Proc. of the 2017 International Symposium on Electromagnetic Compatibility - EMC EUROPE 2017, Angers, France, September 4-8, 2017

Cost-Effective Electromagnetic Compatible Installation on Ships using a Risk Based Approach

Jan-Kees van der Ven[1], Bart van Leersum[2], Merlijn van Rij[1], Frank Leferink[3,4]

[1]RH Marine, Rotterdam, The Netherlands, Jan-kees.vanderven@rhmarine.com

[2]Defence Materiel Organisation, The Hague, The Netherlands

[3]Thales Netherlands Hengelo, The Netherlands

[4]University of Twente Enschede, The Netherlands

***Abstract* – The lack of equipment available on the market which is certified for maritime, or even naval, environments, i.e. in accordance with IEC 60533 [1], makes it hard for shipbuilders to deliver (naval) ships that comply with maritime ElectroMagnetic Compatibility (EMC) regulation. Following the conventional rule-based approach, i.e. implementing standards, results in a deadlock or very costly dedicated hardening of equipment. This problem is acknowledged in the Lloyd's Register Naval Rules and obviated by a risk based electromagnetic compatibility approach. This paper points out the electromagnetic risks identified and mitigated by the technical committee that wrote the IEC 60533, and provides a risk based approach to deal with them.**

Keywords: Risk based EMC, complex installation, ships

I. Introduction

The costs for naval ships are escalating at an unsustainable rate [2] as shown in Figure 1. The data in this figure shows the cost development of surface combatants of the US Navy between 1950 and 1999. The Zumwalt Class DDG1000 cost is more than 4 B$ [3] which is in line with the logarithmic price development between 1950 and 1999, extrapolated until 2016. Several factors contribute to this rapid increase in procurement costs of ships and according [2], 3 out of the top 10 of cost-drivers are related to EMC standards being:

- MIL-STD-461E Electromagnetic Interference (EMI), [4],
- MIL-STD 464A Electromagnetic Environmental Effects (E3) Requirements for Systems [5],
- MIL-STD-469B Radar Engineering Interface Requirements, Electromagnetic Compatibility – Frequency Spectrum Guide for Radar [6].

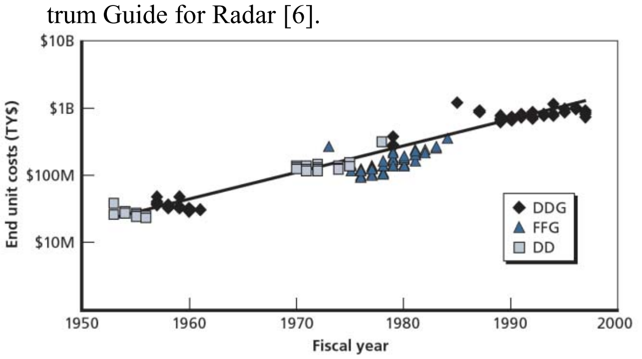

Fig. 1 (from [2]): Cost Escalation for selected surface combatants according. DDG: Guided missile destroyer, FFG: Guided missile frigate, DD: Destroyer

The conventional approach to achieve an electromagnetic compatible system would be to implement the applicable standards without any further consideration. For naval ships this could be aforementioned MIL-STD 461E (now –G [4], or the STANAG 4370, referring to the AECTP 501 series for equipment testing, and AECTP 506 for naval platform testing [7]. The electromagnetic environment is described in MIL-STD 464A [5] (now –C), or AECTP 250 series [8]. For maritime environments the IEC 60533 is the reference. As equipment fulfilling these standards completely is either difficult to acquire, or costly, the only perspective is to 'harden' (Commercial) Off The Shelf (COTS) equipment. This hardening has its costs, as shown in the report of the Defense Science Board Task Force on Integrating Commercial Systems into the DOD, Effectively and Efficiently [9]; It appears that hardening results in an increase of cost of a (relatively simple) naval ship from $220 million to $500 million.

