Investigating the EMC Performance of a Matrix Converter and Measures to Improve It

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***Abstract* - Electromagnetic interference caused by nonlinear loads can significantly affect electronic equipment in a system, especially those that operate on low amplitude control signals. Matrix converters is an example of such nonlinear loads. This paper investigates through measurements, the EMC behavior, radiated and conducted emissions by a matrix converter, compares this performance to conventional converters, and defines mitigation measures employed to improve the EMC performance and reduce any risk of interference. These mitigation measures follows a risk based approach and can thus be designed according to the given electromagnetic environment in question, on board ships.**

Keywords; Electromagnetic compatibility, matrix converters, conventional converters, risk based approach

I. INTRODUCTION

An electrical equipment installed on board a ship must interact harmoniously with the rest of the equipment installed in the same electromagnetic environment, without causing any electromagnetic interference (EMI). This harmonized interaction is referred to as electromagnetic compatibility (EMC) as explained in the definition given in [1]. A converter is one of those equipment. Converters are used on board of ships for the conversion of power either from AC-AC, AC-DC, or DC-DC [2]. For this purpose, conventional and matrix converters have been used. A matrix converter, unlike several conventional converters, does not use line reactors and filters but rather does a direct conversion of ac to ac power using bidirectional switches, while creating much lower harmonic currents [3]. The performance evolution of the switching devices, for instance IGBTs, are exponential, by having a higher current and voltage handling capability and shorter rise time during switching. Due to the short rise times, these devices result into a higher change in voltage over time (dV/dt). These high voltage changes, switching frequency of the converters and the associated common mode disturbances may result into EMI [4]. Figures 1 and 2 show the schematic diagram of a conventional converter and a matrix converter respectively. A conventional converter with diodes for AC to DC conversion has a high harmonic emission. To reduce the harmonic currents, the diodes in a conventional converter are replaced with IGBTs, and this solution is called active front-end (AFE).

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In the physical implementation, these equipment are bulky due to the big inductors, and thus require a larger physical space for installation. As shown in Figure 2 however, the matrix converter does direct AC to AC conversion without additional large inductors and will thus not require as much installation space. The functionality of these converters is fundamentally the same but matrix converters provide upgraded advantages over the conventional ones. Some of the upgraded features include continuous power regeneration, near unity power factor, compact design, higher efficiency and low input current harmonics [5] [6]. Harmonic distortion is one major factor as compared to a conventional converter and the total harmonic distortion (THD) is less than 5%. As EMI is more than just the THD phenomena, the conducted and radiated emissions must also be investigated and addressed in case of possible risk of interference. Since these equipment still use switching semiconductors such as IGBTs, there are conducted disturbances and radiated disturbances that are injected into the electromagnetic environment in which the equipment is installed. Like all other interference sources, this may cause interference in some applications or failure of other, maybe even critical equipment disturbed. In order to prevent interference, it is important to select proper equipment, which is suited for the intended maritime environment and function, and install it following rules that are described for the correct and harmonized installation of equipment on board ships. In this case, rules are followed and for naval equipment, there are even the dedicated equipment made specifically for installation in that specific maritime environment, such as the military standards. Alternatively, a risk based approach can be followed as approved by Lloyds register [7] and referenced in [8] [9] [10] to reduce risks even further.

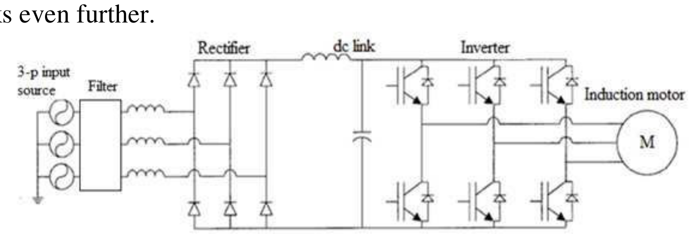

Figure 1. Schematic of a conventional converter

In this case, the risk based approach can also be used to integrate equipment tested against their product standards, but not against maritime EMC standards, e.g. the matrix converter that is tested against product standards especially for harmonics and EMC. This would allow for the possibilities of even limiting interference to the frequency bands that have not been specified and covered by the rule based standards for maritime equipment.

