# Experimental test and characteristic analysis of a real scale HTS coil for a 10 MW HTS generator using a performance evaluation system

C. Kim*, H. J. Sung*, B. S. Go*, J. Park*, S. Kim* and M. Park*
Changwon National University*
capta.paper@gmail.com
Tel : +82-55-213-2866
CAPTA

TUE-PO1-506-06

## 1 Introduction

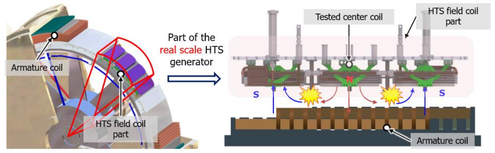
This paper deals with the experimental test and characteristic analysis results of a real scale HTS coil for a 10 MW HTS generator using a performance evaluation system (PES). We have proposed a method to evaluate the characteristics of large-scale HTS wind turbine generators using a PES. The PES is designed and manufactured to examine the electromagnetic properties, stability and cooling performance of a full-scale 10 MW HTS coil. Three HTS coils and corresponding armature modules were designed and manufactured to confirm the characteristics of a real-scale generator using the PES. The system was assembled to withstand the force equivalent to one pole of a 10 MW HTS wind turbine under load conditions. The HTS coil was cooled to 35 K through a neon helium cooling system. The HTS coil operates at a rated field current and generates the same force by flowing a DC current through the armature, which corresponds to the rated armature current of a 10MW generator.

## 2 Description of the performance evaluation system

TABLE I
Specifications of the 10 MW HTS generator

| Items | Value |
|---|---|
| Rated output power | 10.5 MW |
| Rated L-L voltage | 6.6 kV |
| Rated armature current | 918 A |
| Rotating speed | 9.69 rpm |
| Rated torque | 10.34 MN·m |
| Number of poles | 40 |
| Turns of field coil | 310 |
| Number of layers | 4 |
| Operating current | 221 A |
| Operating temperature | 35 K |
| Air-gap length | 15 mm |
| Width of bobbin | 250 mm |
| Width of coil | 60 mm |
| Effective length of coil | 700 mm |
| Height of coil | 77.5 mm |
| Total length of a 1 pole HTS wire | 3.0 km |

The basic design specifications of the 10 MW HTS generator are summarized in Table I.




<10 MW HTS generator> <Performance evaluation system for generator>

| Parameter | Value |
|---|---|
| Rated power | 10.5 MW |
| Rated L-L voltage | 6.6 kV |
| Rated rotating speed | 9.69 RPM |
| Num. of rotor poles | 40 ea |

*Force = Torque / Radius / Num.of poles*

- Rated torque of generator: 10.34 MN·m
- Radius of rotor part: 3.6 m
- **Rated force of 1 pole : 70.6 kN**

Fig. 1. Configuration of the 10 MW HTS wind generator and PES

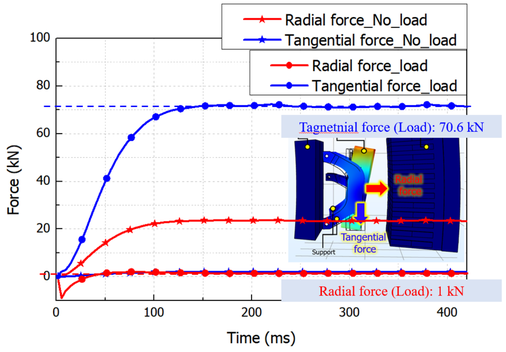



Fig. 2. Tangential and radial force of the 10 MW HTS wind generator

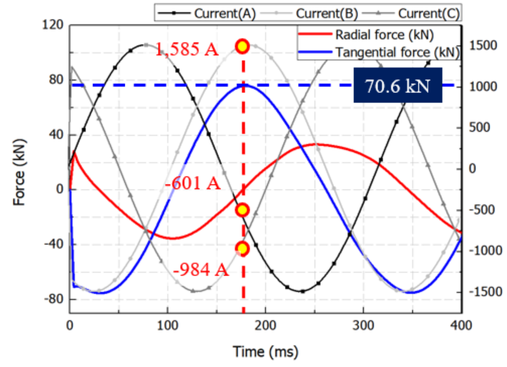



Fig. 3. Tangential and radial forces of the PES, 3-phase AC current supplied in the armature

Fig. 1 shows the configuration of the 10 MW HTS generator and PES. The PES consists of the same HTS coils and armature module that are identical to the actual size generator. The 3-pole arrangement of HTS field coils plays the role of the N and S pole the same as the rotating machine. The force applied to one HTS field coil according to the rated torque of the generator is calculated as 70.6 kN. Fig. 2 shows the tangential and radial force of the 10 MW HTS wind generator. Fig. 3 shows the tangential and radial forces of the PES, 3-phase AC current supplied in the armature. As can be seen from the electromagnetic analysis of the PES, the tangential and radial forces of the HTS coil were identical to the 10 MW HTS generator when the applied instantaneous currents of phases A, B, and C were -601 A, 1,585 A, and -984 A, respectively.

