may continue to contain electrical energy.

When considering the safe distance from a particular piece of electrical equipment, there are two scenarios that need to be considered:

- The first is the instantaneous short circuit fault current (in an ac system) which will exist for a very short time. This would result from an incident such as a live cable being accidentally cut.

  The worst case scenario is that at the time of the cut the ac cycle had just crossed the x-axis, and would then continue to rise to its maximum value. The fault current would therefore exist until the ac cycle next crossed the mid point. This length of time is dependant on the frequency. For example at a frequency of 50Hz the time for a half cycle would be 10ms but at 400Hz it is only 1.25ms. This time can then be used to obtain the maximum safe body current using the relevant graph in IEC 60479 (or the graph in this Code). With this safe body current and the recommended body resistance of the diver (500Ω for medium or high voltages) it is possible to calculate the safe voltage for that specific situation.

  Due to the very short time that this possible electrical hazard will exist, it may well be established that this safe voltage is higher than the voltage that would be applied to the diver and that this worst case scenario is therefore within the safe limits for diver safety.

  A competent person can calculate the instantaneous short circuit fault current (in an ac system) using a method such as a differential equation.

- The second situation is the steady state fault current that will exist due to the supply itself and/or stored energy in the faulty cable/equipment (or a dc supply). In this case a competent person should establish the maximum possible fault current and use this figure to calculate the safe distance using the formula in this appendix.

Values of safe distance in water depend on the ratio of fault current (I_o) to the safe body current (I_b). Guidance on levels of safe body current is given in the Physiology section 3.

Note: The values are: ac I_b value = 10mA
dc I_b value = 40mA

The approximate safe distance in sea water (S_s) in metres is calculated according to the following formula:

$$\mathbf{S_s = (1 + \{(I_o \times 10^{-4})/ I_b\})^{1/2} - 1}$$

A2-1 Worked Examples

A2-1.1 Example 1: Possible faulty ac power supply cable

Consider the case where the inter-connecting cable between two umbilical terminations has a fault, such that the given component short-circuit fault current (I_o) has been calculated as being 40A;

Now, maximum safe body current (I_b) = 10mA (from previous), thus safe distance (sea water):

$$\begin{aligned} S_s &= (1 + \{(I_o \times 10^{-4})/ I_b \})^{\frac{1}{2}} - 1 \\ &= (1 + \{(40 \times 10^{-4})/10 \times 10^{-3}\})^{\frac{1}{2}} - 1 \\ &= 0.18 \text{ metres} \end{aligned}$$

A2-1.2 Example 2: Possible faulty instrumentation housing and/or associated dc signal cable harness

The given component short-circuit fault current (I_o) has been calculated as being 20mA;

Now, maximum safe body current (I_b) = 40mA (from previous), thus safe distance (sea water):

$$\begin{aligned} S_s &= (1 + \{(20 \times 10^{-3} \times 10^{-4})/40 \times 10^{-3}\})^{\frac{1}{2}} - 1 \\ &= 0.025 \text{ millimetres} \end{aligned}$$

In this example, the electrical energy is of such low level that the safe distance separation is, for all practical purposes, imperceptible to a diver, provided he does not actually come in direct contact with the items.

A2-1.3 Example 3: Diver required to approach, or be in the vicinity of, the anode of an impressed current cathodic protection system, whilst it remains operational

In such instances, the short-circuit fault current (I_o) is taken to be equivalent to the impressed current at the anode (in this case 2000A dc)

Now, maximum safe body current (I_b) = 40mA (from previous), thus safe distance (sea water):

$$\begin{aligned} S_s &= (1 + \{(2000 \times 10^{-4})/40 \times 10^{-3}\})^{\frac{1}{2}} - 1 \\ &= 1.45 \text{ metres} \end{aligned}$$

Note 1: As a matter of diver-safety awareness, it should be noted that the above results are obtained from the formula derived for sea water. In fresh water (due to the difference in conductivity to sea water), the safe distance is much greater.

