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Design and property analysis of a performance evaluation system for HTS wind power generators

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1 Introduction

The authors proposed a method for assessing mechanical and electrical stability of a large-scale High Temperature Superconducting (HTS) wind generator based on a Performance Evaluation System (PES) that has the same characteristics as some of the pole-pairs of the HTS generator. The generator and the PES were analyzed using 3D Finite Element Method (FEM). The performance of the HTS coil was evaluated by comparing the tangential, radial and magnetic field distribution of the 10 MW HTS generator with the PES. The tangential and radial forces of the 10 MW HTS generator were 73 kN and 11 kN, respectively. The tangential, radial forces and magnetic flux density of the HTS coils in the PES were equal to one pole in the 10 MW HTS generator. Therefore, the proposed PES-based generator characteristic evaluation method can be used to estimate the mechanical stability of the generator under a high magnetic field and high torque before manufacturing the HTS wind turbine.

2 Design considerations of the HTS wind power generator

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	9.48 rpm
Rated torque	10.57 MN·m
Number of poles	40 poles
Turns of field coil	310 turns
Number of layers	4 layers
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	2.9 km

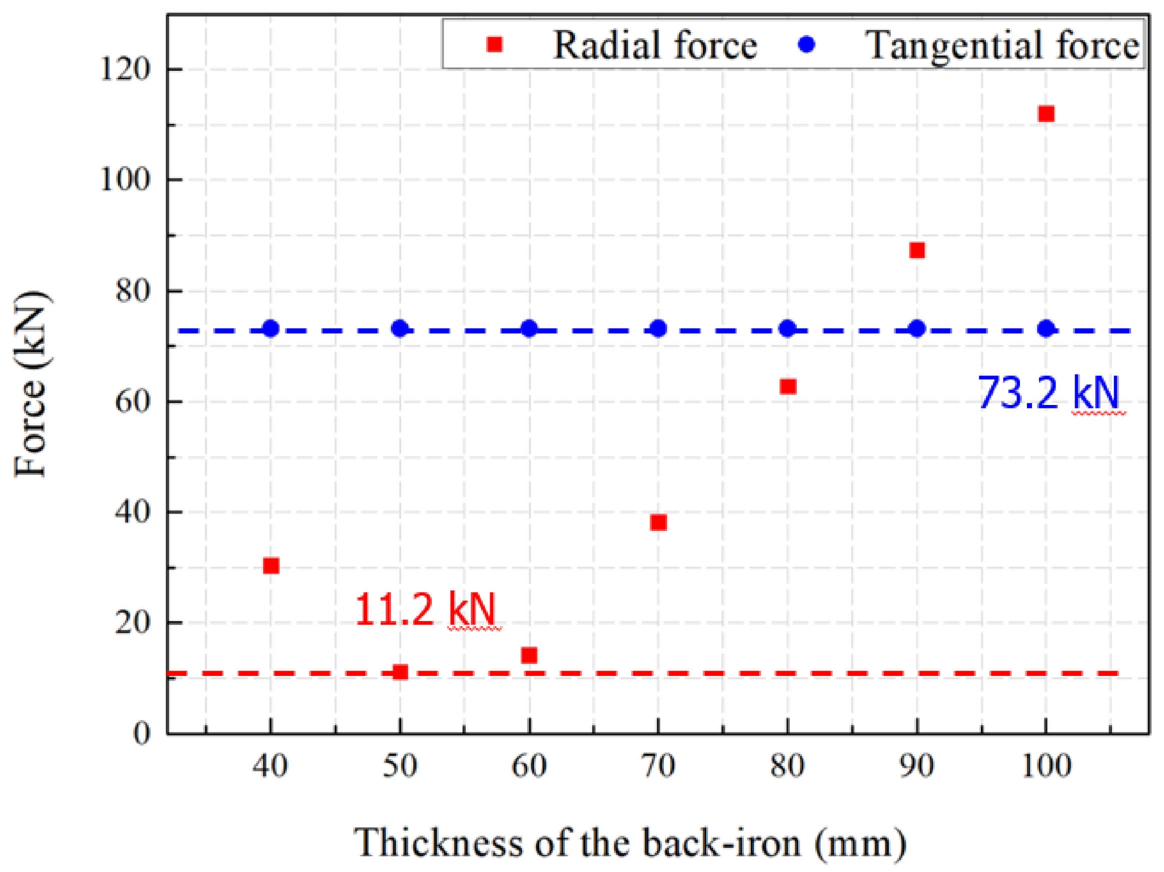

Fig. 1. Radial force of the HTS coil according to the thickness of the back-iron

In order to confirm the force acting on the HTS coil, the thickness of the back-iron was changed from 40 mm to 100 mm in the increments of 10 mm. The radial force from 60 mm to 100 mm occurred in the back-iron direction and 40 mm to 50 mm occurred in the stator direction. The HTS coil had the smallest force when the thickness of the back-iron was 50 mm. The tangential force and radial were 73 kN and 11 kN, respectively.

3 Design considerations of the performance evaluation system

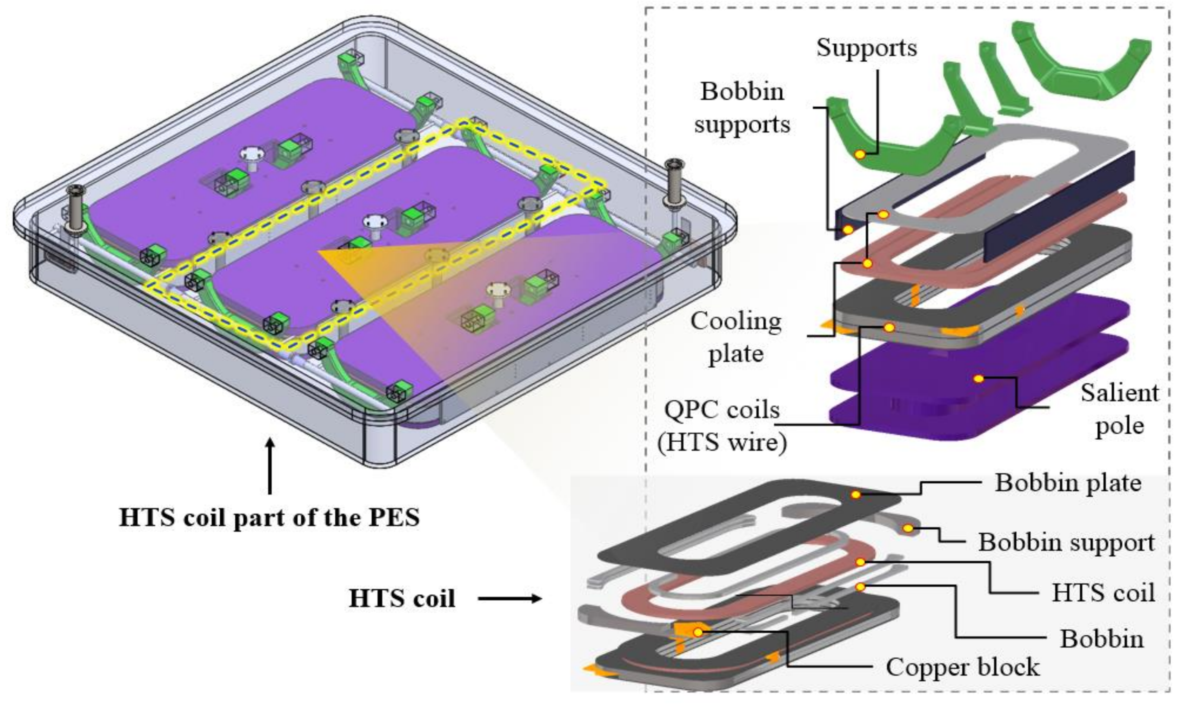

Fig. 2. Composition of the HTS coil part of the PES

The HTS coil part consists of three field coils and the same specifications as the 10 MW HTS generator. In the HTS generator, the HTS coils are arranged in a cylindrical geometry with continuous N-pole and S-pole. However, in the PES, the HTS coils are arranged in a linear geometry with discontinuous poles. Therefore, the HTS coils of PES produce the same interaction as the HTS generator. Fig. 2 illustrates the composition of the HTS coil part in the PES.

