Conducted Emission of a DC Motor Speed Drive: An Approach on Risk Assessment for Ship Application

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***Abstract*—Switching-based equipment such as motor speed drives are widely used in ships. However, mitigating EMI by installing EMI filters on ships is very limited because of leakage currents which can accelerate corrosion. This study proposes a behavioral model approach as an alternative solution to mitigate EMI. This study has observed the behavior of the conducted emission of DC motors. It is presented on a mathematical behavioral model and a heat map. Using a behavioral model and heat map approach, the highest EMI can be predicted without having to carry out complex measurements and simulations.**

***Keywords*—switching-based motor speed drive, conducted emission, behavioral model**

I. INTRODUCTION

Nowadays, due to the lack of generic electromagnetic compatibility (EMC) standards, vast numbers of switching-based equipment use the frequency range from 2 kHz to 150 kHz as a garbage band and it creates electromagnetic interference (EMI) issues [1], one of which is motor speed drives. However, in weak islanded power grids such as warships, the application of this equipment is also inevitable. Also, sailors or ship technicians bring often non-military standard-compliant equipment into the warships, such as commercial off-the-shelf (COTS) drills, household equipment, office equipment or rotating machines to support their daily activity in ships. It is inevitable because equipment that meets the specific standard for commercial ships and warships is very costly and sometimes not available in the market [2], [3].

To comply with marine EMC requirements, a risk-based EMI approach is now allowed [3]. This refers to the Llyod's Register Naval Rules. The risk-based approach is used to determine the possibility of disturbance and define a measure to mitigate EMI [4]. Mostly, EMI mitigation is done by adding an EMI filter, isolation transformer, or shielding [5]. However, in general, COTS equipment is developed for power grids with a grounded neutral point which means more freedom to use EMI filters with capacitors to ground. On the other hand, an isolé-terre (IT) grid such as on a warship has several limitations. Mitigating EMI by adding some components can have an impact on reducing the safety factor and increasing the total weight of the ship. As an example, the limitation of the total ground capacitance value. It is because those capacitors interfere with the detection of the first fault to the ground [6], [7] and contributes significant amount of leakage current [8]. Installing an EMI filter on ships can pose a big constraint in design [7], [9]. Taking these limitations into account, the EMI mitigation procedure should consider the EMI behavior generated by the COTS equipment. Therefore, this study aims to investigate the conducted emission (CE) behavior of a motor speed drive under several speed conditions. The mathematical behavioral model and the heat map proposed in this study can be used to predict CE without doing complex simulations.

II. SIMULATION AND EXPERIMENTAL RESULT

A. Simulink simulation

A buck converter motor drive was modeled in Matlab-Simulink 2020a. It consists of a DC source, a MOSFET-based buck converter, and a DC motor model. The DC motor model is a permanent magnet motor and its specifications are according to the DC motors on the market [10]. To observe the behavior of CE on various types of motors, several DC motor models were applied in this simulation, as shown in Table 1. The switching mechanism to control the speed is triggered by an external pulse generator.

Table 1. The parameters of the DC motor models [10]

Model	Terminal Voltage (V)	Resistance (Ω)	Inductance (mH)	Back EMF (V/RPM)
Motor A	12	0.56	0.97	6.5e-3
Motor B	36	3.39	5.50	16.0e-3
Motor C	48	9.00	13.00	11.5e-3

B. EMC Test

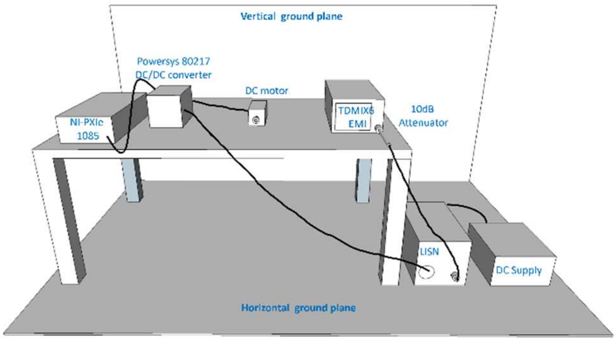

Fig. 1 CE testing setup: refers to CISPR 14-1:2020[11]

The CE EMC testing layout arrangement is done in accordance with CISPR 14-1:2020, as shown in Fig. 1. According to the measurement and the simulation result as shown in Fig. 2 the CE behavior of DC motor drives can be stated as (1). This equation is developed from the Fourier transform of the amplitude of harmonics of a trapezoidal waveform as expressed in (2) [12] and combined with a constant offset value (C). This CE behavior is related to the pulse width modulation (PWM) switching mechanism to control the speed.