The approximate safe distance in fresh water (Sf) in metres is calculated according to the following formula:

$$S_f = (1 + \{I_o/(I_b \times 40)\})^{\frac{1}{2}} - 1$$

This yields a much longer minimum safe distance from a faulty component – for instance in Example 1, above, the calculated safe distance S_f, for fresh water is 9.05 metres (compared to 0.18 metres for salt water).

Note 2: The references for derivation of these two equations and the simplifying assumptions made are in Appendix 1, references OT-R-8273 and OT-R-8274.

Residual Current Devices

Differential current operated residual current devices (RCDs) offer several major advantages over other earth-fault protection devices, e.g. reliability, availability and circuit discrimination. The latter is particularly important in the diving situation since it is undesirable to switch off certain items of equipment whose circuitry is 'healthy' in the event of an earth-fault occurring on another circuit connected to the same isolating transformer.

However, in order that differential current RCDs may operate, a secondary return path must exist. This is conveniently achieved using an earthing impedance (Z_n) between the star-point, or central tapping on the secondary winding of the isolating transformer, and 'earth'. Ignoring the effect of cable capacitance, this will allow a maximum current, I_e, to flow through the earth-return circuit (the water) where:

$$I_e = \frac{V}{Z_n}$$

V being the open circuit voltage between the power supply system and 'earth' at the point of occurrence of the earth-fault. Usually V will be the phase voltage of the system.

The question remains as to the choice of Z_n and hence I_e. From the point of view of risk to the diver from through-water electric currents, the lower I_e the better. However, from the point of view of RCD operation, the higher the I_e the better.

In the event of an earth-fault it is important to ensure adequate tripping margin over the RCD tripping level. The use of RCDs by the coal mining industry with similar systems had suggested that I_e should be at least 10 x RCD trip level. This factor of 10 allows for the reduced tripping current available if a phase-phase fault occurs simultaneously with an earth-fault.

Although satisfactory performance has been experienced with RCD tripping levels of 20mA to 30mA, such a level may lead to spurious tripping problems, particularly with longer cable lengths. However, making 'worst' assumptions about cable lengths and capacitance, a tripping level of less than 100mA (the figure of 80mA has been used in the coal mining industry) will be practicable. Thus, earth fault current restriction at 1 amp is acceptable and has been used in this document.

Commonly used RCDs have a typical operating time of 15ms to 25ms. The trip currents of RCDs should be selected to be as low as possible consistent with freedom from accidental tripping which is inconvenient and can be dangerous. A trip current of 30mA at 20ms has been found to be suitable.

Two alternative types may be used; one uses a differential transformer to detect out of balance current and the other is connected between an isolated supply and earth.

For dc systems, differential transformer RCDs are not applicable, and isolated supply RCDs should be designed for use in dc circuits.

Because of practical limitations in their design, differential transformers may have an upper limit on the rated value of the line current. Isolated supply RCDs are not subject to any limits of load current.

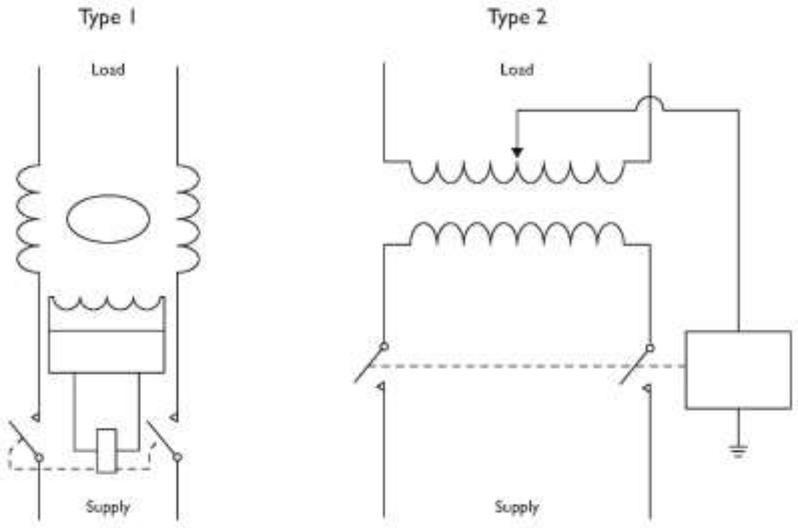


Figure 11 – Schematics of typical residual current devices

Note: Type 1 can only operate if an earth reference exists within the supply circuit.

