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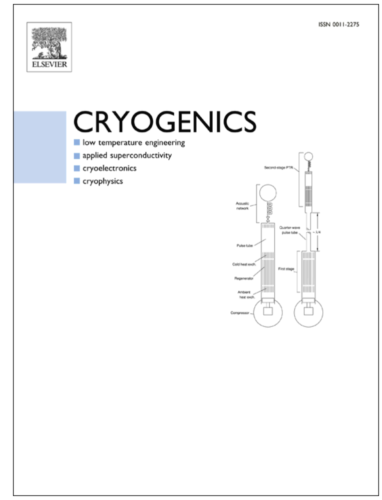

Research paper

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Double-Layer Rotor Magnetic Shield Performance Analysis in High Temperature Superconducting Synchronous Generators under Short Circuit Fault Conditions

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***Abstract*–High temperature superconducting, HTS, synchronous machines benefit from a rotor magnetic shield in order to protect superconducting coils against asynchronous magnetic fields. This magnetic shield, however, suffers from exerted Lorentz forces generated in light of induced eddy currents during transient conditions, e.g. stator windings short-circuit fault. In addition, to the exerted electromagnetic forces, eddy current lossesand the associated effects on the cryogenic system are the other consequences of shielding HTS coils. This study aims at investigating the Rotor Magnetic Shield, RMS, performance in HTS synchronous generators under stator winding short-circuit fault conditions. The induced eddy currents in different circumferential positions of the rotor magnetic shield along with associated Joule heating losses would be studied using 2-D time-stepping Finite Element Analysis, FEA. The investigation of Lorentz forces exerted on the magnetic shield during transient conditions has also been performed in this paper. The obtained results show that double line-to-ground fault is of the most importance among different types of short-circuit faults. It was revealed that when it comes to the design of the rotor magnetic shields, in addition to the eddy current distribution and the associated ohmic losses, two phase-to-ground fault should be taken into account since the produced electromagnetic forces in the time of fault conditions are more severe during double line-to-ground fault.**

***Index Terms*– Joule heating loss, Lorentz force, rotor magnetic shield, transient conditions.**

I. INTRODUCTION

High critical current and low price are two indispensable factors of high temperature superconductors in order to remain competitive with normal conductors. Furthermore, an economic investment in superconductors and associated cryogenic system requires minimum generated loss which is crucial to the design of an efficient HTS machine [1]. HTS synchronous generators have attracted enormous attention recently and research has been performed on their design and characterization [2-7]. There are two sources of losses in an HTS synchronous machine because of which consuming more energy is required to maintain the desired cryostat temperature: the normal magnetic field experienced by HTS coils which gives rise to increase the superconductor losses along with decreasing the critical current [8], and the second is generated ohmic loss in the rotor magnetic shield, RMS, during transient conditions which is emitted into low-temperature environment.

Rotating with synchronous speed, exciting coils of a synchronous machine are sometimes subject to asynchronous magnetic fields in view of using power electronics frequency converters, non-ideal sinusoidally distributed stator windings, or occurring transient conditions. As the losses in HTS tapes (e.g. BSCCO and YBCO tapes) is considerably increased due to time varying and normal magnetic fields, RMS plays a crucial role in preventing asynchronous fields entering the HTS windings zone [9]. However, great care should be taken during the design of an HTS synchronous machine as its performance is remarkably affected by electrical, mechanical, and thermal properties of rotor magnetic shield [10]. As far as electrical properties are concerned, electrical conductivity of the RMS must be high enough to shield HTS coils against zero and negative-sequence magnetic fields during transient conditions, while, having appropriate damping properties requires low electrical conductivity. On the other hand, protecting cryogenic environment from heat penetration, RMS must be of high thermal conductivity and thermal capacity to efficiently absorb generated losses during transient conditions without overheating problems. Having enough mechanical strength against radial and tangential transient forces without any damages and deformations is another significant feature of RMS in an HTS synchronous machine [11].

Since realizing aforementioned characteristics in a single material is not practically feasible, either a fair compromise should be made or two rotor magnetic shields should be used, one of which satisfies thermal requirements and the other one is used to withstand radial and tangential forces in conjunction with having proper electrical conductivity.

Although the RMS performance has been studied using one [12-15], two [11, 16-23], or multi-layer magnetic shields [24-27], in this contribution two magnetic shields, Fig. 1, are employed as it is more common in practical applications.

Some investigations have been performed on the analysis of the RMS performance under short-circuit fault conditions, almost all of them concerned with symmetrical fault [15, 16, 23, 26]. Analytical methods were the early studies on the RMS performance [16, 17], which were followed by finite-element method after its introduction to electrical machines analysis [15, 23, 26]. The exerted electromagnetic torque on the RMS with different thicknesses was studied in [15]. The generated eddy current losses is the other consequence of three-phase short-circuit fault which was studied using one [9], and two