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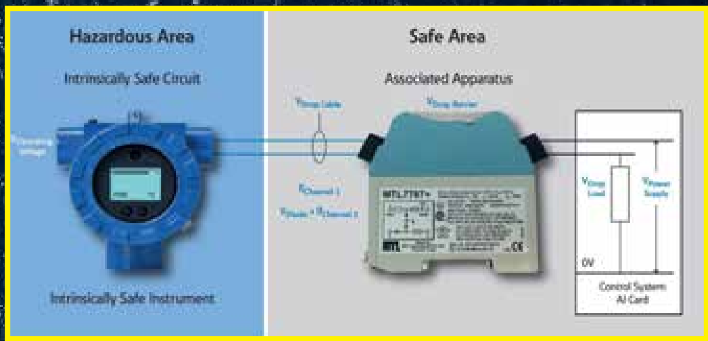

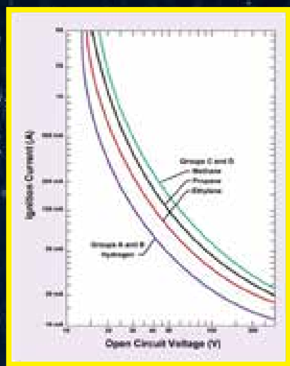

Marine Electrical Equipment Design for Hazard Protection Standards

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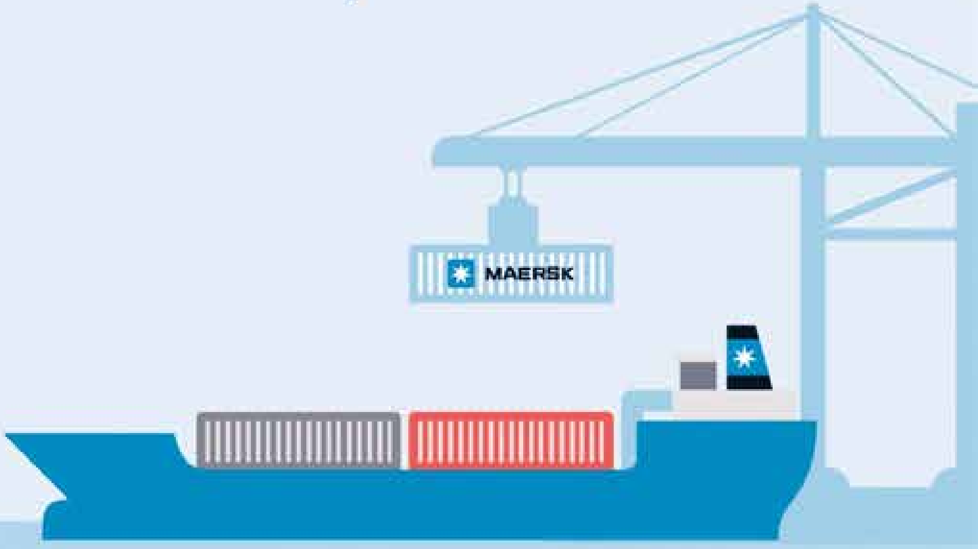

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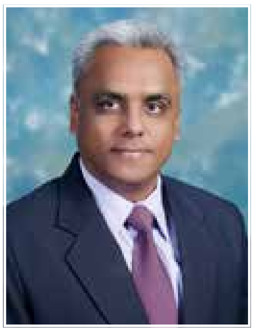

Stability is not immobility.
– Klemens Von Meeternich

The GoI ship continues its voyage, though we may log that a series of bumps were felt as we passed through the straits of democracy. As of now, the Ministry of Shipping, Ports and Waterways continues with its pursuit of global excellence. The vision of Viksit Bharat has not flickered. The plans set out for periods till 2030 and 2047 are still valid and are to be realised. Ports led development, modernisation of the country's ports, fostering an academic ambience for fecundity of ideas and innovations, improving the quality and quantity of the Indian seafarers etc., are all the oft repeated agenda items.

A prudent approach to the action plans would be to build on the existing strengths.

To illustrate, on the strength of global preference for Indian officers, the strategy should be to reinforce quality training and retain the occupied job/training berth slots, rather than shifting the locus to multiplying the numbers. The war on the Russian front has turned many jobs to the Indian shores and this must be capitalised upon. The pandemic-period erosion of quality has to be made good. The on-going discussions on STCW can get a good foot in the door for India for having a better say in matters of maritime education.

In parallel are the initiatives to modernise ports. A productive way to go will be to digitalise and adopt changing ways of doing business while preparing for the transition energy substitutes. In the development din, there are also aspirations to match a maritime mammoth, which include an arbitration centre, P&I Club and a Maritime Centre (all of our own). Throw in the creation of massive funds, fleet expansion and maritime hubs, the Indian dreams get fathomless.

While informing the discourses on shipping and wishing halcyon days for Indian shipping in the coming decade, we may reiterate that stability is more important than the speed and size of progress. And stability does not imply status quo nor a static state.

In this issue...

We start with another educative article on design of marine electrical equipment. Dr. Vedachalam talks about the evolution of the hazardous standards and explains the classification of equipment from the hazards perspective. The concise discussions on 'intrinsically safe' environment, the working of a passive barrier, the PFD levels, layout of the active IS barrier circuit are explained in an easily understandable manner. The section on Ex equipment and zones is quite informative. The concept of purge & pressurisation, surface temperature control, IDMT relays and the standards for marine cables are good additions to the menu. The ending section on grounding might be new knowledge for many of us. This is another enlightening read from the shelves of Dr. Veda, which is highly recommended to all marine engineers.

We are back to the ballast water issue. This time we feature a proposal for a port accommodated sand bed filtration which can help reduce the sediments discharged from ballast water. Dr. Prince et al., from NIOT discuss this proposal based on experiments carried out at laboratory level and on shore-based artificial aquifer deployment. While such proposals require validation in varying conditions, the ideas must flourish, not only for ballast water but also for complex marine problems. The marine researchers would find this interesting.

Following these we feature an essay on the Model Law on Electronic Transferable Records (MLETR).

Dr. Shantanu Paul and Prof. Patrick Donner discuss the evolution and status of cargo documentation that this initiative intends to give a new shape to. The MLETR talks of two documents, namely the Bill of Lading and the Seaways Bill. The Authors provide ample information on the dispositions towards these bills and urges that India should act fast to these changing business practices. Such adoptions are imperative in this era of digitisation.

The Transaction on 'The Economic Selection of Main and Auxiliary machinery' MER Archive-dive from July 1984 is a must-read for all the marine engineers. We have been regularly inviting comments and discussion threads from the readers. Here we persist with our appeal.

Going back to the conversation on continuum, here is the July issue.

Dr Rajoo Balaji
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Electrical System Design Considerations for Hazardous Marine Installations

N.Vedachalam

Introduction

Personnel working on gas carriers, hazardous marine installations and on-shore gas terminals need to understand the importance of safety-centred electrical systems that are essential for minimising the risk of fire and explosion. To ensure safety, these electrical installations are subject to the regulations of flag administration, classification societies, International Maritime Organization (IMO) and International Electro-technical Commission (IEC). Electrical equipment used in these classified hazardous locations is to be Explosion-Proof (EP), provide Intrinsic Safety (IS) and certified safe. The article provides insight on the evolution of hazardous location standards, classification of hazardous areas, intrinsic safety design for low- and high-power electrical systems; controlling the let-through electrical energy by overcurrent protection coordination preventing unsafe equipment surface temperatures, marine-grade power cables, safe multi-layered cable configurations and safe grounding practices. The health monitoring intervals required for ensuring the integrity of the IS devices and EP systems are computed.

Evolution of safety standards for hazardous environments

The historic path of hazardous location standards and temperature class system dates back to the two major mining explosions in 1907 and 1909 that resulted in a catastrophic loss of life, a combined total of 621 miners killed, after which the US Bureau of Mines (USBM) was formed to address mine safety concerns. The USBM progressed beyond electricity into the dangers of electricity mixed with environmental hazards, namely gases and vapours. Over the years, as technology and understanding progressed, more sophisticated testing yielded more exact information about the flammability limits and minimum ignition temperature of gases and vapours present within hazardous locations. Later, the National Fire Protection Agency (NFPA) became more involved with hazardous location electrical safety created the North American Class/Division system to classify the nature of the hazardous substance present (Class), the probability of its presence (Division), and to classify the substance based on its inherent properties (Group).

Subsequently various agencies evolved standards **(Figure 1)** to reliably prevent contact between an explosive atmosphere and ignition sources originating from the use of electrical equipment and thus prevent explosions. The National Fire Protection Agency (NFPA) published NFPA-70, also known as the National Electrical Code (NEC), to define hazardous areas and adopt standards for the safe installation of electrical equipment in the United States which are closely aligned with standards developed by

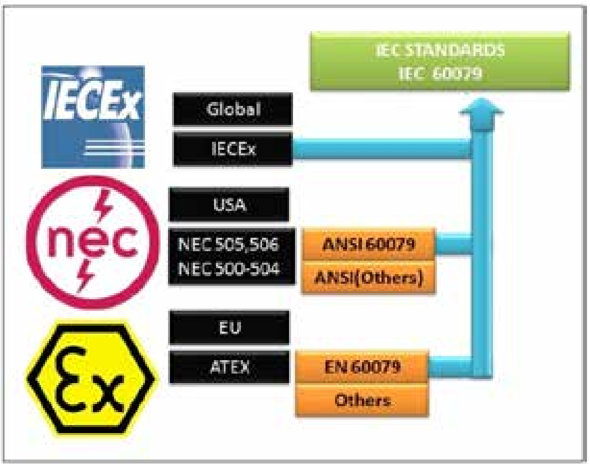

Figure 1. Evolution of electrical safety in hazardous environments

the International Electro-technical Commission (IEC) for intrinsic safety in explosive atmospheres (IEC 60079), and other national and regional standards. Various approval agencies in place hitherto are summarised in **Table 1.**

Modern explosion prevention protocols and strategies are built upon two principles, **the primary fire/explosion protection method is to prevent the formation of an explosive atmosphere (preventing one side of the fire-triangle, Figure 2), the secondary fire/explosion protection method is to prevent ignition of an explosive atmosphere from a heat source**. Various possible sources that produce heat for the ignition (electrically-induced sources highlighted) are also shown in **Figure 2.**The first line of defence to prevent fire/explosion is making sure that the electrical current and any potential sparking are safely contained within a sealed enclosure. But even without an actual flame or spark, equipment can generate

Table 1. Approval agencies in place hitherto

Approvals	Approval Agencies Used	Approvals Accepted
IECE x	CSA, BASEEFA	International
FM	Factory Mutual	North America
CSA	Canadian Standards Association	
CML	CML	Japan
TIIS	TIIS	
SAA	Standards Association of Australia	Australia
NEPSI	NEPSI	China
INMETRO	INMETRO	Brazil
CUTR	FGUP Certification Centre : SC VSI VNIIFTRI Certification Body : OS VSI VNIFFTRI	Russia, Belarus, Kazakhstan & Armenia
ATEX	BASEEFA, KEMA, LCIE	European Union

The first line of defence to prevent fire/explosion is making sure that the electrical current and any potential sparking are safely contained within a sealed enclosure

enough surface heat to ignite the surrounding explosive atmosphere, so a second layer of protection is needed to ensure that the amount of surface heat generated never rises to the ignition temperature of the gases and vapours present in the work area.

Classification of hazardous environments

A hazardous area is any location, either indoors or out, with combustible material such as gases, dusts, vapours, or fibres capable of producing an ignitable mixture. Hazardous areas are classified according to the type of hazard. The definition of zone, class and division is explained in **Table 2.**

The definition for notations used in European CE confirmatory and IEC-EE complementary markings are described in **Figure 3** and described in **Table 3**.

According to the CE marking, Ex II 1 G refers to apparatus used in explosive non-mining environment involving presence of gas, vapor or mist and having very high protection. Likewise CENELEC/IEC marking Exia IIC T2 Ga refers to apparatus protection in environment having hydrogen with temperatures ranging from 215-300°C and provided with electrical intrinsic safety. Group IIC gases are the most easily ignited by an electrical spark, followed by IIB, then IIA and finally Group 1. Similarly, Group IIC gases have flame propagation properties necessitating the most stringent design requirements for flame-proof enclosures. In US classification Class 1: Group A covers Acetylenes, B includes Hydrogen and hydrogen mixtures, Group C: Ethylene, Ethers, Group D: Alkanes, hydrocarbon

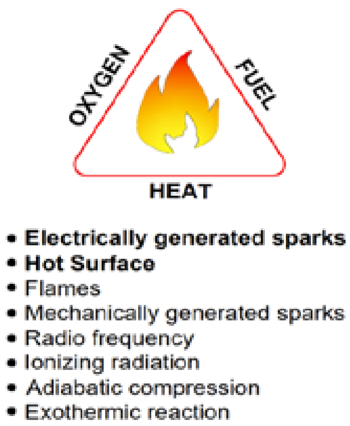

Figure 2. Fire-triangle and electrically-induced ignition

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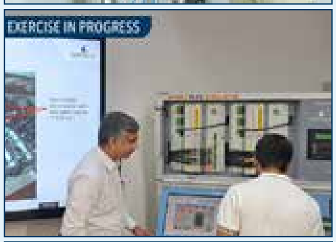

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Table 2. Classification of hazardous areas

Zone	Characteristics (A place in which an explosive atmosphere in the form of a gas/ vapor (or cloud of combustible dust) in air...	
0	...is present continuously, or for long periods or frequently for > 1000h/year.	
1	...is likely to occur in normal operation occasionally, for > 10, but< 1000 h/year.	
2	....is not likely to occur in normal operation but if it does occur, will persist for a short period only, for< 10h/yr., but still sufficiently likely as to require controls over ignition sources.	
Class	**Sources of flammable material**	
1	Contains flammable gases or vapours in quantities large enough to produce an explosion.	
2	Is hazardous due to the presence of combustible dust in the air.	
3	Contains easily ignitable fibres or flying in the air. However, the quantities of fibres&flying suspended in the air are not likely to be large enough to cause an explosion.	
Division	The probability of an explosive atmosphere in normal operation is....	
	Division 1	High
	Division 2	Low

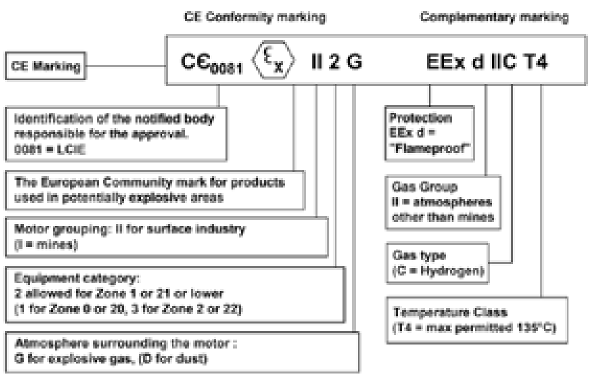

Figure 3. CENELEC/IEC marking for equipment used in hazardous locations

mixtures, alcohol, ketones, esters; Class E: Metallic dusts with resistivity <100kΩ/cm, Group F and G includes non-metallic dusts with resistivity > 100kΩ/cm.

