An Innovative Wind Project on the Development of HTS Magnet, Test Facility, Offshore Floating System, and Network Connection Technologies for 10 MW Class Wind Power System Fully Sponsored by KEPCO

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***Abstract*— This paper proposes development of Korean type large scale floating offshore wind power system platform with a superconducting wind power generator. 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 wind power system platform will be proposed.

***Index Terms*—HTS generator, HTS field coil, Lorentz force, Structural analysis, Torque, Wind turbine**

I. INTRODUCTION

IN 2017, the Republic of Korea's new government has announced a new energy shift strategy in order to increase the rate of renewable energy, including offshore wind and a phasing out of nuclear and coal. The announcement was that the renewable energy would curve the 20% of total electricity energy demand by 2030. It means that approximately 65 GW from renewable energy has to be ready to enter into Korean power network. Therefore, large-scale wind farm is one of the most promising energy sources and should be established in KEPCO transmission network to achieve the target of renewable energy [1]. A floating offshore wind turbine with a superconducting wind power generator is the most innovative proposal to constitute the large-scale and high-capacity wind farm. According to those reasons, KEPCO (Korea Electric Power Corporation) decided to support that proposed development plan with 6 M USD for 3 years [2].

This paper introduces an innovative wind project on the development of high-temperature superconducting (HTS) magnet, test facility, offshore floating system, and network connection technologies for 10 MW class wind power system fully supported by KEPCO.

As the first step, a 10 MW class floating offshore wind power system with the superconducting generator will be designed in detail for more than 1 year. The design process of superconducting generator will be clearly classified as detail as possible. And also, the detail design of the 10 MW floating platform will be carried out considering the superconducting generator. Not only the design of 10 MW wind power system but also HTS magnet as rotor pole of generator will be fabricated and tested under test facility since the mechanical stress and electric characteristics of HTS magnet by Lorentz force is the most critical issue among development of system.

As a result, we will finally discuss the possibility of Korean type large scale floating offshore wind power system with HTS wind power generator.

II. IMPORTANCE AND PARTICIPANTS OF THE KEPCO PROJECT

The development of large wind turbines is a topic of great interest for the wind industry. The European Commission recognized the importance of the topic by including the development of efficient and market affordable technology for increasing wind penetration among the priorities of the H2020 program. In Asia, the governments of the Republic of Korea, China, Japan, Taiwan, Vietnam, and India have taken active steps to expand the wind turbine market and develop [3], [4].

The Republic of Korea's new government announced a major shift toward renewables, including offshore wind, and a

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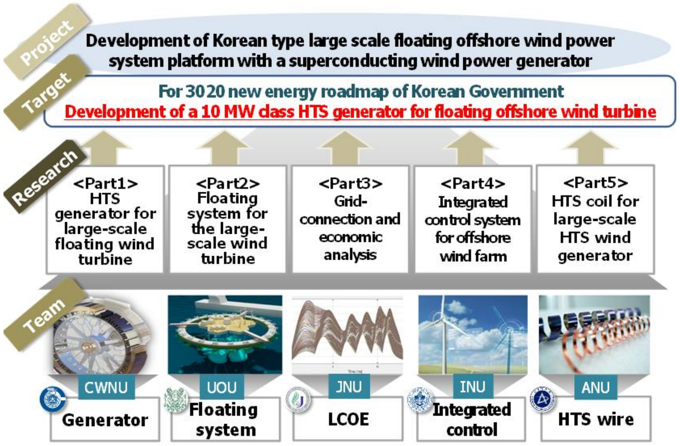


Fig. 1. Research and development objective in the project

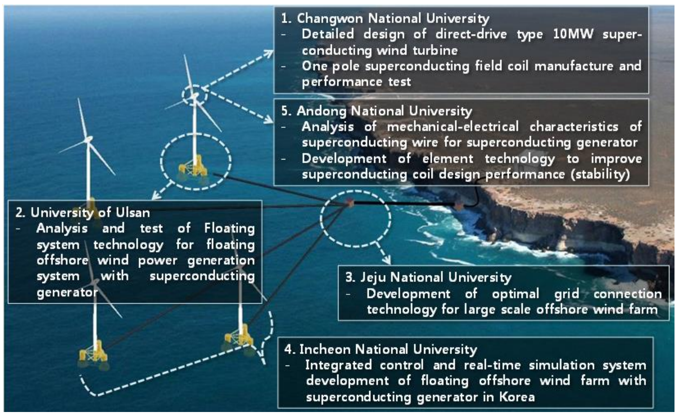


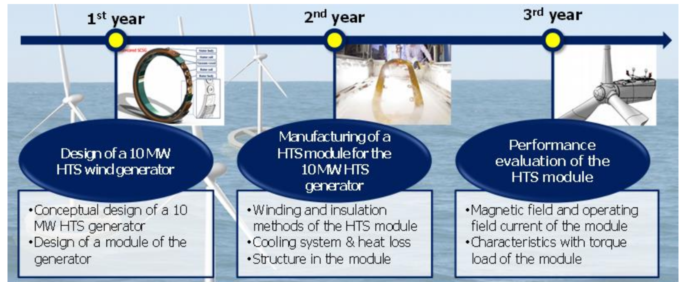
Fig. 2. Research contents of the participating institutions