Instead of following the conventional rule-based approach, a risk-based approach was developed by several companies, knowledge institutes and the government. They decided to tackle the challenge of high EMC related costs on board Naval Vessels together, resulting in the consortium "EMC for Future Ships" which incorporated:

- a navy (Royal Netherlands Navy),
- a Classification Society (Lloyd's Register of Shipping),
- a shipbuilder (Damen Shipyards),
- a combined Combat-System-Integrator (CSI) and equipment manufacturer (Thales Nederland),
- a combined E-System-Integrator (ESI), installer as well as an equipment manufacturer (RH Marine Netherlands) and
- a university (University of Twente).

One of the major results is that the Lloyd's Register Naval Rules were adapted per January 2017 [10], [11] enabling the risk-based approach. Actually the risk-based approach is nothing more than proper EMC engineering, and comparable to the Risk Inventory and Evaluation (RIE) methodologies applied in other domains. With the modification (Volume 2, Part 1, Chapter 3, Section 3.3 and Section 4.13) of the Lloyd's Register Naval Rules the risk based EMI approach is also allowed. This gives the possibility to focus less on emission and immunity levels on which the standards are based and more on interruption of / attenuation by the coupling path. As a consequence this allows ship builders to apply COTS equipment from which the ElectroMagnetic (EM) quality is nowadays much better than ever before without any additional measures, or costs. Reason for this improvement of COTS equipment are the legal requirements posed worldwide on electronic products, like the EMC Directive in Europe [12].

978-1-5386-0689-6/17/$31.00 ©2017 IEEE

Besides, today's civil development has led to rapid mass production of reliable new technology at a much faster pace than in the defense industry, enabling ship builders to deliver state of the art ships.

In the future the problem is that this approach is only applicable for Naval Vessels built under Lloyd's Register Naval Rules while many ships are built under different regimes. A standard that is widely accepted to achieve EMC on board ships is IEC 60533. Unfortunately this standard requires dedicated equipment which is hardly available on the market. This paper investigates the possibilities to supplement IEC 60533 into a standard that also allows a risk based EMI approach to overcome the lack of IEC 60533 certified equipment.

II. Risk based EMI approach

A risk based EMI approach involves the following four steps:

A. An EMC management plan

The EMC management plan has three important goals. The first one is to define the ElectroMagnetic Environment (EME) in which the ship will operate. In other words what does the customer want with his ship and what kind of EM threats follow from these requirements? Examples are: Impact from direct or indirect lightning strikes and Emcon (Emission Control) requirements.

The second one is what requirements does the customer have, for example:

- The use of mobile radios (walkie-talkies) on board introduces a disturbance source which can create significant field strengths at any location on board, possibly causing interference. Nowadays there are devices that require much less field strength (IP-Dect / VoWIFI).
- Radio communication equipment to be installed

The third goal is to share the responsibilities between all parties involved: contractor, sub-contractors, and suppliers. If all contractors, sub-contractors, system- and equipment suppliers, and component manufacturers take all necessary steps that whatever purchased parts they use, their delivery is completely suited to be used in a maritime environment, the ship will be too expensive. If none of these parties take these steps, there is a high risk on interference resulting in malfunctions. The challenge is to make sure that the party that can prevent EMI in a naval environment, against the lowest overall costs, will do so. Other topics to be dealt with in the EMC management plan are the legal and contractual EMC obligations. If there are standards to be adhered to, what kind of standards are they and under what conditions are they applicable.

Since cooperation between all partners is important to reach EMC and a reliable ship at the lowest costs, it is important to facilitate this cooperation for example by means of an EMC working group.

Finally some thought should already be given on what kind of inspection, verification and validation is required to convince classification society and customer of the reliability of the delivered installation. Inspection, verification and validation can be real cost drivers so all involved parties should roughly know what is expected from them if they make their offer.

To summarize the management plan defines the EM threats that follow from the requirements of the customer and states who is responsible for what.

