Modeling of Power Cables in Shipboard IPES for assessing High Frequency Disturbances Propagation

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Abstract—Nowadays, shipboard power distribution systems deal with a huge increase in power electronic devices. The study of the propagation of high frequency disturbances (caused by the converters operation) into a shipboard power system is not trivial, eventually leading to the need of a frequency-dependent models. In fact, the modern power converters inject high frequency disturbances into the system, reaching frequencies up to the MHz range. The common models, based on low frequency (or even DC) parameters can be unsuitable for the task, leading to the need of developing new modeling approaches. In literature, many papers highlight the problems arising from high frequency disturbances in single cables, but methodological approaches to the overall system modeling are not provided. Thus, the goal of this work is to present the state of the art about power cables modeling, discussing their applicability to the high frequency disturbances propagation determination. Moreover, the need of a frequency-dependent model is assessed, by means of a case study. In particular, it results that frequency-dependent parameters are to be taken into account for frequencies over 10^5 Hz.

***Index Terms* – High Frequency Disturbances Propagation, Integrated Power and Energy System, Frequency-dependent Cable Parameters, Power Distribution System**

I. INTRODUCTION

Today's power electronic technologies improvements are leading to new design possibilities for electrical power systems. The exploitation of power lectronics devices is a key enabler in the design of new shipboard Integrated Power and Energy Systems (IPES). Thus, the integration of full-controllable power converters in the IPES enhances the 50/60 Hz system capabilities [1] or leads to harness Direct Current (DC) power system sections [2], [3]. Given this scenario, the performance of the IPES can be improved by leveraging power electronics, resulting in significant advantages:

- More functionalities can be implemented in the same component, resulting in a more compact power system design. Moreover, using static converters in place of electromechanical components can lead to a reduction in the equipment size (e.g. Solid State Transformers can replace the traditional transformers [4]);
- The widespread presence of power electronic devices can enable power flow management and current limiting in short circuit scenarios [2];
- In navy application, the integration of new sensors and weapon systems is easier, given the availability of a DC power supply [5], [6].

On the other hand, the switching frequency of the converters has an important impact on the system's power quality. Not only conventional issues like harmonic induced heating in the machines or electromagnetic compatibility (EMC) issues, but also accelerated ageing of insulating systems can occur. To avoid this, passive or active harmonic filters can be used to enhance the power quality of the IPES [7], but their design implies evaluating how the harmonic pollution affects the power system. The study of the disturbances propagation is complex, requiring both a deep understanding of the harmonic pollution sources behavior and an evaluation on their mutual interaction. Actually, the IEEE Std 519-2014 [8] sets an upper limit to the harmonics produced by a converter up to the 50^{th} one (i.e. 3 kHz in a 60 Hz system), which is only a subset of the possible harmonics injected into the system. Such a limit provides that the harmonics with a significant energy level are contained, thus avoiding both the excessive heating in the system components and the deformation of voltage waveform.

Conversely, for EMC studies the addressed frequencies are higher (more than 20 kHz) but the considered energy is lower. In this latter case, the aim is to assure the limitation in the interferences induced in other components. While a separated approach (low frequency analysis for a set of issues, and high frequency analysis for another) was feasible in the past, it is rapidly becoming untrustworthy due to the advancements in modern power electronics components. As an example, Pulse Width Modulation (PWM) converters not only inject disturbances due to their carrier wave (up to 10 kHz), but higher frequency disturbances (up to some MHz) due to the switching process of each single static component. Thereby, in an IPES it is now possible to have high frequency disturbances injection with a significant energy level, thus leading to possibly harmful consequences for the system.

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