AP6-0-INV

Efficient cryogenic cooling methods for HTS (High Temperature Superconductor) applications; from stationary cooler to moving HTS coils

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An HTS system typically requires cryogenic temperature which is much lower than the critical temperature of the superconductor for its normal operation. In the case of modern applications of HTS coils, this demanded temperature is passively determined by not only the cryocooler as a cooling source but also the thermal connection mechanism between the cryocooler and the target HTS system. Regardless of HTS applications, an efficient thermal communication is, therefore, very important to reduce unnecessary temperature difference between cooling source and target and the resultant parasitic entropy load of the cryocooler. In many cases, the real cooling load is insignificant unless the superconducting coil is operating in a ramping or ac (alternating current) mode with relatively large current. The virtual cooling load which is originated from thermal conduction or radiation heat leak from room-temperature environment frequently becomes the dominant factor to determine the size of the cryocooler. This paper addresses rather peculiar thermal bridging issue for moving HTS system. Instead of utilizing stationary cryocooler and implementing a complex configuration of thermal communication to take heat from the moving HTS coil, an innovative on-board cryocooler concept is introduced and systematic conduction-cooling is proved to be possible for superconducting rotor. Due to the bulkiness and inherent inefficiency, GM or JT cryocooler is not appropriate for on-board cryocooler. If the magnitude of heat generation and parasitic heat leak is manageable as in this example, a two-stage Stirling cryocooler or Stirling-type pulse tube refrigerator shall be readily applicable for this purpose. The first stage is used for thermal anchoring and the second stage is for cooling HTS coil. As demonstrated in this paper, a close collaboration with adequate communication between cryocooler developer and superconductivity community can produce genuinely competitive application of HTS system.

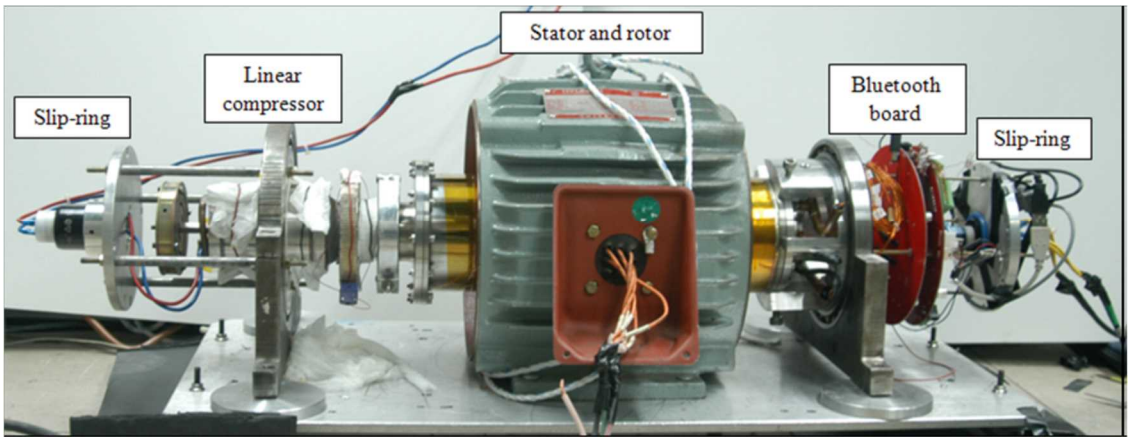

Fig. Superconducting rotor with onboard cryocooler

Keywords: Cryocooler, Entopy load, HTS coil, Parasitic heat leak, Thermal anchoring

AP6-1-INV

Superconducting Power Generators for Offshore Wind Turbines

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Offshore wind turbines, far away in the ocean, require light and compact power generators that can be easily shipped and installed. Superconducting power generators are a perfect option, which significantly reduce the mass of wind turbines and consequently result in substantial cost saving for installation and maintenance. However, excessive amount of superconductors are required that make superconducting power generators suffer from high cost and cooling and reliability issues. This presentation will introduce our latest research on an improved design of stackable superconducting power generators with a stationary superconducting field winding. This new design enables further mass reduction based on mechanical optimization of the rotation mechanism. Its stackable structure benefits on-site installation due to the flexible small modules that can be easily transported. We will also present our research work on the reliability of superconductors for offshore wind turbines. The change of superconductors after several cooling processes will be clearly demonstrated, which gains new knowledge essential to developing reliable superconducting power generators. This work is supported by the UK Research Council, under collaboration with Scottish Microelectronics Centre and Centre for Science at Extreme Conditions.