Salinity of Water

Pure water is essentially non conductive, but when impurities such as salts are added to water, the resistivity of the solution decreases significantly. This effect has a significant bearing on the safety of a diver immersed in such water, in relation to electrical shock hazard.

The reason for this is that when the human body is immersed in water that conducts an electric current, the path of the electric current through the water is determined by the relative resistivity of the body and the water. If the water is less resistive than the immersed body (as is the case with sea water), much of the current that would have been flowed through the water displaced by the body will flow around the body rather than through it. However, if the water is more resistive than the body (as is the case with fresh water), a larger portion of the current will take the path of least resistance and 'collect' or 'concentrate' through the body.

The presence of the body distorts the electric field and paths of current flow in the water. The least distortion of the electric fields and current paths will occur when the resistivity of the water is nearly the same as the resistivity of the body parts displacing the water. However, since the body is not homogenous, the presence of a body in the water will always distort the electric field and current paths to some extent.

The strength of the electric field (in V/cm) is equal to the resistivity (in Ω.cm) times the current density (in A/cm^2). Therefore, for two parallel paths with the same electric field across them, the path with the lower resistivity will carry a proportionately higher current density.

The table below gives some typical resistivities.

Types of Water (Typical)	**Resistivity (Ω.cm)**
Sea water	22
Swimming pool water	300
Tap water	1,300 to 16,000
Rain water	Up to 420,000
Resistivity of Human Body Parts	
Bone	1,600
Trunk	415
Arm	160

There are many variables that affect the values of density, salinity, conductivity and resistivity of water, the main ones being temperature and pressure. The values given here are therefore typical examples only.

The salinity of sea water varies around the world with a typical average value being 3.5% (the range is 3.1 to 3.8%). That is to say that each 1000g of water has 35g of salts dissolved in it. Around 90% of these salts are sodium chloride. The average density of sea water is 1.025g/ml.

In contrast fresh water has a salinity of 0% and a density of 1.0g/ml.

The safety advice given in this Code is based on the diver being immersed in 'normal' sea water (that is, having a salinity between 3.1 and 3.8%). For the vast majority of offshore diving this will be the case. However, at the planning stage for each project one of the factors that will need to be considered is whether the water surrounding the diver will indeed be 'normal' sea water or if it may have reduced salinity and therefore different conductivity and resistivity to that used when arriving at the advice given in this document.

The sort of situations that could result in reduced salinity in the water might be diving in a bay where there was a large volume of fresh water being discharged by a river (this effect can sometimes be encountered several miles offshore) or diving in an inlet or similar protected area of water again with fresh water emptying in to it from nearby hills or rivers.

If there is any possibility of the salinity of the water being outside the 'normal' range then a competent person should be involved in the planning. This person should establish what the exact salinity of the water is and then consider whether any of the electrical safety considerations (such as safe distance) need to be modified to allow for the altered salinity.

Note: The appendix gives an outline of the effect of salinity on the electrical safety of a diver. If more detail is required then the reader is referred to document IEC 60479-2 Section 10 or to the many research papers available on the internet.

Design Considerations

A5-1 Introduction

This appendix is intended for the equipment designer or selector of equipment intended for use inside a diving bell, under water habitat, or deck compression chamber, or otherwise in possible contact with a diver's breathing gas supply. It gives more detailed information on certain aspects of equipment specification than is contained elsewhere in this document.

In the event of a fire or even overheating, many commonly used electrical materials give off noxious and toxic fumes. As a diver is confined within his environment (particularly inside a diving bell, habitat or deck compression chamber) and unable to escape from any fumes, it is important always to use low-toxicity cables and other materials.