B. An EMC control plan

The EMC control plan is all about: controlling the identified risks, defining measures (best practices to mitigate those risks, and translating them into purchase specifications for sub-contractors and system- / equipment suppliers. The input of the EMC control plan consists of the EM threats and operational requirements from the customer combined with the equipment that will be used on board. An easy tool to identify the risks is a "source victim matrix". In a source victim matrix interference risks are identified and mitigated with best practices. The use of a source victim matrix is discussed in [13] and [14]. Based on the risk analysis the output of the control plan will be a number of documents and instructions which enables the system integrator to properly inform all involved parties which requirements are made with respect to their delivery and the installation work.

C. An EMC implementation plan

The control plan states "what needs to be done to prevent interference", but not in detail "how this should be done". This subject will be dealt with in the implementation plan. An implementation plan gives for example information about: how to arrange cables into different groups with roughly the same disturbance levels, separation distances between those cable groups, preferred communication busses and so on. With this information installers / system integrators can create electrician's manuals / instructions. An electrician's manual states in detail "how the components that will be used need to be installed". Items to be discussed: whether earth connections should be made inside or outside a cabinet, how an EMC gland needs to be mounted, where to earth cable screens and so on. It is important that requirements are specific and measurable, so it is easy to verify whether the work has been performed correctly.

The equipment manufacturer's installation instructions can conflict with the requirements from the EMC control plan. In this case a memo will be added to the implementation plan. This memo explains: how the conflict is to be dealt with, what the chosen solution is, what the consequences are and who is responsible for implementing the solution. An example is when the equipment manufacturer requires the earthing of the cable screens at only one point, whilst the EMC control plan states that they are to be earthed at multiple points.

D. An EMC validation and verification plan

The test plan exists of two major parts: a verification part, primarily performed during construction phase and a validation part, primarily performed during harbor acceptance and sea acceptance trials.

The verification is all about checking if the best practices are implemented correctly and if the instructions from the electrician's manual are lived up to. This needs to be done during the construction phase because for example: "after an EMC gland is mounted, it is hard to see if this was done properly". The same applies for topics like: creating earth connections, cable separation and so on.

The validation is performed to check if the best practices are as effective as expected. Simple tests can determine this like checking the goodput of data busses, checking reception of radio signals, measuring noise levels in receiver bands, and things like that.

III. DEVIATIONS BETWEEN IEC 60533 AND GENERIC EMC STANDARDS

A. Introduction on the IEC 60533

The IEC 60533 is a product standard, this means that it is used to specify the EM requirements of certain products. On board ships there all sorts of equipment which certainly do not belong to a single product group. In general a product standard selects tests, and test levels, defined in the basic standards, to be performed for a specific type of product. Most of the equipment installed onboard a ship is not specifically developed for a maritime environment, instead it complies with its specific product standards e.g.: UPSs with IEC 62040-2 [15] and computers with NEN-EN 55032 [16], and not necessarily with IEC 60533. So theoretically this kind of equipment is strictly not allowed to be used on board since it does not comply with IEC 60533. To the authors experience, on board any ship there is equipment present which is not compliant with IEC 60533 and these ships still operate satisfactorily.

The most important drawback of IEC 60533 is that there is hardly any equipment available on the market that is tested according this standard which makes it almost impossible for shipbuilders to apply this standard. On the other hand, the annexes of IEC 60533 are very useful since they provide good procedures and mitigation guidelines which could be used to manage EMC.

B. Divergence of IEC 60533 in relation to other standards

The question arises how ships can operate satisfactorily even with noncompliant IEC 60533 equipment on board? A cause could be that the requirements in product standards are similar to the IEC 60533. A simple comparison shows that this is not the case. As an example a comparison is made for the immunity requirements of an AC power port which can be found in the IEC 60533 and in the generic standards (e.g. [17], [18], [19] and [20]), which are often the basis for product standards, see table I. A generic standard defines tests and test levels for a certain EM environment.

