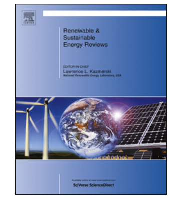
Renewable and Sustainable Energy Reviews 38 (2014) 404–414

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



# A review of high temperature superconductors for offshore wind power synchronous generators

J. Lloberas [a], A. Sumper [b,a], M. Sanmarti [a], X. Granados [c]

[a] IREC Catalonia Institute for Energy Research, C. Jardins de les dones de negre, 1, Pl 2ª, 08930 Sant Adrià de Besòs, Spain
[b] Centre de Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC), Departament d'Enginyeria Elèctrica, Universitat Politècnica de Catalunya, EU d'Enginyeria Industrial de Barcelona C, Compte d'Urgell, 187, Pl. 2, 08036 Barcelona, Spain
[c] Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus de la UAB, 08193 Bellaterra, Spain

ARTICLE INFO

*Article history:*
Received 22 July 2013
Received in revised form
16 April 2014
Accepted 1 May 2014
Available online 26 June 2014

*Keywords:*
High temperature superconductor synchronous generators
Offshore wind market
First and second generation HTS tape
HTS coils
Cryogenic and vacuum equipment
Torque transmission

ABSTRACT

Large synchronous generators with high temperature superconductors are in constant development due to their advantages such as weight and volume reduction and the increased efficiency compared with conventional technologies. The offshore wind turbine market is growing by the day, increasing the capacity and energy production of the wind farms installed and increasing the electrical power for the electrical generators installed, consequently raising the total volume and weight for the electrical generators installed. The HTS synchronous generators (HTSSG) are an alternative to consider due to their low dimensions and low weight per megawatt. This article presents a detailed review of the geometric configurations of the large HTSSG for offshore wind energy followed by an explanation of the main non-conventional technological parts. Additionally, the experience from the most important projects – both ongoing and completed – by companies and research institutes related to the design and construction of HTSSG for offshore wind energy is reviewed.



**Contents**



*Abbreviations:* HTS, high temperature superconductor; HTSSG, high temperature superconductor synchronous generator; PMSG, permanent magnet synchronous generators; PMSGDD, permanent magnet synchronous generators Direct Drive; DFIG, doubly fed induction generator; MLI, Multi-Layer Insulation; 1G, first generation; 2G, second generation

*E-mail address:* jlloberas@irec.cat (J. Lloberas).

http://dx.doi.org/10.1016/j.rser.2014.05.003
1364-0321/

## 1. Future prospects for offshore wind turbines electrical generators technology

Wind energy is the world's fastest-growing energy. Both in Europe and worldwide, offshore wind power is being developed rapidly due to the stronger and stable winds produced at sea and the huge areas where it can be installed.

Offshore wind power systems have relevant advantages compared with the onshore wind power systems, due to the attractive and easier transport of the components, as well as lower visual impact and noise [1–3].

The wind energy production of recent years has risen and a high and linear evolution of the growth of electrical wind energy is expected as shown in Fig. 1a. Also, a high growth of wind turbines capacity is expected to be installed in the following decade, shown in Fig. 1b.

The average size of offshore wind farm installations in 2012 was 286 MW whereas in 2013 it was 482 MW [5]. Regarding the fleet wind farm size in the EU-12 compared between 2009 and 2013 an increase of the wind turbine power per unit could be observed. By 2009 the average wind power unit was 2.62 MW and by 2013 it had been increased to 3.29 MW [5]. This could be because of the lower operational and maintenance costs required for the overall fleet of the total units.