This paper thus evaluates the EMC performance of a matrix converter by measuring radiated and conducted emissions, as well as harmonic distortion generated by the converter. The results of these measurements are compared to conventional converters (Active front end). More so, measures are described considering the possibility of risk, to improve the EMC performance where necessary and enable the installation of such converters on board ships.

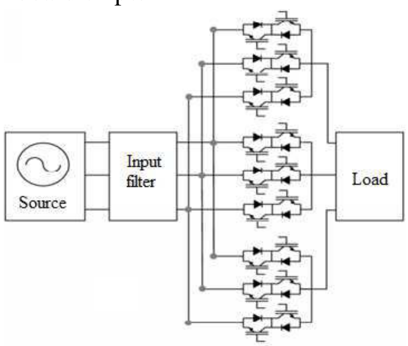

Figure 2. Schematic of a matrix converter

II. MEASUREMENT SET-UP

The switching semiconductor devices generates EMI and this can either be conducted or radiated. The presence of these disturbance may cause failure or malfunction of different other equipment installed in the vicinity. Understanding the coupling mechanism and the path characteristics enables a clear understanding when designing mitigation measures for any interference that may be. Thus, conducted emissions and radiated emissions have been measured with an EMI receiver following the AECTP 500 standards. Figure 4 shows the pictorial arrangement of the equipment in the anechoic chamber.

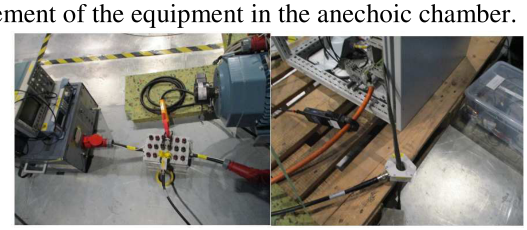

Figure 3. Photo of the set-up for common mode current measurement (a) input to converter, (b) output to the motor

A. *Conducted emissions*

CE tests are done on the power input cables to the converter, in order to see what interference the converter could be introducing to the power network. AECTP-500 standards have been followed for this measurement and the setup is as given in Figure 3. The measurement is done inside an anechoic chamber. A LISN is used to stabilize the impedance as seen by the noise signals emanating from the power supply, and to attenuate any noise originating from the supply grid so that it doesn't influence the measurement results. This ensures repeatability. The motor is connected and running at no load. Previous studies prove this does not affect the conducted emissions results of the converter significantly.

B. *Radiated emissions measurements*

This measurement is done to establish the levels of the radiated emissions from the converter assembly. The radiated emissions measurement are also done in the anechoic chamber. The results of this measurement however may not be quite reproducible if the same environment is not maintained for subsequent measurements and with different cable lengths for instance. A biconical antenna is used both in the horizontal and vertical orientations, placed at a distance of 1 m from the converter as described in the AECTP 500 standards. The measurements were done in several situation, with the converter off, and with the converter running. The settings of the converter were also varied to switch at different frequencies, 4 kHz, 6 kHz and 8 kHz. Also, the low harmonic functionality was either enabled or disabled.

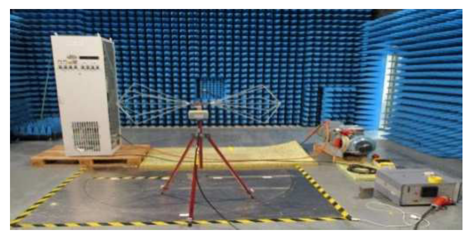

Figure 4. Radiated emissions measurement with a biconical antenna in the horizontal orientation

III. RESULTS AND DISCUSSIONS

Interfering current can be propagated in the same direction by the cable and the ground plane. The source of this disturbance current would be the radiation from the converter that will couple to the exposed cables and ground plane. These currents are eventually converted to either common mode or differential mode currents and may vary the impedance of the different paths they follow and thus the impedance of the grid that supplies several other equipment. The converters inherently generate common mode voltages within the motor winding, which causes capacitive coupling between the windings and the motor frame, and hence high dv/dt. The results are shown for the conducted emissions in Figures 5 and 6, for the different converter settings. No much difference in terms of EMI reduction is observed for the various settings. The common-mode interference is most dominant, and is determined by the dv/dt, since the radiated emissions is much limited to within the circuitry of the converter and contained by the casing or the enclosure of the converter. Thus interference at higher frequency is converted to conducted emissions and transmitted along the lines. The main objective thus, is to minimize the common- mode currents.