TABLE 1: COMPARISON OF IEC 60533 WITH GENERIC STANDARDS

<table>
<tr><th>Phenomenon</th><th>IEC 60533 [1]</th><th colspan="2">IEC 61000-6-1 [17]</th><th colspan="2">IEC 61000-6-2 [18]</th></tr>
<tr><td>Conducted low frequency interference</td><td>10 %: 50 → 900 Hz;
10→1 %: 0.9→6kHz;
1 %: 6→10kHz</td><td colspan="2">Not mentioned</td><td colspan="2">Not mentioned</td></tr>
<tr><td rowspan="4">Power supply variation (IEC 60533)

Voltage dips (Generic standards)</td><td rowspan="4">U: ± 20 % 1.5 s
f: ± 10 % 5 s</td><td>Unom %</td><td>Cycle 50 / 60 Hz</td><td>Unom %</td><td>Cycle 50 / 60 Hz</td></tr>
<tr><td>0</td><td>0.5 / 0.5</td><td>0</td><td>1 / 1</td></tr>
<tr><td>0</td><td>1 /1</td><td>40</td><td>10 /12</td></tr>
<tr><td>70</td><td>25 / 30</td><td>70</td><td>25 / 30</td></tr>
<tr><td>Power supply failure</td><td>60 s interruption</td><td colspan="2">5 s interruption</td><td colspan="2">5 s interruption</td></tr>
<tr><td>EFT-B</td><td>2 kV</td><td colspan="2">+ 1 kV</td><td colspan="2">+ 2 kV</td></tr>
<tr><td>Surge voltage:
line to line
line to earth</td><td>
0,5 kV
1 kV</td><td colspan="2">
+ 1 kV
+ 2 kV</td><td colspan="2">
+ 1 kV
+ 2 kV</td></tr>
<tr><td>Conducted RF interference</td><td>3 V: (0.01) 0.15 → 80 MHz</td><td colspan="2">3 V: 0,15 → 80 MHz</td><td colspan="2">10 V: 0,15 t→ 80 MHz</td></tr>
</table>

It would be useful if it was possible to compare the requirements of IEC 60533 with other standards in order to determine to what extend a product complies and limit eventual additional testing. This is impeded by the fact that IEC 60533 deviates in a number of its test specifications from the basic standards. A basic standard describes how a test should be performed and is often referred to by product and generic standards. E.g. for the conducted low frequency interference test is referred by IEC 60533 to IEC 61000-4-16 [21] as reference. However IEC 61000-4-16 requires very different test levels (1, 3, 10 or 30V depending on the environment) than stated for the "conducted low frequency interference" test of IEC 60533 as shown in Table 1.

For emission requirements the same applies as can be seen in Figure 2 and Figure 3.

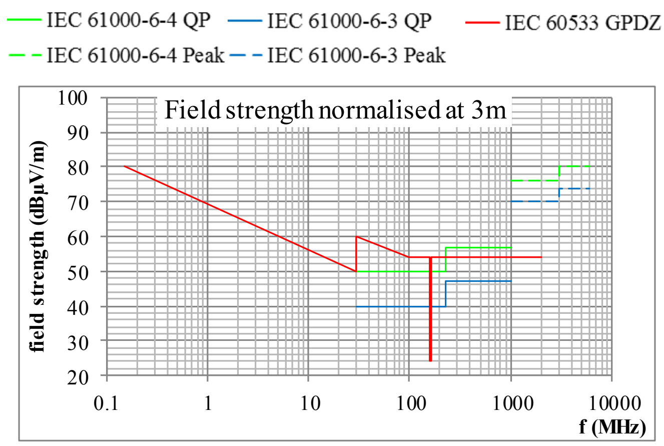

Figure 2: Radiated emission comparison [1] [19] [20]