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$$A_{\mathrm{BHV}} = 2V_{\mathrm{in}}\frac{\tau}{T}\left|\frac{\sin(n\pi\frac{\tau}{T})}{n\pi\frac{\tau}{T}}\right|\left|\frac{\sin(n\pi\frac{\tau_r}{T})}{n\pi\frac{\tau_r}{T}}\right| + 65 \qquad (1)$$

$$A_{\mathrm{TPZ}} = 2A\frac{\tau}{T}\left|\frac{\sin\left(n\pi\frac{\tau}{T}\right)}{n\pi\frac{\tau}{T}}\right|\left|\frac{\sin\left(n\pi\frac{\tau_r}{T}\right)}{n\pi\frac{\tau_r}{T}}\right| \qquad (2)$$

where A_{TPZ} is the amplitude of harmonics of the trapezoidal waveform, A is the amplitude of the pulse which is equal to the input of the DC voltage (V_{in}), n is the harmonic 1,2,3…, T is the pulse period, τ is the duration of the ON pulse, τ_r is the rise time.

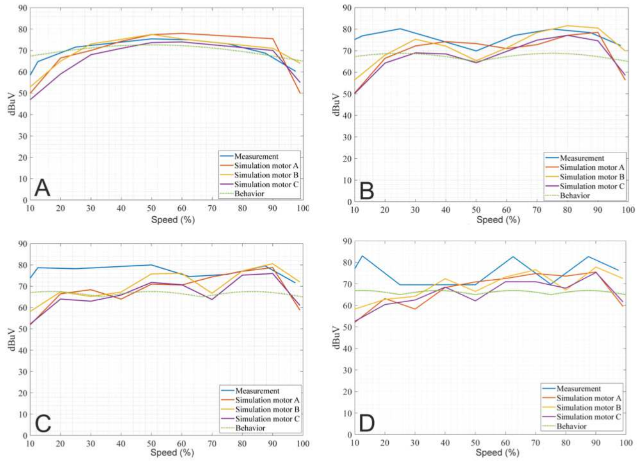

Fig. 2 Behavior of CE under different speed conditions: a. Switching frequency, b. 2nd harmonic, c. 3rd harmonic, d. 4th harmonic

However, this equation also has a limitation that did not perfectly represent the real CE behavior at high speed (above 50 % of the maximum speed). It is because, at a higher speed, the motor drive draws a higher root mean square (RMS) current. It makes the CE level of the actual condition higher than the value obtained from the equation. This behavior will be observed and evaluated in future research.

III. CONDUCTED EMI RISK DURING THE MOTOR OPERATION

Fig. 3 shows the heat map of the conducted EMI that was generated from the CE behavioral model of the motor speed drive under various speed conditions. It shows the highest CE EMI at its switching frequency is generated when the motor is operated at 50% of its maximum speed. From the PWM point of view, it is related to 50% of the duty cycle. This figure also implies that operating the motor at its maximum speed or 100% of the speed will generate less CE EMI than when it is operated at 90%. This is because when the motor runs at its maximum speed, there is no PWM switch. This condition can be chosen as an option when a lower EMI is required. Displaying the CE EMI in the form of a heat map will be very useful in determining the best operating condition of the motor; it will help to avoid high CE EMI in the ship environment.

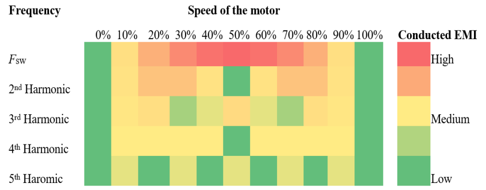

Fig. 3 CE EMI behavioral model heatmap: various speed conditions

IV. CONCLUSION

The objective of this study is to observe the CE behavior of the switching-based motor driver. The CE EMI behavior of a switching-based motor driver is crucial, especially on islanded power distribution system applications such as ships. It is because the application of the EMI filter in ships is very limited. The results show that the highest CE at the switching frequency occurs at 50% of the maximum speed. This operating condition also causes high EMI at odd harmonics. Regarding mitigating EMI on ships, apply a DC motor drive at this speed should be avoided. The highest CE level can be predicted using the behavioral model approach. This model can be useful for predicting CE without performing complex simulations. Related to EMI risk assessment, the mathematical behavioral model can be used to simplify the computational process of the observation of CE behavior.

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