Keywords: superconducting power generator, wind turbine, mass reduction, reliability

AP6-2-INV

EcoSwing – Development, test, installation, and commissioning of a 3 MW superconducting wind power generator

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In the EU funded EcoSwing project the world's first large-size superconducting lightweight multi megawatt wind turbine generator was designed, built and tested in a real wind turbine.

In order to realize this generator a technology to produce high quality HTS coils for reliable industrial use was developed and successfully qualified. Due to the high magnetic fields generated by the superconducting coils in the rotor a decrease of diameter from 5.4 m to 4 m and corresponding weight reduction was achieved.

In 2018 the generator was first tested in a nacelle test rig on ground and then installed on an existing wind turbine with 128 m rotor diameter in a demanding coastal site in Western Denmark. There, the previously installed PM direct drive generator was replaced with the much smaller superconducting EcoSwing generator. During commissioning early 2019 in total 650 h of operation were achieved and power up to 3 MW was delivered to the grid. Electromagnetic characteristics were met or even exceeded expectations. Cooling of the rotor was reproducible demonstrating the reliable performance of the cryocoolers.

An overview on the design, manufacture, and operation will be given, and main design features will be explained with a special focus on the superconducting coils and cryocooling.

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Keywords: HTS coils, wind turbine generator

AP6-3-INV

Current Status and Future Expectation of HTS Rotating Machines in Korea

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Recently, many researchers have been actively researching superconducting rotating machines, in particular, superconducting generators for wind turbines and superconducting motors for propulsion aircraft. In Korea, research on the superconducting rotating machines has been ongoing. In the case of the superconducting motor, much attention has recently been paid to localization of electric propulsion systems for aircraft. Research on the superconducting motors for propulsion aircraft using liquid hydrogen has been conducted. In this paper, the world and Korea R & D trends of superconducting motors were discussed.

In the case of the superconducting generator, a large-scale floating offshore wind turbine with a superconducting wind power generator was suggested to achieve the renewable energy target which is 20% renewable energy achievement by 2030 in Korea. This paper introduces a new wind project for developing 10 MW class high-temperature superconducting (HTS) magnet, test facility, offshore floating system, and network connection technologies sponsored by Korea Electric Power Corporation. First step is a design of a 10 MW floating offshore wind power system with the superconducting generator. The design process of the 10 MW superconducting generator are developed, and the modeling method for the large-scale wind farm is suggested using real time simulator. Second step is the detail design of the 10 MW floating platform in which the floating system of the wind power system is designed considering the superconducting generator. Algorithms for control systems of the superconducting wind farm are developed. Korean type large scale floating offshore wind power system platform is suggested in the last-step. The fabricated superconducting pole is tested using a performance evaluation device. The mechanical stress and electric characteristics by Lorenz force are analyzed, and economic analysis result of the floating offshore wind power system is provided. As a result, we will discuss the possibility of large scale floating offshore wind power system, and Korean type large scale floating offshore wind power system platform with the HTS wind power generator will be proposed.

Keywords: Aircraft, HTS generator, HTS motor, Rotating machine, Wind turbine

AP6-4

Development of Hydrogen Supply and Exhaust System for Liquid Hydrogen Cooled Superconducting Rotating Machine

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Superconducting generator has been developed with NbTi superconducting field winding cooled by liquid helium, but not yet commercialized.Superconducting motor and wind generator has been recently developed using BSCCO or REBCO wires which are mainly cooled by liquid nitrogen or refrigerator.

On the other hand, hydrogen based energy infrastructure is now promoted and liquid hydrogen is becoming an important energy carrier.We proposed to utilize liquid hydrogen as a coolant for superconducting generator.The superconducting generator can improve the power system stability and hence promote the introduction of renewable energies to the power system.Liquid hydrogen immersed cooling is preferable for rotor field winding of middle or large capacity commercial generator.

Experimental facility for the development of hydrogen supply and exhaust system for the hydrogen cooled rotor was introduced as one of the important component technology.

Keywords: liquid hydrogen, superconducting generator, cooling system