It is assumed that before reading this section the design engineer has already read the other parts of this document.

Adequate records should always be kept of the reasons for selection of any items of electrical equipment, which should be available to a designer of any future modifications.

A5-2 New Techniques

This Code is based on equipment and practices which are in current use but it is not intended in any way to hamper development of new or alternative techniques, provided at least the same levels of safety are provided.

Designers should use the basic guidance contained within this Code to evaluate new equipment and to establish levels of safety.

A5-3 Toxicity Hazard in Gaseous Environment

All organic materials decompose at elevated temperatures to produce toxic products, but the rate of decomposition and the degree of toxicity of the products vary.

Particular care should be taken when selecting electrical components which will be in contact with breathing gas circuits or the atmosphere inside a diving bell, under water habitat or deck decompression chamber.

The amount of potentially toxic material should be minimised by limiting the electrical equipment inside a chamber or in contact with breathing gas supplies. Short cable runs should be used whenever possible. The thickness of the insulating material should be chosen to minimise the quantity of toxic material in the chamber, consistent with adequate electrical protection.

Where practicable, toxicity hazard should be reduced by keeping the electrical equipment separate from spaces containing breathing gas. The choice of position is influenced by the availability of the equipment to work in the surrounding environment.

Electrical components used inside a chamber may need some specialised containment to withstand the working pressures and to protect against any toxic emissions which may occur. The wiring should be mechanically protected. The possibility of high humidity or even total immersion should also be considered as moisture could cause toxic fumes.

Current ratings should be chosen to keep the normal operating temperature within accepted limits for a given insulation material. Acceptable voltage drop and the possible sustained fault current should be considered. Earth fault, overload and short-circuit protection should be provided.

A5-4 Selection of Insulating Material

Insulation materials should be chosen which do not readily ignite and which emit the minimum of smoke and toxic gas when overheated. The definition of such performance is not strictly laid down, but a number of manufacturers provide materials which are stated to provide this facility and these are preferred. PVC is not recommended since it readily decomposes to hydrogen chloride when overheated.

Cable manufacturers should be consulted about any particular application before a cable is selected. The following parameters should be determined:

- normal current;
- fault current and duration;
- ambient temperature and pressure;
- atmosphere and volume of environment;
- possible contamination;
- length of cable run;
- supporting and termination methods;
- identification required;
- mechanical strength required.

A5-5 Terminal Blocks and Circuit Boards

The materials used for terminal blocks, circuit boards and cable markers should be chosen with toxicity in mind because these items may reach high temperatures as contacts deteriorate. Terminals of higher thermal capacity and substantial thermal conductivity reduce the rate of temperature rise in the event of contact deterioration.

A5-6 Protection Against Explosion and Fire Risk

In normal circumstances the gaseous environment of a diver or submersible pilot is not explosive, but there may be a fire hazard in certain circumstances as a result of oxygen enrichment (caused either by increase of oxygen or by increased pressure), particularly when using compressed air.

Potential electrical sources of ignition include electrical arcs, sparks and hot surfaces.

Some equipment intended for use in potentially explosive atmospheres (often referred to as 'increased safety 'e"), incorporate supplementary protective measures to prevent the possible occurrence of excessive temperatures and arcs or sparks in apparatus which does not normally produce them. Apparatus which complies with these requirements may be applicable in the under water case.

Where apparatus contains components which may normally arc or spark, or hot surfaces capable of causing ignition, or where the possibility of potential ignition sources cannot be discounted, the apparatus should be of a protected type.

There are a number of standards and publications which deal with the types of electrical equipment to be used in explosion or fire risk areas. However, great care should be used in applying them to under water usage as all such standards refer to atmospheric pressure, and existing techniques for surface use are not necessarily applicable directly under water. Expert advice should be sought from manufacturers as to whether particular equipment is suitable for the environment. It may be necessary to carry out tests in some cases. Temperature classifications also vary under conditions of increased ambient pressure and they should also receive careful consideration.