The notation used, mode of protection and IEC standards for explosion and flame-proof enclosures are summarised in **Table 4.**

Intrinsic Safety (IS) for low-power systems

Based on the described principles, as on date, electrical equipment recognised as safe for hazardous environments

Table 3. Description of CE, CENELEC and IEC notations

European CE	
Ex	Marking for equipment used in explosive environments
Equipment group	I for mines and II different from mines
Equipment category	1- Very high protection; 2- High protection, 3- Normal protection
Hazardous atmospheres	G – Gas, Vapor, Mist D – Dust
CENELEC/IEC	
Ex	Marking for equipment used in explosive environments
Functional aspect	ia: 2 fault-tolerant operation (Zone 0/ Division1), ib: Single fault-tolerant operation; ic: normal/no-fault tolerance (Zone 2/ Division2)
Gas group	Class 1, II & III indicate gas dust and fibre atmosphere, Zone 0, 1 & 2 indicate area with continuous, Intermittent and abnormal conditions hazard; Group 1: Methane (180µJ), IIA: Propane (180µJ), IIB: Ethylene(69µJ), IIC: Hydrogen(29µJ), IIIA: Fibre
Temperature class	T1: 450°C, T2: 215-300°C, T3: 160-200°C, T4: 120-135°C, T5: 100°C, T6:85°C.
Equipment protection level	Intrinsic safety based on energy limitation, non-sparking, explosion containment and separation of explosive atmosphere from ignition Gas : Ga, Gb &Gc Dust : Da, Db, Dc

fall into two major categories namely Intrinsically Safe (IS) and Explosion-Proof / Flame-Proof (EP/FP) equipment. The share of IS systems in industrial instrumentation and control category is shown in **Figure 4.**

Intrinsically safe system includes the equipment and wiring that are incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration. This is achieved by limiting the amount of power available to the electrical equipment in the hazardous area to a level below that which will ignite the gases. The use of 'IS' is normally limited to instrumentation, control and alarm systems because of the very low energy levels **(Figure 5).**

A reliable IS system ensures that the maximum thermal and electrical energies released in a hazardous location are much less than the Minimum Ignition Energy (MIE) of the specific atmosphere, while voltage and current are limited in the region below the ignition curves **(Figure 5).** The ignition curve illustrates the relationship

Table 4. Protection codes for EP and FP equipment

Notation	Characteristics	Standards
Ex d	Contains explosion & prevents propagation	IEC 60079-1 IEC 60079-15
Ex e	Apparatus must not arc, spark, or produce ignition capable hot surfaces in normal operation	IEC 60079-7 IEC 60079-15
Ex o	Protection by immersion in oil.	IEC 60079-6
Ex q	Protection by filling electrical enclosure with powder	IEC 60079-5
Ex m	Protection by encapsulation of electronics	IEC 60079-18
Ex p	Purged/ Pressurised to keep the flammable gas out	IEC 60079-2
Ex ib	Intrinsic safety, Limit the energy of sparks &surface temperatures	IEC 60079-11, IEC 61241-11
Ex nA	Non-sparking	IEC 60079-7, IEC 60079-15

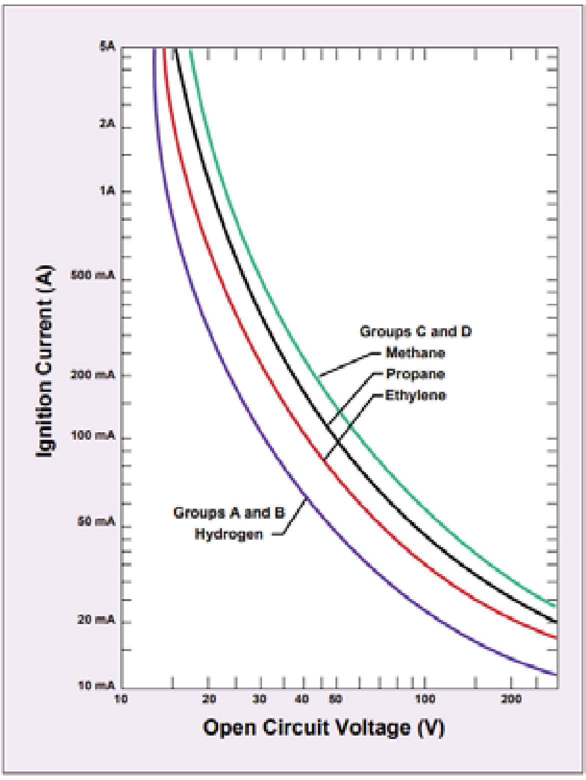

Figure 5. Ignition curves (voltage and current limitation)

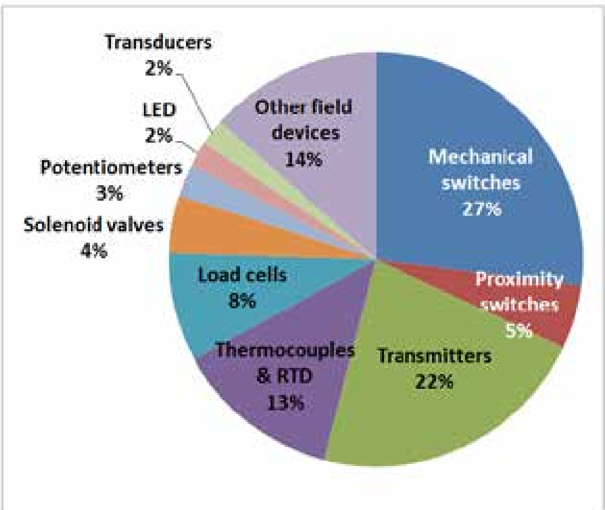

Figure 4. Use of IS systems in instrumentation & control circuits

between the maximum safe open-circuit voltage, Voc, and the maximum safe short-circuit current, Isc, for a stoichiometric mixture – the air/fuel ratio for perfect combustion.

A circuit with a combination of 30V and 150mA would fall on the ignition level of gases in Group A. This combination of voltage and current could create a spark large enough to ignite the mixture of gases and oxygen. The IS applications always stay below these curves where the operating level of energy is about 1 watt or less. The sources of stored energy, including circuit inductance and capacitance increase the energy of any resulting spark and thus the risk of ignition. Therefore, these sources of stored energy must also be considered. The capacitance ($Q= 0.5\ C\ V^2$) and inductance ($Q= 0.5\ LI^2$) curves must also be examined in IS circuits **(Figure 6).**

Intrinsically safe system includes the equipment and wiring that are incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration

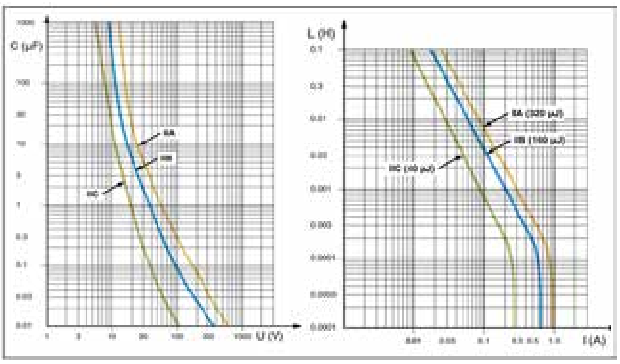

Figure 6. Capacitance and Inductance curves for IS application

> *Under faulty conditions, it protects the field circuit by preventing excess voltage and current from reaching the hazardous area*

When devices are approved as IS under the "entity" concept, they have the following entity parameters: Vmax (maximum voltage allowed); Imax (maximum current allowed); Ci (internal capacitance); and Li (internal inductance). The Vmax and Imax values are straight-forward. Under a fault condition, excess voltage or current could be transferred to the IS-rated field device. If the voltage or current exceeds the apparatus' Vmax or Imax, the device can heat up or spark and ignite the gases in the hazardous area. The Ci and Li values describe the device's ability to store energy in the form of internal capacitance and internal inductance **(Figure 7).**

To protect the IS device/apparatus in a hazardous area, an energy-limiting device must be installed. The IS technique helps to avoid costly and bulky EP/FP enclosures. All IS circuits have three components: the field device, referred to as the IS apparatus; the energy-limiting device, also known as a Redding barrier or the IS associated apparatus; and the field wiring.

Passive IS barrier

A passive IS barrier uses Zener Diodes (ZD) to limit voltage, resistors to limit current and a fuse (Figure 8). Under normal conditions, the device is passive and allows IS apparatus to function properly. Under faulty conditions, it protects the field circuit by preventing excess voltage and current from reaching the hazardous area. The ZD (that are pulse-tested and de-rated by a factor of 1.5 for IS application) limits the voltage to a value referred to as open-circuit voltage, Voc. The resistance of a ZD is very high until it reaches its breakdown voltage, beyond which its resistance reduces markedly, conducting current. The rated voltage of the ZD is a few volts above the circuit design voltage, and the resistor size only allows the design amperes. Under conduction, the ZD keep the circuit voltage at the rated voltage, and the resistors limit the current to the looked-for value. If the current is excessive, the fuse will open the circuit, arresting its flow.

Associated Apparatus (barrier)		Apparatus (field device)
Open circuit voltage Voc	≤	Vmax
Short circuit current Isc	≤	Imax
Allowed capacitance Ca	≥	Ci
Allowed inductance La	≥	Li

Figure 7. V, I, L and C limitations for IS barrier and device

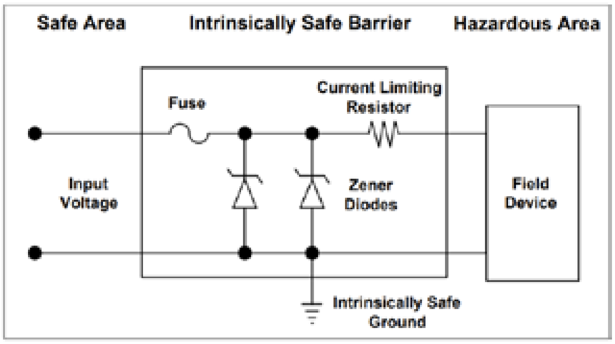

Figure 8. Typical passive IS barrier used in hazardous area

Typical fuses used for IS applications have rated currents ranging from 40 to 250mA and pre-arching I^2t of 40mA fuse is 0.00006. The fuse will blow when the ZD conducts. This interrupts the circuit, which prevents the ZD from burning and allowing excess voltage to reach the hazardous area. There always are at-least two ZD in parallel in each IS barrier. If one diode should fail, the other will operate providing complete protection **(Figure 8 & 9).** IEC/EN 60079-14 describes a mathematical verification method that is based on the respective characteristic values.

The increasing use of automation requires field-bus protocols (such as Foundation field bus and Profibus) for digital, two-way communication between distributed measurement devices and control equipment. The field-bus system comprises of components, power supply, cables, field-bus junction boxes, field devices, displays, etc to be IS. The individual devices with their summated ignition curves would have to be connected to a system with a total ignition curve and assessed regarding critical

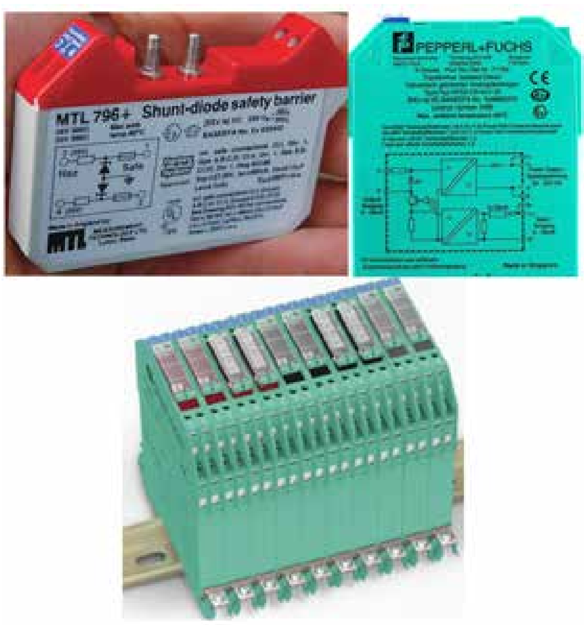

Figure 9. IS barrier devices used for low voltage circuits

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values using Field-bus Intrinsically Safe Concept (FISCO, European) or Entity (North American) models.

On-Demand Reliability (ODR)/ Safety Reliability (SR) is one of the key requirements for IS circuits used in hazardous locations. IEC 61508/11 is a standard provides a framework for implementing instrumented safety systems, using the principles of the Safety Life Cycle and Safety Integrity Level (SIL) concepts. SIL requirements for a plant is computed taking into consideration the risk consequence, alternate Safety Instrumented Function (SIF) in place, human occupancy and the demand rate for the SIF. Protection systems need to perform their intended operations on demand.

Active IS barriers use isolation transformers, opto-couplers, and relays to provide isolation between safe and unsafe areas

The Probability of failure (PoF) is the unavailability of a safety system on demand. If a demand occurs after a time, the probability that the system has already failed, is the probability of failure on-demand (PFD). The SIL defines the degree of safety protection required by the process and consecutively the ODR/SR of the IS system necessary to achieve the function. SIL has four levels, 1 to 4. The higher the safer. **Table 5** describes the various SIL levels, with the corresponding PFD.

According to MTL instruments, the failure rate of a passive ZD-based IS barrier is 98.5 FIT (failure-in-time, failures/ 1 billion hours). With FIT as input, SIL module of TOTAL-SATODEV GRIF tool is used for computing the ODR and the healthiness monitoring interval (HMI) requirements of the ZD-based IS barrier for SIL3 compliance **(Figure 10).** It is found that passive IS barrier should have an HMI of 40 days and ~1 year for SIL4 and SIL3 compliances, respectively.

Table 5. SIL level and PFD per year

Safety Integrated Level (SIL)	Probability of Failure on Demand (PFD per year)
1	10^{-1} to 10^{-2}
2	10^{-2} to 10^{-3}
3	10^{-3} to 10^{-4}
4	10^{-4} to 10^{-5}

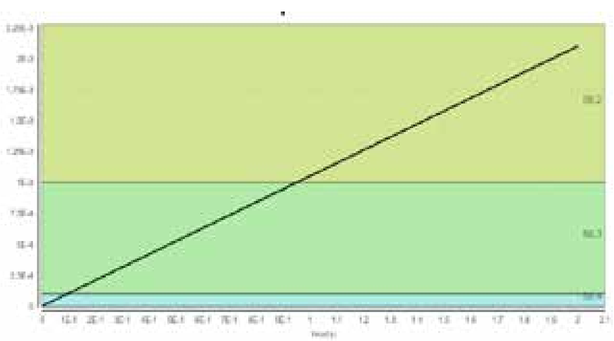


Figure 10. ODR and HMI of ZD-based passive IS barrier

Active IS barrier

Active IS barriers use isolation transformers, opto-couplers, and relays to provide isolation between safe and unsafe areas **(Figure 11).** The active barrier can drive a higher power load as compared to a ZD barrier. It does not require an intrinsically safe ground connection. This is the safest barrier to use, if a high quality intrinsically safe ground connection is not available.

