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A survey of harmonics in power systems of ships with electrical propulsion drives

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Abstract: The number of commercial ships with electric propulsion is in continuous increase due to their versatility and fuel efficiency. Total harmonic distortion consequences on marine electrical power systems will be discussed. This paper aims to highlight the need for harmonic filter implementation on electric propulsion with static converters. For this study, a simulation in Matlab Simulink will reveal the effect of electrical filters on THD and voltage end current waveforms.

Keywords: static converter, THD, waveform, harmonic filter

1. General aspects

This simulation represents a DC to AC conversion unit - 3-phase MOSFET inverter, connected to a DC voltage source of 325 V feeding a 3-phase squirrel-cage motor rated 3 HP, 220 V, 60 Hz, 1725 rpm. "Constant V/Hz" block controls the motor speed, varying the stator voltages amplitude in proportion with frequency, the stator flux is kept constant [1].

The purpose of this simulation inspired from Marworks examples is to illustrate the high frequency harmonics generated by the inverter.

The inverter uses a SVPWM Generator (3-Level) that generates pulses for three-phase three-level Neutral-Point-Clamped (NPC) converter, this block generates twelve pulses using the space vector pulse width modulation (SVPWM) technique [1].

$$V_{out} = m\frac{V_{dc}}{\sqrt{2}} \tag{1}$$

where; V_{out} - is the line-to-line rms voltage generated by the NPC,
m - is the modulation index and $0 < m < 1$,
V_{dc}- is the DC current flowing in or out of the DC link.

The motivation of using DC to AC conversion is the electric propulsion simulation, either by using batteries for full electric propulsion or using a hybrid electric propulsion with a.c-d.c.-a.c. converter.

Electrical installations containing electrical converters are present on all ships, from the supply of communication and navigation equipment, alarms and monitoring systems, electric motor operation, pumps, fans, or winches, to high-power installations for electric propulsion.

At present, electric propulsion is widely used in the following types of ships: cruise ships, ferries, drilling ships, transfer ships, supply ships, warships.

The ship's propulsion plant plays a critical role for a high-performance one, thus being the prime consumer of electricity on board, hence the high efficiency of electrical converters plays an important role in the ship's economy.

Power factor as an effect on the phase shift between voltage and current, without THD involving [2]:

$$\text{Power factor} = \cos(\varphi_v - \varphi_i) = \cos(\varphi) \tag{2}$$

where: φ_v-voltage shift, φ_i-current shift, φ- phase shift between voltage and current [2].

$$\text{Distorsion factor} = \sqrt{\frac{1}{1+THD_{current}^2}} \tag{3}$$

where: $THD_{current}$ - current total harmonic distortion

From (2) și (3) → Power factor with THD_{curent} involving is calculated as follows:

$$\text{Power factor} = \cos(\varphi)\sqrt{\frac{1}{1+THD_{curent}^2}} \tag{4}$$

2. Simulation of an induction motor fed by MOSFET inverter

To observe the amount of harmonics injected by the inverter feeding the asynchronous motor, the matlab simulation was run without harmonic filters [3].

