Superconducting Power Transmission for Mobility Applications and Investigation of AC Loss Effects

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ABSTRACT

This paper analyzes the effect of AC transport current on a superconducting motor supply line. Based on a comprehensive literature review, the influence of the transport current frequency, waveform and distortion are evaluated. Exact knowledge of the loss behavior of the superconducting motor supply line is relevant for a holistic optimization of the cryoelectric powertrain. The dependencies of the losses on the mentioned parameters are shown, differences in results, assumptions, and measurements are determined and the need for further investigations in this area is highlighted.

KEYWORDS

Power dissipation, AC losses, HTS, superconducting power transmission, on-board grid, cryogenic engineering, aviation

INTRODUCTION

Demands for sustainable and climate-neutral transportation drive higher performance requirements for mobile on-board grids. Conventional cable systems are a limiting factor in increasing power density. Raising the system voltage lowers the thermal load on cables. Simultaneously, the voltage increase causes challenges in ensuring the insulation strength. At constant system voltage, an increase in current implies a rising heat loss in the cables. The cross-section can be increased to achieve a reduction. This simultaneously leads to a disadvantageous weight and required installation space, which is disadvantageously, especially in aviation. A possible solution may be to use superconducting materials in power transmission due to the specific behavior of the idealized resistance-free current transmission. Currently, this technology can only be used under cryogenic temperatures, making a specific design of the overall system necessary.

One potential solution for promoting sustainable transportation and significantly reducing greenhouse gas emissions is implementing a propulsion system based on hydrogen. This can be accomplished by using either a fuel cell or a turbine. In a fuel cell-powered propulsion system, such as the one described in [1], liquid hydrogen (LH2) can be utilized in a hybrid configuration. A possible schematic for this hybrid setup as a cryoelectric on-board grid is shown in figure 1.

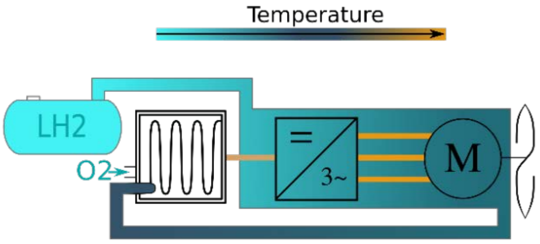

Fig. 1: Schematic of a Liquid Hydrogen-Based Powertrain in Aviation

To design the overall system and its reliable cooling, it is essential to understand all components' heat input. This paper focuses on how the AC loss behavior of superconducting cables can affect the performance. The power dissipation of superconductors based on AC losses can be classified into two categories. Magnetization losses describe the loss behavior of the HTS conductor due to an external alternating magnetic field. On the other hand, transport or self-field losses occur due to the transmission of an alternating current. Based on the definitions of the losses, they can also occur simultaneously. [2], [3]

In order to be able to evaluate the heat input, coupling factors that influence the loss behavior are first determined. The focus is on the AC transmission as a motor supply line due to the additional transport current losses that occur compared to the DC link. The long-term research work aims to provide design recommendations for a complete mobile system using superconducting AC transmission. Based on the identification of the coupling parameters and their specific influence on the AC loss behavior, an evaluation can be made for the optimized design of the overall system. It is mandatory to consider the dependence between the components to aim for a loss-optimized system. For the entire requirement analysis of an AC superconducting cable in the presented system, numerous parameters must be analyzed and identified coupling parameters influence must be evaluated holistically. In the following section, *Coupling Parameters* they are initially presented schematically. Due to the limited scope of this paper, further analysis is restricted to one parameter – transport current. Based on the application area presented, the AC current to be transmitted can vary in the following factors: amplitude, frequency, waveform and distortion. Based on numerous publications increasing loss behavior with increasing transport current amplitude is assumed to be known and is therefore not discussed in detail. [4],[5],[6] The current specifications frequency, waveform and distortion are evaluated on a detailed level. Based on the design of the electrical machine, the transport current must have the corresponding fundamental frequency and waveform. Due to the switching behavior of the power electronics, the fundamental wave can be superimposed by harmonics. The influence of the variation of these parameters is analyzed based on a literature review and is presented in the corresponding subsections *Transport Current Frequency*, *Transport Current Waveform* and *Distorted Transport Current*. In the *Conclusion*, the identified dependencies are summarized and their relevance for the cryoelectric powertrain is shown.