Contribution ID: **595** Type: **Poster Presentation (120m)**

Innovative cryogenic systems for cooling superconducting wind turbine electrical generators in the 20-65 K temperature range

Thursday 25 July 2024 14:00 (2 hours)

As part of the energy transition, the off-shore wind power market is booming with many very large-scale projects emerging or already in operation in Europe, Asia and America. Wind farms are commonly made up of several dozen turbines, the power of which has steadily increased in recent years, now exceeding more than 10 MW each, or soon even beyond.

Installed more than 150 meters above the waves, the nacelles housing the electric generators nowaday weigh more than 400 tonnes. This includes in particular several tons of rare earths used in electromagnets that operate at room temperature.

By cooling the electromagnets located in stators or rotors down to cryogenic temperatures, a superconducting state can be achieved, where electrical conductors do not oppose any resistance anymore. The weight of the generator and therefore that of nacelles might then be reduced by several dozen tons, while the mass of necessary rare earths in classical permanent magnets (PM) might be reduced by two or even three orders of magnitude.

Indeed, literature about superconducting wind power generators shows about 7 tons of rare earths are needed for classical PMs in a 10 MW-scale generator working at room temperature, while market prospects for off-shore wind power show about 1200 gigaWatts of generating capability might be installed worldwide before 2050. This would increase demand for rare earths by almost 1 million tonnes over the next two decades, putting this market in competition with other applications, such as ground-based electric mobility, thus straining supply chains, not to mention geopolitical tensions.

This paper will first present an existing single-stage turbo-Brayon cooler able to provide up to 17 kW of cooling power at 65 K, which could go down to about 40 K. Being an extremely compact and standalone cryocooler, it would be well suited for cooling large superconducting electrical power generators aboard offshore wind turbines working in this range of temperatures.

Then the paper will present an innovative cryocooling concept based on the same industrially-proven turbo-Brayton technology using several-stage turbomachines that is able to provide about 1 kW of cooling power in the 20-30 Kelvin temperature range (or 5-6 KW at 65 K), enough for cooling a 10 MW-scale wind turbine generator. Other versions in the future might operate at 4 K. It is based on Air Liquide's extensive experience on the mature reverse turbo-Brayton refrigeration technology (from the International Space Station, HTS ground applications to LNG ship carriers) and on large superconducting systems for scientific instruments (CERN-LHC, ITER, SLAC, etc⋯).

A compact, hermetic and extremely reliable system, this standalone cooler is composed of a few small turbo-machines and heat exchangers mounted on a unique plate. An internal manifold distributes the cold gas to the various magnets using closed loops. The complete system can cool down either stators or be mounted onto a direct drive rotor to rotate with it.

Superconductivity is now a mature technology that has been demonstrated on the field for wind turbines. A game-changer, these extremely compact and powerful cryocoolers working in a wide range of temperatures and powers pave the way to a new era in offshore wind power, reducing the demand in critical raw materials while improving the LCOE of wind turbines.

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Session Classification: Thu-Po-3.2

Track Classification: Tracks ICEC 29 Geneva 2024: ICEC 07: Cryogenic Applications: power application and power transmission lines