Development of requirements for fuel cells in the marine environment - Performance and prescription

by N. Rattenbury and E. Fort

Lloyd's Register

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Norman Rattenbury has been employed by Lloyd's Register for over 26 years where he is currently Principal Surveyor within the Research and Development Department, a position he has held since 1999. He is responsible for developing technical requirements that may be applied by Lloyd's Register for classification purposes covering a wide range of engineering topics concerned with the safety and reliability of machinery and systems for marine and industrial applications. Prior to joining Lloyd's Register he served an engineering apprenticeship followed by 10 years in the merchant navy as an engineer officer on a wide range of ship types.

Edward Fort has over fifteen years experience in fuel cell power generation. He has a degree in electronic engineering and is currently a senior engineer within the Research and Development Department of Lloyd's Register. He completed his marine engineering cadetship with Mobil Shipping Co. Ltd after which he served on board tankers within the company fleet. In 1984, he moved to the European Space Agency's technical centre, ESTEC assuming responsibility for the testing of space craft power systems including fuel cell technology in support of the European space agency's Hermes space shuttle programme. In 1998, he joined Lloyd's Register specializing in shipboard automation. He took up his current position in 2002 following a period in industry identifying potential marine markets for a fuel cell manufacturer and designing automation systems for LNG carriers. He currently represents Lloyd's Register on two EU fuel cell projects, FCSHIP and FCTESTNET.

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Synopsis

The technology associated with the design, manufacture and operation of marine equipment is changing rapidly. The traditional manner in which regulatory requirements for marine electrical power supply systems have developed, based largely on incidents and failures, is no longer acceptable. Current international requirements for marine electrical power supply equipment and machinery such as engines, turbines and batteries have evolved over decades and their applicability to new technologies and operating regimes is now being questioned by organisations responsible for the regulation of safety and reliability of ships.

This paper reviews the development of international requirements for marine electrical power supply equipment from the first relatively low powered units to the current complex and high power installations installed onboard ships. The background to the current classification Rules for marine electrical power supply systems, originating in part from SOLAS (Safety of Life At Sea) and from IACS (International Association of Classification Societies) requirements is also be covered. The current requirements for marine electrical power supply equipment are largely prescription based, addressing components and equipment rather than a system as a source of electrical power. Safety and reliability, the cornerstones of classification, are built on requirements that have to be acceptable to all stakeholders involved in the design, construction, installation, testing, operation and regulation of marine equipment.

The current classification process for verifying that marine electrical power supply equipment satisfies the requirements depends on plan appraisal, materials inspection, survey and testing in accordance with the classification societyís Rules. Such a process is acceptable if the system design and intended application is consistent with the Rules and the philosophy behind the Rules. New designs of electrical systems such as fuel cells incorporate systems, equipment and materials that may not be currently addressed in the Rules and it is necessary for classification societies to develop ways of assessing their suitability for the proposed application. This ad hoc approach can lead to inconsistencies in acceptance of different systems and different engines by different classification societies.

The main hurdles in the assessment of fuel cells as a marine electrical power generator for classification purposes may be overcome by gaining an understanding the designerís intent and the operatorís desired functionality. These two areas are mainly concerned with system performance rather than compliance with any particular prescriptive requirements that may in fact, not be relevant to that particular design.

The importance of the integration and the performance of the system in relation to a safe and reliable fuel cell installation needs to be recognised and the paper provides a high level approach with defined objectives and processes for demonstrating that a fuel cell system is acceptable to all stakeholders. Such an approach with defined objectives provides the basis for a common performance based assessment process for marine electrical power supply systems while recognising extant prescriptive requirements. The paper also discusses the use of Goal Based Standards in line with the current debate within IMO (International Maritime Organisation) linking acceptance standards and high level safety objectives.

1 Introduction

Maritime legislation that sets standards for power supply arrangements has always been generally of a goal setting nature and it has been up to the classification societies to put some flesh around the basic objectives. Stemming from the Titanic disaster and the publication of the first SOLAS, there were four key requirements relating to power supply arrangements for propulsion, auxiliary and emergency purposes.

1. "*Ships shall have sufficient power for going astern to secure proper control of the ship under all circumstances.*"

2. "*Provision shall be made for an electric or other system of lighting, sufficient for all requirements of safety, in different parts of the ship, and in particular on decks on which lifeboats are stowed. There must be a self contained source capable of supplying, when necessary, this safety lighting system and placed in the upper parts of the ship above the bulkhead deck.*"

3. "*Sufficient power must be available in a ship station at all times to operate the main radiotelegraph installation efficiently under normal conditions over a defined range.*"

4. "*The emergency (reserve) installation must be provided with a source of energy independent of the propelling power and of the main electricity system and must be capable of being put into operation rapidly and of working for at least six continuous hours.*"

These first international requirements for maritime power supplies provide important objectives and identify the basic aims of power supply arrangements on board ships. It should be remembered that these requirements stemmed from the Titanic disaster and were formulated and agreed as result of lessons learnt from that incident. Over the years SOLAS developed further and new requirements were agreed mainly in response to incidents and accidents.

Different flag administrations applied the SOLAS requirements in different ways but it was not until the 1988 Protocol to the 1974 SOLAS did international requirements applicable to power supply arrangements and in particular to diesel engines become evident. SOLAS Chapter II-1 now contains over twenty relevant regulations that include requirements in terms of prescriptive statements together with goals and objectives that are applicable to the safe design and operation of power supply systems and arrangements. These requirements provide for the safety of personnel and availability of the ship's propulsion and electrical power supplies.

The applicable SOLAS regulations will be described later in this paper as the validity of some the requirements is now being questioned with the different configurations and developing technology that is now being applied to power supply arrangements in terms of design, control and operation.

Within the scope of ship classification relating to the safety and reliability of propulsion machinery, classification societies first published requirements for internal combustion engines for marine use in the early 1900s with the first engines being installed in ships being of the petrol/paraffin fuelled spark ignition type.

