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Superconducting light generator for large offshore wind turbines

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Abstract. Offshore wind market demands higher power rate and reliable turbines in order to optimize capital and operational cost. These requests are difficult to overcome with conventional generator technologies due to a significant weight and cost increase with the scaling up. Thus superconducting materials appears as a prominent solution for wind generators, based on their capacity to held high current densities with very small losses, which permits to efficiently replace copper conductors mainly in the rotor field coils. However the state-of-the-art superconducting generator concepts still seem to be expensive and technically challenging for the marine environment. This paper describes a 10 MW class novel direct drive superconducting generator, based on MgB₂ wires and a modular cryogen free cooling system, which has been specifically designed for the offshore wind industry needs.

1. Introduction

Wind power is the renewable energy source that has seen the most successful deployment over the last two decades, from less than 3 GW to 282 GW of global cumulative capacity [1]. In the EU, five countries source more than 10 % of their electricity from wind [2] and wind energy will provide at least 12 % of EU electricity by 2020, significantly contributing to the 20/20/20 goals of European energy and climate policy [3].

Offshore wind energy is rapidly developing motivated by the stronger, more regular winds at sea and more limiting sitting restrictions on land. According to the International Energy Agency, global offshore wind cumulative capacity could reach 100 GW in 2020 and 375 GW in 2030 [4].

Table 1. Cumulative offshore wind capacity prediction [4][5]

	2020 (GW)	2030 (GW)	2050 (GW)
Europe	40	150	460
World	100	375	1150

The offshore wind industry, in order to be more competitive and be able to meet the market predictions (see table 1), demands important capital and operation costs reduction. Several cost reduction opportunities have been identified, which are mainly focused on technology development,



improvement of the supply chain efficiency and finance. The increase of turbines' power rating has been pointed out as one of the issues with higher LCOE (Levelized Cost of Energy) reduction potential [6]. Indeed, there is already a trend toward larger turbines, in 2012 the average size of installed offshore wind turbines has been 4 MW, while ten years before it was 2 MW [7].

Nowadays, the dominant technology is the geared drive train induction generator, while direct drive permanent magnet synchronous generator still represents a small market share of 3.16 % [8]. Direct drive solutions are expected to dominate the offshore wind market in the coming years based on its higher reliability, efficiency and better scalability in comparison to geared solutions.

2. Superconducting generators for offshore wind

Wind turbines state-of-the-art shows that both geared and direct-drive synchronous and permanent magnet generators are difficult to scale up to 10 MW and beyond. Their huge size and weight drives up the cost of both fixed and floating foundations as well as installation and operation and maintenance costs. New solutions to provide better power scalability, topside weight reduction and reliability are needed. Superconductivity combines such features and allows scaling to 10 MW and beyond by radical reduction of the head mass.

In recent years, superconducting materials have emerged as real alternatives to conventional resistive materials such as copper. These materials have the potential to construct higher power rate generators with lower volumes and weights driven by the following advantages. They can achieve stronger magnetic fields by means of DC field superconducting windings. They require less iron in the magnetic circuit, which allows more space for AC stator winding. And they permit higher air-gap shear stress, which allows smaller and lighter direct-drive machine design.

Today superconductivity in wind turbines is an active R&D trend and there are several superconducting generator concepts, as those proposed by General Electric, AMSC, RISO-DTU or AML [9]. However these concepts face certain technical barriers that complicate their industrial feasibility for the very challenging offshore wind sector. Cryogenic fluids are used to cool down the rotor, and compatibility of the use of cryogenics with the marine environment may not have been taken into account. Reliability of the cooling system has to be carefully considered with handling and availability of cryogenic fluids in offshore locations. The huge torque to transmit from the room temperature environment to the cryogenic temperature is also a challenging mechanical problem. Finally, most of the superconducting generator concepts are based on still expensive and not always commercially available materials, such as second generation high-temperature superconductors (2G HTS), or materials without attractive cost reduction perspectives in the future, such as 1G HTS.

3. Suprapower: Superconducting light weight generator

The present work describes SUPRAPOWER EU FP7, a cofounded research project that started in December 2012 and which is expected to finish at the end of 2016. It aims to provide an important breakthrough in offshore wind industrial solutions by designing and validating an innovative, lightweight, robust and reliable 10 MW class MgB₂ superconducting generator for offshore wind turbines, on the basis of the TECNALIA's patented generator concept [10].



Figure 1. 10 MW superconducting generator concept (left) and 500 kW scale machine (right)

This generator overcomes the presented barriers for other superconducting concepts while the design is oriented to the offshore wind industry demands. The main advantages of this solution are the reduction of turbine head mass to about 30 % with respect to conventional generators, a modular cryogen free cooling system that requires a reduced maintenance and the no need of rare earth materials which have shown high price volatility and supply problems.

The generator concept will be validated through a scale machine in the range of 500 kW (figure 1). To keep the maximum similitude between the model and the full scale generator (figure 2), the power reduction will be obtained by reducing the number of poles from 60 to 4, maintaining the size of the SC rotor coils identical both in full and small scale generator. Basic full scale generator features as specific shear stress, superconducting and cryogenic implementation, modularity, quench detection or torque transmission will be similar, too.