phasing out of nuclear- and coal-generated power in 2017. The announcement was that Korea would have a 20% renewable energy target by 2030. By 2030, the installation of wind power will reach up to 16.5 GW in which 12GW will be offshore wind power.

Pioneer companies around the world are already working on developing a large-capacity wind turbine generator based on superconductors. Currently, EU is studying the detailed design of 10 MW and 12 MW superconducting generators and superconductor properties in the InWind business. In the US, AMSC is working on 10 MW class superconducting wind power generator (SeaTitan), and GE is working on the development of superconducting generators for 10 MW and above wind turbines. Superconducting generators can be a high added-value product for the industry [5]-[7].

Furthermore, as superconducting wind generators dramatically reduce the rare earth requirement (from 100 kg per MW in a conventional PM generator to about 100 grams of rare earth per MW in an HTS generator), economic dependence on countries which exclusively own these resources is avoided [8]-[15].

The aim of the project is to develop a floating type offshore wind turbine platform for 10 MW class large-scale superconducting wind turbine in Korea to achieve the renewable energy of 20% until 2030. This can be achieved by creating turbines with large rotor diameter and height, to maximize energy capture. In particular, we focus on ultra-high capacity superconducting wind power generator. The project



Year	Contents
1st yr. Design of a 10 MW HTS wind generator	Confirm 10 MW wind turbine output power with the HTS generator, and design the module of the HTS generator in detail
2nd yr. Manufacturing of a HTS module for the 10 MW HTS generator	HTS module of the 10 MW HTS generator is manufactured considering winding and insulation methods, cooling system, and structures
3rd yr. Performance evaluation of the HTS module	Measure the magnetic field and operating current of the module and check the characteristics with torque test of the module

Fig. 3. Technical load map of the superconducting wind turbine

is for three years and started in early March 2018. In the first year, a floating offshore wind power generation system using the HTS generator is designed, and HTS magnet as rotor pole of the HTS generator will be fabricated in the second year. In the final third year, the characteristics of the HTS magnet at high torque condition will be evaluated.

Total of 5 organizations which are Changwon National University, University of Ulsan, Jeju National University, Incheon National University, and Andong National University, are participating in this project as shown in Fig. 1.

Fig. 2 illustrates research contents of the participating institutions schematically. Changwon National University is the lead organization of this project and aims to design the 10 MW HTS generator and to fabricate and test the HTS magnet of the generator. University of Ulsan conducts analysis and test of a floating system technology for the offshore wind turbine with the HTS generator. In the cases of Jeju National University and Incheon National University, they develop models and grid connection technologies of floating offshore wind farm including the HTS generator. Andong National University analyzes mechanical-electrical characteristics of the HTS wire for the HTS generator and develop element technologies to improve HTS coil design performance.

Fig. 3 shows the detail plan for the HTS generator of the floating offshore wind turbine. For three years, the 10 MW HTS generator is designed in detail. The HTS magnet as rotor pole is fabricated and tested. We also develop a performance evaluation system (PES) to test the magnet under torque condition.

III. 10 MW Class Wind Power Generator and Performance Evaluation System

The detail plan for design of the 10 MW class HTS generator is shown in Fig. 4. The lab-scale HTS wind generator was fabricated and tested to confirm the design process of the HTS generator before designing the 10 MW class HTS generators.

The 10 MW HTS generator was designed based on the design process using multi-physics FEM program. The output torque and Lorentz force of large-scale HTS generators should be carefully investigated due to the high current density and magnetic field of the generators.

For this purpose, a PES is required to test the HTS field coils before installing them on the HTS generators. The design