Classification Societies have influenced the design and installation of electrical systems in ships since March 1890 when the Secretary of Lloyd's Register (LR) issued a Circular in which it was stated:

"The attention of the Committee of the Society had been drawn to the circumstance that in vessels lighted with electricity, fires had occurred through defects in fittings or in the insulation of the wires."

Following this circular (shown in Annex A), in September 1890, a Notice was issued entitled "Use of Electric Lights on Board Vessels" which gave suggestions relating to its installation. These suggestions, the principles of which are still followed today, formed the foundation of the first Rules published by Lloyd's Register in 1895, which remained largely unchanged until 1915 when the Institution of Electrical Engineers (IEE) set up a special committee which culminated in the issuing in 1919 of the first edition of the IEE Regulations for the Electrical Equipment of Ships. These IEE Regulations were adopted by Lloyd's Register as Rules in 1920. The class notation "**Elec Light**" was entered in Lloyd's Register of Ships against the name of vessels having such equipment from 1895 until the practice was discontinued in 1934.

During their development, the electrical engineering Rules initially considered the electrical installation with regard to electrical hazards related to the risks of electric shock, fire and explosion. They developed to take into account the provision of a secure electrical power supply system to feed those services which were electrically powered and essential for the safe operation of the ship. Now, in addition, they also consider the safety of the crew and, where applicable, the passengers.

The purpose of electrical engineering classification rules is to ensure that the electrical power generation and distribution systems are safe, both from fire and personnel aspects, are of an adequate quality and provide a secure source of power to the consumers commensurate with their intended duty. The matter of electrical safety in respect of fire and personnel is also addressed. These cover all the fixed electrical systems on board the vessel and would be applied irrespective of the vessel type and use.

Throughout the early part of the 20th century the marine diesel engine experienced the development of configurations and arrangements driven by designers trying to achieve effective and efficient machinery to replace the labour intensive and relatively inefficient reciprocating steam engines. The physical arrangements of the developing engine designs with opposed pistons, double acting pistons, multiple camshafts, air blast fuel injection were engineering feats of the time. Classification societies had difficulties in developing effective rules for assessment of the different designs that were being produced by over 200 different manufacturers mainly in Europe. The term "special consideration" in classification society approval had an important significance during the development stages of the early marine diesel engines.

In the 1970s the International Association of Classification Societies (IACS) was formed. As part of the structure of the organisation, Working Parties for Machinery and Electricity (WP/MCH) and (WP/E) were established with a remit that included the development of Unified Requirements (URs) and Unified Interpretations (UIs) of International Convention requirements for machinery and electrical systems. These URs and UIs include extensive requirements relating to the design, installation and testing of marine diesel engines. Examples of URs include M9 and M10 for crankcase explosion protection (currently under revision), M3 for speed governor and overspeed protection and M61 for starting arrangements. Examples of UIs include SC184 for dead ship starting arrangements and SC76 for engine bearing temperature monitoring.

In a similar manner to the rapid development of new technology in the mechanical systems for marine diesel engines in the 1900s we are now seeing rapidly changing technology applicable to the control and operation of systems that are used to ensure the functional capability of an engine. The use of electronic and hydraulic control systems for functions that were traditionally mechanically controlled and for which many of the existing requirements have been developed is posing challenges to engine-builders and those charged with regulating the safety and reliability of diesel engines installed in ships.

2 SOLAS

The starting point for recognising the applicable standards for marine machinery is SOLAS. The detailed requirements developed by classification societies and other organisations mainly stem from the SOLAS regulations.

The guiding principle of SOLAS, the preservation of life at sea, is applied through a safety hierarchy methodology. The technical requirements for ship classification can best be encapsulated in terms of three criteria shown in Figure 1 that are directly related to the standards for marine machinery.

1. Safety of the Ship: No failure of a component or system shall cause loss of propulsion capability or otherwise endanger the safety of the vessel or its crew. An example of this criterion is the requirement for redundancy in lubricating oil pumps to ensure that the loss of lubricating oil pressure due to a pump failure will not in turn result in the loss of the propulsion machinery. Single essential propulsion components may be accepted where special consideration is given to their reliability.

2. Safety of Personnel: No failure of a component or system shall directly cause injury or loss of life. Examples are the appropriate use of guards, suitable insulation and standards for the strength of piping and pressure vessels.

3. Safety of Machinery: No failure of a component or system for the machinery essential for the safety of the ship shall cause the loss of ability of equipment to meet its design intent. An example is the specification of crankcase explosion relief valves which should protect the engine to prevent loss of propulsion power in the event of a crankcase explosion.

Central to the three safety criteria is the need for equipment and systems to be dependable for the performance of the