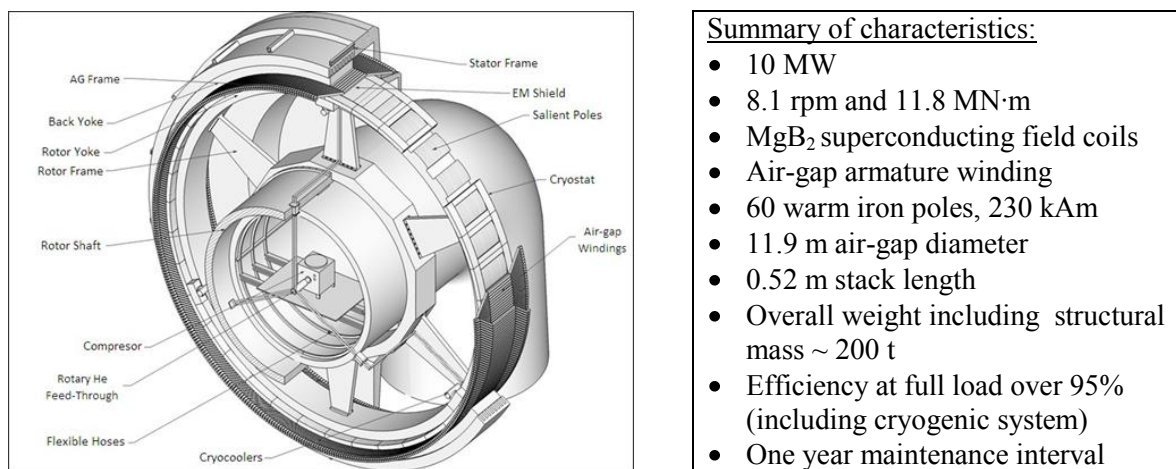


Figure 2. Superconducting generator concept patented by TECNALIA (left). Main features of the 10 MW generator design (right)

The superconducting generator is a direct drive salient poles synchronous machine, based on the use of MgB_2 wire in the superconducting field coils, which is an industrial solution with a very competitive cost, near to copper, and several times lower than other HTS wires. MgB_2 wires in the form of sandwich tape with outer Cu stabilization layer, will be specifically designed, manufactured and characterized for this generator.

The field coils will be constituted by a stack of several double pancakes of MgB_2 racetrack coils, placed between 2 thick copper plates for the refrigeration of the assembly (see figure 3 right).

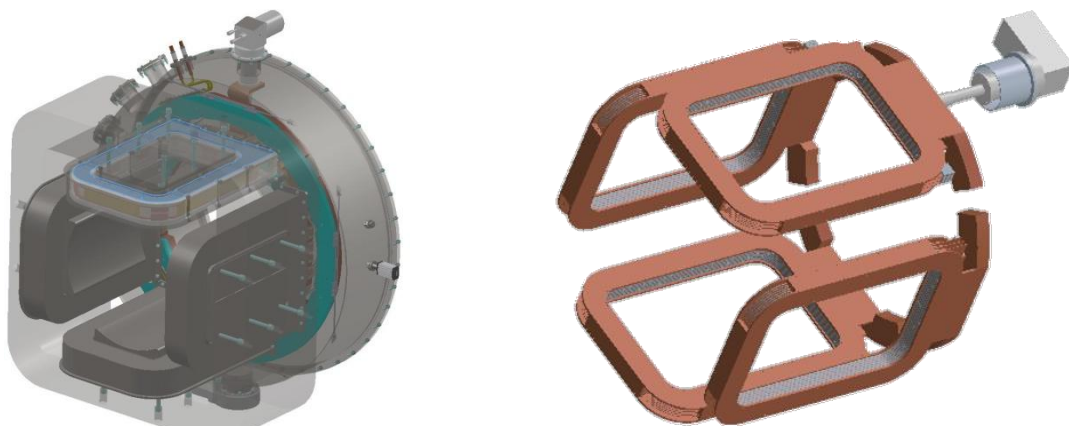


Figure 3. SUPRAPOWER's superconducting scale machine cooling system

The cooling system is an essential part of the superconducting rotating machines, up to now circulating cryogenic liquids solutions have been used, but this is a low reliable option for offshore applications. In this case a cryogen free cooling system in rotating configuration has been designed. As it is shown in figure 3, it basically consists of two parts, one modular cryostat able to accommodate one coil and a thermal collector which links all the modules, while the heat is extracted by two stage G-M cryocoolers, which rotate jointly with the rotor. Heat will be extracted by conduction through two high conductivity thermal circuits, enclosed by the thermal collector. One of them will be connected to the cryocoolers first stages and to the thermal shield ($T \sim 80\text{K}$), and the other one will be thermally linked to the second stage of the cryocoolers and to the superconducting coils, maintaining them at operation temperature ($T \sim 20\text{K}$).

The rotor has a warm iron poles configuration, which means that each modular cryostat only encloses the superconducting coils, thus the mass to be cooled is reduced and the high torque (11.8 MN·m) transmission will be shared between the cold part (superconducting coils) and the warm one (Fe poles). In addition, the modular cryostat solution makes the construction, assembly and maintenance operations affordable in offshore conditions.

4. Conclusions

A novel concept of a lightweight, reliable and robust 10 MW class superconducting generator has been presented. It aims to fulfil the offshore industry demands on LCOE reduction by means of higher power rates and more reliable turbines.

Starting from an already patent-applied concept by TECNALIA, this generator is based on the use of MgB_2 wires for the rotor field coils; cryogen free modular cooling system; warm iron poles configuration and modular cryostat.

The generator highlights are, a 30 % weight reduction with respect to conventional generator technologies, reduced maintenance requirements, design fully oriented to the offshore environment and very competitive life cycle costs.

Acknowledgments

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