The comparison between passive ZD and active isolation interface are summarised in **Table 6.**

All transformers have capacitance between the secondary and primary windings, which allows higher frequencies (10kHz-100kHz) of common-mode (CM) noise to pass. In isolation transformer, electrostatic (faraday)

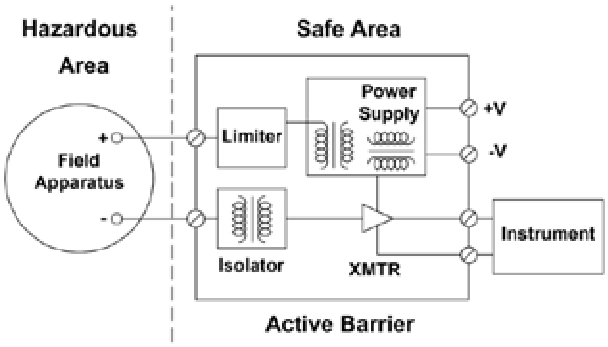


Figure 11. Typical active IS barrier used in hazardous area

Table 6. Comparison between ZD and isolation interface

Feature	Zener barrier	Isolation interface
Earthing	Essential	Not required
Insulation test	Must be able to withstand 500V	Not required
Tolerance to input power supply variation	Poor	Very good
Power requirements	Low	High
Reliability	Exceptionally good	Less than ZD

shield between the windings reduces this capacitance and provides a path for this CM noise to flow back to the source **(Figure 12)**. The shield reduces the amplitude of CM noise and transients through the isolation transformer such that the leakage current is < 60μA. Such kind of galvanic isolation is recommended by IEC 60079-14:2013 clause 16.3 for Zone 0 and Zone 20 systems.

The efficacy of the isolation transformer (decibels, db.) is measured by ratio of the CM noise on the input to that of the output. In the test circuit for CM noise **(Figure 13),** when Vin is 100V at 10 kHz, Vout is 0.06V at 40 kHz, the CMA is 20 log(100/0.06) = 64.4 db. Various configurations of faraday shielding and its features are summarised in **Table 7.**

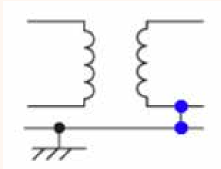
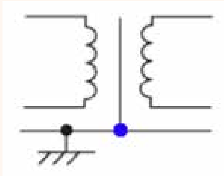
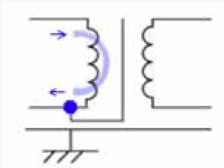
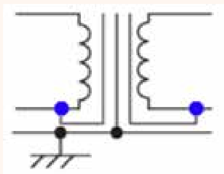
EP/FP, Purged and Pressurised Equipment

In electrical equipment, potential sources of ignition include arcs produced in motor starters, motor terminals, commutators and from damaged power cables. Traditionally, protection from explosion in hazardous environments has been accomplished by either using EP apparatus which can contain an explosion inside an enclosure, or pressurisation or purging which isolates the explosive gas from the electrical equipment. The representation showing various gas zones and allowable Ex electric equipment is summarised in **Figure 14.**

In EP/FP (ExD) equipment, the surrounding explosive atmosphere can enter the equipment enclosure that could lead to internal explosions. The enclosure has to be strong enough not to fracture or distort under the internal pressures generated. Flame paths (length in air between inside and outside of the enclosure) must be a minimum length, and flame gaps must not be above a prescribed maximum dimension. As the flame path is increased and flame gap decreased, the extinguishing effect on any flame trying to escape from the enclosure is increased. The resulting hot gases or flame would emerge at such velocities that surrounding flammable gas would not be ignited by the explosion **(Figure 15).**

To achieve this, threaded joints must have a minimum number of threads engaged, cables must enter the

Table 7. Various shielding configurations

Configuration	Features
	It is an unshielded transformer. Secondary of the transformer is connected to safety ground to eliminate ground-neutral voltage.
	Single faraday shield in which the shield is connected to safety ground for common mode protection.
	Single faraday shield is connected to the noisy side neutral wire for differential mode protection.
	In triple faraday shield, the shields are connected to safety ground for common mode and the neutrals are connected for differential mode noise.

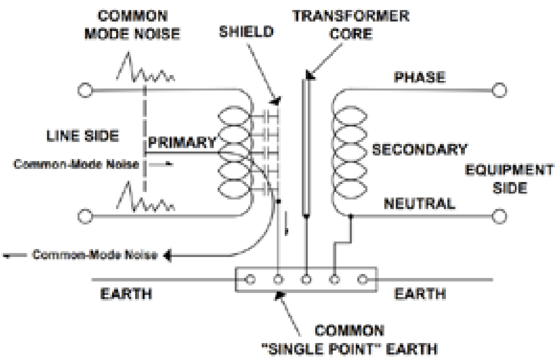


Figure 12. Typical active IS barrier used in hazardous area

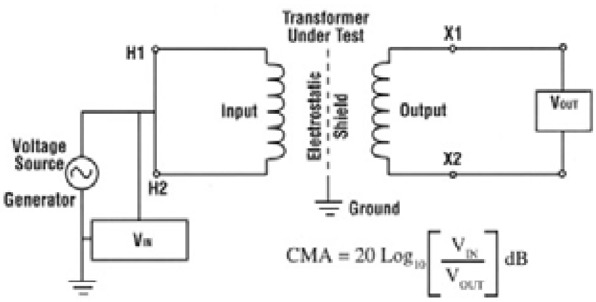


Figure 13. Arrangement for testing isolation transformer

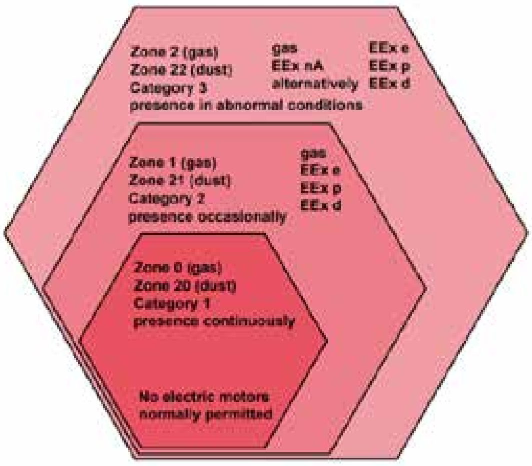


Figure 14. Summary of zones and Ex electric equipment categories

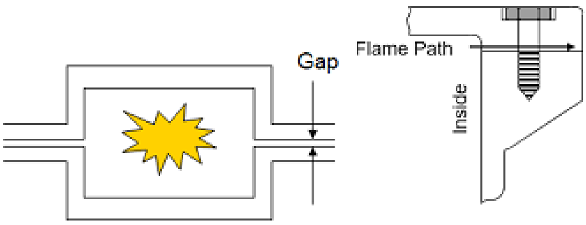


Figure 15. Flame path gap in EP/FP equipment

enclosure through flameproof glands, or if conduit entry is used a stopper (encapsulated) box is required, windows must be tough and must be sealed to prevent transmission of an explosion, spindles and rotation shafts must comply with special dimensional requirements, and the equipment must be tamper-proof to prevent unauthorised entry. Every enclosure must be subjected to routine pressure tests of 1.5 to 3 times the maximum pressure attained during test with prescribed gas, according to whether the pressure rise time is < 5ms. A certificate for the integrity of the equipment is issued after laboratory testing.

Purging and pressurization (P&P) is an explosion protection method (Ex p) that uses compressed air or inert gas to eliminate and prevent hazardous substances such as explosive gas, dust, or a combination of the two, from entering the enclosure and causing a fire or explosion. **The concept works on the principle of keeping the flammable substance away from the source of ignition and ensuring the surface temperature of the purged enclosure to be non-incendiary.**

> **In electrical equipment, potential sources of ignition include arcs produced in motor starters, motor terminals, commutators and from damaged power cables**

P&P systems provide protection for standard ordinary location electrical equipment within a standard enclosure designed to operate in a hazardous area. Compared to EP/FP protection methods, this protection concept is more cost-effective and prevents an explosion. IEC 60079-2 and NFPA 496 define the regulations for P&P enclosures for the protection of electrical equipment, such as switch and control cabinets, analysis devices, and large motors. The P&P (Ex p) enclosures excludes gas entry by positive pressure differential, static, leakage compensation and continuous dilution methods.

The enclosures that house the equipment to be purged must have sufficient physical integrity to withstand impacts and overpressures, as well as designed to facilitate the free flow of air. As enclosure integrity is required to a level of IP40 (no holes > 1mm) and any non-metallic material must be tested for durability. The Ex p devices are certified by NEC, IECEx, ATEX, CSA & UL. A typical P & P motor system is shown in **Figure 16.**

P&P is a two-step process done prior to energising electrical equipment inside an enclosure located in hazardous environment. Purge is the process that removes potentially hazardous gas from the interior of the enclosure prior to pressurisation. The purge cycle performs air-exchanges that displace any explosive (hazardous) gas with inert protective gas. Once purged (typically 4-5 cycles), pressurisation is carried out. Pressurisation is the process of creating a higher internal pressure that is provided by a protective gas supply, preventing any hazardous gas or dust from entering the enclosure. Any penetrations or leak areas will have protective gas exiting the enclosure rather than hazardous gas or dust migrating into it.

NFPA requires a minimum pressure 25Pa for class I applications, while IEC/ATEX requires a minimum pressure of 50 Pa for type X and Y and 25 Pa for type Z equipment. If at any time the pressurisation is lost, the enclosure must be de-energised and the P&P process must be repeated before the enclosure is re-energised. Type X purging systems also require the power be automatically disconnected if pressurisation is lost. Both NFPA and IEC/ATEX do allow for alarm only options with Type-X purge systems if it is known to be more dangerous to cut power off automatically. They are classified into continuous flow for enclosures < 0.5 m^3, and leakage compensation for larger enclosures > 0.5 m^3. Type-X purging devices reduce the zone classification within an enclosure from Division-1 or Zone 1 to non-hazardous. Type Y reduces the classification from Division 1 or Zone 1 to division 2 or Zone 2, while Type Z reduces division 2 or Zone 2 to non-hazardous.

Figure 16. Typical purge and pressurized (P&P) motor system

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An effective P & P system needs to be connected to a protective gas supply suitable for this purpose. The gas supply can be air or inert gas but must be clean, non-flammable, originate from a non-hazardous area and be free of water and oil per BS ISO 8573-1 or relevant local standards. Pre-start purge (one of the special measures that may be applied to HV Ex e, N or n motors) prevents ignition risk due to rotor or stator sparking during starting. Air flow sensors and timers may monitor this process before allowing the starting of the motor. Once the motor is started, no further air flow monitoring is provided. Pressurisation should continue for a defined time period after the motor has stopped to prevent any surrounding hazardous atmosphere being drawn into the motor during the cooling down period, whilst motor internal temperatures may remain above the T-class rating. On-demand analysis performed on a typical P &P monitoring system involving air flow switch and motor contactor interlock indicate that the monitoring system should have anHMI of 32days and ~0.6 years for SIL4 and SIL3 compliances, respectively. The identified HMI shall form the basis of monitoring system maintenance strategy.

Controlling equipment surface temperatures

EP/FP equipment carry a temperature classification, or T-code, that represents the maximum surface temperature of the equipment enclosure. The T-code system was developed as a way reducing the risk by carefully assessing and controlling heat side of the fire triangle. Basically, the T-code is a method of comparison between the maximum amount of surface heat produced by equipment and the ignition temperature of flammable materials. Making sure that each the equipment specifications for class, division, groups, and the temperature class are matched precisely to the conditions of the hazardous location is the most effective way to prevent ignition and explosion in hazardous work areas.

Several sources of ignition are possible in cage motors. High surface temperatures in induction cage motors can be controlled by derating and attention to hot spots. Embedded temperature sensors can be used to provide an active (instrumented) high- temperature alarm and trip function. If the machine is stalled (electrically-energised and mechanically jammed),

Table 8. Characteristics of IDMT relays

Type of protection	Characteristic
Normal Inverse (Type A)	$\frac{0.14}{(I/I_p)^{0.02}-1} \cdot T_p\ [s]$
Very Inverse (Type B)	$\frac{13.5}{(I/I_p)^{1}-1} \cdot T_p\ [s]$
Extremely Inverse (Type C)	$\frac{80}{(I/I_p)^{2}-1} \cdot T_p\ [s]$
Long Inverse (Type D)	$\frac{120}{(I/I_p)^{1}-1} \cdot T_p\ [s]$

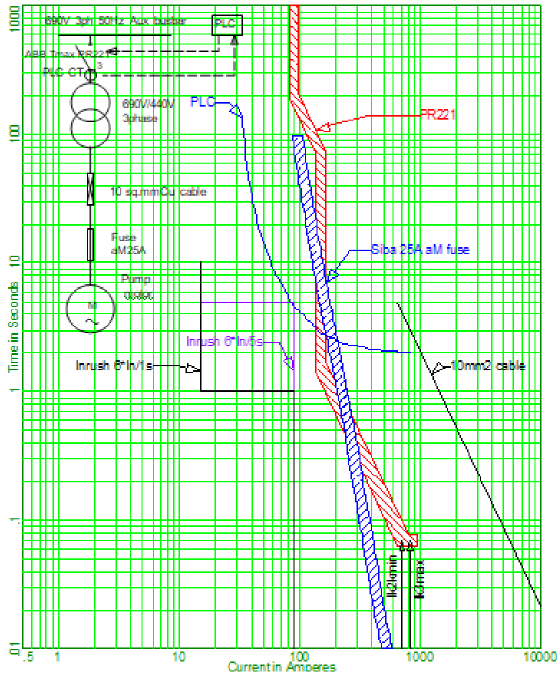

Figure 17. Protection Coordination in a typical LV system

it will heat up more rapidly than in normal operation, and protection for the stalled condition can be provided by the user by electrical protection relays. Proper Protection Coordination (PC) of the over-current relays can reduce the let- through current/energy resulting in motor surface heating leading to higher unsafe temperatures. The functionality and integrity of all such active protective functions are managed based on IEC 61508 / IEC 61511 recommended practices. The IDMT relay is Inverse Definite Minimum Time relay in which the time to operate is inversely proportional to the magnitude of fault current near pickup value and becomes substantially constant slightly above the pickup value of the relay **(Table 8).** The steeper the inverse characteristic, lower the let-through energy to the downstream motor. The PC should take into consideration of the duly cycle of the motor (defined from S1 to S10) according to IEC 60034-1 in ensuring that the surface temperature rise is within safe limits.