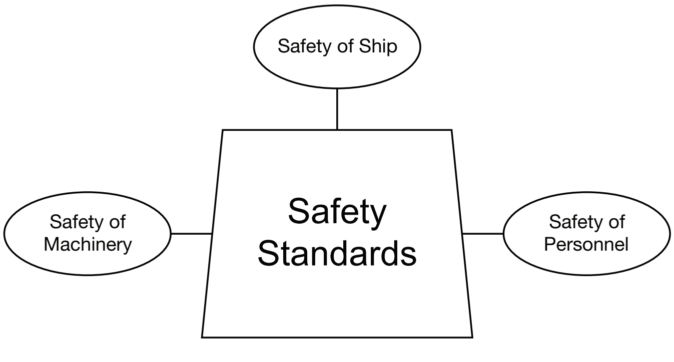

Figure 1: Safety standards for marine power supply systems

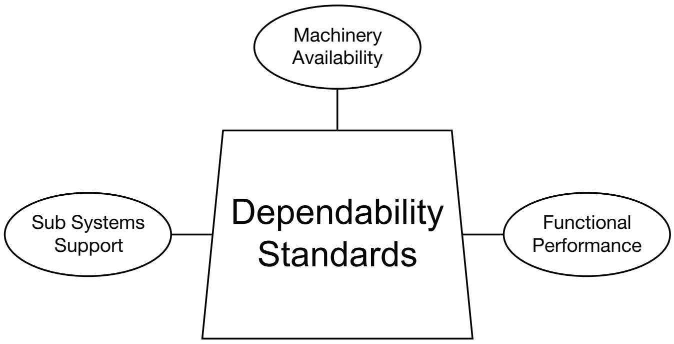

Figure 2: Dependability standards for Marine power supply systems

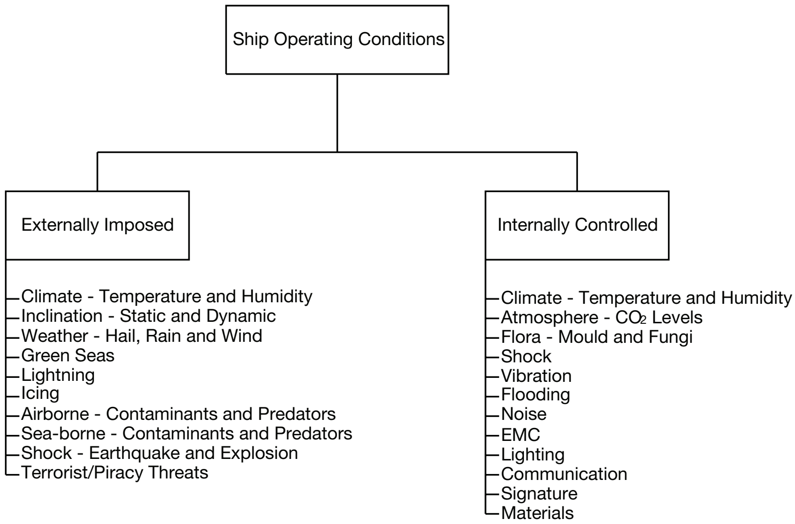

Figure 3: Ship operating conditions

tasks intended in the environment where they are being operated. The dependability of marine machinery relies on standards that address three key areas shown in Figure 2.

1. Machinery Availability: Equipment and systems necessary to provide and maintain propulsion and steering capability and for the safety of personnel on board should be available under all normal operating conditions and foreseen emergency conditions.

2. Functional Performance: Equipment and systems necessary to provide and maintain propulsion and steering capability and for the safety of personnel on board should be capable of maintaining its design functional performance under all normal operating conditions and foreseen emergency conditions.

3. Sub-Systems Support: Equipment and sub-systems necessary to support the operation of propulsion and steering systems and for the safety of personnel on board should be available under all normal operating conditions and foreseen emergency conditions.

Ship operating conditions need to recognise those conditions externally imposed on the ship and those controlled onboard as shown in Figure 3.

The external conditions imposed on the ship need to be assessed for the effects on the operation of a marine power plant. The internally controlled conditions are those that need to be addressed in a design assessment. The requirements of the SOLAS regulations address most of the issues shown in Figure 3.

SOLAS Regulations contain extensive requirements relating to the safety and dependability of diesel driven marine power generation machinery and the practical application of specific requirements needs an understanding of the regulations to be addressed in the design, installation and operation of the machinery. The key SOLAS regulations that are applicable to these issues are now summarised. A listing and brief explanations are shown in Appendix B.

It will be noted that the identified SOLAS regulations have significant implications on the design, installation and operation of marine power plant. Classification societies have developed rules and regulations that enable compliance with the SOLAS requirements to be demonstrated. Classification society rules and regulations for marine power plant are in main based on IACS Unified Requirements (URs).

3 IACS

The key IACS Unified Requirements applicable to marine power plant and electrical installations are contained in the requirements for Machinery and Electrical Installations. There are also applicable requirements in the Fire Protection and Pipes and Pressure Vessels sections of the Unified Requirements. A listing of the applicable requirements to marine power plants is shown in Annex C of this paper.

The IACS Unified Requirements are generally in the form of prescriptive statements that provide a definition or identify what has to be done and in some cases how to do it. These URs relate to safety and dependability of marine power plant and support systems/arrangements but do not directly identify SOLAS Regulations. Classification societies in transferring the requirements into their rules and regulations are able to recognise where there is an interface with the SOLAS requirements. Comparing the list of subjects in the IACS Unified Requirements and those in the identified SOLAS regulations it will recognised that most of the key issues have been addressed. There are also IACS Unified Interpretations of the SOLAS requirements but currently there are only a few that relate to the design and operation of marine power plant and these are listed in Annex E.

The current requirements in SOLAS and IACS Unified Requirements and Interpretations have generally been developed on the basis of incidents and experience from existing installations plus where necessary the need for definitions. The technology associated with the design and operation of modern power generation systems is advancing at a rapid pace and it is being recognised that trying to apply existing requirements to new arrangements is not always correct or effective and indeed, with the introduction of new technologies, not always appropriate.

There is a growing recognition that there is a need for an alternative approach to the assessment of new power generation technologies together with associated equipment and systems from safety and dependability considerations.

4 Alternative assessments

Analysis tools are now gaining general acceptance in the marine industry and in particular the use of Failure Mode and Effects Analysis (FMEA). The adoption of analysis tools requires a structure and the use of agreed standards. The use of analysis tools must also recognise lessons learnt from past incidents and experience and it is vital that the background to existing requirements stemming from SOLAS or IACS are understood. Consistent with the current assessment philosophy, there needs to be two tenets to the process - safety and dependability. A safety analysis for a fuel cell power generation system and its installation on board a ship could use a hazard assessment process such as outlined in Figure 4.

The hazard assessment should review all stages of a systems life cycle from design to disposal. The design concept needs to address the marine environment in terms of those imposed on the ship and power plant and those that are internally controlled as shown in Figure 3. It is also necessary to address the effects of fire, flooding, equipment failure and the capability of personnel required to operate the system.

In carrying out a hazard assessment it is vital that there are clearly defined objectives in terms of what is to be demonstrated. The assessment should address the consequence of a hazard and possible effect on the system, its subsystems, personnel and the environment. An assessment for dependability and availability of a fuel cell power generation system and its installation in a ship could use a FMEA tool as outlined in Figure 5.