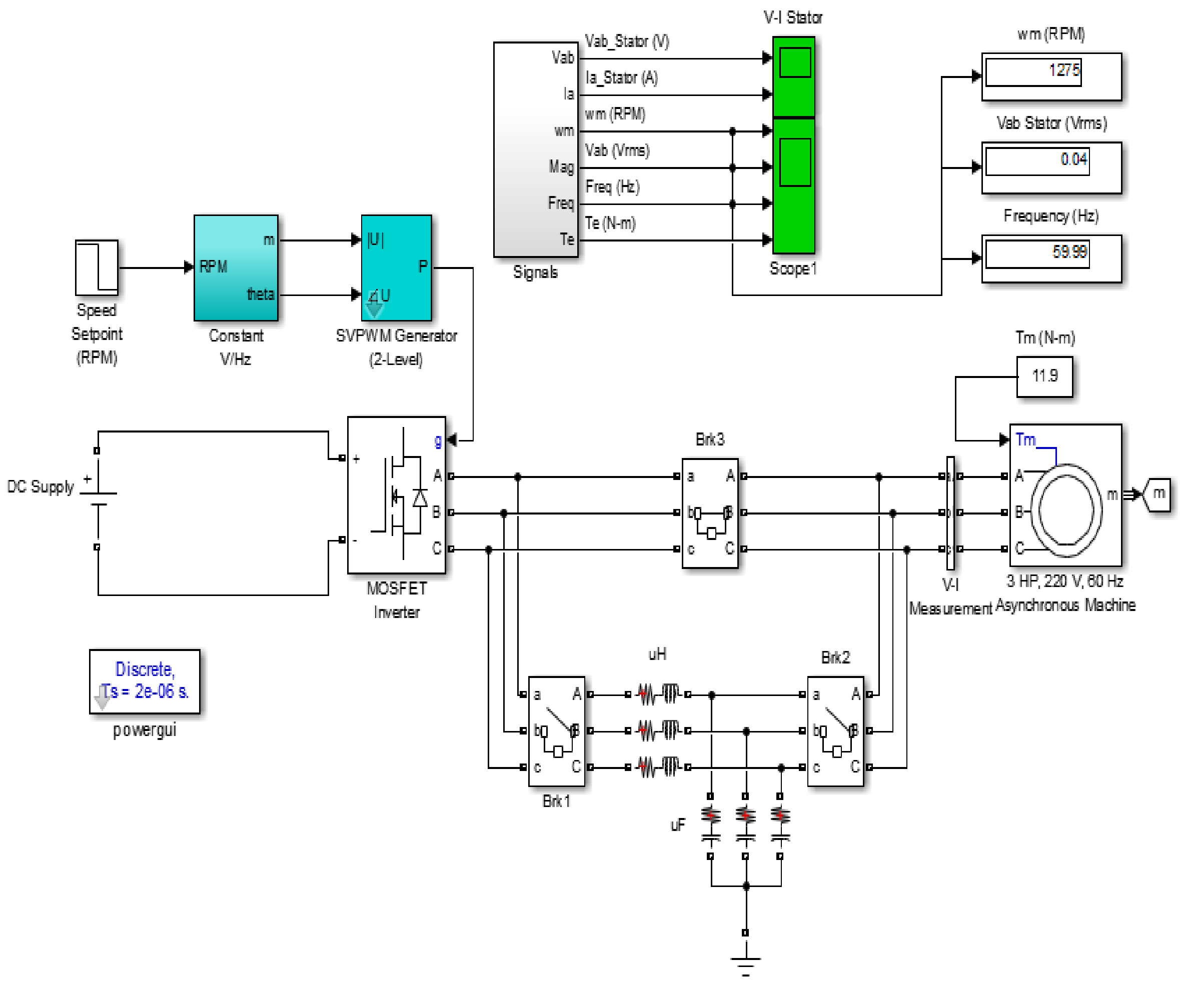

Figure 1. Simulation of an induction motor fed by MOSFET inverter without harmonic filters

After Fast Fourier Transform analysis, the amount of harmonics introduced in asynchronous motor supply network can be expressed, as can be seen in the following figures.