As an illustration, the PC study carried for a typical low-voltage (LV) system comprising of a utility bus, step-down transformer, cable, induction motor and protection devices including circuit breaker with in-built short circuit and overload protection, Programmable Logic Controller (PLC) -based over-current protection system commanding the circuit breaker and protection fuse is shown in **Figure 17.** The IDMT characteristics of ABB PR221 circuit breaker, 25A aM fuse, PLC-based overload sensing, transformer inrush current and the 10 mm^2 power cable are shown in the PC graph.

From the PC graph it could be inferred that the protection devices are insensitive to the transformer inrush current (90A for 1s). The PLC-based IDMT relay provides over-current protection in 30A-150A range. In the 150-200A range, the circuit breaker (CB) is more responsive (~1s) than the fuse (~8s). In 200-250A range, both CB and fuse have equal response time (~1s) and for higher short circuit currents (say 300A), the fuse is more responsive (~1s). The cable that has the higher short circuit withstand capability (600A for 5s to 10kA for 200ms) and the induction motor are well protected from over currents preventing high surface temperatures.

Cables

Marine grade cables are specially designed and manufactured (to be compliant with IEC, JIS standards and approved by ABS, BV, RINA, DNV, LR, NK certificates) to withstand the hostile sea environments such as cold, humidity, saltwater corrosion, oil, vibration, and more. These cables are to be halogen-free, low smoke, flame retardant, and has fire-resistant features with low surface temperatures during normal and abnormal operation in hazardous environment. **The major factors to be considered for selecting a marine grade power cable include operating voltage, cross-section area, conductor material, number of cores, voltage drop, short circuit rating, type of armour, sheathing material, insulation grade, shielding, de-rating factors, bending radius, operating environmental conditions, fire resistance, smoke generation limits and the corrosion resistance.** The IEC standards recommended tests for marine grade cables are shown in **Table 9.**

To ensure proper PC, the short time current rating of power cables is calculated based on the guidelines provided in IEC 60364-4-43.

Ish = k A/ sqrt(t)

Where k depends on the cable construction material **(Table 10).**

When the power cable is laid in cable trays in a multi-layered configuration in the hazardous location, appropriate ampacity de-rating factors are to be applied **(Table 11)** so that the hot spot temperature of the cable is within the safe operating limits.

When the cables are used in an environment other than defined by cable manufacturer specifications, electro-thermal finite element analysis (FEA) should be performed as per the guidelines of IEC TR 62095 considering the cable material properties to ascertain the safe application of the cable. As an example **Figure 18** shows the FEA results for a 3 core, 6 mm^2 copper 37.5mm diameter marine power cable operated in four layers in a metallic cable tray carrying a current of 30A at an ambient temperature of 30°C. The electro-thermal FEA was done using Infolytica Corporation's MagNet and ThermNet FEA softwarev7.4.1. The assumptions include 2-D heat flow, convective heat transfer coefficient of 15 W/m^2 and cable material thermal conductivity of 0.25W/m-k. The higher temperature in the second and third layers is due to the reduced heat flow in the underlying and overlying layers. The lower temperature in the first and fourth layers is due to the conductive heat transfer with the metallic cable tray and convective heat transfer with air, respectively.

Table 9. Special standards for marine grade cables

IEC	Tests
IEC 60331-1,2,21	Fire resistance when exposed to a flame at 750˚C for 90 minutes.
IEC 60092-360	Temperature withstand of 90ºC with halogen-free sheath and flame-retardant thermoplastic compound
IEC 61034	Smoke density
IEC 60754	Conformity to halogen free cable materials
IEC 60092-300	Manufacturing quality
IEC 60754-2	Corrosion resistance and acidity attack

Table 10. Cable material & time constants with Cu conductor

Insulation material	Max Temperature	K
Thermoplastic PVC	90ºC	100
Thermosetting XLPE	90 ºC	143
Thermosetting Silicone rubber	185 ºC	132

Table 11. Derating of bunched cables in tray

Number of layers	% Ampacity de-rating
1	0.85
2	0.65
3	0.45
4	0.35

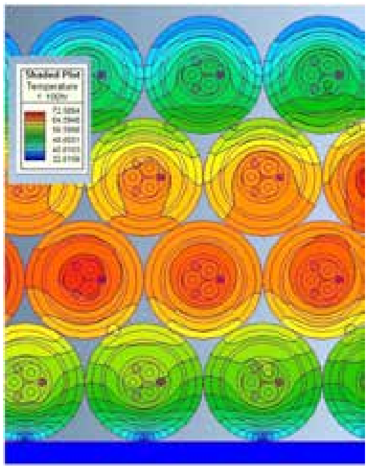

Figure 18. Electro-thermal FEA of multi-layered cables

Grounding

The ship/marine installation hull is the zero potential reference for the vessel/platform power, electronics and radio communication systems. The vessel onboard antennas require a proper ground reference for reliable transmission. The IEEE Practice for Shipboard Electrical

Installations recommends that the grounding of 600 Volts (or lesser) systems should ensure minimum transient over voltages, continuity of service during single line-ground (L-G) faults and minimise ground fault current in the hull/ platform structure.

The IEEE Practice for Shipboard Electrical Installations recommends that the grounding of 600 Volts (or lesser) systems should ensure minimum transient over voltages, continuity of service during single line-ground (L-G) faults and minimise ground fault current in the hull/ platform structure

The flow of fault current in a solidly grounded vessel power network is depicted in **Figure 19.** When a ground fault occurs in a power distribution panel, the fault current flows through the alternator grounded phase winding, interconnecting cable, grounded equipment inside the distribution panel, ship deck / platform and back to the star point of the alternator. Large capacity alternators, low-impedance power distribution networks (mainly due to the physical proximity of generation and loads, and the use of high cross-sectional electric conductors) results in high fault current levels. As the distance between the alternator and fault location is less (few tens of meters), the potential gradient/voltage difference between nearby points on the deck will be high and unsafe, normally refereed as step and touch potentials in substation engineering. These potential differences leads to arcs/flashes during ground fault conditions, which are unsafe in hazardous environments. Hence marine power systems are normally ungrounded and equipped with continuous L-G fault monitoring; and in the case of high resistance grounding, the currents during single L-G faults should be <3A so as to limit the potential difference. Hence solid grounding systems are limited only to non-critical circuits in marine applications, especially in non-hazardous environments.

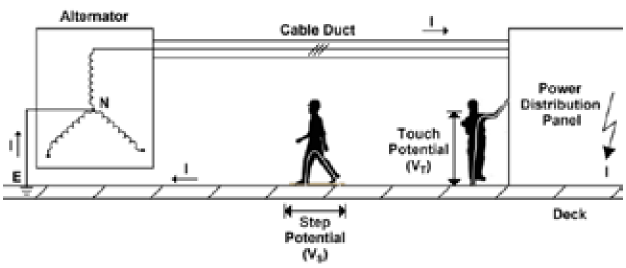

Figure 19. Potential difference leading to arcs/flashes

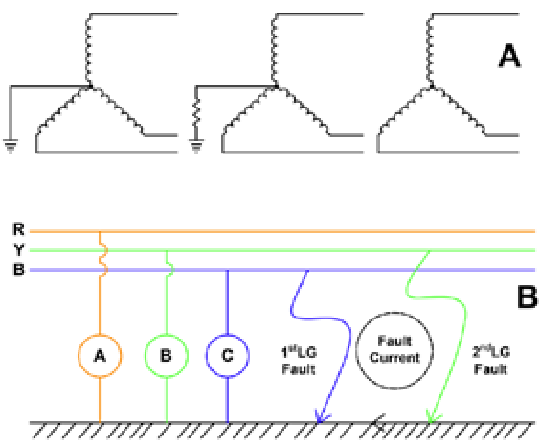

Figure 20. a. Solid, resistance and ungrounded systems b. Faults in ungrounded system

Both the high resistance and ungrounded systems allow continuous service (with the hull energised and without any human risk) unless a second ground fault occurs on another phase **(Figure 20).** Hence the first ground fault has to be cleared as early as possible. With the presence of one ground fault the voltage on the other healthy phases will increase by up to 1.73 times that of the normal line-to-neutral values. It is imperative that all equipment should withstand the higher-than-normal voltage. In marine power systems, the traditional mechanism used for detecting the first L-G fault is of immense use, as the second fault leads to power outage. As the second fault generates sparks at the locations within the hazardous zone, the first ground fault has to be detected and cleared. The healthiness of the system ground based on the indicators A, B and C **(Figure 20)** is summarised in **Table 12.**

At present, advanced online insulation monitoring systems (IMS) measure the insulation between the completely galvanically interconnected AC network and its protective ground. The IMS injects a sequentially coded measuring signal into the monitored system. The signal flows to ground through the path of the insulation fault and the level of flow indicates the insulation resistance. The measuring accuracy is not influenced by any normal kind of load attached to the AC network. Based on the recommendations of IEC 61557-8, the IMS based on three different principles include DC superposition method,

Table 12. System ground monitoring using three indicators

Status of indicators/Relays			Nature of fault
A	B	C	
0	0	0	System healthy
0	1	1	Red phase grounded
1	0	1	Yellow phase grounded
1	1	0	Blue phase grounded

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Abbreviations	
AC	Alternating current
ATEX	Atmosphere Explosible
BASEEFA	British Approval Service for Electrical Equipment in Flammable Atmospheres
CB	Circuit Breaker
CE	Conformite Europeenne
CM	Common-mode
CML	Certificate Management limited
DC	Direct current
EP	Explosion-Proof
FEA	Finite Element Analysis
FIT	Failure-In-Time
FISCO	Field bus Intrinsically Safe Concept
FP	Flame-Proof
HMI	Healthiness Monitoring Interval
IEC	International Electro-technical Commission
IDMTR	Inverse Definite Minimum Time Relay
IMO	International Maritime Organization
IMS	Insulation Monitoring System
IP	Ingress Protection
IS	Intrinsic Safety
L-G	Line to Ground
LV	Low Voltage
MIE	Minimum Ignition Energy
NEC	National Electrical Code
NEPSI	National Supervision and Inspection Centre for Explosion Protection & Safety Instrumentation
NFPA	National Fire Protection Agency
ODR	On-Demand Reliability
PC	Protection Co-ordination
P&P	Purge and Pressurization
PFD	Probability of Failure on-demand
PLC	Programmable Logic Controller
PoF	Probability of failure
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
SR	Safety Reliability
USBM	US Bureau of Mines
V_S	Step Voltage
V_T	Touch Voltage
ZD	Zener Diodes

double frequency principle and zero-sequence current. Amplitude comparison method helps to monitor both symmetrical and asymmetrical deteriorations in the insulation.

Acknowledgements

The author gratefully acknowledges the Ministry of Earth Sciences, Government of India in encouraging this work.

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Efficacy of Sediment Management in the Ship's Ballast Water Tank Enables Effective Compliance with the Ballast Water Management Convention – A Pilot Study

J. Prince Prakash Jeba Kumar, S.Ragumaran, A.Karthikeyan, Sajeev Krishna kumaran Nair, B. Rajan Babu, M. Venkatramani, Purnima Jalihal

The use of steel for the ship's hull building started 130 years ago, and sea/river water was utilised to stabilize these ships on ocean-going voyages, ballasting technology. This ballast water generates sediments in their tanks as an array of chemicals and various diapausing stages of the marine biota due to their contaminated intake sources. Indeed, our ports are industrial and global trade hubs. As a result of international shipping, the movement of sediments containing these biotic reproductive stages worldwide can result in biological contamination of receiving port areas. Its accumulation depends on the ship's ballast management practices, the type of ballast tanks onboard, and the time since the tanks were last cleaned in drydock.

The sediment removal usually occurs during the regular ship's drydock maintenance. It is mandatory to complete an inspection of the hull in a drydock twice within five years, while the period between two inspections should be no longer than 36 months, according to the International Convention for the Safety of Life at Sea (SOLAS). Sediment accumulation in the tanks varies from several cm to more than 30 cm in thickness, corresponding to tens and hundreds of tons of sediment, and most of them are fine mud with a mean particle size of <20 µm.

The current system of treatment practices for ballast water has also been ineffective, as this sediment provides asylum for microbiota to avoid exposure to ballast water treatments like UV radiation and chlorination in the ballast tank. Even though UV radiation and chlorination techniques dominate ballast water treatment, filtration is often used before or after the treatment techniques as efficiency promoters. Hence, a port-based, eco-friendly, energy-efficient filtration system is proposed to restrict the source for sediment entry, like suspended particles and organic matter reduction, into the ballasting systems of vessels [1].

An artificial sand filtration technique was adopted by mimicking a natural aquifer to curb suspended particles. The laboratory and in-situ model performance depicted an efficient filtration capability of more than 90%. It includes planktonic organisms with a size class of 0.45µ[2]. Avoiding the entry of these organisms into the ballasting tank curbs the IAS spread as the juveniles are planktonic and comply with the D2 standard of BWM effectively with the available UV and chlorination technologies. This technology could be effective in ports with muddy waters (Haldia, Kandla, etc.) for the initial treatment stages.

> *As a result of international shipping, the movement of sediments containing these biotic reproductive stages worldwide can result in biological contamination of receiving port areas*

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Introduction

Steel-hulled shipbuilding started 130 years ago, and sea\river water was utilised by ballasting technology to stabilize these ships on ocean-going voyages. Ballasting a ship primarily involves taking water to maintain the ship's stabilisation. The water comes with suspended sediments associated with floating planktonic organisms, and the resting stages of benthic forms are also taken on board. Later, it settles out of suspension and accumulates in the ballast tank. The volume of accumulated sediment in a ballast tank depends on the ship's ballast water management practices, the type of ballast tanks involved, and the duration of subsequent tank cleaning in a dry dock. The deposits generally vary between 2 and 30 cm (sampled from ferries, containers, and cruise ships), translating to 10 and even 100 tons of sediment in the ballast tanks of larger vessels in England and Wales (Lucas et al. 1999).

This accumulation varies considerably within and between ballast tanks of the same vessel and between ships where most of the sediment was fine mud with a mean particle size of < 20 µm. These sediments containing fine mud harboured both living active stages and various diapausing or resting stages of biota. As a result, this could cause bio pollution in port areas worldwide during international shipping activities where the interchanging sediment containing these biotic stages occurs.

Subsequently, the International Maritime Organization's (IMO) International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention 2017) addressed this problem, considering that aquatic invasive alien species (IAS), including harmful aquatic organisms and pathogens (HAOP), as the greatest threats to coastal and marine environments around the world. Also, it brought out the dual management problem of water and sediment quality management, thereby allowing the efficient treatment of the ballast water with various technologies as a priority and solving the sedimentation problem by filtration.

It stated that the onboard ballast water intake or disposal water treatment by modern technologies like chlorination & UV radiation kills the suspended forms that settle in the ballast tank. If left untreated, it could become a hiding place for micro and macro-organisms entering through consequent intakes, leading to loss of efficacy of these treatment systems. However, though the Convention adequately addresses the treatment of ballast water (BW) to control IAS and HAOP, the problems generated by sediments during implementation must be prioritised.