An effective FMEA needs a structured approach with clearly defined objectives and IACS is currently developing standards that can uniformly be applied to marine systems and equipment where an analysis is required. The work currently being undertaken by IACS will identify those systems and machinery that require analysis.

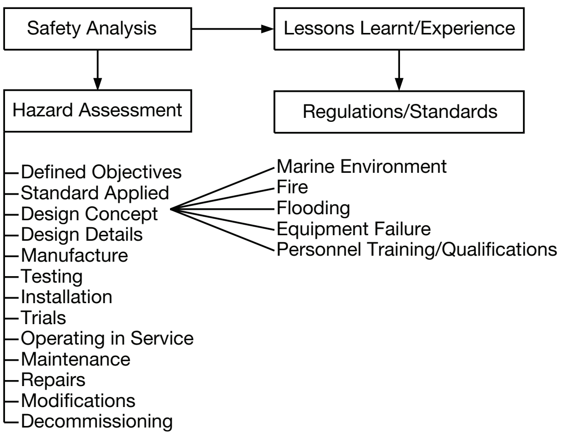

Figure 4: Safety Analysis for a Marine Fuel Cell Power Generation System

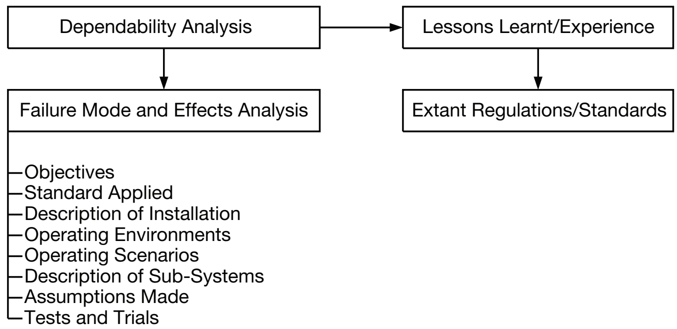

Figure 5: Dependability Analysis for a Marine Fuel Cell Power Generation System

For a hazard and failure mode analysis it is necessary to use recognised standards and there are a number of generic standards that can be applied and adapted for analysis of a fuel cell system.

- IEC 61882, Hazard and operability studies (HAZOP) studies - Application guide
- IEC 60812, Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)
- IEC 61508, Functional safety of electrical/ electronic/programmable electronic safety-related systems.

The assessment analysis processes for safety and dependability need to identify defined objectives. It is essential that the designer's intent and the operator's desired functionality are declared and understood by those undertaking the assessment. These two issues are concerned with system performance rather than compliance with a prescriptive requirement in a standard.

The importance of performance and integration of systems that are related to safety and dependability is now recognised and the assessment tools now available offer such means.

Formal Safety Assessment (FSA) is recognised by the IMO as being an important part of a process for developing requirements for marine regulations. IMO has approved *Guidelines for Formal Safety Assessment (FSA)* for use in the IMO rule-making process (MSC/Circ.1023/MEPC/ Circ.392).

There is now a clear emphasis, supported by IMO, for goal based regulations and this is evidenced in the revised Chapter II-2 of *SOLAS Construction - fire protection, fire detection and fire extinction* where objectives and functional requirements are clearly identified. The assessment of alternative design and arrangements has to be carried out using a structured engineering analysis and evaluation process.

IMO is also tentatively embracing the use of goal based standards for ship construction and this process can be equally well applied to machinery power plants. Figure 6 illustrates the proposed goal based regulatory framework for new ship construction that could be readily adapted for marine power plant application. The basic principles of the proposed goal-based regulatory framework that could be applied to a marine power plant are as follows:

- The goal-based standards should represent the top tiers of the framework, against which a marine power plant should be verified both at design and construction stages, and during plant operation.
- The goals are not intended to set prescriptive requirements or to give specific solutions. However, they should be clear, demonstrable, verifiable and long-standing and capable of adapting to changes in technology.
- The goals should aim to ensure that a properly operated and maintained marine power plant remains safe for its entire life.
- The goals should be achieved either by compliance with published technical standards or by means of alternative solutions providing an equivalent level of safety.
- The requirements developed and applied by regulatory organisations should be capable of demonstrating compliance with the goal-based standards.

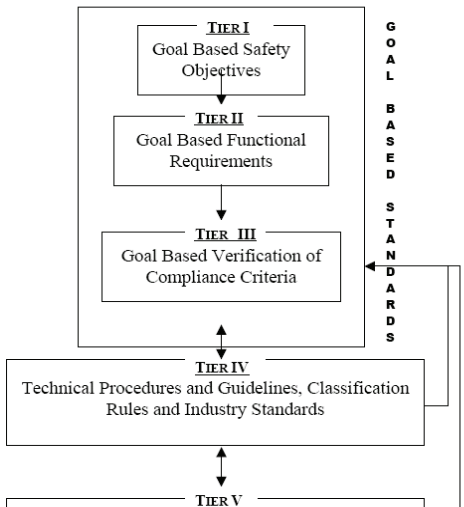

Figure 6 - Goal Based Regulatory Framework

Tier I for the safety objectives would define a set of goals to be met and verified during plant design and construction, in order to assemble/build and operate safe and environmentally friendly power plants on board a ship. This tier would typically include design life, environmental conditions, plant safety, plant accessibility and quality of construction.

Tier II for the functional requirements would define a set of requirements related to the functions of the power plant to be complied with and verified during design and construction to meet the safety objectives in Tier I. The functional requirements relevant to marine power plant would be applicable to any type of marine power plant. The functional requirements would typically include power output - continuous and limits, stability of power output, operation under environmental conditions, operability, accessibility and quality control procedures.

Tier III for the verification of compliance criteria would provide the instruments necessary for demonstrating the compliance with goal based standards during design, construction and operation. In respect of design, the power plant compliance with goal-based standards should be demonstrated at the design stage either by applying requirements proving to meet the goal-based standards, or by alternative means which provide an equivalent level of safety.