Conducted emissions have been measured for a frequency of 10 kHz to 30 MHz. In Figure 7, the results are compared for these emissions when the converter is running at different frequencies, with no filtering implemented.

Even though the THD as promised by the manufacturer is quite low, this does not provide much improvement in the EMC performance of the converter. As can be seen in the Figures 7 and 8, the emissions are above the limits as given in the standards. This may result into interference. However, from the manufacturer, there are different settings that allow switching at different frequency, as well as settings to enable or disable low harmonic function. The EMI is evaluated for all these different settings. The results are as captured in Figures, 5 through 8. Publications have been made of the EMC performance of different conventional and matrix converters. Figure 9 for instance shows the emissions levels of a conventional converter (AFE) that has been measured in the past. From the results presented in this paper, not much improvement in EMC performance has been noted for the matrix converter as compared to the conventional converter. A few suggestions are discussed below to realize an improvement in the EMC performance.

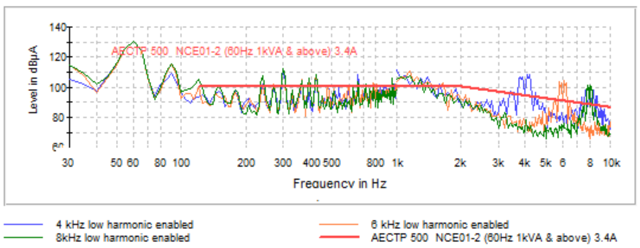

Figure 5. Conducted emissions results for various converter frequency settings

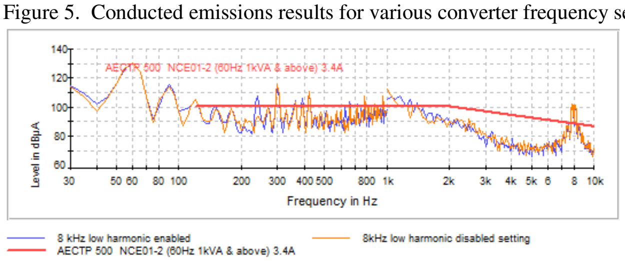

Figure 6. Conducted emissions results for various converter harmonic settings

IV. RISK BASED MEASURES

It is evident from the results that the matrix converter (nonlinear load) causes disturbance to the power grid. Both the conducted and radiated disturbances exceeded the limits as given in AECTP standards, for almost the entire band of frequency for which the converter is tested. The problem is more prevalent in the lower frequencies from 30 Hz to 10 kHz. Most standards however, especially for commercial ships, do not cover these lower frequencies than 150 kHz, thus according to standards [11] [12], the converter is allowed to be used on board ships regardless of higher emissions at these frequencies. However, one needs to be careful of what the converter emits. Risk based approach is used to ensure that the disturbances in these frequencies are mitigated, through proper installation practices and other measures. Some of the means for achieving EMI control include filtering, cable shield, enclosure shielding, proper grounding etc. These measures are discussed below;