Explosive gaseous mixtures can be produced during welding by the decomposition, by heat, of organic insulating materials. Similar operations can produce flammable and toxic gases and vapours which may accumulate in pockets or enclosures and increase the hazards. These gases may not disperse as in freely ventilated locations at the surface.

On electrolysis, water produces hydrogen and oxygen in proportions which form a potentially explosive mixture. Installations should be arranged to minimise entrainment of hydrogen and oxygen as they significantly increase the risk of ignition and the consequential danger of explosion and fire.

Precautions necessary to ensure electrical safety depend on the risks involved, the particular application, the nature of the gas mixtures present and the ambient pressure. Where, because of the nature of the application, it is considered that the area is not normally hazardous, due account should be taken of any possible unforeseen hazards. Particular account should be taken of the degree of control of gases present and their relative proportions, especially in manned environments.

Electrical safety in hazardous areas should be considered in a logical sequence.

- Where reasonably practicable, electrical apparatus should be located outside the hazardous area;
- If electrical apparatus has to be situated in a hazardous area then it should not contain arcing or sparking components, or hot surfaces capable of causing ignition during normal operation unless it is protected by suitable containment;
- Electrical equipment intended for use in any area where moisture is likely to be present should be selected to eliminate moisture tracking and be otherwise suitable for the environment.

Batteries

In the past, batteries have often been considered to be electrically 'safe'. However as in many cases they are not used as a primary power source, but rather as a reserve or back-up, they are frequently omitted from electrical safety assessments.

In practice batteries can present very real hazards and considerable care should be taken when using them.

Primary cells (non-rechargeable batteries) have a limited life and when discharged are notorious for producing corrosion products.

Short-circuiting of primary cells can be potentially hazardous and adequate short-circuit protection should be provided.

Secondary cells (rechargeable batteries) are normally of higher power than primary cells, so the same basic recommendations apply. In addition, however, there can be an explosive hazard from hydrogen gases produced during recharging and discharge.

Secondary cells should normally be recharged out on the surface in a properly ventilated area. If fixed installations are required to have submerged recharging facilities, the charge should be limited to a level below the gassing voltage; as a result, extra cells may be required to attain the working voltage and the required battery capacity.

Where devices are provided for the recombination of free hydrogen and oxygen, care should be taken to prevent overcharging which may lead to carry-over of the electrolyte and malfunction of the device.

If water enters a battery compartment, an explosive or toxic gas mixture may be produced. Battery compartments should be completely watertight.

Fuses should be fitted in the battery compartment as close as possible to the batteries and should be encapsulated to prevent a blown fuse from igniting the possible hydrogen atmosphere in the compartment.

The state of batteries in battery-powered equipment should be checked before use.

Batteries should be handled with caution. Since a battery cannot be turned off, it constitutes, even in a low charge state, a shock risk and also a burn risk, if accidentally short-circuited by metal tools. Electrolyte spillage or carry-over can also provide a leakage path from a high potential terminal.

Where there is any possibility of relative movement between batteries, then flexible electrical connections should be used.

Note: Further information on the use of batteries in diving operations can be found in IMCA D 002 – *Battery packs in pressure housings* – and IMCA D 041 – *Use of battery-operated equipment in hyperbaric conditions.*

Installation Practices

To maintain the integrity of all forms of protection, portable and fixed electrical equipment should be regularly inspected by competent personnel. Only such personnel should carry out installation or rewiring, and any temporary electrical equipment used should be to the standard described in this Code.

Contractors responsible for under water electrical equipment should authorise staff in writing as competent for specific functions.

Competent personnel should be familiar with proper installation procedures and be aware of the hazards and problems particular to under water work.

Frequent inspections should be made for signs of mechanical damage on cables and for any general deterioration of equipment.

The following measures should be adopted for the installation, modification and repair of all electrical equipment for use under water.