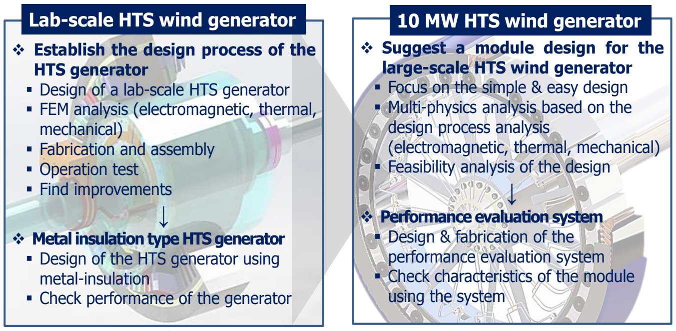


Fig. 4. Detail plan for 10 MW HTS wind generator in the KEPCO project

TABLE I
SPECIFICATIONS OF THE DESIGNED 10 MW CLASS HTS GENERATOR

Items	Value
Rated output power	10.5 MW
Rated L-L voltage	6.6 kV
Rotating speed	10 rpm
Rated torque	10.02 MN·m
Number of pole pairs	20
Rated frequency	3.33 Hz
Material of the field coil	2G HTS wire
Width/thickness of the HTS wire	12 mm / 0.15 mm
Operating temperature	30 K
Total length of HTS wire	113.20 km
Volume of generator	141.02 m^3
Weight of generator	148.09 ton

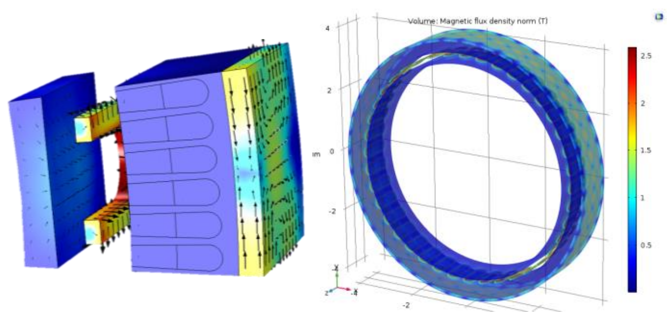


Fig. 5. Electromagnetic analysis results of the 10 MW class HTS generator

specifications of the 10 MW class HTS generators are summarized in Table I. The rotating speed and rated torque of the designed 10 MW class HTS generator are 10 rpm and 10.02 MN·m, respectively. As a result of the FEM analysis, the 10 MW HTS generator requires a length of HTS wire of 113.2 km. The HTS coils consist of the racetrack-type double pancake coils (DPC). The HTS wire is coated with flat conductive tape of 0.15 mm thickness and 12 mm width. Fig. 3 illustrates the electromagnetic analysis results of the 10 MW class HTS generator. The maximum magnetic field of the 10 MW HTS generator was 3.1 T. Based on the electromagnetic analysis results, the cooling system and structure of the HTS generator was developed. Fig. 6 shows a schematic of developed cooling system for large-capacity superconducting wind turbines. The existing neon thermosyphon structure and internal sealing circulation structure are applied. Simplification of the thermal path makes it easy to maintain and repair the cooling system. The structure of the HTS field coil was designed considering developed cooling system. The structures of the HTS generator should be analyzed and tested for their ability to withstand the torque and force of the HTS generators using PES. The PES is designed based on the basic parameters of the 10 MW class HTS generator such as the HTS pole number, rotational speed, operating current, and so on. The design process of the swing and fixed-type PES is represented in Fig. 7. As a design result, the output torque and the tangential force of the PESs were about 285 kN·m and 75 kN, which is identical to the designed specifications and the calculation results of the HTS generator.

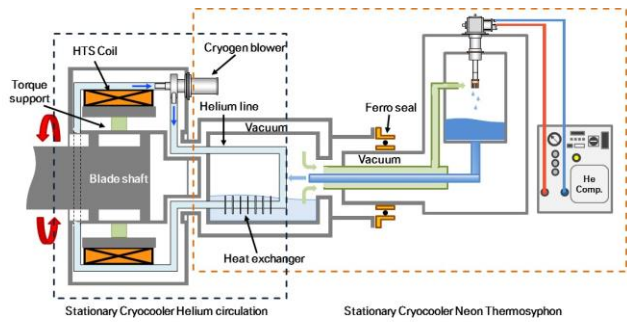


Fig. 6. Schematic of developed cooling system (stationary cryocooler helium circulation + stationary cryocooler neon thermosyphon)

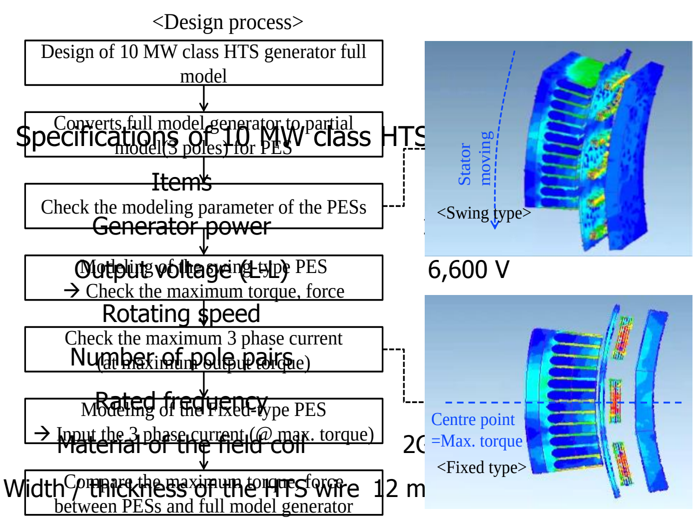


Fig. 7. Design process of the swing and fixed-type PESs

Specifications of 10 MW class HTS
Items
Generator power
Output voltage (L-L) 6,600 V
Rotating speed
Number of pole pairs
Rated frequency
Material of the field coil 2C
Width / thickness of the HTS wire 12 m
Operating temperature 30 K
Total length of HTS wire 113.23 km
Volume of the gener 141.02 m^3
Weight

