Finite element assisted method of estimating equivalent circuit parameters for a superconducting synchronous generator with a coreless rotor

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Abstract — The paper outlines methods developed to obtain circuit parameters of a superconducting synchronous generator with a coreless rotor. The need for full 3D finite element modelling is emphasised and appropriate techniques devised to estimate relevant equivalent characteristics.

I. Introduction

Recent advances in high temperature superconducting (HTS) materials have opened opportunities to consider new generation of electrical power devices. However, a successful prediction of circuit parameters for such novel machines can pose significant difficulties. Classical techniques are not always applicable to superconducting machines because of a different construction. This paper reports on some of the challenges faced during the process of circuit parameters estimation for a superconducting synchronous generator with the coreless rotor designed at the University of Southampton.

II. HTS coreless rotor design

The rotor is of a coreless type, i.e. coils are not wound around an iron core and instead a magnetically neutral material is used. This approach poses several significant difficulties. The lack of a magnetic core increases the magnetic field in the superconductor; to alleviate this problem, the rotor is designed as a stack of coils and *flux diverters* (see Fig. 1) made of 9% nickel steal, a material suitable for low temperatures and of high saturation flux density. The rotor is placed in a 0.9mm thick copper tube which acts as a shield against higher order harmonics induced by the stator winding [1].

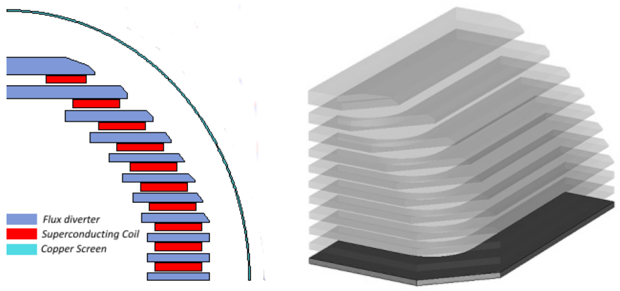

Fig. 1. Initial HTS rotor design.
Stack of coils, diverters and the copper screen shown on the left, while a 3D view of the rotor on the right.

III. Stator

The stator has been adopted from an existing 100kVA, 2-pole induction machine, with the bore diameter of 330mm and iron length of 325mm. A short-pitched (14/24) conventional 2-layer winding with 3-turn coils is distributed in 48 slots and connected in a parallel star arrangement. Using an existing stator introduced additional constraints on the design.

IV. Modelling considerations

Modelling methods employed by most designers are based on a 2D representation of the machine [2]. The parameters are obtained straight from the magnetic field solution of a FE model, or by coupling it with an external circuit to monitor voltage and current outputs and thus obtain the parameters by simulating one of the classical tests as performed on a real machine. All these techniques are based on a well established general machine theory aided by a number of simplifications which make it possible to use a 2D model. The true 3D nature of the filed is then accommodated by introducing extra parameters, such as the end winding reactance. The approach is often accurate enough for machines of classical construction with iron cores. Moreover, the majority of machines have a damper winding with well defined current paths, which can be modelled in a similar manner. Unfortunately, the 2D simplification has proven inappropriate for the HTS coreless generator. Particular difficulties arise when analysing eddy current distribution in the copper screen, or the effects of the ends of the diverter rings (in terms of the additional flux paths), and their representation in the equivalent circuit.

The machine is modelled predominantly in the rotor frame of reference. Hence space harmonic components of the stator winding current appear at high frequencies. At low frequencies, the only stator currents that need to be considered on the rotor are the direct/quadrature axes sinusoidal components.

Using an arbitrary set of mode shapes to define the current distribution in the copper screen due to stator MMF harmonics would be difficult. Instead, it is proposed that the effects of the screen on the field of a single opposite pair of stator coils should be analysed. This can be done using a 3D model of the stator and the screen of the rotor. By omitting the rest of the rotor the model gains symmetry, which allows the results to be used for any pair of stator coils. It is assumed that the screen will prevent the rings and coils of the rotor from having any significant effect on the impedances of the stator winding.

It is expected that the use of a 2D rotating machine model may be sufficient to determine the effects of rotor fields at multiples of stator slot passing frequency.

The full paper will provide details on how to obtain circuit parameters for a machine with three dimensional features such as the screen and rings using the minimum of 3D finite element modelling. Comparison between 2D and 3D results will be shown to provide better insight.

V. References

[1] M. K. Al-Mosawi, C. Beduz, and Y. Yang, "Construction of a 100 kVA High Temperature Superconducting synchronous generator," IEEE Trans. on Applied Superconductivity, vol. 15, pp. 2182-2185, 2005.
[2] A. B. J. Reece, and T. W. Preston, *Finite Element Methods in Electrical Power Engineering*, Oxford University Press, 2000.

IEEE CEFC 2008