- All conductors should be adequately protected by suitable fuses and/or circuit-breakers;
- Conductors should have an adequate cross section, based, not only on full load current and voltage drop along its length, but also on sustained overload current if applicable, and the fault current which can flow for the time taken for any protective devices to operate;
- A minimum number of joints should be used in a circuit to reduce the possible number of poor connections;
- Terminal connections of proven integrity should be used, and conductor 'tails' should be supported to avoid fatigue failures;
- Wiring should be spaced to avoid cross-circuit breakdown or tracking;
- Conductors should be routed clear of areas where they may be liable to mechanical damage, or else provided with some form of mechanical protection. Fixed cables should be positioned so that they do not form a convenient hand grip;
- Terminal chambers should be sealed against entry of moisture;
- Common power return circuits should not be used. Each circuit should function independently. Similarly each protected circuit should be separate so that a fault on one cannot interact with a second circuit;
- Identification sleeving is potentially toxic when heated and should be fitted at a distance from the termination;
- A good tracking index material should be used and adequate tracking distance should be incorporated in the design of plugs, sockets, connections and printed circuit boards to make allowance for any salt which may be present on the surface. Penetrators, where continued tracking erosion can cause failure of the pressure seal, are particularly vulnerable;
- Solder should not be used on stranded or flexible cables, unless the wiring is fully supported, to avoid any stress or fatigue at the joints resulting from vibration;
- Records should be maintained to ensure that the design safety standards are met;
- Records should be kept of maintenance carried out and any modifications made to equipment;
- Records should be kept of routine testing of active protection devices.

Note: More detailed information on testing and certification practices can be found in IMCA D 018 – *Code of practice on the initial and periodic examination, testing and certification of diving plant and equipment.*

Methods for Protection Against Shock

Available methods of protection against electric shock fall into two groups, passive and active. Passive methods (insulation, screening and earthing) constitute a first line of defence against shock, and one or more of them should always be used.

When a passive method fails, due for example to water ingress or deterioration of earthing connections, the system may be in an undetected dangerous condition and constitute a shock risk. Consequently, a passive method alone may be inadequate where a high level of protection is needed and the use of active protection in addition, such as a residual current device, should be considered.

A8-1 Passive Protection

There are five ways of providing passive protection.

A8-1.1 Insulation

The primary means of providing passive protection against shock is by insulation of the power system and the appliance it serves. Insulation is less effective under water than on dry land, because a defect at any point might allow current to flow in the water and part of this current may be intercepted by the diver.

The effectiveness of insulation as a means of protection may be improved by using two layers of insulation with a conducting screen in between. Two defects are then needed to constitute a risk. The first defect can be detected by continuously monitoring the insulation level between the conducting screen and the load, and between the screen and the outer casing. Entry of water could cause simultaneous failure of both sections of insulation; consequently sealing arrangements (such as 'O'-rings and pressure balance terminations) should be incorporated if double insulation is to be more effective than single insulation.

Insulation should be further improved by supplying the load via an isolating transformer, the whole of the electrical system (including the transformer secondary winding and all the appliances) thus being insulated from earth. This prevents, for example, contact with a crane wire from the surface, the leg of a steel platform or a ship's hull from forming an earth return path and thereby creating a hazard.

If a first defect is not rectified, contact with the circuit or the occurrence of a second defect may then cause current to flow through the diver. However, this can be avoided by incorporating an active protection device for detecting the first defect. The whole of the circuit (transformer, secondary winding, connected cable and the load) should have a high insulation resistance to earth. It is also necessary to restrict the capacitance of the circuit to earth.

In practice, the capacitance usually imposes a limit on the maximum length of cable connecting the transformer secondary winding to the load.

A8-1.2 Fixed Barrier (Safe Distance)

When electrical equipment requires direct contact with sea water to function correctly (e.g. an impressed current anode) a fixed barrier can be installed to keep the diver a specific safe distance away from it. This barrier should be non-metallic and non-conducting if possible.

In addition to such equipment, high-power fixed installations (eg cables, motors etc.) can feed large currents into the water if a fault occurs. Again fixed barriers (or other means of restricting the diver's access) can be used to keep the diver at a safe distance (see Appendix 2).