TABLE II
Specifications of the PES

Items	Value
Number of poles	3 poles
Number of layers per pole	4 layers
Turns of field coil	310 turns
Operating current of HTS coil	221 A
Operating temperature	35 K
Number of slots	34 slots
Operating current of the armature	918 A_{rms}

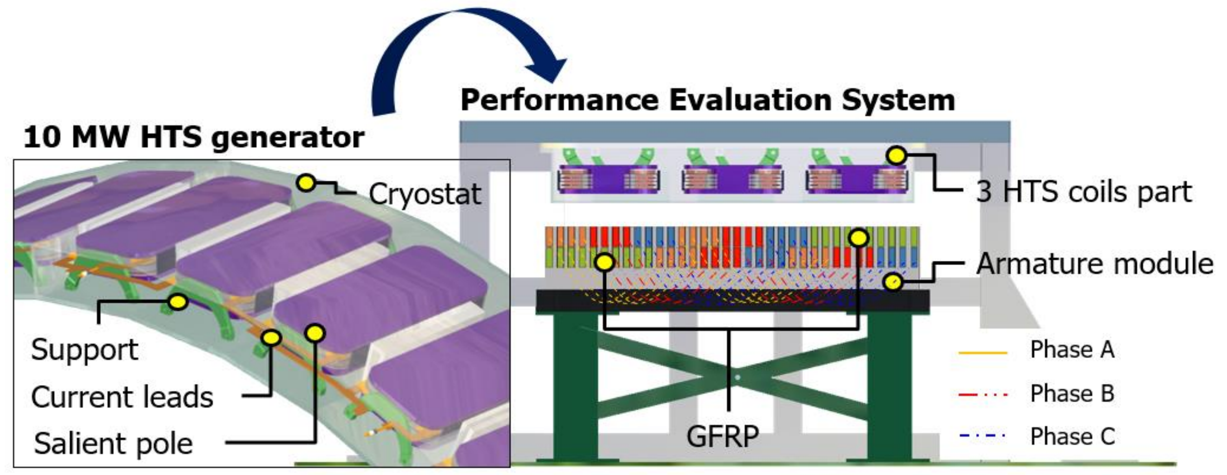

Fig. 3. The rotor part of the 10 MW HTS generator and the cross-sectional view of the PES

Firstly, supply the rated AC current of the 10 MW generator to the armature coil of PES, and check the magnitude of the instantaneous value at the moment when the middle field coil of the PES receives the same forces as the field coil at the rated operation of the 10 MW generator. Secondly, the armature is supplied with DC currents corresponding to the magnitude of the identified three-phase instantaneous current. At this time, the HTS coil of the PES interacts with the armature to generate the same electromagnetic force and torque as the generator. Since this force affects the HTS coil of the PES and supports, it is possible to evaluate the mechanical and electrical stability of the HTS field coil of the 10 MW HTS generator.