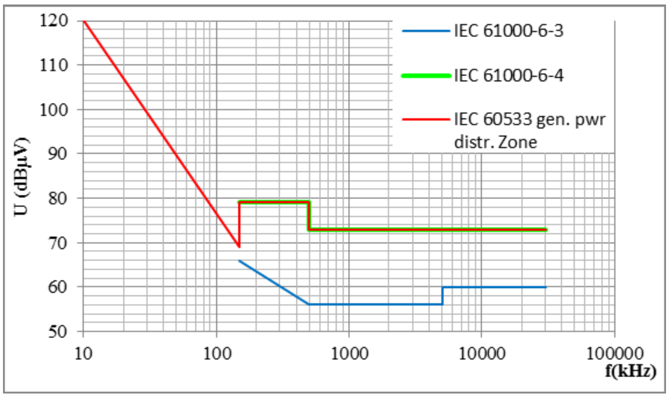

Figure 3: Conducted emission comparison [1] [19] [20]

If the test requirements were more similar, the test results obtained to show compliancy with other standards could have been used to show that the product will also fulfil the requirements of IEC 60533 (partially).

IV. REASONS TO DIVERGE FROM GENERIC STANDARDS.

The maritime EM environment has its own specific characteristics which justifies the focus of the IEC 60533 on these characteristics. This resulted in the following specific tests:

A. Radiated emission measurements from 150 kHz to 30 MHz

In this frequency range several mobile services are in use specifically intended for the Maritime sector, as can be found in [17] where an overview of maritime radio communication system is given such as:

- NAVTEX 518 kHz, 490 kHz and 4209.5 kHz,
- MF/HF Voice 2182 (distress calls), 4125, 6215, 8291, 12290, 16420 kHz
- MF/HF Digital Selective Calling (DSC) 2187.5, 4207.5, 6312.0, 8414.5,12577, 16804.5 kHz
- Narrow band direct print (NBDP) 4210, 6314, 8416.5, 12509, 16806.5, 19680.5, 22376.0, 26100.5 kHz
- HF Digital data 4 to 26 MHz

Some of these systems are obligatory to have on board and the minimal signal levels that need to be received can be defined by SOLAS.

B. Radiated emission measurements from 156 MHz to 165 MHz

Also in the VHF band from 156 to 165 MHz very strict emission limits apply since the following mandatory systems operate in this frequency range [22]:

- AIS 161.975& 162.025 MHz
- VHF voice 156.025 to 161.950 MHz (Distress calls)
- VHF data 156.025 to 161.950 MHz
- VHF Digital data 156.025 to 161.950 MHz

C. Conducted emission measurements from 10 kHz to 150 kHz

According to [23]: "Conducted emissions are defined from power ports for the frequency range 10 kHz to 30 MHz which reflects the frequency band where the ship also has receivers and where conducted emissions may cause a problem." This being true for the moment the IEC 60533 was originally developed, however nowadays this frequency range is used less often. Systems like Omega and Decca are obsolete [19] and according [24] only the following two optional maritime radio systems are operational in this frequency range:

- Loran and e-Loran 100 kHz (Hardly used anymore)
- DGNSS 285 to 325 kHz (Quite common)

D. Conducted low frequency interference measurements

Onboard ships often power grids are applied from which the star point is not connected to earth (IT). The integrity of those grids is verified with Power Insulation Monitors (PIMs) [25], which put a limit on the maximum capacitance to earth in order to ensure proper operation. This limits the use of filters with Y-capacitors and as a consequence the low frequency interference, particularly common mode interference increases.

E. Power supply variation

Most power supply grids are powered by diesel generator sets. Since the power rating of these diesel engines is relatively small compared to the load steps they encounter, deviations in voltage and frequency will occur often. Especially the deviations in frequency are characteristic for power supply grids on board ships.

V. A RISK BASED APPROACH

The previous two paragraphs discussed the differences between IEC 60533 and generic standards and the rational for those differences. Still the question remains why all those ships sail safely around the globe without IEC 60533 compliant equipment onboard. Apparently there is another way to ensure everything works satisfactorily. The following sections will deal with this question per identified risk.