Tier IV and Tier V with technical procedures, guidelines, standards, codes of practice, safety and quality schemes for plant equipment construction, plant operation, maintenance, training and manning etc provide the necessary information for verification of the compliance criteria. These may be extant, tailored from an existing process or developed specifically for a new application.

The development of requirements for fuel cells in the marine environment power plant application could usefully recognise the benefits of adopting a goal-based approach. To demonstrate how this could be applied, a look at the scope of shipboard electrical services is considered. All ships have electrical loads concerned with:

- The propulsion, navigation and safety of the vessel
- The seagoing functional operations of the vessel
- Conditions of habitability and/or
    - the transport of cargo
    - the transport of passengers
    - a work function.

Dependant on the operating role of the vessel, there may be differing combinations of these various electrical loads.

In order to determine the power supply capacity and system architectural arrangements required and to give specific requirements for services that affect the propulsion and safety of the vessel the various services are grouped under a number of headings. Services may be defined as **essential**, and these include those that provide services for the main propulsion machinery, i.e. cooling and lubricating pumps etc., and those for steering gear, flood prevention and lighting; these services may vary from vessel type to vessel type. These essential services may be sub-divided into:

- **Primary essential services**, i.e. the loss of which for any duration may hazard the propulsion and the safety of the vessel, for example: lubricating oil and cooling water pumps for the main propulsion machinery and steering gear
- **Secondary essential services**, i.e. the loss of which for a short duration would not hazard the propulsion and safety of the vessel, for example: service air compressors, machinery space ventilation fans and ballast pumps.

In addition to essential services it is necessary to consider other services such as services that are considered necessary for minimum comfortable conditions of habitability. These services are those such as cooking, heating, domestic refrigeration, mechanical ventilation and sanitary and fresh water.

In order to maintain the vessel in a normal seagoing operational and habitable condition commensurate with its intended purpose requires further additional services such as those for cargo handling, hotel services and bow thrusters. These services are defined as non essential and the design and installation of their equipment is to be such that risk of fire due to its failure is minimized. This equipment is required, as a minimum, to comply with a national or international standard, revised where necessary for marine ambient conditions. For the majority of equipment, which includes electrical cables, the IEC (International Electrotechnical Commission) 60092 series of standards are the most appropriate.

5 Conclusions

The paper has illustrated that there is an extensive range of standards and issues that are applicable to marine power generation systems and that there are alternative methods of assessment that can be applied to technology for which the current standards do not fit a recognised design and operating scenario, however, the lessons learnt from experience and from failures need to be understood before using alternative methods.

Prescriptive requirements do have their place in a regulatory regime for safety and dependability particularly in the areas concerned with component design, manufacture and testing. Performance based standards that make use of alternative methods of assessment outlined in this paper also have a place in areas of system design and power plant operation.

Marine power generation has undergone over a hundred years of development and continues to evolve and there is a clear need for all those involved to understand all the issues involved to provide safe and dependable systems on board ships.

6 References

- International Maritime Organisation (IMO) SOLAS Consolidated Edition 2001 and 2000 Amendments
- International Association of Classification Societies (IACS) Resolutions
- Safety and Reliability of Electronic Engines - Robert D McColl, 2002 MSc Thesis, Department of Mechanical Engineering, UCL
- Selection and Use of Standards for Naval Ships - Norman Rattenbury, INEC 2004
- Development of Standards for Marine Diesel Engines - Prescriptive to Performance Based - Norman Rattenbury, CIMAC Congress 2004
- IMO MSC 78/6 Goal Based New Ship Construction Standards

ANNEX A

CIRCULAR No. 756.

LLOYD'S REGISTER OF BRITISH AND FOREIGN SHIPPING.

2, White Lion Court, Cornhill, London, E.C.
13th March, 1890.

THE ELECTRIC LIGHTING OF VESSELS.

SIR,

The attention of the Committee of this Society has been drawn to the circumstance that in vessels lighted with electricity, fires have occurred through defects in fittings or in the insulation of the wires.

As such accidents are of great importance to all concerned in the safety of Vessels, the Committee are very desirous of obtaining the fullest and best information possible respecting the use of the electric light for lighting Vessels.

I am directed, therefore, to address you on the subject and to intimate that the Committee will feel much obliged to you for any remarks and suggestions with which you may kindly favour them with regard both to methods of installation and also to the most satisfactory means of maintaining the insulation of wires and fittings unimpaired, so as to eliminate as far as practicable the risk of fire which at present appears to attend the use of the electric light.

I am, Sir,
Your obedient Servant,
B. WAYMOUTH,
Secretary.

25th September, 1890.

Notice No. 783.

LLOYD'S REGISTER OF BRITISH AND FOREIGN SHIPPING.

USE OF ELECTRIC LIGHT ON BOARD VESSELS.

NOTICE IS HEREBY GIVEN: that the Committee of this Society have determined to issue as suggestions for the consideration of Shipowners, and others, the following proposals relating to the use of the electric light on board vessels, viz. :—

(1) **POSITION OF DYNAMOS AND OF ELECTRIC MOTORS.**—Dynamos and Electric Motors should be placed as far as possible from all compasses, and should be at least 30 feet from the standard compass.

(2.) **CABLES.**—In vessels fitted with continuous current dynamos, and wired on the single-wire system, no single cable should be carried within 15 feet of any compass, and cables conveying a heavy current should be fixed at still greater distance. If it is necessary to fix the cables within this distance, then for all parts of the vessel lighted from this cable the double-wire system should be adopted, the return wire being carried as near the flow as possible in the vicinity of the compasses.

(3.) **ADJUSTMENT OF COMPASSES.**—The compasses should be adjusted with the dynamo not working, after which the vessel's head should be put upon the different courses, with the dynamo running at full speed, and on each course the indications of the compass should be noted with the dynamo running with open circuit and with all possible combinations of the current switched "on" and "off" all circuits passing near the compasses. These indications should be compared with those obtained with the dynamo stopped, and any serious deflections of the compasses remedied before the vessel sails. In vessels wired on the "double-wire" system this is not so important as in those wired on the "single-wire" system but at least the effect should be tested of the dynamo running with open circuit.