4 Simulation results of the generator and PES

A. FEM analysis of the 10 MW generator and PES

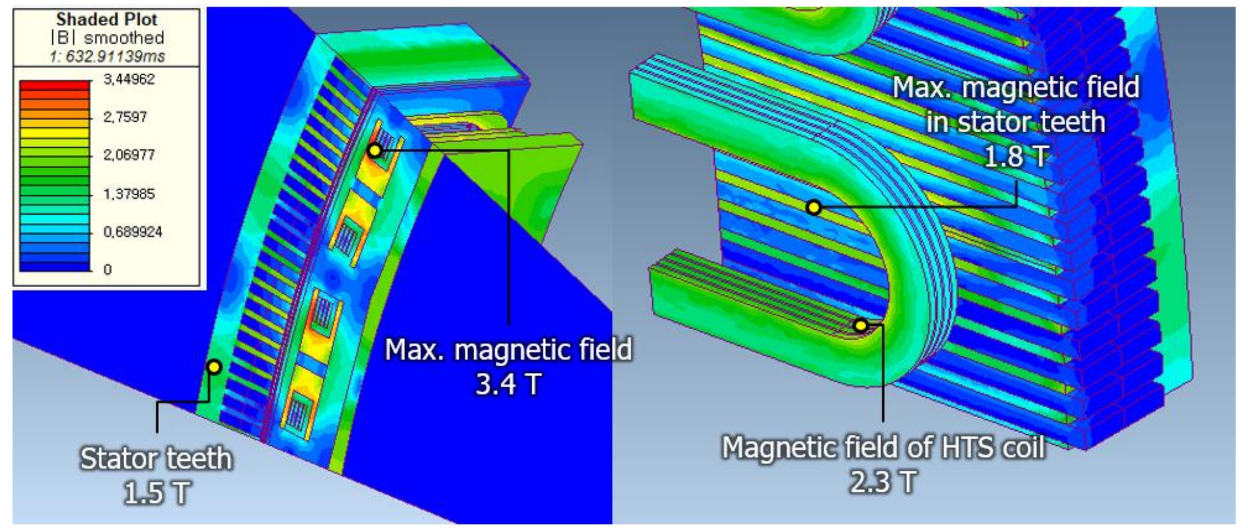

Fig. 4. Magnetic field distribution of the 10 MW HTS generator

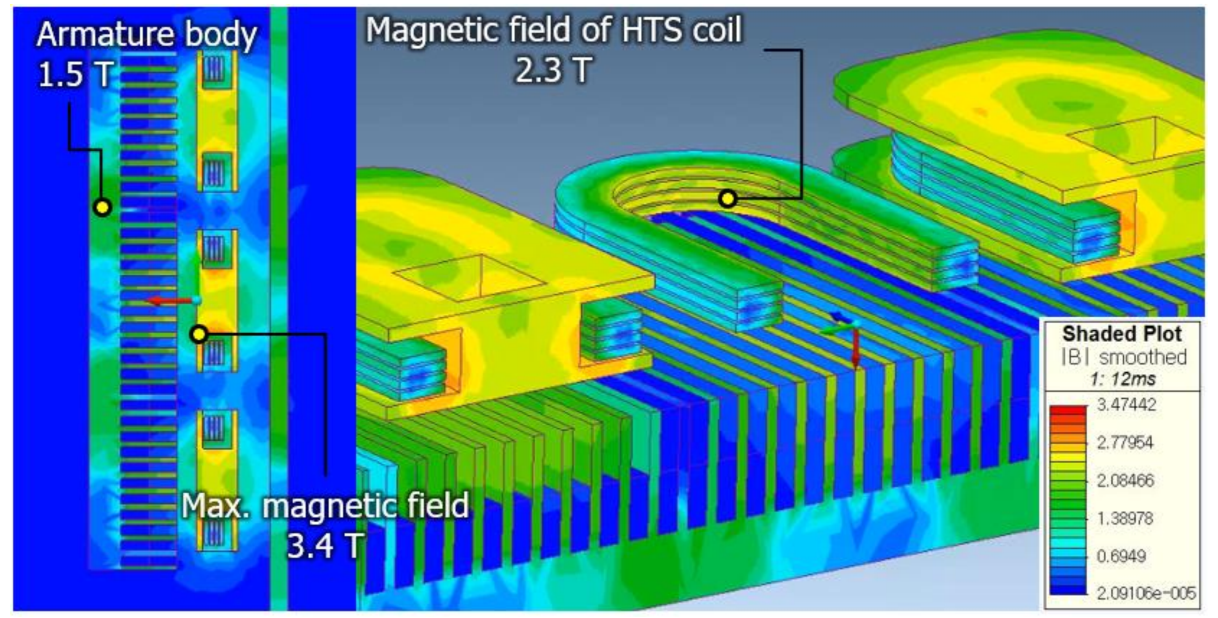

Fig. 5. Magnetic field distributions of the PES

B. Comparison of the 10 MW generator and PES

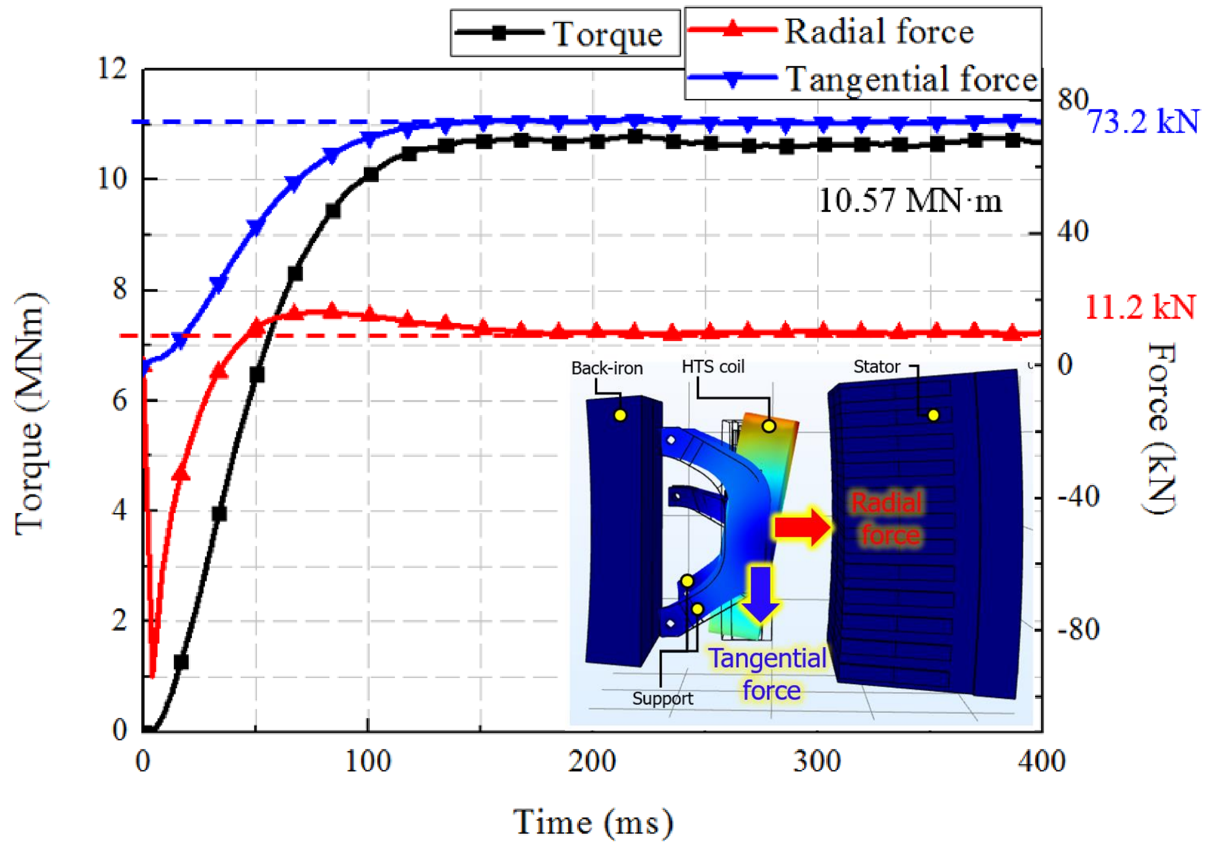

Fig. 6. Tangential, radial force, and torque of the 10 MW HTS generator