A. Radiated emission measurements from 150 kHz to 30 MHz

There is not one general solution to ensure that no interference occurs. The IEC 60533 assumes that all of these previously mentioned systems are onboard. This is also to be expected since the title of this standard is: "Electrical and electronic installations in ships – Electromagnetic compatibility (EMC) – Ships with a metallic hull", and so the requirements stated in this standard should cover all types of ships with a metallic hull, whatever communications systems they have onboard. Of course in practice this will not always be the case and systems which are not onboard do not need protection. Besides that, not all systems onboard have the same coupling with the receive antenna. IEC 60533 differentiates between emission limits for equipment in the deck and bridge zone and for the general power distribution zone, but this is a rather black and white solution. In practice there are all shades of gray. E.g. Imagine a luxurious mega yacht, where does the deck and bridge zone stop and the general power distribution zone / accommodation zone start with all its large EM openings in the superstructure. Another point to consider is that in this frequency range the equipment itself is in general a poor transmitter. It needs the connected cables as antennas. If screened cables are applied, from which the screen is properly terminated, the cable will be a poor antenna. So by making a proper design with attention for equipment placement, what kind of cables are used, proper termination of the cable screens and a well-considered antenna location, it might not be necessary to meet the firm radiated emission requirements between 150 kHz and 30 MHz. Proof of a proper approach can easily be delivered by a noise measurement at the receiving antenna output and comparing the results with the requirements in IMO Resolution A.803(19) [26] for example.

B. Radiated emission measurements from 156 MHz to 165 MHz

The same method can be applied for the frequency band from 156 to 165 MHz. In Figure 4 a measurement is shown on board a ship which is in operation and has a significant amount of equipment on board that is not tested according IEC 60533. However the noise level on the receiver input is below 0 dBµV which is an interpretation of SOLAS requirements as explained in [27]. There are a few signals exceeding the 0 dBµV and it is quite easy to determine their source by tuning in on these signals. These measurements have been repeated under different operational conditions and deliver similar results. Also measurements onboard other ships confirm these results.

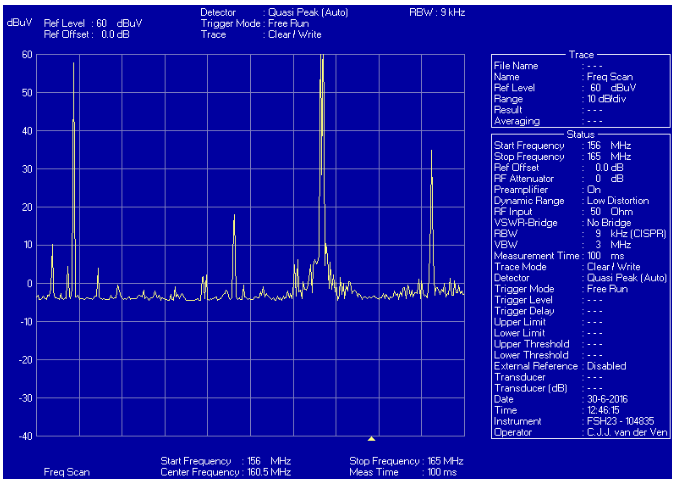

Figure 4: signals measured on the VHF antenna of the HNLMS Snellius

This evaluation method will also point out equipment which is in compliance with IEC 60533, but still causes interference because it is placed too close to the reception antennas. IEC 60533 assumes that equipment is placed at least at 15 m distance from the antenna [23], however, equipment can be placed much closer to the antenna as the problems with IEC 60533 compliant navigation lighting indicates [28].

C. Conducted emission measurements from 10 kHz to 150 kHz

As explained in the rationale [23] the conducted emission in the frequency range from 10 to 150 kHz is primarily limited to prevent interference with radio equipment. Conducted emissions on long cables will radiate and couple into the RF spectrum. The few maritime radio systems still operational in this frequency are not mandatory to have on board, so only if these systems are on board, special attention need to be paid to this frequency range. The frequency ranges of the conducted and radiated emission requirements also overlap, whereas IEC usually defines only conducted emissions below 30 MHz and radiated emissions above 30 MHz. Both radiated and conducted emission requirements serve for the protection of the Radio Frequency (RF) spectrum. Since it is difficult to measure EM fields below 30 MHz, (radiated fields cannot be properly measured in the near field or cannot be translated to far field radiated effects), the requirements have been translated into voltages on cables. This means the disturbance on the cable cores is measured with a Line Impedance Stabilization Network (LISN) and the results are compared with the limits stated in IEC 60533. However if screened cables are used this will highly reduce the field originating from the cable cores, IEC 60533 does not take this effect into account. Again measurements on the antenna output of installed systems onboard (Loran / DGNSS) can prove that the equipment onboard is not interfering with the systems or show that additional measures are required.