"However, achieving the D2 standard at the discharge point is ambiguous if the sediment is not removed from ballast water tanks even with a modern BWMS is installed in a vessel"

Ballast tank sediments

In general, ballast sediments contain eight major constituents: clay particles of 2 µm or less in size, silt particles of 2 – 63 µm in size, sand particles of 63 µm – 2 mm size class, larger soil particles of over 2 mm, products of corrosion processes in the tanks and associated piping, weathering of protective coatings, Non-living and living organic materials [10]. It is recognised that under Article 5 of BWM Convention Sediment Reception Facilities, Parties undertake to ensure that ports and terminals where cleaning or repair of ballast tanks occurs have adequate facilities for the reception of sediments. However, sediment management does not set definite treatment procedures or discharge standards. It encourages the open-minded adoption of procedures without any unwanted side effects. As a result, a general practice of dumping it at sea can be followed at least 200 miles offshore and in at least 200m of water depths.

It was identified that the estimates of total viable cell numbers in sediments were higher than those counted in the ballast water [3,6]. As a result, it indicates the importance of sediment management and necessitates a retrospective approach towards ballast water exchange in the high seas to reduce marine bacterial populations. Subsequently, active and resting stages of 160 species of invertebrates are contained in the ballast sediment of transoceanic vessels operating on the North American Great Lake basin; among them, 22 freshwater species of nonindigenous to the Lake basin [4].

The activation of resting stages (eggs) in hatching was observed on every ship to be 'meagre' (0.5 individuals per 500 g sediment), not from all sediments on all ships. It typically involves activation of < 0.05% of the total eggs of five rotifers and copepod nauplii hatched from ballast sediments, indicating the occurrence of reproduction in ballast tanks. This can eventually lead to chances of non-indigenous species introduction events, and the risk caused is trivial but potentially important [5]. However, achieving the D2 standard at the discharge point is ambiguous if the sediment is not removed from ballast water tanks even with a modern BWMS is installed in a vessel.

Considering the impacts of sediment accumulation apart from biological effects, the area of sediment accumulation in a vessel is also encouraged by the structural components of the vessel's ballast tanks. The obstruction by the scallops deposited in the walls of the ballast tank's structures and the impediment of the non-direction of sediment movement during the traditional cleaning process by the BW suction bell led to the initial thought of structural alterations of the

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vessel's ballast tank [7]. It is proposed that modifications in the deballasting systems of ships be implemented in existing ships or incorporated in new construction to ensure the structural and operational integrity of vessels and facilitate the flow and subsequent removal of sediments from the ballast tanks [8].

Since sediment originates from suspended and dissolved solids of the ballast water, the existing treatment scheme of filtration seems to be an effective solution among various physical chemical treatment technologies

The long-term studies on the integration of environmental efficiency and finance in maritime shipping through the sustainable implementation of BWM (Ballast Water Management) measures in the Adriatic Sea under the BALMAS project found apart from bio pollution, the heavy metal pollution caused insignificantly by ballast sediment [9]. The possible sources are compounds from the deterioration of tank plates, tank coating residues, and ballasting water contaminants such as clay, silt, sand, and organic materials [9]. However, it also depends on the quality of the ballasting water source, which is contaminated by various chemicals, as ports are hubs for industrial activities, global trade, and the state-of-the-art analytical instrumentation's utility for quantification of chemicals. Hence, ballast sediment requires treatment levels of deceased biological forms and a non-toxic range of chemical composition. Since sediment originates from suspended and dissolved solids of the ballast water, the existing treatment scheme of filtration seems to be an effective solution among various physical chemical treatment technologies. Their inbuilt disadvantages are listed elsewhere among the current onboard ballast water treatment methods [11]. However, porous barrier filtration systems have the disadvantage of a robust nature, occupying space onboard, energy inefficiency, loss of microparticles, and filter sediment disposal. Hence, a port-based traditional sand filtration system will overcome these technical disadvantages.

Eco-friendly Filtration for suspended particle removal

In nature, water passes through the sand, and the suspended particles in water are larger than the pore size between the sand particles of the sediment bed and settle in the voids of the sand bed. The trapped particles form a mat on the sand grains by specific bacterial action and improve straining capacity by reducing pore size. It also creates an environment where sand grains and suspended particles in water get oppositely charged. When the suspended particles come in contact with the sand grains, their charges neutralise and change the characteristics of water to its purer form, and the water from aquifers attains its refinement. The benthic organisms and bottom-feeding fishes usually consume the organic matter in the sediment column, making the sea\river bed sediment's filtration efficiency in a renewed manner for prolonged periods. The sediment transport also contributes to keeping the filtration work from ceasing. Based on the requirement, the existing sea bed sand filtration efficiency mechanism was utilised by putting a bore in the sandy sea floor at 5 to 10m water depths, which can yield a desirable quantity of filtered water **(Figure 1).** Three types of bore well designs satisfy the various requirements (Vertical well, angel well, and Ranney well) [1]. However, these are all limited to geology and proximity of sub-seabed aquifer to the said well systems to achieve the desired yield of suspended sediment-free filtrate; if the aquifer transmissivity is too low and in case of unfavourable geology like clayey and muddy terrain beaches, seabed gallery or beach galley could be constructed instead of wells **(Figure 2)** [1].

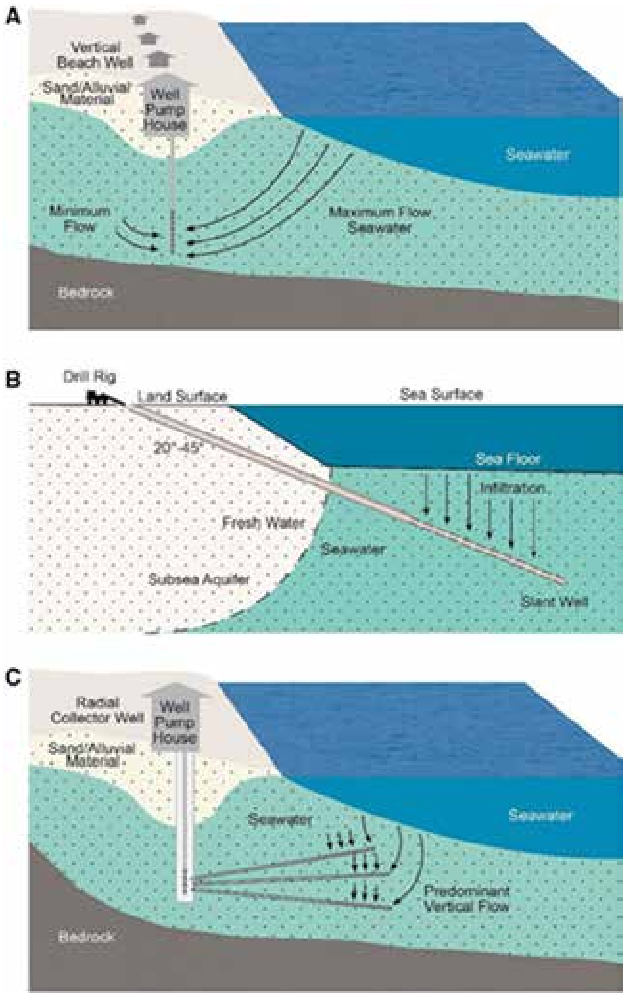

Figure 1. Various type of subsurface intake systems for water filtration. Well, intake designs for obtaining ballast water, A. Conventional vertical well located near tidal water (or a beach), B. Angle well that can be constructed at some distance from the shoreline, C. Ranney well that would need to be constructed on the beach

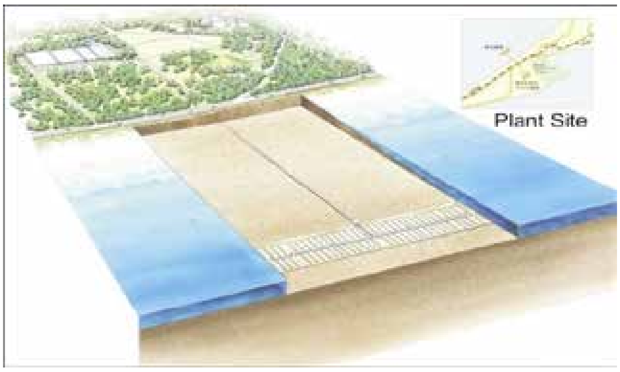

Figure 2. Seabed gallery system for water filtration system

Figure 3. Laboratory scale artificial Aquifer for water filtration

The water quality meets the D2 requirements of BWMC, as the well and gallery systems work successfully in desalination plants [1]. The existing technology may be adopted in the ports and harbour sector as a port-based filtered water supply system [1]. However, the Indian coast has some special conditions, such as the ports at the river mouth, mangrove embanked port premises, or gulf areas such as Kutch, Khambhat, and Mannar, with limitations to cater for the needs of wide shore area in proximity to install a seabed gallery system of filtration necessitates an artificial aquifer filtration system which mimics the natural seabed filtration system was envisioned. As shown in the picture, an artificial aquifer system was planned to filter suspended solids at a laboratory scale model designed in a pipe-in-pipe system **(Figure 3).** The 58cm diameter inlet pipe (with filter media sand) can be filled with gradient sand as filter media, and a perforated 10 cm diameter small pipe (filtrate collection pipe) can collect the filtered water.

A eutrophicated pond water (an indicator of heavy suspended solid load) was poured into a big pipe (58cm diameter) with sand filter media. Within 6 minutes, the small pipe (10 cm diameter) was filled with clean, algal-free water. The filtrate was subjected to microscopic examination, and a few planktonic cells were found, as a suspended solid load ensured 98% removal **(Figure 4)**. The laboratory scale saturation of sand media was reached after 26 days to generate a standard quantity of filtrate up to 21 minutes for a sand quantity of 48595 cubic centimetres after filtering 650 litres of eutrophicated water. This saturation point was reached without natural aquatic ecosystem services like benthos and fishes, improving filtration efficiency by foraging the filter sediment continent.

Based on the laboratory model, a macro-scale pilot process demonstration was envisioned to utilise the natural aquatic ecosystem services by making a pilot plant in a marshy land water body inside the NIOT campus **(Figure 5). A horizontal flow system was conceived in field conditions to conserve energy for filtration and utilise the natural water pressure as a water head driving force.**

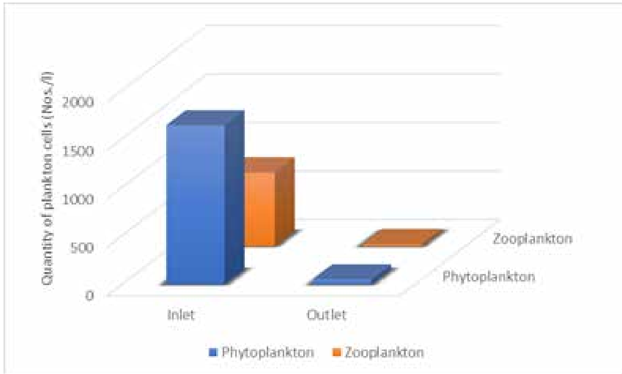

Figure 4. Plankton reduction after filtration in the microscale artificial aquifer developed in laboratory

> **The problem caused by sandblasting leads to the loss of compaction between sand grains and minor sliding of soil layers**

A 4-meter-long, 41 cm diameter HDPE pipeline was one-third slit up to 2-meter length fitted with a filter covered by 300-micron geotextiles and filled with graded sand to act as filter cartridge and remaining two meters after the filter act as void in an aquifer enables filtered water extraction. The sand-filled area was also draped with 300-micron pore-sized geotextiles to avoid the escape of sand particles from the tube. Another HDPE pipeline of the same size was bottom-fused with the non-filter media side welded by butt fusion technology to act as a collection sump, forming an L shape structure **(Figure 5).** The whole structure was placed in the marshy pond bottom at 2-meter depths in a 3-degree slope ratio of 1:38 between the horizontal filter cartridge and the vertical collection sump of the 41cm bottom fused tube.

The green colouration due to the algal bloom indicates the suspended solid presence in the pond water. The

Figure 5. Pilot plant of artificial aquifer deployment at NIOT campus

water filtration happens through the sand column of the slit pipe side and pass-through the non-sand pipe length, as it acts like voids in an aquifer. Finally, it is collected in the vertical 41cm diameter pipe based on water hydraulics without any energy expense like a natural aquifer, enabling water percolation from the overlying water column. The fish population conglomeration over the geotextile-wrapped sand column allows ecosystem service since the filtration happens in a natural gradient. However, the filtration efficiency was not as expected, at 98%. Consistently acquiring the desired water quality is also a problem that needs to be solved by utilising the design on a commercial basis. The problem caused by sandblasting leads to the loss of compaction between sand grains and minor sliding of soil layers **(Figure 7).** It reduced the quality to 65% (average of various parameters) against the expected 98% **(Table 1).** The filter water yield was calculated as 1800 litres per hour. The filtration efficiency can be improved by altering the plant's design and changing the filter media's quality. The fine-tuning of the process in progress to achieve the desired 98%, and the remaining may be removed by chlorination, will avoid sediment formation in ships' ballast tanks.

Figure 6. Filtration efficiency of artificial aquifer as chlorophyll as indicator

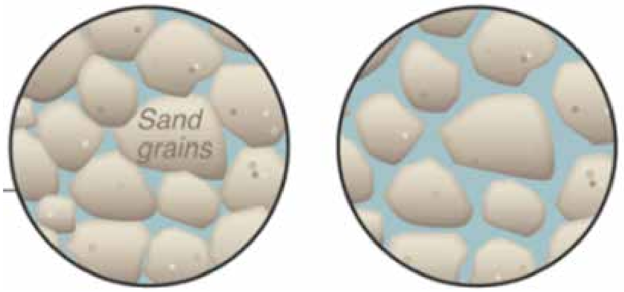

Figure 7. Depicts the impact of sandblasting between sand grains

Table 1. Impact on water quality by artificial aquifer filtration system

Water quality parameters	Inlet water quality	Outlet water quality	Filtration efficiency (% reduction)	Standard methods
Dissolved oxygen (mg/l)	6.22	1.18	81	Titrimetric/ diaphragm electrode method
Total suspended solids (mg/l)	33	10.5	68	Gravimetric
Turbidity (NTU)	22.06	7.93	64	Nephelometric
Chlorophyll (mg/l)	58.7	11.49	80	Titrimetric
Phytoplankton (Nos./l)	3460	660	81	Microscopic
Zooplankton (Nos./m^3)	500	110	78	Microscopic

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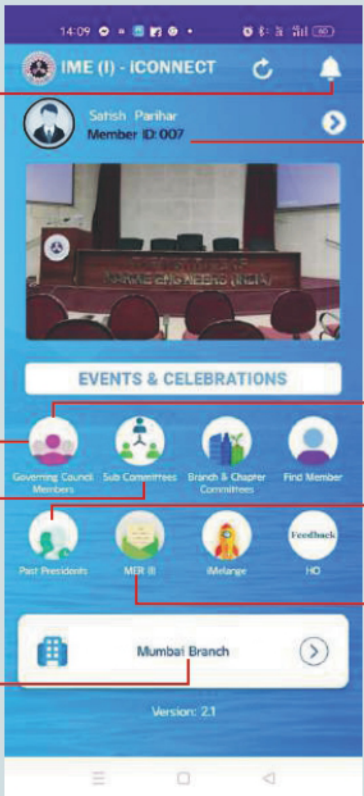

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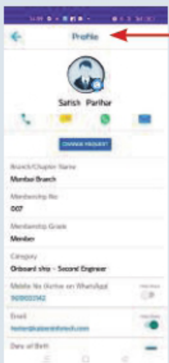

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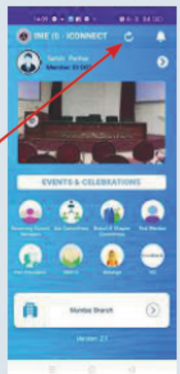

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The port-based facility of seawater filtration systems will enable suspended sediment-free ballast water discharges in the port waters. **The same may be adopted in ports like Haldia & Kandla, where the heavy suspended solid load can be reduced by this type of semi-intensive filtration system installed within the port premises as a port-based facility.**

Conclusion

The area of the filter surface, grain size, and compactness of the soil media are used to determine the quality and yield of filtered water without organic matter and suspended solid loads. The reduction in suspended solid loads will indeed reflected in the decrease in sediment accumulation in the ballast tank. It will improve the efficiency of BMWS installed in the ships as there are fewer chances of hiding micro & macro organisms in ballast tank sediments. Further, ports like Haldia & Kandla, with highly suspended solid contents, may consider the use of the proposed one to use this filtration system as a port-based facility to provide water supply to ship ballast inside the port premises. However, this might slow down the BW exchange procedure, whereas time is a critical parameter in the shipping industry. However, considering the operational cost of getting suspended solid free water and maintenance cost reduction in ballast sediment removal, the time delay may be worth spending. In general, the filtered water by this technology ensures the discharge quality of ballast water from the ship as per the statutory requirement.