(4.) **LEADS OR CIRCUITS.**—1. The copper used in all leads should have a conductivity of at least 98 per cent. that of pure copper, and the sectional area should be at least in the proportion of one square inch per 1,000 ampères carried.

2. No single wire of less than 16 standard wire gauge should be used. For portable leads stranded cables composed of smaller wires may be used.

3. The insulation resistance of all wires should be not less than 600 megohms per statute mile, after 24 hours' immersion in sea water.

4. If india-rubber insulation is used, the wires should be first covered with a layer of pure rubber, then with a separator, then with a layer of vulcanizing india-rubber, and then with a layer of india-rubber coated tape. The whole should then be vulcanized together. The cable should afterwards be satisfactorily protected, preferably with a braided covering of tarred fibre.

5. Wires which are insulated with any other material than india-rubber should fulfil the same conditions as to insulation resistance, and should be of equal durability with those above specified.

6. The leads should be placed where they can always be accessible; if they are laid in wood battens the covers should be screwed on, not nailed, and care should be taken that the casings are impervious to moisture. If the leads are not encased they should be secured by screwed clips, not staples, but unprotected leads should only be used where it is impossible to enclose them. Cables which are properly covered with protective metal sheating may however be unencased.

7. All cables which are liable to be exposed to moisture, more especially when they are also exposed to heat, should be lead covered, or be otherwise specially protected. This refers to such places as open alleyways, near galleys, oil lamps, boiler casings, engine room, &c.

8. All cables led through cargo spaces or coal bunkers should be lead covered and further protected by wrought iron casings or be led through metal tubes.

9. Where cables pass through beams or bulkheads they should be led through special fittings of hard wood to prevent their being chafed, and where they pass through decks they should be led through metal tubes lined with wood or fibre and securely fastened to the decks, standing at least six inches above the deck level.

10. In vessels having spaces allotted alternately for passengers and cargo, the lamp fittings in these spaces should be portable, and the terminals so arranged that they can be properly covered up with insulating covers. The switches and cut-outs should be outside these spaces and should be fitted so that they are under lock and key.

(5). **JOINTS IN LEADS.**—1. Joints in main leads should be avoided if possible. If joints cannot be avoided in the main leads they should, after the wire is carefully jointed, soldered and insulated, be encased in a satisfactory watertight junction box. If the cables are lead covered, perfectly sound lead soldered junctions should be made over the joints.

2. Joints in branches, or of branches with main leads, should have the copper wires thoroughly soldered; the insulation should be craefully carried out and all the joints should be made watertight Joints in flow and return wires should not be made opposite one another.

3. For soldering wires, resin only should be used as a flux.

(6).—**JOINTS WITH HULL.**—In vessels fitted on the single-wire system, all the joints with the hull should be in accessible positions. They should be made with brass screws not less than three-eights of an inch in diameter, carefully tapped into the steel, having white brass washers, between the wires and steel, or the wires should be soldered to brass faced washers.

(7).—**SWITCHES AND CUT-OUTS.**—1. A main switchboard should be fitted in the dynamo room, to which all the main circuits throughout the ship should be brought, a switch and cut-out being fitted for each circuit. If auxiliary switchboards for further sub-division of the current are necessary, they should be placed in conveniently accessible positions, and each small circuit should be fitted with a separate switch and cut-out.

2. The switches should be mounted on slate or other uninflammable bases, and should be so constructed that they must be either full "on" or completely "off," that is, they must not be able to remain

ANNEX B

Key SOLAS Regulations Applicable to Marine Power Plant - Chapter II-1

- Regulation 26, Machinery installations
- Regulation 27, Machinery
- Regulation 28, Means of going astern
- Regulation 31, Machinery controls
- Regulation 32, Steam boilers and boiler feed systems
- Regulation 33, Steam pipe systems
- Regulation 34, Air pressure systems
- Regulation 35, Ventilating systems in machinery spaces
- Regulation 36, Protection against noise
- Regulation 37, Communication between navigation bridge and machinery space
- Regulation 39, Location of emergency installations in passenger ships
- Regulation 40, General
- Regulation 41, Main source of electrical power and lighting systems
- Regulation 42, Emergency source of electrical power in passenger ships
- Regulation 43, Emergency source of electrical power in cargo ships
- Regulation 44, Starting arrangements for emergency generating sets
- Regulation 45, Precautions against shock, fire and other hazards of electrical origin
- Regulation 46, Unattended machinery spaces - General
- Regulation 47, Unattended machinery spaces - Fire precautions
- Regulation 49, Unattended machinery spaces - Control of propulsion machinery from the navigation bridge
- Regulation 51, Unattended machinery spaces - Alarm system
- Regulation 52, Unattended machinery spaces - Safety systems
- Regulation 53, Unattended machinery spaces - Special requirements

Other Applicable SOLAS Regulations
There are other important SOLAS Regulations that are applicable to marine power plant and the most important are related to fire safety in Chapter II-2. The most important is Regulation 4 which deals with the prevention of fire and explosion in ships. Regulation 4.2 requirements that are applicable to diesel engines relate to arrangements for oil fuel, lubrication oil and other flammable oils. Included in the requirements are the need for jacketed piping systems for high pressure fuel lines between high pressure fuel pumps and fuel injectors and restrictions in the use of grey cast iron for valves and fittings. The requirements also contain restriction on the use of flexible hoses and the need for the use of fire resting materials in their construction.

SOLAS Regulation 26 - Machinery installations
Consistent with SOLAS Regulation II-1/26 for machinery installations, the arrangements are required to be such that single essential components in machinery for propulsion purposes are reliable or have a separate source of propulsion power sufficient to give the ship a navigable speed, **and** be such that ship mobility can be sustained or restored in the event of a single failure in an operational sub-system.

The operational sub-systems applicable to the operation of a marine power system and specifically mentioned in SOLAS include the following:

- Sources of electrical power
- Sources of steam supply
- Oil fuel supply systems
- Sources of lubricating oil pressure
- Sources of water pressure
- Sources of air supply
- Sources of compressed air for starting and control purposes
- Hydraulic, pneumatic and electrical means of control for main propulsion machinery.