D. Conducted low frequency interference measurements

This phenomenon is in particular a problem in IT power grids. So if a power grid with an earthed star point is used (TN or TT) this test is not that important. Also equipment especially developed for IT power grids will be able to deal with the higher levels of common mode disturbance. In the remaining situations additional attention needs to be paid to the robustness of equipment against common mode disturbances. This means that additional requirements need to be made to equipment exposed to these high levels of common mode disturbances or the equipment needs to be protected from it for example by using transformers. So if the power distribution grid with all systems that contribute to the conducted emissions are properly installed, the disturbances can be contained to that grid. [29]

E. Power supply variation

Power supply variation in voltage and frequency can be a problem but a lot of equipment on the market nowadays can withstand these variations easily as shown in Figure 5. These devices can deal with a large range of input voltages and frequencies.

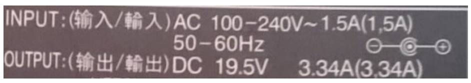

Figure 5: Example of a type plate

If the equipment is not tested against these frequency variations but powered by a power source that does not introduce these voltage and frequency sweeps when exposed to load steps, e.g. uninterruptable power supplies, or power electronics belonging to alternative power sources (battery, solar converter etc.), this requirement is no longer applicable. So rather than testing all equipment against these voltage and frequency variations it is advisable to check if this is really necessary.

6) Relation with the risk based EMI approach

The measures stated in chapter V are not a risk based EMI approach as intended by the Lloyd's Register Naval Rules [10].They are merely a small step to mitigate the risks and need to be integrated in the source victim matrix and in the implementation plan.

VI. CONCLUSION

This paper discusses the drawback of following the conventional rule-based approach, which relies on applying standards for equipment without consideration for quality of the installation. The described risk-based approach is making use of the knowledge of the complete platform, is based on sound EMC engineering, and is now incorporated in the Lloyd's Naval Rules. Experience and measurements in the shipbuilding industry have already shown that this is a viable solution.

The IEC 60533 could also, as in Lloyd's Naval Rules, be expanded with the risk-based approach. This route to compliancy allows also other ship types and ships build under other classification societies, to benefit from the risk based approach, besides naval vessels built under Lloyd's Register.

Acknowledgment

The authors like to thank: Lloyd's Register of Shipping, Netherlands Defence Materiel Organisation (DMO), University of Twente (the Netherlands), Thales Nederland, Damen Shipyards (the Netherlands), and RH Marine (the Netherlands) for making resources available and providing back ground knowledge to perform the research that enabled the modification in the Lloyd's Naval Rules with respect to EMC.