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About the authors

Dr. Prince Prakash Jeba Kumar J., a senior marine biologist, conceptualized the subsurface filtration system to create a suspended particle-free, eco-friendly filtration system. He conducted systematic studies and collaborated with biologists and engineers to develop a pilot plant. He also prepared the manuscript detailing the research on artificial aquifer systems. Over the past decade, he has gained recognition for his expertise in marine pollution monitoring and management, novel materials production using waste-to-wealth concept, eco-friendly filtration systems, Biopollution management, coastal fishery enhancement through artificial reefs, and green facade development for ports. He has been awarded for his innovative research ideas.

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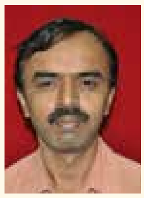
Marine biologists **Mr. Ragumaran**, **Mr. B. Rajan Babu**, and **Dr. M. Venkatramani** conducted a study on the ecological impact of the filtration system, using scientific principles to assess filtration efficiency.



Mechanical engineers **Er. A. Karthikeyan** and **Mr.Sajeev Krishna Kumaran Nair** developed the engineering structure, deployed the system in the natural pond at the NIOT campus, and conducted filtered water yield studies.

Dr. Purnima Jalihal, a senior civil engineer, led the conceptualization process for pilot plant development and oversaw the study process of the artificial aquifer system. She has led the first-ever ocean energy and desalination projects, including setting up the first ocean thermal gradient-based desalination plant at Kavaratti island in the Lakshadweep group. This has transformed the lives of the island community. Dr. Purnima was awarded the Vishwakarma Medal in 2006 for her work by the Indian National Science Academy. She is now working on scaling up the technology and powering such plants using ocean renewable energies.

Suitability of Electronic Transport Documents in International Seaborne Trade

Shantanu Paul,
Patrick Donner

Abstract: Paper-based transport documents are still very commonly used in the international carriage of goods by sea. These would include, amongst others, traditional Bills of lading or Seaway bills that evolved with the change in seaborne trade patterns. While both transport documents should be suitable for electronic equivalence in today's era of digitisation for fast, reliable and cheaper transactions, the former is less suitable. However, the UNCITRAL Model Law on Electronic Transferable Records (MLETR) 2017 is showing promise for better acceptance in the post-COVID 19 world, particularly after its adoption by the UK in 2023. India needs to embrace the same to maintain the growth in overseas trade. This paper highlights the evolution, characteristics and complexities of two bills, the BoL and the Seaway Bills.

Keywords: *Bill of lading, Seaway bill, Electronic equivalence, MLETR 2017.*

Introduction

In international transactions where goods are carried by sea, the suitability of a transport document depends upon how best it suits the requirements of all the parties involved, with respect to the existing legal regime and global practices. Various paper documents for sea transport evolved with the change in seaborne trade patterns trying to fulfil such requirements. Traditionally the Bill of lading (BOL) and then other types of paper documents, mainly the Seaway bill, served their required purposes in the international seaborne trade. However, the applicable rules that govern the contract of carriage by sea often create conflicts due to anomalies in the underlying characteristic of these documents as perceived in different countries and enacted in their laws (Richardson, 2003). The COGSA (Carriage of Goods by Sea Act) that defines various aspects of shipper-carrier relations such as rights, immunities, liabilities under the Hague Rules 1924 or Hague-Visby Rules 1968 for paper BOL also differs across the globe.

If a transport document is not considered as a BOL, such as an electronic Bill of lading (e-BOL) or seaway bill, it does not automatically come under the legal regime of the Hague or Hague-Visby Rules as enacted in the law of shipment country which is compulsorily applicable to a paper BOL or "similar document of title". The legal systems and procedures in many countries have developed over a long period lack clarity and moreover, their revisions are also very slow.

However, the applicable rules that govern the contract of carriage by sea often create conflicts due to anomalies in the underlying characteristic of these documents as perceived in different countries and enacted in their laws

In India, the BOL Act which is from 1856, does not even define what the BOL is. In 2001 in the SCI Ltd vs C.L. Jain Woolen Mills case, the Supreme Court of India had to mention the characteristic of BOL (Thacker & Qazi, 2022). The Indian COGSA is also from 1925, since amended, but fundamentals remain unchanged.

The law which governs the carriage of goods by sea is not uniform globally. When most countries adhered to the content of Hague-Visby Rules, USA has not adopted it. Hence the US COGSA and UK COGSA are different and both countries follow the Common Law system. Under this diverse and complex legal environment globally, replicating uniformly all such paper sea transport documents electronically with its all-underlying characteristic that also needs to give a sense of security to various players, including banks that finance transactions under the documentary credit system is a big challenge. The difficulties experienced during the COVID 19 pandemic made the world realise that an electronic equivalence of sea transport documents is imperative when technology is already available, but legal obstacles need to be overcome globally.

The Model Law on Electronic Transferable Records (MLETR) 2017 developed under the United Nations Commission on International Trade Law (UNCITRAL) is now showing great hope for the long pending issue of electronic equivalence of all sea transport documents

The Model Law on Electronic Transferable Records (MLETR) 2017 developed under the United Nations Commission on International Trade Law (UNCITRAL) is now showing great hope for the long pending issue of electronic equivalence of all sea transport documents (UNCTAD, 2023). Singapore passed legislation in 2021 adopting the MLETR and it has now been accepted into English Law by the UK Electronic Trade Documents Act, which entered into force on 20 September 2023 (Dickinson, 2023). This new Act could truly revolutionise international trade (Northage, 2023). The following discussion will try to highlight the evolution, characteristic and complexity of two main paper transport documents used in international carriage of goods by sea today, the traditional Bill of lading (BOL) and the Seaway bill and their current suitability for electronic equivalence in the era of digitisation for fast, reliable and cheaper transactions and the benefits MLETR 2017 can provide to the world and especially India, when the country is embracing digital technology in every sphere of business transactions.

Evolution of seaborne trade documents

The main seaborne trade document that evolved over centuries is the BOL. Today there are different types of BOL with variations in the characteristics such as Straight BOL. However, a traditional BOL is regarded as evidence of a contract of carriage, evidence of the receipt of goods, and a document of title of the goods. While the history of BOL can be traced back to fourteenth century when the BOL as receipt of goods first came into existence, its modern history started with the Lickbarrow vs Mason (1788) case under the English law, which recognised the document of title character for the first time (Naseri, 2021). In the 17th and 18th centuries, Britain became a major global power and English law cases were in dominance**. Countries following English law are called common law countries where the doctrine of *stare decisis* applies and earlier court decisions have bearing in similar future cases**.

As seaborne trade increase continued, disputes also increased and many landmark judgements enriched the English law on various critical aspects of BOL that became precedence for new similar cases. The Himalaya (1954) case and the clause named after it in BOLs thereafter is an example that protects agents, employees or subcontractors of a carrier against any legal action.

Another sea transport document that evolved with the change in seaborne trade patterns is the Seaway bill, which only fulfils the first two mentioned characters of the traditional BOL and is not a document of title. As globalisation has been increasing since the last few decades, a major percentage of manufactured goods transported by sea are transactions between a main company and its subsidiaries, mainly in containers, that are not for sale. The majority of liner shipments are "House to House" where payments are only book entries and the negotiability is not required. In some liner routes, the majority of cargo is now carried under documents that are not BOL. The use of the Seaway bill in preference to BOL is listed in the UN recommendations for trade facilitation (UN, 2002). **Hence the Seaway bill, which was less prevalent earlier, has become more useful now when transported cargo is not for sale**. (Donner, 2008). The Seaway bill is also a key document now required to export from India. (Amazon, 2022).

To keep pace with the evolution of seaborne trade patterns and containerisation, the legal regimes are also trying to protect the interests of stakeholders to facilitate trade. Accordingly, different countries enacted their COGSA with the adoption of international rules such as the Hague Rules or Hague- Visby Rules, and Hamburg Rules that suit their national interests in the seaborne trade. Also, contractual codes like International Commerce Terms (Incoterms) and the necessary documentation for payments under the Uniform Customs and Practice (UCP) for Documentary Credits system have been developed and updated from time to time to suit changing trade practices, **but documentation remained mostly on paper despite the development of modern electronic communication and digitisation technology**. This is primarily due to the prevailing legal regime globally and some underlying characteristics of most commonly used trade documents including BOL that need to be physically on paper. Legal recognition today for various characteristics of BOL and Seaway bill are the result of many landmark decisions in various court cases over the last few centuries.

Characteristics of BOL and Seaway bill

The main advantage of BOL is the negotiability, which makes it unique in shipping. It allows buyers to engage

in trading of the goods further while they are in transit. Under the Seaway Bills, cargo cannot be traded to another party when it is in transit. To be more precise, the goods could, in fact, be sold, but in sale of goods, possession is an essential element and since the goods are in transit, possession of the physical goods cannot be passed from seller to buyer and this is where the traditional BOL has an advantage – in the eyes of the law, possession of the BOL is equivalent to possession of the goods themselves and the Seaway Bill lacks this characteristic.

"A Seaway Bill is normally issued when transactions are between companies in the same business group or between parties that have a well-established business relationship"

A Seaway Bill is normally issued when transactions are between companies in the same business group or between parties that have a well-established business relationship. It is very handy when a shipper wants to clear goods immediately from customs without presenting the transport document as needed with a traditional BOL. The importer does not have to show the original transport document if it mentions the Seaway Bill. The document of title function of BOL, which the Seaway Bill does not have, provides more security for the shipper to get paid and consignee to get the goods for which he has paid in advance.

As the Seaway bills do not offer possession / ownership of the consignment, banks do not accept it in the payment process that occurs with the "letter of credit" under the documentary credit system. Seaway bills require a high level of trust between shipper and consignee for payment; however, it eliminates the complexity of bank payment if the BOL is "claused," as the description of the goods in the BOL must exactly match with the letter of credit issued by the bank as per the contract of sale terms. Nevertheless, the parties should carefully assess the terms mentioned in the Seaway Bill, as it does not provide legal certainty and protection for disputes as a result of damage or loss of goods.

The Hague-Visby Rules and COGSA are to be mentioned in a Seaway Bill if they are meant to be applicable and the value of the cargo has to be mentioned for the insurance purpose, required for high-value goods, as carrier may assume limited liability for certain types of damages or losses.

Complexity of seaborne trade documents

A BOL can be non-negotiable when issued to a named consignee only, often with the words "not to order" added. Such a Straight BOL has in some jurisdictions, since long been regarded as akin to a Seaway bill in the absence of any clear authority in law. However, the English Court of Appeal clarified the position in the Rafaela-S (2002) case, that it does not come under the domain of Seaway bill (UNCTAD, 2003).

The court decided that a straight BOL is a "similar document of title," and therefore, the package limitation as per the Hague-Visby Rules is also applicable. Nevertheless, presentation for the delivery of cargo is required. In the APL v Peer Voss (2002) case, the Singapore Court of Appeal decided that a Straight BOL with a named consignee is non-negotiable, but it is a document of title.

The negotiability or transferability and document of title are two different aspects. In a Straight BOL, negotiability is absent, but there is no reason to believe that the parties intended to do away with the document of title characteristic (Marissen, 2004). Hence, it requires presentation for delivery as required in the case of a traditional BOL. Today, Singapore, a common law country, has become a major place for maritime dispute settlements after the traditional place of London**. Maritime laws being international, today courts in common law and civil law countries are willing to follow decisions of foreign courts on matters of interpretation for the application of the Hague and Hague-Visby Rules** (Tetley, 2004)**, but their application in e-BOL has to be recognised by law or in court cases acting as legal precedence.**

Benefits of electronic transport documents

Switching from paper transport documents to electronic versions will facilitate faster transactions, lower costs, and reduce fraud risks due to digital authentication. Research indicates the total cost of processing paper-based BOL incurs three times the expenses compared to e-BOL (JMB, 2020). It is estimated that e-BOLs can save up to $ 6.5 billion in direct costs for stakeholders and enable $30-40 billion in annual global trade growth. (McKinsey, 2022). Although the effort has been on for at least the last two decades, the urgent need was realised during the COVID-19 pandemic, when paper document transactions often caused delays and complications as well as loss. If the paper BOL is not presented due to delayed arrival, loss, or any other reason, the carrier has to take the risk either not to discharge and encounter the consequence of delay or deliver the cargo to the claiming receiver against a letter of indemnity with its trustworthy financial standing. In the Sze Hai Tong case (1958), the Singapore Court of Appeals verdict was that a ship owner who delivers without the production of BOL does so at its peril (Todd, 1990). P&I coverage is not applicable for wrong delivery or delivery against a letter of indemnity (Mills, 2005). Forged BOL cases are also not very uncommon. Seaway bills are free from all such risks, as presentation of the document is not the "key to delivery". However, electronic equivalence of BOL and Seaway Bill can provide huge benefits in seaborne trade.