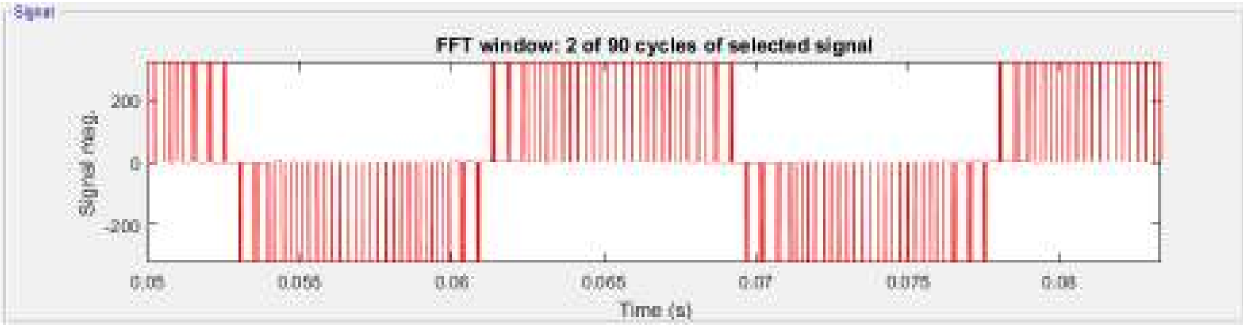

Figure 2. Voltage waveform without harmonic filters

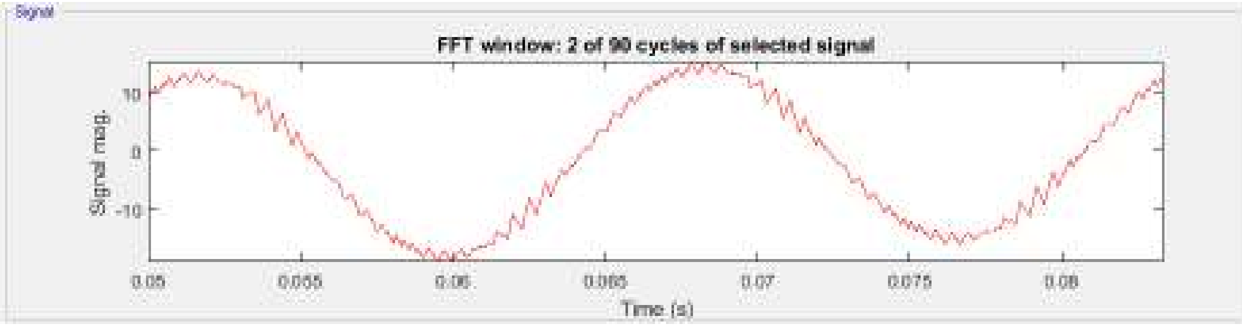

Figure 3. Current waveform without harmonic filters

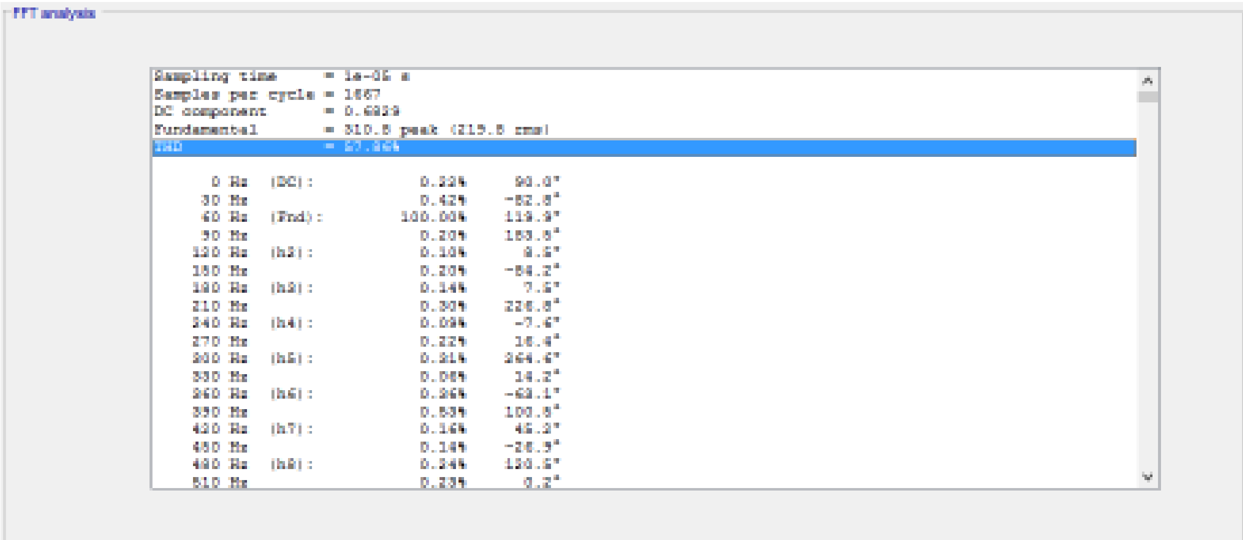

Figure 4. THD voltage

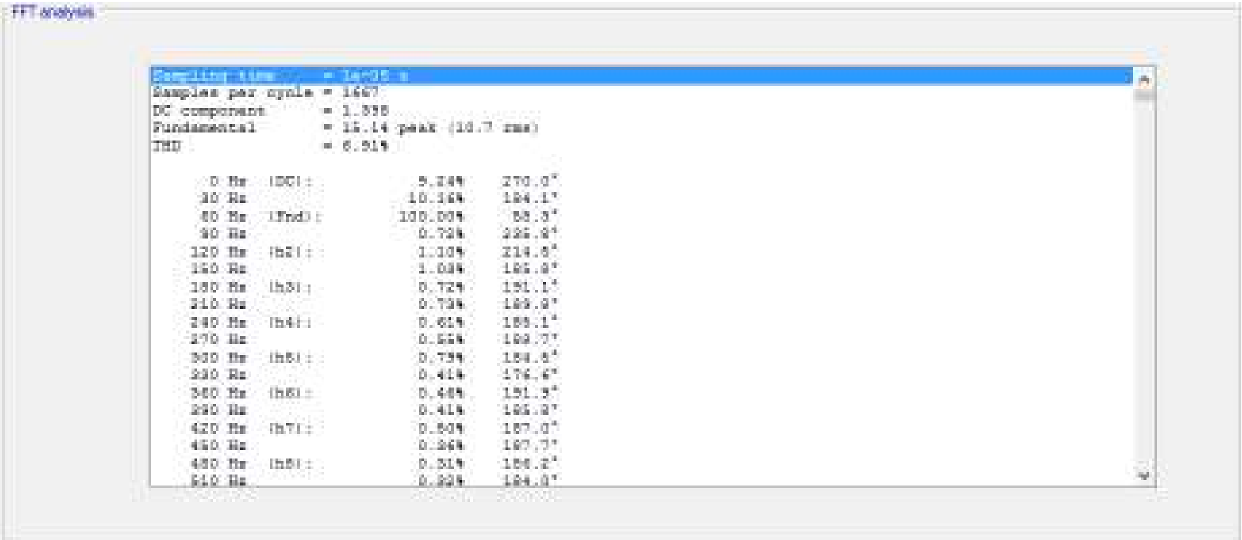

Figure 5. THD current

As we can see, the amount of THD voltage is 57,86% and THD current is 6,91.

By calculating the POWER FACTOR with THD involvement, we obtain:

$$\text{Power factor} = \cos(\varphi_v - \varphi_i)\sqrt{\frac{1}{1+THD_{curent}^2}} \rightarrow$$

$$\text{Power factor} = \cos(61.6°)\sqrt{\frac{1}{1+0.0691^2}} = 0.3324 * 0.9976 = 0.3316$$

The phase shift between voltage and current $\varphi_v - \varphi_i = 61.6°$

3. Harmonic filters effect connected between inverter and asynchronous motor

For this experiment were used LC single tuned filters, the resonant frequency is calculated according to the formula [4], [5]:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

After FFT analysis, the voltage and current harmonics with the most significant amplitudes were selected, table 1 (for which the filters will be chosen).