## 3 Fabrication of the HTS field coil and the performance evaluation system

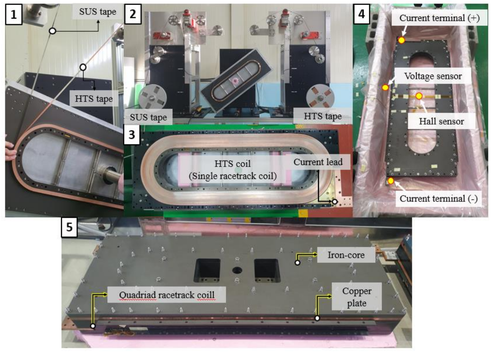



Fig. 4. Fabrication process of the HTS coil for the 10 MW HTS wind generator

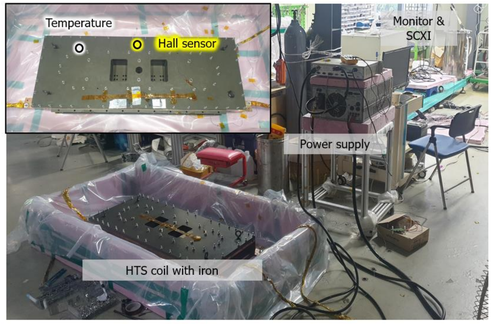



Fig. 5. Experimental setup and the critical current measurement test of the HTS field coil equipped with iron-core under the $LN_2$ cooling

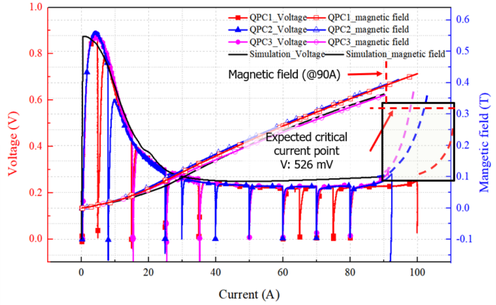



Fig. 6. Test results of the HTS field coils equipped with iron-core under the $LN_2$ cooling

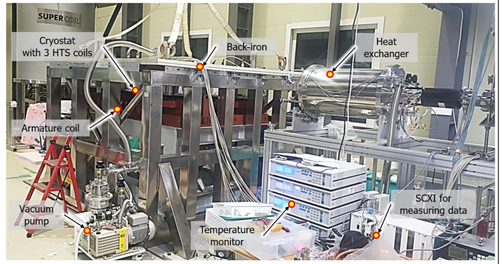



Fig. 7. Assembly complete of the performance evaluation system

Fig. 4 and Fig. 5 show the fabrication process of the HTS coil for the 10 MW HTS wind generator and experimental setup and the critical current measurement test of the HTS field coil equipped with iron-core under the LN2 cooling. Fig. 6 shows the test results of the HTS field coils equipped with iron-core under the LN2 cooling. The QPC 1 was manufactured by combining wire A and wire B and QPCs 2 and 3 were manufactured with wire B. Wire A has better critical current performance under magnetic field than wire B. Therefore, the critical current of QPC 1 was larger than QPCs 2 and 3. Fig. 7 shows the assembly complete of the performance evaluation system.

## 4 Test results of the PES

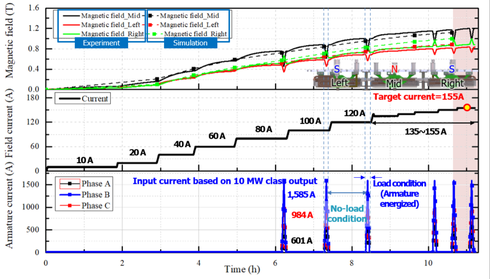



Fig. 8. Testing results of magnetic field characteristics of the PES

TABLE II
Comparison of the force acting on the generator and the PES

| Items | Rated torque | Tangential force | Rated current |
|---|---|---|---|
| 10 MW HTS generator | 10.34 MN·m | 70.6 kN | 918 $A_{rms}$ |
| Performance evaluation system | 10.39 MN·m | 71.0 kN | Phase A: -601 A<br>Phase B: 1,585 A<br>Phase C: -984 A |

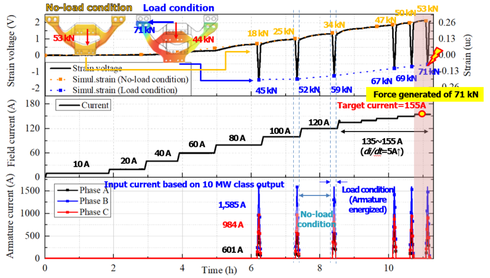



Fig. 9. Testing results of force characteristics of the center HTS field coil

Fig. 8 and Fig. 9 show the testing results of the PES about magnetic field and force characteristics about HTS field coils. The 3-pole HTS field coil was charged from 0 to 155 A. The Hall sensor was placed at an arbitrary position, and a magnetic field was measured. The strain of the HTS field coil supports was checked by energizing the armature coil input current based on 10 MW class output. When the field current reached 155 A, the force in the armature side direction due to no-load was 53 kN, and the force generated when the armature current was applied considering the load was confirmed to be 71 kN.

## 5 Conclusions

In this paper, the authors dealt with an experimental test and characteristic analysis of a real scale HTS coil for a 10 MW HTS generator using the performance evaluation system. The 3-pole HTS field coil equipped with iron-core was manufactured and tested at 77 K. The PES was fabricated and the HTS field coil was tested at 35 K the same as the actual HTS wind generator condition. The tangential forces of the simulated 10 MW HTS generator and the test results of the PES were 70.6 kN and 71.0 kN, respectively. As a result, it was found that the PES produced the same force as the field coils of the HTS generator.

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