Ships are required to be provided with a means of bringing into operation its machinery from a dead ship condition without external aid.

There are specific requirements relating the capability of propulsion and essential auxiliary machinery to operate under defined seaway conditions of list and trim as well as rolling and pitching. There is also a requirement for the effects of any mode of vibration will not cause undue stresses in the machinery when operating in normal operating ranges.

It is also a requirement that all parts of machinery, steam, hydraulic, pneumatic and other systems that are under internal pressure in service are subject to a pressure test before being put into service. All items of propulsion and auxiliary machinery are required to have provision to facilitate cleaning, inspection and maintenance.

SOLAS Regulation 27 - Machinery
The requirements of this regulation deal with the safety of personnel and of machinery. Included in the regulations are requirements for the following items applicable to marine power systems:

- Over-speed protection
- Over-pressure protection
- Maximum working stresses
- Crankcase explosion protection
- Automatic shutdown on lubricating oil supply failure

SOLAS Regulation 28 - Means of going astern
This regulation deals with the safety of the ship and the ability to achieve reversal of propeller thrust and have sufficient astern power to secure control of the ship. The regulation only deals with means of going astern.

SOLAS Regulation 31 - Machinery controls
The requirements of this regulation relate the arrangements for operation and control of main and auxiliary marine power systems that are essential for propulsion and the safety of the ship. The control systems essential for propulsion machinery are required to be independent or designed so that failure of one system does not degrade the performance of another system.

The requirements deal extensively with requirements to be applied to the control of propulsion machinery from the navigation bridge where the machinery space is operated in the attended mode. It is a requirement that propulsion machinery is capable of being controlled locally even in the event of failure in any part of the remote control system. It is required to be able to control the auxiliary machinery essential for propulsion and safety of the ship at or near the machinery. The automatic starting, operational and control systems are required to have provisions for manually overriding the automatic controls and failure of the systems is not to prevent the use of the manual override.

SOLAS Regulation 32 - Steam boilers and boiler feed systems
This regulation deals with the safety of steam boilers in terms of safety valves, water level indication, fuel shut-off arrangements, integrity of feed water systems and prevention of contamination. The requirements are prescriptive are related directly to a boiler.

SOLAS Regulation 33 - Steam pipe systems
This regulation addresses the need for adequate design of steam piping in terms of strength, drainage to prevent water hammer and provision of relief valves.

SOLAS Regulation 34 - Air pressure systems
This regulation deals with the safety of compressed air systems installed in ships in terms prevention of overpressure and provision of pressure relief devices. Specifically it also deals with starting arrangements for marine diesel engines for protection against the effects of engine backfiring and internal explosion in starting air pipes. These later requirements stem directly from the explosion in the starting air system on the *Capetown Castle*.

SOLAS Regulation 35 - Ventilating systems in machinery spaces
This regulation relates to the safety of the ship and personnel to ensure that there is an adequate supply for the operation of machinery under full power under all weather conditions.

SOLAS Regulation 36 - Protection against noise
This regulation addresses the need to reduce machinery noise levels for the safety of personnel who may enter machinery spaces.

SOLAS Regulation 37 - Communication between navigation bridge and machinery space
Two independent means of communication are required to be provided between the navigating bridge and the engine room to so that orders for the speed and direction of the propulsion machinery can be instructed. There must be a visual indication on the bridge and in the machinery space of the orders and responses for operating the propulsion machinery.

SOLAS Regulation 39 - Location of emergency installations in passenger ships
Emergency machinery vital to the safety of a ship, is not to be installed forward of the collision bulkhead.

SOLAS Regulation 40 - General
This regulation addresses the electrical installations in general such that all electrically operated equipment and machinery necessary to maintain the ship in normal operational and habitable conditions is to be supplied without recourse to the emergency source of electrical power. All electrical services essential for safety are to be ensured under various emergency conditions and the safety of passengers, crew and the ship are to be ensured.

SOLAS Regulation 41 - Main source of electrical power and lighting systems
This regulation addresses the capacity, the number and the arrangement of electrical generators providing power for electrical distribution and the location and arrangement of the switchboard to which the generators are connected. Lighting arrangements are also addressed.

SOLAS Regulation 42 - Emergency source of electrical power in passenger ships
This regulation addresses the capacity, the location and the arrangement of the emergency source of electrical power onboard passenger ships.

SOLAS Regulation 43 - Emergency source of electrical power in cargo ships
This regulation addresses the capacity, the location and the arrangement of the emergency source of electrical power onboard passenger ships

SOLAS Regulation 44 - Starting arrangements for emergency generating sets
Emergency generating sets are vital to the safety of a ship, personnel on board and in many cases for restoring power to the propulsion machinery from a dead ship condition. The requirements deal with being able to readily start the engine from a cold condition - 0oC, and sources of stored energy for starting the engine.

SOLAS Regulation 45 - Precautions against shock, fire and other hazards of electrical origin
This regulation lists prescriptive requirements to mitigate the risks posed by particular hazards associated with electrical installations.

SOLAS Regulation 46 - Unattended machinery spaces: General
The operation of machinery in unattended machinery spaces is now commonplace and the regulation requires the arrangements to be such that the safety of the ship in all sailing conditions, including manoeuvring, is equivalent to a ship having manned machinery spaces. There are to be means of ensuring that the machinery and equipment are functioning in a reliable manner with arrangements for regular inspections and tests to ensure continuous reliable operation.

SOLAS Regulation 47 - Unattended machinery spaces: Fire precautions
The requirements of this regulation address the safety of machinery and personnel. Means are required to be provided to detect and give alarms at an early stage in the scavenge belts of propulsion diesel engines and air supply and exhausts for boilers. It is a requirement to provide warning of a potential crankcase explosion in diesel engines.

SOLAS Regulation 49 - Unattended machinery spaces: Control of propulsion machinery from the navigation bridge
The standards in this regulation deal with the means and arrangements for starting, controlling and stopping propulsion machinery together with the feedback/alarm systems and effects of failure that needs to be considered to provide for the safety of the ship when under bridge control.