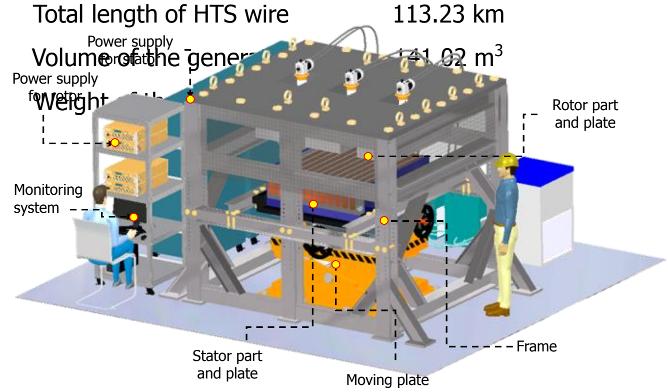


Fig. 8. Conceptual design structure of the PES for 10 MW HTS generator

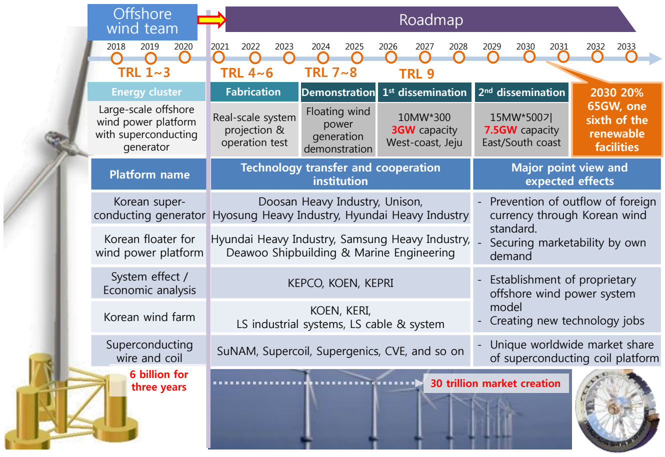


Fig. 9. Research roadmap for large scale floating offshore wind power system with a superconducting wind generator

Therefore, the designed PESs can evaluate the performance of the HTS generator. The fixed-type was better suited for evaluating the torque and force of the HTS field coils for large-scale HTS generators in terms of accuracy and safety of the system than the swing-type PES. The conceptual design structure of the fixed-type PES for 10 MW HTS generator is shown in Fig, 8. The design and FEM analysis results of the PESs are believed to be effective for the development of large-scale HTS wind power generators and the PES will be fabricated and tested in the near future.

IV. Vision and Future Plan

The primary target of this project is to design the final 10MW class HTS wind generator and to test 3 HTS magnet poles of generator with very strong torque as same as that between rotor and stator. After completing these target, real feasibility fabrication of HTS wind generator will be occurred after passing the evaluation of next step. In case of floater, the real fabrication projects are already started and a few new big programs regarding to offshore floating system are also on planning stage.

At next step, the industry related with generator or magnet has to participate the real fabrication project. Now, all participating institutes are universities. In order to move to the real fabrication level, universities only is not making a sense. And also, the fabrication only is not enough, so the full load test has to be carried out with proper rotating speed pattern.

According to the development level of large scale HTS wind generator, there needs at least 3 years to fabricate real scale 10MW HTS wind generator. After that, the field test is also obviously required more than 2 years. Consequently, after 7 or 8 years, the commercially available HTS wind generator could be ready considering only the technical point of view. However, the industrialization means that both sides not only technically but also economically have to meet the proper requirements. Technically the HTS magnet should withstand with extremely strong torque on operation, but the economical remained worry is the price of HTS wire. Considering the width of HTS wire is 12mm, totally more than 100km length of wire is required to fabricate 10MW class wind generator. Due to the recent price of HTS wire, the benefit; light weight and small volume, of HTS wind generator is not enough value to overcome the demerit of fabrication cost. The price of HTS wind generator is not needed to be the same or cheaper price of conventional wind generator since the ultimate advantages of superconductivity. However several times more expensive than that of the conventional is still unsolved and crucial problem against commercialization.

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