Table 1. Harmonics with the most significant amplitudes

Nr.	Harmonic number	Associated frequency (Hz)
1	h29	1740
2	h31	1860
3	h35	2100
4	h37	2220

Power factor improving

Except for harmonics injected in network by inverter, there is also a problem of large phase shift between voltage and current, therefore this aspect must be improved as well. Referring to the data of the asynchronous motor supply network: $\cos(\varphi) = 0.3324$, $I_n = 10.7A$, f=60Hz; and intending to obtain a power factor of about 0.8, it is necessary to calculate the value of capacitors to be mounted in parallel with the asynchronous motor, and their reactive energy.

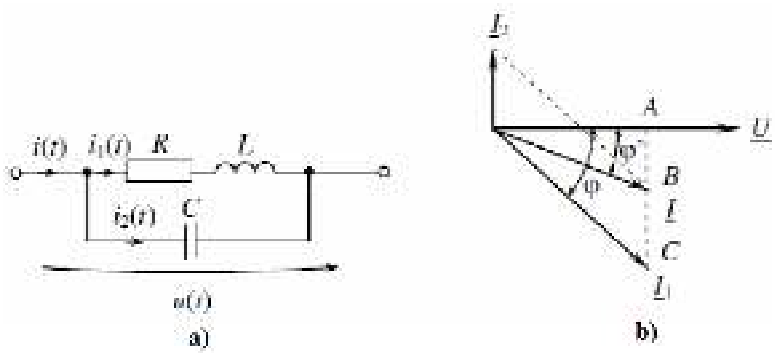

Figure 6. AC circuit with compensated RL load:
a) equivalent electrical scheme; b) phasor diagram

According to the diagram of figure 6, where as phase origin was chosen the U voltage and then the current phase vector I_1 was shifted with φ angle to U [6], [7].

The current absorbed by the capacitor and shifted with $\frac{\pi}{2}$ before the voltage U, vector compound with current I_1 will give a total current I shifted with $\varphi^{'}$ after the voltage U. Observing the diagram you can write:$I_1 \cos\varphi = I \cos\varphi^{'}$ [6], [7].

$$I = \frac{\cos\varphi}{\cos\varphi^{'}} I_1 = \frac{0.3324}{0.8} 10.7A = 4{,}445A$$

$$\sin\varphi = \sqrt{1-\cos^2\varphi} = \sqrt{1-0.3324^2} = 0.9431$$

$$\sin\varphi^{'} = \sqrt{1-\cos^2 C} = \sqrt{1-0.8^2} = 0.6$$

$$AC = I_1 \sin\varphi = 10.7A * 0.9431 = 10.091$$

$$AB = I \sin\varphi^{'} = 4.445 * 0.6 = 2{,}66$$

$BC = AC - AB = 10.091 - 2{,}66 = 7{,}424A$ - Capacitor absorption current

Capacitor value: $I_2 = \omega CU \rightarrow C = \frac{I_2}{\omega U} = \frac{7{,}424}{376*110} = 183\mu F$

Capacitor reactive power is:

$$Q = UI_2 = 110 * 7{,}424 = 0.816kVAR$$

As a result of the of harmonic filters connected between inverter and asynchronous motor, a significant improvement of voltage and current waveform can be observed, as can be seen in the following images, fig. 7-8.