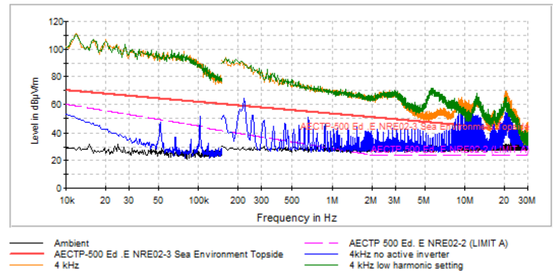

Figure 7. Conducted emissions results when no mitigation measures are applied

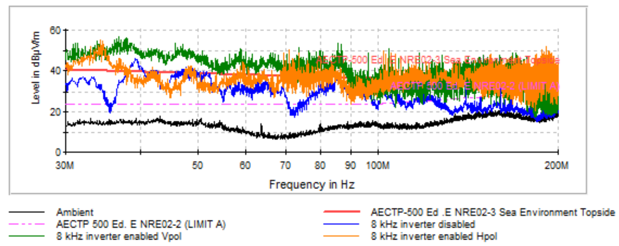

Figure 8. Radiated emissions measurement results

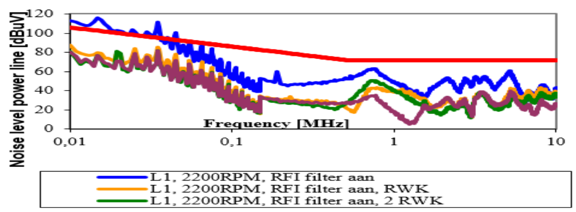

Figure 9. Conducted emissions result of a conventional converter (AFE)

A. Filtering

The matrix converter has the advantage of small physical space during installation and a higher efficiency as compared to conventional converters. However in terms of EMI, the performance is not as good. Filtering is one way to reduce the common mode interference and other related interference. Installation of a common mode filter will improve the measurements. Figure 10 shows the implementation of a COTS filter, both at the input to the converter and output to the motor. Several factors are taken into consideration when choosing or designing a filter, as discussed in [4] [13] to fit the need. In one of the modification, a filter was installed in the input and output of the converter and as seen in Figure 11, improvement of at most 40dB between the frequencies of 50 kHz and 500 kHz was observed. This is one of the COTS filters and thus a better filter with better values will ensure a greater improvement. Several filter topologies have been discussed in the past, thus a similar topology as described in [14], can be used in determining the best filter for safe integration.

B. Proper grounding

Having the converter properly grounded and applying EMI control technique both at the input and output of the converter will minimize the propagation of disturbances and reduce any risk of interference. Proper grounding, for the sole reason of controlling EMI, involves achieving sufficiently low impedance return path for the high frequency interfering currents. Effective grounding will ensure that the different disturbance coupling internal and external to the converter are minimized. This, for ideal EMC situation, should be very minimal and close to zero impedance, thus providing a combination of different current returning to ground causes no interference. This however is practically impossible, thus maintaining as low an impedance path for all the returning currents is very requisite.

Figure 10. Installation of a filter at the input and output of the converter for improved EMC performance

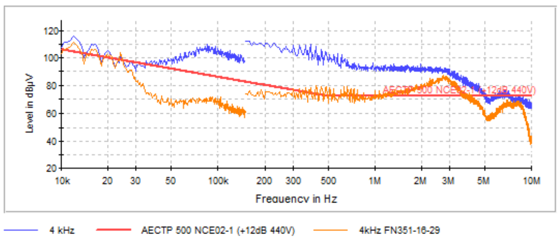

Figure 11. Conducted emissions measurement results with and without the implementation of filtering

C. Distancing

Keeping sufficient distances between the converter and some other vulnerable equipment on board will reduce the risk of interference. The space on board is however very limited and the distances that can be practically maintained, may not be very sufficient to reduce interference

D. Shielding and/or zoning

Placing different equipment in different zones will attenuate EM field thus reducing risk of electromagnetic interference. In combination, using screened cables between the shielded zones helps conduct the CM currents through defined paths. The connection of these cables as well as the equipment is important. On the other hand the use of transformers also limits the CM currents.

V. CONCLUSION

EMC measurements have been performed on a matrix converter to see how well it performs with respect to EMC. Both conducted and radiated emissions measurements are performed and mitigation measures discussed to reduce interference and improve EMC performance. The matrix converter as compared to the conventional converters performs a little bit better. The harmonic reduction however is not great. For further improvement in the EMC performance, installation of common mode and differential mode filters, or a hybrid filters that reduces both common mode and differential mode disturbances is necessary, both at the input and output of the converter. This could be tailored to specific values depending on the amount of disturbance that is allowable at any given electromagnetic zone on board ship. Otherwise, generally speaking installation of filters will result in the reduction of risk of interference. The filter provides a low impedance path to ground for components of leakage current at high frequency. This limits the area in which common mode current will be found and improves the EMC performance of the converter motor assembly.

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