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Comparison of Electromagnetic Performance of HTS DC Generator with Outer/Inner Iron-cored Rotor

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Abstract

Superconducting (SC) direct-drive wind generators have been proposed as a possible approach for offshore wind energy application due to their inherent high torque density and small mass compared with conventional electrical machine. A large number of studies have been done to find the suitable topology for reliability and high power density. This paper is intended to propose a new out-rotor superconducting direct current (SCDC) generator for large offshore direct drive wind turbines. The key is to put the armature iron core to the outer side while the superconducting excitation in the inner. As a result, the power volume ratio in-creases with the cost of SC material reduced. And the outstanding controllability of DC motor realizes constant voltage output over wide ranges of speed and loads. The generator design is illustrated by finite-element analysis (FEA) first and then com-pared with traditional DC generator.

Topology introduction

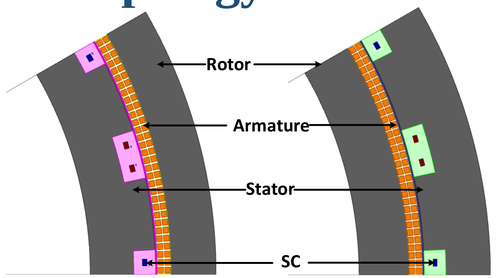


Fig. 1. 2D model of Generator with Outer/Inner Iron-cored Rotor

According to working principle of DC motor, the power developed in the armature is given by

$$P = E_a I_a = \frac{\Phi Z p n}{60N} I_a = \pi^2 B A D_r^2 L$$

Position of the rotor will affect the magnetic flux per pole Φ and the electrical load A, so the length and cost will be different with the same output.

SC Tapes and Operation Current

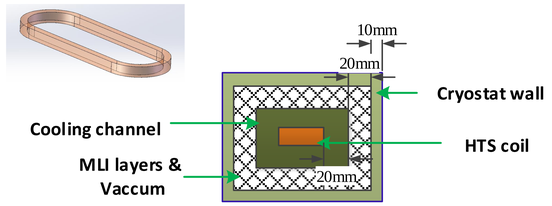
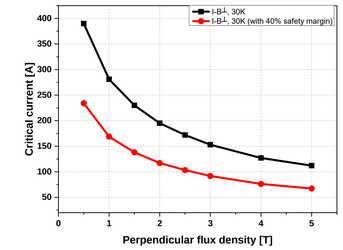


Fig. 2. HTS tape & Cryostat

HTS material	YBCO
Dimension of tape [mm × mm]	4×0.165
Operating temperature [K]	30
Price [euro/m]	18
Safety margin	40%



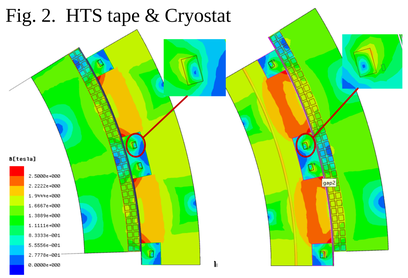
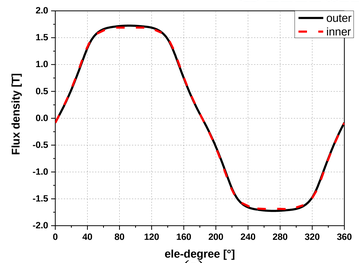
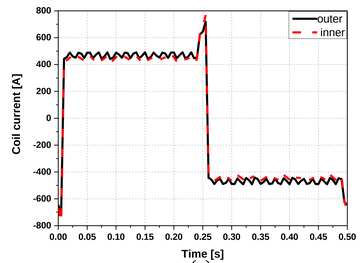


Fig. 3. Flux density distribution at average air-gap flux density 1.2T

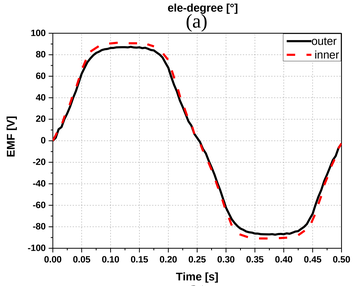
Simulation results



(a)

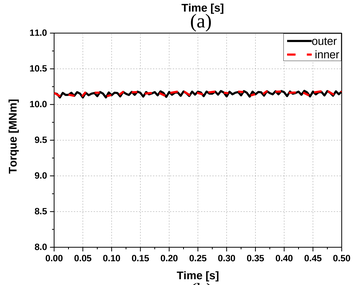


(a)



(b)

Fig. 5. No-load simulation (a)flux density distribution; (b) back EMF



(b)

Fig. 6. Rated load simulation (a)coil current; (b) Torque

Mass & Cost comparison

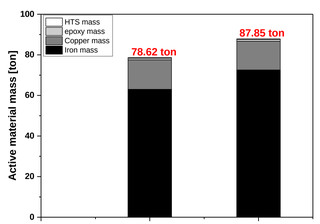


Fig. 9. Mass comparison

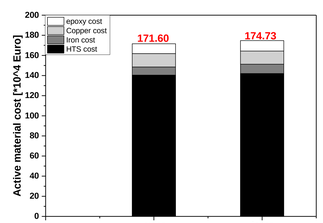


Fig. 10. Cost comparison

Parameter	Outer rotor	Inner rotor
Output power [MW]	10	
Rated revolution [rpm]	10	
Outer diameter [mm]	6148	
Active stack length [mm]	820	915

Conclusion

The output of SC DC generator is convenient for medium voltage class DC transmission. At the same time, SC excitation in the stator largely simplify the design of cryostat. The acitive material cost of outer rotor topologies is less than the inner one while the active material mass is lighter. What's more, with the same torque output and outer diameter, the stack length of outer rotor machine is 10.4% shorter than the inner rotor machine. All these characteristics are beneficial for manufacture, transportation and installation. The outer rotor can be directly connected to the hub of turbine, eliminating the use of a rotating shaft. Although the heat load of the outer rotor machine is slightly higher at the same current density, winding at the outside will obtain better heat dissipation.