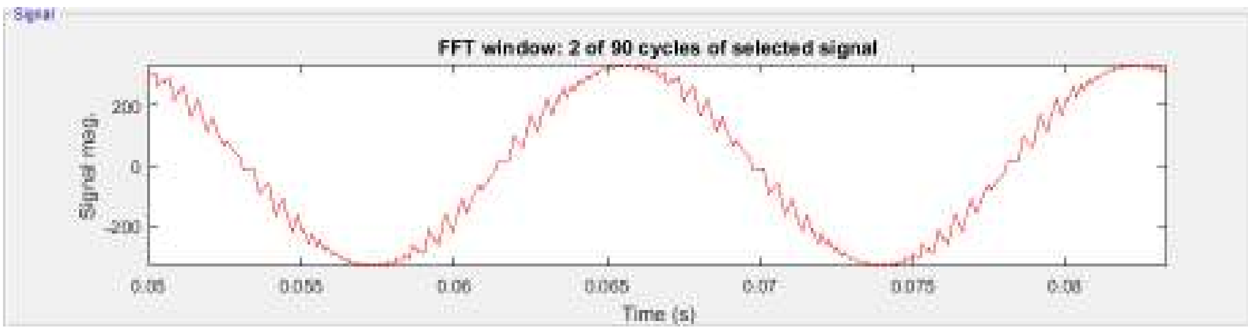

Figure 7. Voltage waveform with harmonic filters connected

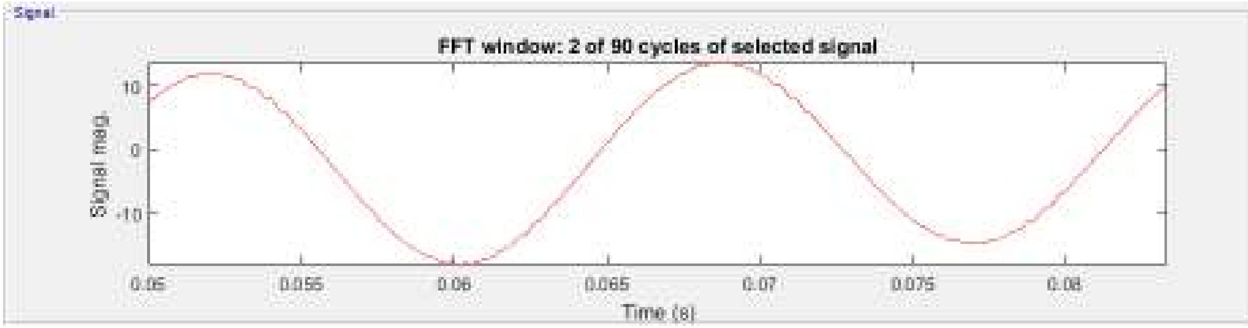

Figure 8. Current waveform with harmonic filters connected

4. Conclusion

In this paper, a naval electric propulsion equivalent model was presented. Although the initially circuit power factor was very low (0.33) due to the large phase shift between voltage and current coupled with a high THD factor, a capacitor bank parameters to determine the power factor compensation on desired value (0,8) were determined by calculation. Taking into account the values of the elements determined by calculation, an electrical diagram was drawn up and the phenomenon of power factor compensation and THD decrease was highlighted. Therefore, the importance of power factor compensation and THD factor reduction.

References

[1]*** https://www.mathworks.com/help/physmod/sps/powersys/ref/svpwmgenerator3level.html

[2] **Shantanu Das**, Note on Harmonic Distortion Control & Power Factor Correction Circuitry for Switched Mode Power Supply, ResearchGate, December-2016.

[3] *** https://www.mathworks.com/help/physmod/sps/ug/three-phase-sv-pwm-converter.html?s_tid=srchtitle

[4] V Mocanu, V Dobref, P Popov, Aspects regarding the use of passive filters for harmonic mitigation in power rectifiers, Scientific Bulletin of Naval Academy, Vol. XXIII 2020, pg.80-91,

[5] **Omar Turath Tawfeeq**, *Single Tuned Passive Harmonics Filters Design For A Buck Type Rectifier D.C Motor Drive Using Fuzzy Controller*, International Journal of Engineering and Innovative Technology (IJEIT) Volume 4, Issue 11, May 2015

[6] ABB Guide, Power factor improvement Application guide, Jan 2015

[7] **Samarjit Bhattacharyya**, Case Study On Power Factor Improvement, International Journal of Engineering Science and Technology (IJEST), ISSN:0975-5462, Vol. 3 No.12 December 2011