The safe distance can be reduced by incorporating an impedance in the star point to earth line of the supply to limit the fault current. Care should be taken to ensure that all protective devices will function at the low level. A fault current limit of 1A is recommended.

A8-1.3 Protective Clothing

Any practice which limits the flow of current through the diver is beneficial.

Rubber gloves can be worn by a diver who may be working on, or in close proximity to, a piece of equipment that may constitute an electrical hazard to him. This is particularly important during welding or burning. The gloves worn should have a cuff to give the wrist area some degree of protection.

The degree of protection offered by existing diving suits varies and they should not be relied upon for protection.

A8-1.4 Shielding

The electrical equipment may be enclosed within a conducting shield to prevent current from flowing into the water. Where a shield is fitted it should be suitably connected to earth, to prevent a dangerous voltage by an internal fault.

Protective screens should be constructed from high-conductivity material and have low-resistance joints, otherwise a fault current flowing in the screen can produce a dangerous voltage gradient over its external surface. However, this deficiency can be greatly reduced by the use of a double screen. The conducting screen (the external screen in double-screened systems) should also be in contact with the water to restrict the voltage difference between the screen and the surrounding water.

A8-1.5 Earthing

On any unit which operates at a voltage which is higher than the unprotected safe limit (30V dc maximum or 7.5V ac maximum) then the conductive structure or frame should be connected to earth to dissipate any fault current. The connection should have a low impedance to minimise any rise of voltage on the conductive structure or frame, and sufficient mechanical strength to prevent accidental breakage when the equipment is operated within the stated limits. The connection should be through purpose-designed conductors in the power cables. The earth return path can be augmented by an area of bare metal (even corroded steel) in contact with the water; such an arrangement can be many times more effective than normal earth leads.

A8-2 Active Protection

In addition to passive protection, and wherever practicable, the system should provide active protection against shock resulting from direct contact with the live circuit of the equipment and indirect contact via the structure or the sea. Active protection may be provided by a residual current device (RCD) coupled to a circuit breaker device. (See Appendix 3 for further detail on residual current devices)

Summary Table of Safe Practices

Using the values contained elsewhere within this document, the following have been established as voltage levels for the equipment that the diver is being asked to work on or near that should provide the necessary level of safety. The table below is only a summary of what is contained in this document and the more detailed information elsewhere within this Code should be referred to.

(Numbers in brackets refer to explanatory notes at the end of this table)

	Supply Source (1) (2)	**Safe Body Current mA (3)**		**Body Resistance Ohms (4)**		**Voltage (5)**	
						Maximum V	**Nominal V**
		(I)	**x**	**(R)**	**=**	**(V)**	**(V)**
1 Diving on Subsea Equipment or Cables (the generic scenario)	ac with Trip Device	500		500		250	220
	dc with Trip Device	570		500		285	250
	ac without a Trip Device	10		750		7.5	6
	dc without a Trip Device	40		750		30	24
2 Electrically Heated Diving Suits (6)	ac with Trip Device	200		100		20	18
	dc with Trip Device	228		100		22.8	18
	dc without a Trip Device	70		100		7	6
	No figure is given for ac without a trip device as the voltage would be so low as to be impractical						
3 Impressed Current Anode Systems	dc without Trip Device	40		750		30	24
	By definition impressed current anode systems cannot be fitted with trip devices or they would not be able to serve their purpose. Similarly such systems are always dc. For these reasons no other safe values are given.						
4 Diver Carried or Operated Equipment Note: This category includes any electrical equipment carried by or mounted on the diver (such as cameras and lights) as well as hand held tools, NDT equipment etc.	ac with Trip Device	500		500		250	220
	dc with Trip Device	570		500		285	250
	ac without a Trip Device	10		750		7.5	6
	dc without a Trip Device	40		750		30	24
5 Wet Welding, Cutting and Burning	dc without Trip Device	40		750		30	24
	N.B It is recognised that 30V dc is not a high enough voltage to be practical in many circumstances. In such cases it would be difficult to provide active protection to ensure that the diver is safe from electric shock at all times. Safety therefore depends on good equipment and operational practices (Refer to section 8.5)						
6 Inside a Hyperbaric Chamber	ac with Trip Device (7)	500		500		250	220
	dc with Trip Device (7)	570		500		285	250
	ac without a Trip Device	10		750		7.5	6
	dc without a Trip Device	40		750		30	24