References

[1] Electrical and electronic installations in ships - Electromagnetic compatibility (EMC) - Ships with a metallic hull, IEC 6053, ed. 3, IEC, Geneva, 2015.
[2] V. F. Neradka, T. R. Konen and J. W. Coleman, "Specification Innovation as a part of building an affordable fleet," NAVSEA, 2010.
[3] http://www.cbsnews.com/news/uss-zumwalt-the-next-generation-destroyer/
[4] Requirements for the control of electromagnetic interference characteristics of subsystems and equipment, MIL-STD 461E, 20 August 1999.
[5] Electromagnetic environmental effects (E3) Requirements for systems MIL-STD 464A, Department of Defense Interface Standard, 19 December 2002.
[6] Radar engineering interface requirements, Electromagnetic compatibility – Frequency spectrum guide for radar, MIL-STD-469B, 24 June 1996.
[7] Electromagnetic environmental effects tests and verification, NATO STANDARD AECTP-500, Edition E, Version 1, January 2016, nso.nato.int/nso/zPublic/ap/AECTP-500EdEV1.pdf
[8] Electrical and electromagnetic environmental conditions, NATO STANDARD AECTP-250 Edition C Version 1, December 2014, nso.nato.int/nso/zPublic/ap/AECTP-250EdCV1.pdf
[9] "Buying commercial: Gaining the cost/schedule benefits for defense systems", Report of the Defence science board task force on integrating commercial systems into the DOD, effectively and efficiently, February 2009, http://www.acq.osd.mil/dsb/reports/ADA494760.pdf
[10] L. Register, Rules and regulations for the classification of naval ships, Lloyd's Register, 2017.
[11] L. Register, "Notice No.4 Rules and regulations for the classification of Naval ships," Lloyd's Register, 2016.
[12] Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the Harmonisation of the Laws of the Member States Relating to Electromagnetic Compatibility, Eur. Union Directive, 2014.
[13] C.J.J. v. d. Ven, et al., "Converting best practices for electromagnetic compatibility into naval rules," in Conference proceedings MECSS, Bristol, 2015.
[14] C.J.J. van der Ven, "The process and documentation needed to assure a riskbased approach to EMC for naval vessels, enabling the use of COTS equipment," in 13th International Naval Engineering Conference and Exhibition INEC, Bristol, 2016.
[15] Uninterruptible power systems (UPS) - IEC, 62040-2 Part 2, IEC, Geneva, 2006.
[16] Electromagnetic compatibility of multimedia equipment - Emission Requirements, NEN-EN 55032, NNI, DELFT, 2015.
[17] Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity standard for residential, commercial and light-industrial environments, IEC 61000-6-1 IEC, Geneva, 2016.
[18] Electromagnetic compatibility (EMC) - Part 6-2 Generic standards - Immunity for industrial environments, IEC 61000-6-2, IEC, Geneva, 2005.
[19] Electromagnetic compatibility (EMC) - Part 6-3 Generic standards - Emission standard for residential, commercial and light-industrial environments , IEC 61000-6-3, IEC, Geneva, 2006.
[20] Electromagnetic compatibility (EMC) Part 6-4: Generic standards - Emission standard for industrial environments, IEC 61000-6-4, Geneva, IEC, Geneva, 2006.
[21] Electromagnetic compatibility (EMC) - Part 4-16: Testing and measurement techniques - Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz, NEN-EN-IEC 61000-4-16, NNI, Delft, 2016.
[22] ITU Radiocommunication study groups, working group 5B-3 Maritime, "Working document towards a draft new report on ITU coordination to support a maritime radio communication plan ITU-R M", e-NAV 14-10-3, ITU, 2011.
[23] K.P. Fisher, L. Moore, "EMC requirements for ships," in Ninth International Conference On Electromagnetic Compatibility, 1994.
[24] B. v. Leersum, Requirements with rationale and quantitative rules for EMC on future ships, Den Haag : s.n., 2017. ISBN: 978-90-365-4155-8.
[25] F. Leferink, P. van Vught, R.B. Timens, "Grounding and filtering effects on power insulation monitoring in naval power networks", in Conference proceedings of MECSS, Imarest, Amsterdam, 2013.
[26] Performance Standards for Shipborne VHF Radio Installations Capable of Voice Communication and Digital Selective Calling, Int. Maritime Org. Resolution A.803(19), Dec. 15, 1995.
[27] B. v. Leersum, C. van der Ven, W. Haverkamp, H. Bergsma, N. Smit, F. Leferink, "Analysis of limit setting rationales for the protection of maritime VHF radio", IEEE transactions on electromagnetic compatibility, IEEE Transactions on Electromagnetic Compatibility (unpublished).
[28] Subcommittee on navigation communication and search and rescue, "Electromagnetic disturbance due to lighting using LED technology," IMO, 2015.
[29] B. v. Leersum, "Quantification of minimal needed cable terminations," APEMC 2015, Taipei, 2015.