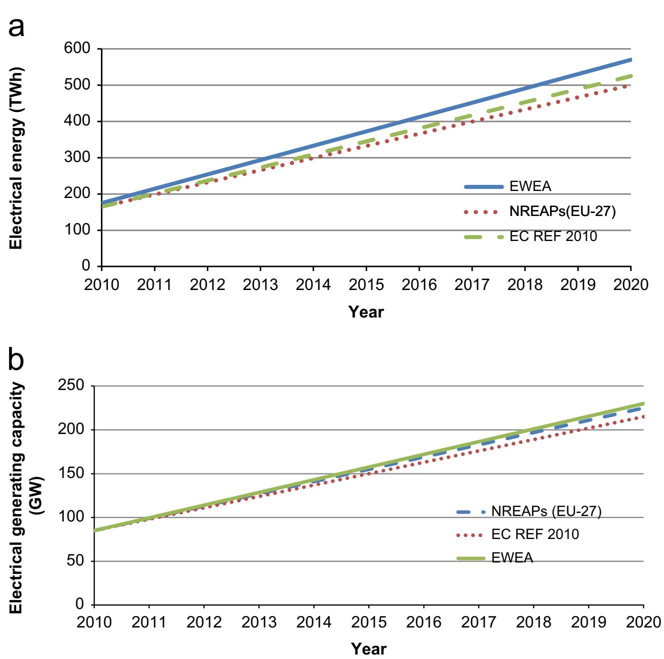



**Fig. 1.** a) Expected growth in electrical wind energy production (TWh) [4] and b) Expected growth installed in electrical generating wind power capacity [4]

As exhibited in Fig. 2, there is a trend showing an increase in the average wind turbine unit rating every year with the prospects of the higher than 8 MW wind turbine project concept designs and installations for the coming decade.

Table 1 presents the most relevant offshore wind turbines using conventional technologies for more than 4 MW unit rating that have been installed. The wind turbine electrical power, the electrical machine technology used and the gearbox coupled were mainly recorded. As Tables 1–3 indicate, the highest number of offshore wind turbine projects installed and in development for powers more than 4 MW using PMSG exist there, and a significant number of them have a Direct Drive transmission system.

Wind turbines for the offshore market must be extremely reliable and do not need high maintenance. The simplicity and the highest overall efficiency, reliability and low noise for the conventional drive trains without gear boxes for large powers are demonstrated [6–8].

However, for wind turbine electric ratings higher than 8 MW, its geometric dimensions and consequently the total weight of the generator increase exponentially [9]. For this main reason, it is required to search for alternative technologies for offshore wind turbines with powers more than 8 MW to achieve the electrical power with a lower electrical generator volume and a low total weight with reasonable costs.

## 2. HTSSG for offshore wind energy

High temperature superconductors (HTS) evolve continuously with better electrical, mechanical and magnetic characteristics with a minor cost for application in industrial sectors as wind energy systems.

The result of the high current density in HTS tapes is the high power density obtained in HTS generators. The conventional copper coils in a conventional machine typically operate with a current density between 3 and 5 A/mm$^2$ while the current density in the wire in a HTS coil can operate at 200 A/mm$^2$ [10]. As a consequence a higher induction could be obtained by using HTS coils; for this reason it is possible to reduce the main radial and axial dimensions of the electrical generator to obtain the same electrical power. Because of the lower dimensions required a lower weight compared with conventional machines of the same electric rating and nominal speed is needed, proving to be attractive for wind energy.

HTS generators cannot be commercially successful in the wind market without low cost volume production of HTS wire.

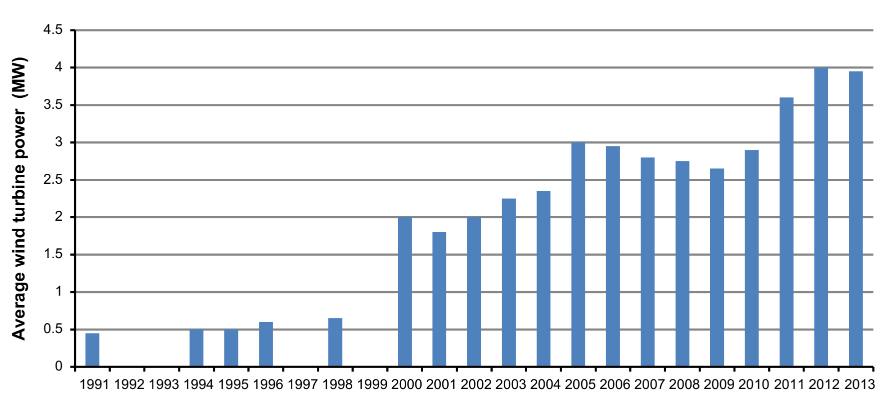



**Fig. 2.** Annual average sizes of offshore wind turbines in MW [5].