An important requirement of this regulation which applies to the design and operation of machinery is that it must be possible to control machinery essential for the safety of the ship from a local position even in the case of a failure in any part of the automatic or remote control systems.

SOLAS Regulation 51 - Unattended machinery spaces: Alarm system
This regulation contains a number of requirements relating to the arrangements for the provision of audible and visual alarm systems for fault conditions in the machinery space that require attention by the ship's personnel. The alarm system is as far as practicable required to be designed on the fail-to-safety principle.

SOLAS Regulation 52 - Unattended machinery spaces - Safety systems
This is a complex regulation to apply in practice. It deals with the safety of the ship and the safety of machinery. The requirement is to provide a safety system to ensure that any serious malfunction in machinery operation which presents an immediate danger initiates the automatic shutdown of that part of the plant and gives an alarm. Shutdown of the propulsion system is not to be automatically activated except in cases which could lead to serious damage, complete breakdown or explosion. Where arrangements for overriding the shutdown of the main propulsion machinery are fitted they are to be such that inadvertent operation is precluded.

SOLAS Regulation 53 - Unattended machinery spaces: Special requirements for machinery, boiler and electrical installations
This regulation mainly deals with the continuity of electrical power supplies for propulsion and steering and for the safety of the ship. The regulation contains a requirement for the control system to be such that the services needed for the operation of propulsion machinery and its auxiliaries are ensured through the necessary automatic arrangements.

ANNEX C

IACS Unified Requirements Applicable to Marine Power Plant

- M2, Alarm Devices of Internal Combustion Engines
- M3, Speed Governor and Overspeed Protective Device
- M5, Mass production of Internal Combustion Engines, Procedure and Inspection
- M6, Test Pressures for Parts of Internal Combustion Engines
- M9, Safety Valves for Crankcases of Internal Combustion Engines
- M10, Protection of Internal Combustion Engines Against Crankcase Explosions
- M11, Protective Devices for Starting Air Mains
- M12, Fire Extinguishing Systems for Scavenge Manifolds
- M14, Mass Production of Internal Combustion Engines: Definition of Mass Production
- M18, Parts of Internal Combustion Engines for which Material Tests are Required
- M21, Mass Production of Internal Combustion Engines: Type Test Conditions
- M23, Mass Production of Engines: Mass Produced Exhaust Driven Turboblowers
- M25, Astern Power for Main Propulsion
- M28, Ambient Reference Conditions
- M29, Alarm Systems for Vessels with Periodically Unattended Machinery Spaces
- M30, Safety Systems for Vessels with Periodically Unattended Machinery Spaces
- M32, Definition of Diesel Engine
- M35, Alarms, Remote Indications and Safeguards for Main Reciprocating I.C. Engines Installed in Unattended Machinery Spaces
- M36, Alarms and Safeguards for Auxiliary Reciprocating I.C. Engines Driving Generators Installed in Unattended Machinery Spaces
- M40, Ambient Conditions - Temperatures
- M43, Bridge Control of Propulsion Machinery for Unattended Machinery Spaces
- M44, Documents for the Approval of Diesel Engines
- M45, Ventilation of Engine Rooms
- M46, Ambient Conditions - Inclinations
- M47, Bridge Control of Propulsion Machinery for Attended Machinery Spaces
- M50, Programme for Type Testing of Non-Mass Produced I.C. Engines
- M51, Programme for Trials of I.C. Engines to Assess Operational Capability
- M53, Calculation of Crankshafts for I.C. Engines
- M58, Charge Air Coolers
- M59, Control and Safety Systems for Dual Fuel Diesel Engines
- M61, Starting Arrangements of Internal Combustion Engines
- M63, Alarms and Safeguards for Emergency Diesel Engines
- E10, Test specification for Type Approval
- E11, Unified requirements for systems with voltages above 1 kV up to 15 kV
- E13, Test requirements for rotating machines
- E19, Ambient Temperatures for Electrical Equipment in Areas other than Machinery Spaces
- E20, Installation of electrical and electronic equipment in engine rooms protected by fixed water-based local application fire-fighting systems
- F32, Fire detecting systems for unattended machinery spaces
- F35 Fire protection of machinery spaces
- F42, Fire testing of flexible pipes
- P1, Rules for pipes
- P2, Rules for piping design, construction and testing
- P4, Production and application of plastic pipes on ships

ANNEX D

IACS Unified Interpretations of SOLAS Regulations Applicable to Marine Power Plant

- SC 1, SC2, Main source of electrical power
- SC3, SC4, Emergency source of electrical power
- SC5, Emergency source of electrical power in passenger ships
- SC6, Emergency source of electrical power in cargo ships
- SC7 - SC13, Precautions against shock, fire and other hazards of electrical origin
- SC14, Special requirements for machinery, boilers and electrical installations
- SC70, Area classification and selection of electrical equipment
- SC76, Engine Bearing Temperature Monitors for SOLAS Regulation II-1/47.2
- SC82, Protection Against Noise for SOLAS Regulation II-1/36
- SC123, Machinery Installations - Service Tank Arrangements for SOLAS Regulation ii-1/26.11
- SC124, Emergency source of electrical power in passenger and cargo ships
- SC133, Oil Mist Detector on High Speed Engines - "Equivalent Device" for SOLAS Regulation II-1/47.2
- SC134, Essential Services & Arrangements of sources of power, supply, control & monitoring to the different categories of essential services
- SC136, Connecting means by which the main busbars of the main source of electrical power are normally connected
- SC151, Location of the main generating station with respect to the main switchboard and associated section boards
- SC152, Use of Emergency Generator in port
- SC157, Main source of electrical power
- SC167, Electrical distribution boards
- SC184, Machinery Installations - Dead Ship Condition for SOLAS Regulation II-1/26.4
- SC185, Starting arrangements for emergency generator sets
- SC186, Acceptable voltage variations when the emergency loads are supplied from a battery via an electronic converter/inverter.