	Supply Source (1) (2)	Safe Body Current mA (3)		Body Resistance Ohms (4)		Voltage (5)	
						Maximum V	Nominal V
		(I)	x	(R)	=	(V)	(V)
7 Inside a Welding (or other) Habitat	ac with Trip Device (7)	500		500		250	220
	dc with Trip Device (7)	570		500		285	250
	ac without a Trip Device	10		750		7.5	6
	dc without a Trip Device	40		750		30	24
	A supply fed from an ac isolating transformer with non-earthed secondary. Using a line insulation monitor with circuit breaker (7)	n/a		n/a		(8)	
	A supply fed from an ac isolating transformer with the secondary earthed through an impedance to limit fault current to 1A, and trip device (7)	n/a		n/a		(9)	
8 Divers Working with ROVs	ac with trip device	500		500		250	220
	A supply fed from an ac isolating transformer with non-earthed secondary. Using a line insulation monitor with circuit breaker (7)	n/a		n/a		(8)	
	A supply fed from an ac isolating transformer with the secondary earthed through an impedance to limit fault current to 1A, and trip device (7)	n/a		n/a		(9)	

NOTES:

Supply source

1. This summarises the manner in which electricity can be used safely. Where a trip device is specified it is based on an overall operating time of 20 ms.
2. Where dc is referred to it is assumed that the ripple content is not more than 5% otherwise it should be treated as ac. Where ac is referred to the voltage is RMS.

Safe body current

3. This is the maximum current which can be allowed to flow through the diver's body safely which has been derived from IEC 60479-1: 2005-2007. It is **not** the current flowing in the electrical equipment.

Body resistance

4. This is the resistance offered by the diver's body. The values are based on experimental data and are for limb to limb contact except in the case of diver heating where front to back of the chest was chosen.

Voltage

5. This is the voltage derived from the maximum current allowable through the diver's body and the body resistance. It is expressed as a maximum value which should never be exceeded and also as a commonly used nominal value. The voltages stated are maximum values to which the diver may be subjected without serious physical harm.

Electrically heated diving suits

6. This is a unique situation where there is a high possibility that in the event of an electrical fault it could result in a front to back of chest fault path. For this reason the body resistance used is an especially low value. Similarly the normal safe body current limits used elsewhere are divided by 2.5 to reflect the proximity to the heart and diaphragm (which could seriously affect breathing if involuntarily contracted).

Trip device

7. If a trip device (such as an RCD) is used then it should be able to be reset by the diving supervisor after necessary safety checks. They should have an override facility which may only subsequently be operated by the diving supervisor if he considers the danger to the diver as a result of loss of power to be greater than the possible electrical hazard.

Divers working with ROVs

8. In this case a single fault does not present a hazard and thus no maximum voltage need be stipulated provided the protective devices are able to prevent the occurrence of a second fault constituting a hazard.

9. No voltage limit is stated as the diver is protected by the fault current limit and the associated trip device.

Clarification

10. The above table lists the 'safe' voltages. If the electrical supply involved cannot be guaranteed to be below one of these 'safe' voltages then there is only one other way in which the electrical supply can be maintained while also ensuring diver safety. That is, if the diver can be physically restricted such that he can be assured to remain at least the minimum safe distance away from any energised components or cables.

11. If neither of these points can be confirmed then it will be necessary to electrically isolate the components and cables. Such isolations may only require isolation of part of a system until one of these points can be met. Any isolations need to be carried out very thoroughly and carefully and detailed information on this subject is contained within IMCA D 044 – *Guidelines for isolation and intervention: Diver access to subsea systems.*

It is not intended to limit the electrical safety protections to only these methods above and if another method can be established as providing the necessary level of diver/occupant safety then that method can be considered