Evolution of electronic transport documents

The evolution of the electronic equivalence of sea transport documents has not been smooth with respect to its current legal recognition in many countries. Hence, the electronic version of all such transport documents needs legal recognition globally. Until the last decade, there was neither case law nor statutory provision to recognise the e-BOL as a document of title. In the absence of such recognition and established cases, banks have been reluctant to finance e-BOLs and preferred paper documents as security. Currently, its limited usages have been under a few closed or club-based systems, such as BOLERO (Bills of Lading Electronic Registry Organization), where parties agree contractually; hence, it needs a "rulebook" to ensure that the terms and conditions usually seen on the reverse of the BOL will also apply to e-BOL. The e-BOL is not a softcopy or electronic version of the traditional BOL but a series of computer-generated messages exclusively transferable and readable electronically; hence, it needs application of appropriate technology.

Research indicates the total cost of processing paper-based BOL incurs three times the expenses compared to e-BOL

In BOLERO, by multi-party agreement, it grants the holder of e-BOLs the same rights and responsibilities as a legitimate holder of a paper BOL, including documents of title. There are a few similar private platforms, such as essDocs, CargoX, WaveBL, etc. All these platforms are secured and work on mature technology. While BOLERO works on a central repository model, others adopted blockchain technology. Currently there are twelve such systems that have been approved by the member clubs of the International Group of P&I Clubs (Shipowners, 2024), which means any liability arising under an e-BOL is treated for club cover purposes in the same way as paper BOLs. The requirement of membership is one of the major obstacles to this model, and none of the existing platforms have succeeded in reaching a critical mass in their membership. As these platforms relay on contractual mechanisms hence not interoperable, a third-party outside this contractual framework, such as a buyer or an endorsee, will not be able to assert his title over the goods (Merchant & Miranda, 2021), but legislation can empower such rights, which is lacking globally. Inter-operability will require a common digital language and technical standard for e-BOL generation. Currently, platforms have defined their own way of working, but work is in progress for a uniform standard. In 2022, Baltic and International Maritime Council (BIMCO) along with other organisations, developed e-BOL for the bulk shipping (BIMCO, 2022), and progress in the legislation front is an urgent need.

Current status of electronic transport documents

Currently e-BOL accounts for only 1.2 percent of the 45 million traditional BOL issued each year by ocean carriers (UNCTAD, 2023). Among the reasons for the low usage till date are both legal uncertainties and some other factors, such as data confidentiality and limited benefits for some data providers. While others factors can be resolved technically and by industry cooperation, the legal uncertainty issues may take much longer time, as countries need to overcome inertia and incorporate legislation into their laws.

As the Seaway bill is without the document of title character, electronic equivalence or e-seaway bill solutions are easier and already adopted by many ocean carriers worldwide. However, these solutions vary in functionality as well as the method of documents being sent. In some cases, it is automated through a carrier's website or attaching it by email in PDF format based on commercial invoice or booking confirmation etc. Seaway bill contents also vary and standardisation will make its use more convenient. **Nevertheless, the use of negotiable BOL still dominates over the Seaway bill in global trade**. Hence, electronic equivalents to the BOL are increasingly being developed to facilitate paperless digitised trading.

Consequently, UNCITRAL developed MLETR 2017, which aims to enable the legal use of electronic transferable records, including e-BOL, both domestically and across borders. MLETR primarily addresses the existing legal provision that an electronic trade document cannot be "possessed", hence a reliable system, maybe a registry or blockchain technology, is needed to identify the electronic document as an original. It is intended not to affect the existing national substantive laws applicable to paper transport documents but to mirror its application in electronic transport documents (UNECE, 2023).

MLETR is a blueprint and individual countries can use it for their legal reforms for recognition of electronic transport documents including e-BOL. As countries can adopt necessary legislation with adjustments depending on national specificities, jurisdictional divergences in the MLETR adoption can result in different regimes globally, hence further legislative progress or efforts to establish mutual recognition of regimes are needed, to facilitate truly global trade on a level playing field (Masons, 2023). Nevertheless, MLETR is expected to transform the ocean trade documentation process by legal recognition of electronic equivalence or paperless process for fast, reliable and cheaper transactions in international trade.

Current developments on the legal front

Difficulties faced during the COVID-19 pandemic, such as the cancellation of international flights transporting the physical BOL, have accelerated the adoption of MLETR 2017 or its provisions in the national legislation of some countries, yet in most jurisdictions, the e-BOL does not benefit from full legal recognition as equivalent to a paper-based BOL or similar documents of title. In April 2020, the International Chamber of Commerce (ICC), requested governments and central banks, specifically the United Kingdom (UK) due to the influence of English law in global trade, to take emergency measures to void all existing legal obstacles to the use of electronic trade documentation, removing requirements for BOL to be presented in paper format.

Currently e-BOL accounts for only 1.2 percent of the 45 million traditional BOL issued each year by ocean carriers

Adoption of MLETR by Singapore in 2021 was undoubtedly a forward-looking step by the regional leader, as Singapore has become the most important place in maritime trade related matters after the UK. Furthermore, in July 2023, legislation was adopted in the UK, the Electronic Trade Documents Act 2023, to ensure that electronic trade documents, including electronic equivalents to traditional BOLs, enjoy the same legal status as traditional paper-based documents. As international contracts of around 80% (Simmons, 2023) are subject to English law, by agreement of the parties, this new UK Act is expected to boost the use of electronic transport documents globally. Traditionally, the UK has been the source of many international practices based on paper documentation. Hence, the reliance of the new UK Act on provisions contained in the MLETR will undoubtedly support its adoption in other jurisdictions. However, users need to overcome the inertia of paper documentation as they will have both options: paper BOL or e-BOL.

In 2022, ICC along with BIMCO and three other industry organisations formed "FIT Alliance" to raise awareness and accelerate adoption of e-BOL, which is now catching significant momentum (DCSA, 2024). Recently, some of the leading container lines, such as Maersk, MSC, CMA-CGM, Hapag-Lloyd, etc., committed to using e-BOLs exclusively by 2030 (Seatrade, 2024). Now with legal recognitions in countries like Singapore as well as the UAE, which are India's important trading partners, and increasing global interest in e-BOL, including G7 countries and especially China, active to bridge the gap between their national legislation and the MLETR (UN, 2024), India needs to act fast to put in place legislation to recognise all electronic sea transport paper documents, including e-BOL, for India's growth in foreign trade that is primarily by sea, as major trading patterns are all overseas.

The Indian maritime legal framework needs urgent attention

The Indian COGSA 1925 was made in line with the UK COGSA 1924, which gave effect to the Hague Rules 1924. In 1971, the UK COGSA was updated, which brought into force the Hague Visby Rules. The Indian COGSA, although amended in 1993 to include certain provisions of the Hague-Visby Rules, such as higher package limitations, does not give the Hague Visby Rules the force of law in India. A BOL being a document of title is transferable, but contractual rights customarily remain with the original contracting partners. Accordingly, the UK COGSA was further modernised in 1992 to give rights to the holder of the BOL to sue as if he had been a party to the contract. The 1992 COGSA is also applicable to both the traditional BOL and the Seaway Bill. It replaced the UK Bills of Lading Act 1855, but India is still continuing with its Bills of Lading Act 1856 and many other British era maritime legislations. Nevertheless, in a recent development to reform various British era laws governing maritime relations and claims in India, the Admiralty (Jurisdiction & Settlement of Maritime Claims) Act, 2017 was enacted, which replaced the existing Admiralty Court Act 1840 and Admiralty Court Act 1861. It is reported that India, within the framework of the G20, expressed preliminary interest in MLETR adoption (TFG, 2023), and that will be an important milestone to achieve in Indian maritime law.

Indian initiative towards electronic trade documentation

The Indian government, with a vision to transform India into a digitally empowered society and knowledge economy, launched the "Digital India" programme in July 2015 (CSC, 2015). Accordingly, the Port Community System (PCS 1x) was launched in December 2018 and designed as a single digital platform to connect various stakeholders in EXIM trade, including customs agencies (PIB, 2018). PCS 1x is currently operational for 19 ports, including 13 major ports, where the messages being exchanged are predominantly vessel related. It is built on a secure cloud-based platform to enable the intelligent, easy, efficient, and secure exchange of information to improve the "ease of doing business."

During the COVID-19 pandemic, an effort was initiated to accept e-BOL by integrating PCS 1x with the Cargo-X platform for all trade documents, including e-BOL. PCS1x's ability to integrate seamlessly with various other systems makes it possible to become NLP (National Logistics Portal) Marine in January 2023 for other trade related services, i.e., regulatory bodies, PGA (Partner Government Agency) services, banking and financial services, cargo and carrier services (PIB, 2023). All the above indicate that there is no dearth of technology and trained manpower in India, and progress on the regulatory front, including the adoption of MLETR or its content, will make India more advantageous in international sea trade to support India's growth.

Conclusion

Documents used in the international carriage of goods by sea, traditionally BOL and then Seaway Bill, evolved with the change in seaborne trade patterns. The underlying characteristic of these documents, which are paper based, was established over centuries during the settlement of various disputes by court cases. The legal regimes globally have also evolved to protect the interests of all stakeholders. Modern technology for electronic communication and digitisation has only been around for the last few decades and must facilitate international trade transactions by lowering costs. The main obstacles to electronic equivalence of sea-trade documentation are a lack of legal recognition and the interoperability of various platforms that currently acknowledge the electronic equivalence, especially the e-BOL, which is the same as paper BOL. However, losses and delays, which occurred during the COVID-19 pandemic, have accelerated the industry's efforts. To address the issues, leading industry organisations such as BIMCO are working on standardising documents to facilitate interoperability within platforms, and UNCITRAL have developed the MLETR 2017 that aims to enable the legal use of electronic transferable records, including e-BOL. Acceptance of MLETR by the regional and global leaders of maritime law, Singapore and the UK, in the post COVID-19 scenario, is expected to overcome the main hurdle for electronic sea-trade documents, including e-BOL, and boost legal reforms in many jurisdictions globally. India, in the recent past, has made remarkable progress to embrace electronic and digital technology in various business activities related to sea trade, but legal reforms in India are extremely slow and need urgent government attention. The adoption of MLETR or its content will be an important milestone to maintain India's trade growth in the years come.

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Marine Renewable Energy Scenario in India: Prospects and Challenges (Part 1)

Photo from the Ministry of New and Renewable Energy, India

Yash Jain

Keywords

Marine renewable energy, India, wave energy, tidal energy, ocean thermal energy, offshore wind energy, prospects, challenges, policy frameworks, interdisciplinary collaboration

Abstract

Marine Renewable Energy (MRE) holds significant promise as a sustainable energy source to meet India's growing energy demand while reducing greenhouse gas emissions and enhancing energy security. This article provides a comprehensive overview of the current scenario, prospects, and challenges of MRE in India. Various forms of MRE, including wave energy, tidal energy, ocean thermal energy, and offshore wind energy, are discussed in terms of their current status, potential, and comparative power generation capacity. Successful projects and initiatives, such as the Gujarat Offshore Wind Farm Pilot Project and the Tamil Nadu Offshore Wind Farm, are highlighted to demonstrate progress in MRE development.

The article examines the regulatory and policy frameworks governing MRE development in India, emphasising the role of government initiatives and public-private partnerships. Challenges related to technology maturity, project financing, and environmental considerations are addressed. Furthermore, the potential role of MRE in supporting the electrification of India's transportation sector, particularly in the maritime industry, is explored.

Marine engineers play a crucial role in driving MRE development, requiring interdisciplinary collaboration with oceanographers, environmental scientists, and policymakers. The article underscores the need for continued research, technological advancements, and international cooperation to unlock the full potential of MRE in India's energy landscape. Overall, this article contributes valuable insights to the discourse on MRE and underscores the pivotal role of marine engineers in driving its sustainable development.

1. Introduction

Marine Renewable Energy (MRE) holds significant promise as a sustainable source of power that harnesses the natural energy present in oceans and seas. As the world seeks to transition towards cleaner and more sustainable energy sources, MRE emerges as a key component in reducing reliance on fossil fuels and mitigating the impacts of climate change. This introduction provides a comprehensive overview of MRE, its importance in the


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"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, ..."

Charles Dickens comes to our minds as we reflect upon the state of shipping today. Juxtaposed between Trade Wars, Galloping Technology, Regulatory Challenges and Climate Change issues, we could be looking like a deer caught in the headlights, unable to comprehend where our future lies.

The Lehman Brothers crisis of September 15, 2008, now close to 15 years ago; yet we have not been able to overcome its impact, just as we have never been able to avoid the odd bout of flu every winter, and of course the Covid-19. There has been a continuous stream of regulations, in the wake of galloping technology, escalating political gamesmanship across nations, and also with safety management continuing to be an issue, duty of care towards crew remains questionable.

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On behalf of the Organising Committee and The Institute of Marine Engineers (India), Chennai Branch, we extend a warm invitation to you and your organisation to actively participate and support the three day event, between December 4-6, 2024 in Chennai. We provide you in attachment, a copy of the canvas, and we hope to engage you in cool pre-winter periods in India.

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global energy landscape, and the specific significance of its development in India.

1.1 Definition of Marine Renewable Energy (MRE)

Marine Renewable Energy (MRE) refers to the renewable energy derived from various sources in the marine environment, including tidal movements, wave energy, ocean thermal gradients, and offshore wind. These energy sources are abundant, predictable, and have the potential to provide a clean and sustainable alternative to conventional fossil fuels [3].

1.2 Importance of MRE in the Context of Global Energy Transition

In the context of the global energy transition, Marine Renewable Energy (MRE) plays a pivotal role in diversifying the energy mix and reducing carbon emissions. The world is increasingly focusing on transitioning towards renewable energy sources to combat climate change and achieve energy security. MRE offers unique advantages such as high energy density and predictability, making it a valuable contributor to the global renewable energy portfolio [4].

1.3 Significance of MRE Development in India

India, with its extensive coastline spanning over 7,500 Km, holds immense potential for Marine Renewable Energy (MRE) development. The country's energy demand is rising rapidly, and MRE offers a strategic opportunity to meet this demand sustainably. Developing MRE can enhance energy security, reduce greenhouse gas emissions, create employment opportunities, and drive economic growth in coastal regions [5].

2. Various Forms of Marine Renewable Energy

Marine renewable energy (MRE) encompasses various forms of energy derived from the ocean's natural resources, offering promising alternatives to conventional fossil fuels. This section provides an in-depth overview of different forms of MRE, including wave energy, tidal energy, ocean thermal energy, and offshore wind energy, along with the current status, potential, and comparative analysis of their power generation capacity in India.

2.1 Overview of Different Forms of MRE

Marine renewable energy comprises several distinct forms, each harnessing different oceanic processes:

Wave Energy: Wave energy involves capturing the kinetic energy of ocean waves to generate electricity. Devices such as wave buoys, oscillating water columns (OWCs), point absorbers, and attenuators are used to convert wave motion into mechanical energy, which is then converted into electrical power.

Tidal Energy: Tidal energy utilises the gravitational pull of the moon and sun to generate electricity from tidal movements. Technologies like tidal stream turbines and tidal barrages are employed to capture kinetic energy from tidal currents and convert it into electrical energy.

Ocean Thermal Energy: Ocean thermal energy exploits the temperature difference between warm surface water and cold deep water to drive a heat engine and produce

None of these marine energy devices are large scale commercially available—yet. With help from an updated data collection and processing tool, India could soon get clean energy from waves, tides, and river and ocean currents. *Photo from the U.S. Department of Energy*

Sources: Sustainable Marine, Altum Green Energy, Andritz Hydro Hammerfest, Nova Innovation

electricity. Ocean thermal energy conversion (OTEC) systems utilise this temperature gradient to generate power.

Offshore Wind Energy: Offshore wind energy involves the deployment of wind turbines in coastal waters or offshore locations to harness wind energy. Offshore wind farms benefit from stronger and more consistent winds compared to onshore sites, resulting in higher energy yields.

2.2 Current Status and Potential of Renewable Energy in India

As of March 2024, India has made significant strides in renewable energy, with a combined installed capacity of 190.57 GW, including large hydropower. The country has set ambitious targets to reduce carbon intensity, aiming for less than a 45% reduction by the end of the decade and achieving 50% cumulative electric power installed from renewables by 2030. Additionally, India aims to achieve net-zero carbon emissions by 2070 and has set a target of 500 GW of renewable energy installed capacity by 2030. These targets align with India's commitment to creating a sustainable world, as it ranks as the 3rd largest energy-consuming country globally.

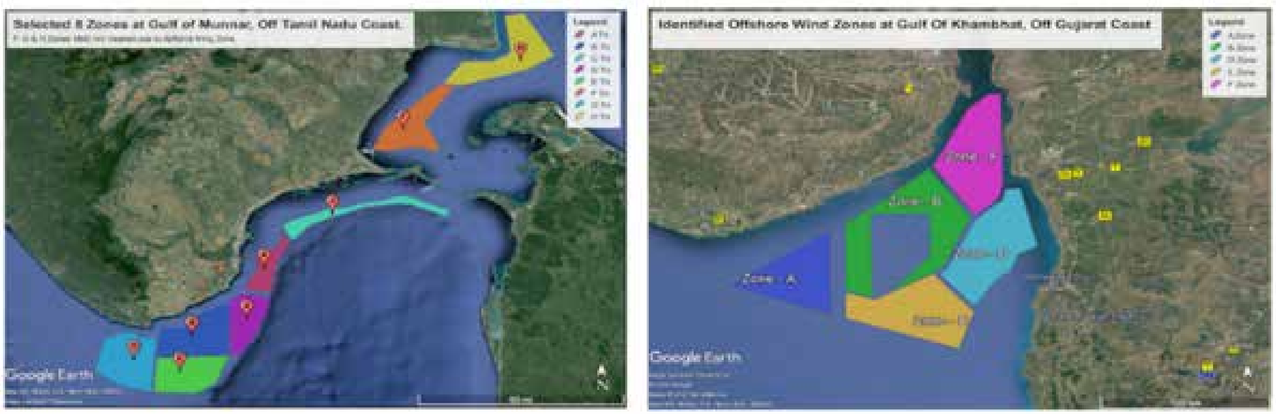
India's renewable energy achievements are noteworthy, standing 4th globally in renewable energy installed capacity, 4th in wind power capacity, and 5th in solar power capacity [6]. The country has pledged an enhanced target of 500 GW of non-fossil fuel-based energy by 2030, making it the world's largest expansion plan in renewable energy. Non-fossil fuel capacity in India has surged by 396% over the last 8.5 years, reaching more than 198.75 GW as of March 2024, accounting for about 45% of the country's total capacity.

India witnessed significant year-on-year growth in renewable energy additions, with a remarkable increase of 9.83% in 2022. The nation is on a rapid clean energy transition path, aiming for offshore wind installations totalling 5 GW in Gujarat and Tamil Nadu by 2032. These achievements highlight India's commitment to clean energy and its contribution to global sustainability efforts [8].

2.3 Comparative Analysis of MRE Resources in Terms of Power Generation Capacity

A comparative analysis of MRE resources in India reveals distinct characteristics and potential power generation capacities:

- Wave Energy: While wave energy technologies are in the early stages of development, the theoretical potential for wave energy in India is substantial, with estimates suggesting hundreds of megawatts of potential capacity [1,2].
- Tidal Energy: Tidal energy projects benefit from predictable tidal patterns, enabling consistent power generation. India's tidal potential is estimated to be significant, with installed capacities projected to reach several hundred megawatts [2,9].



Different zones/sub-zones in the region of Gulf of Mannar, off Tamil Nadu coat and Gulf of Kambhat, off Gujarat coast. Figure by NIWE.

- Ocean Thermal Energy: India's ocean thermal energy potential is vast, with the ability to generate gigawatts of electricity using OTEC systems. Pilot projects are underway to demonstrate the feasibility and scalability of OTEC technology [3].
- Offshore Wind Energy: Offshore wind energy has emerged as a major focus area, with the potential to contribute significantly to India's renewable energy targets. Offshore wind farms could deploy large-scale turbines to harness strong coastal winds, offering gigawatt-scale capacities [7].

Key Successful Projects and Initiatives

- Gujarat Offshore Wind Farm Pilot Project: A joint initiative by the Government of Gujarat and Suzlon Energy to establish India's first offshore wind farm [7].

- Tamil Nadu Offshore Wind Farm: An ongoing project to assess the feasibility of offshore wind energy along the Tamil Nadu coast [7].

The diverse forms of marine renewable energy present substantial prospects for India's sustainable energy transition. Each MRE resource offers unique advantages and challenges, requiring tailored approaches for development and deployment. Continued research, technological innovation, and policy support are essential to unlock the full potential of marine renewable energy in India [10].

All References shall be provided in the concluding part of the article.

About the author

Yash Jain (F-13831) is a Marine Engineer and is with Goodwood Marine Services Pvt. Ltd. He holds a BE degree from Govt. Engineering College, Bikaner and a PGD in Marine Engineering from MERI, Mumbai. His other interests include marine renewable energy and holistic wellness practices. He is a Fellow of IME(I) and a member of the Maritime Union of India. He has co-authored a book titled 'Barriers and Facilitators of Geriatric Smart Home Technology Implementation'.

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Going Astern into MER Archives...

MER
MARINE ENGINEERS REVIEW
Journal of the Institute of Marine Engineers (India).
16th floor, Nirmal, Nariman Point, Bombay 400 021

The July 1984 issue Editorial underlines the importance of Classification Societies being impartial and maintaining high standards of integrity. The OPINION wonders at the ancillary industries doing good business in spite of the recession bear running amok. Two mentions require attention: one on IMarE doing audits and other MER team visiting expos and interviewing industry exhibitors. The last piece of the section talks about an offshore structure corrosion-prevention product in the form of a silicon rubber m-polymer. We have come a long way and it would be worth looking at what the modern technology has in store for offshore and on sea hulls. Any articles forthcoming?

The first of the technical article advocates micro/ manual vibration monitoring as a good measure for predictive maintenance. The philosophy lies in 'listening to the engine'. Fixed transducers send in signals to a hand-held device from which data is taken to a central processing unit (to store and analyse data). The vibration spectrum corresponds to the state of the machinery and the spectral analysis is done by the computer. Detecting the deviation from the normal, the machine proposes when the predictive maintenance (intervention) needs to be done. This clearly is the forerunner to the present day, sophisticated AI-ML architectures.

Following this is an article on Engine Fault Analysis. This is a very interesting article for practicing marine engineers. Focussing on faulty combustion and shaft power, the article ahs some valuable insights. As a sample. I have inserted the list of damages due to vibration (experimental results over a period). A bonus read slotted in the same pages is on how TBO can be extended for turbochargers.

Table 1: Inspection codes and definitions.

INSPECTION CODE	
0	No Inspection
1	Machine Normal
2	Not Operating
3	Fluctuating Vibration
4	Hot Bearing
5	Bad Belts
6	Abnormal Noise
7	Leaks
8	Loose/Broken Parts
9	Machine Overheating
10	Machine Overhaul/Repair
11-15	Customer-Selected

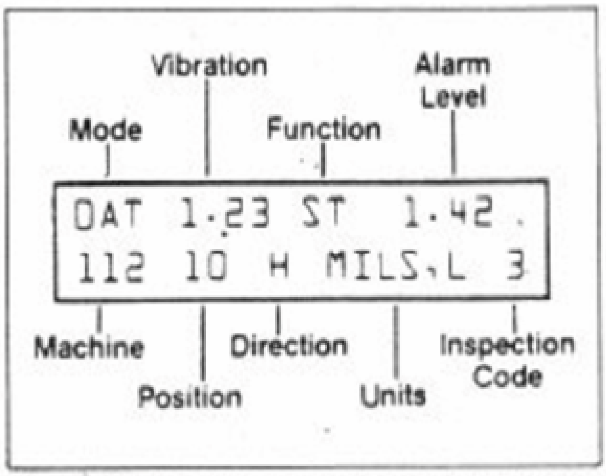


Fig 1: Typical data collector LCD prompting display.

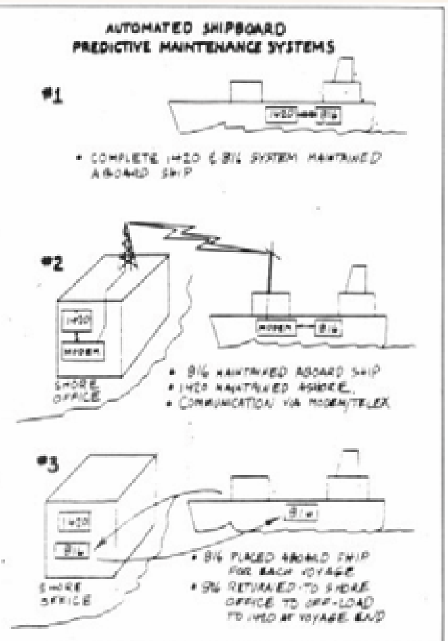


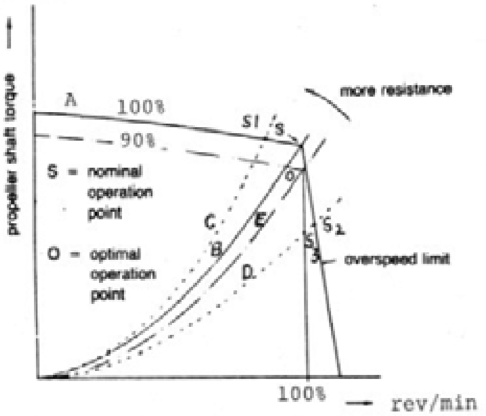
Fig 4: Three applications of computer-based vibration predictive maintenance system.

The next article is on pollution and Civil Liability Convention. With the Singapore spill this assumed significance. Would welcome thoughts from the readers.

This is followed by an interview (by MER) of Dr. Peter Milne, Managing Director of Merchant Shipbuilding & Composite Division. The interview captures the declining state of UK shipbuilding and how the industry is trying to have its feet in the labour issues. Productivity and performance are also discussed. A significant discussion point is the R&D work taken up at Newcastle University on minimum energy ships. This academia-industry synergy is what is needed in the Indian maritime shores.

Following this is an article on Sulzer (150 years) announcing expansion of its RTA power envelope.

Fig 1: Propeller curves plotted in engine performance graph.



1. Excessive wear of piston rings and cylinder liners.
2. Cracking of connecting pipes (cooling water, exhaust, etc).
3. Leaky joints.
4. Cracking of parts mounted on the engine, such as fuel-filters, coolers.
5. Cracking of blower supports.
6. Loose foundation bolts.
7. Cracking of crankcases.
8. Serious wear of pin bearings, sometimes main bearings.
9. Wear in auxiliary engines in the vicinity of the main engine.
10. Collapse of ball or roller bearings in gearboxes.
11. Serious wear in gears and/or spline shafts.
12. Defective cpps.

Continuing the vibration topic, the next article focusses on shaft generators with torsion-reaction device connected to the foundation. Though simple in principle, the operational issues could tell another story. Any engineers who had worked on such arrangements... on cruise ships, particularly.

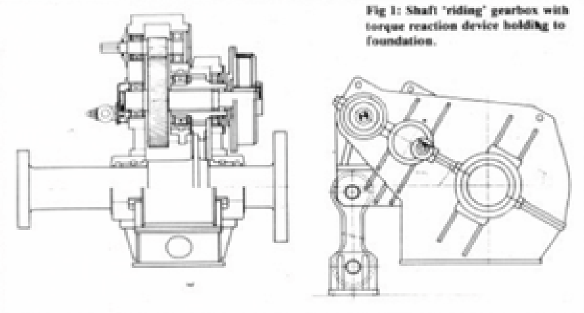
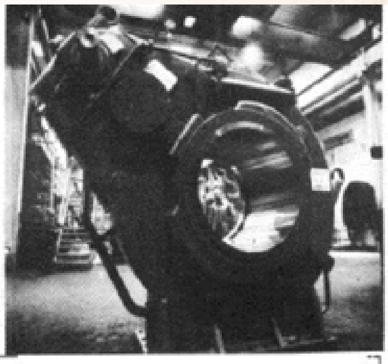
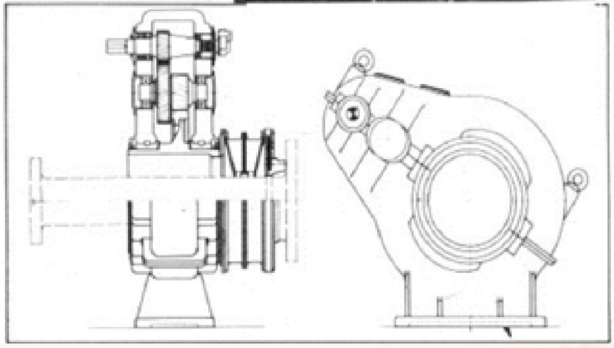


Fig 1: Shaft 'riding' gearbox with torque reaction device holding to foundation.

Fig 3: The view on the right shows a Tacke SHH 11-1600 hollow shaft generator gear drive for a slow-speed engine. The generator rating is 1920 KW, the input speed is 106 rev/min and the output speed 1212 rev/min. The view below is the configuration of the SH 11 gear.





Next, we find a very absorbing Transaction on 'The Economic Selection of Main and Auxiliary machinery'. This is a very valuable paper for researchers and PG students doing projects. The end section on queries and the responses from Authors by itself is quite educative. I will highlight a few exemplar ones: one query is on deployment of variable speed motors (which have gained good acceptance. – Hon.Ed.); another one on engine costs to ship costs and fuel costs as a percentage of operating costs and how B&W has attempted to bring these economics to digestible levels; Mr. Buxton's observations on predicaments of economic evaluations. The Transaction is a must read for marine engineers.

There is another paper presented at the forum of Madras Branch of IMarE and TN Centre of IEI, on 'Prevention and Abatement of Marine Oil Pollution from Ships'. A lot of data apart, a section of interest is the discussion on why oil pollution has reduced over a considered period.

A tailpiece note on 'From Marine Engineering to Ocean Engineering' has a few points on what else can become of marine engineers.

We invite observations, discussion threads from readers, taking cues from these sepia-soaked MER pages. – Hon.Ed.

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