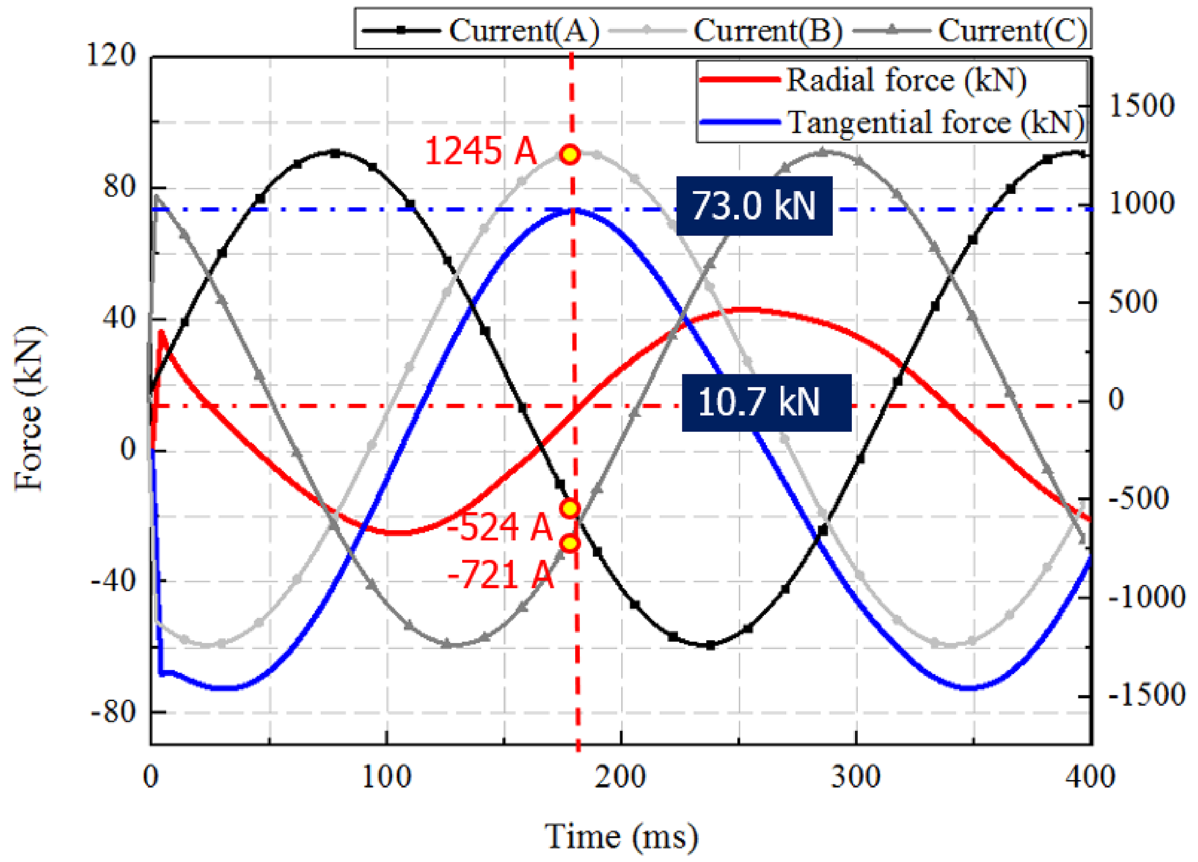

Fig. 7. Tangential and radial forces of the PES, 3-phase AC current supplied in the armature

Fig. 7 shows the tangential and radial forces of the PES when the rated 3-phase AC current of 10 MW HTS generator was supplied to the armature of the PES. The tangential and radial forces of the PES were 73.0 kN and 10.7 kN, respectively. The tangential and radial forces of the HTS coil of the electromagnetic analysis result of the PES were the same as the 10 MW HTS generator when the applied instantaneous currents of phase A, B, and C were -524 A, 1245 A, and -721 A, respectively.

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

Items	Radial force	Tangential force	Rated current
10 MW HTS generator	11.2 kN	73.2 kN	918 A_{rms}
Performance evaluation system	10.7 kN	73.0 kN	Phase A: -524 A Phase B: 1245 A Phase C: -721 A

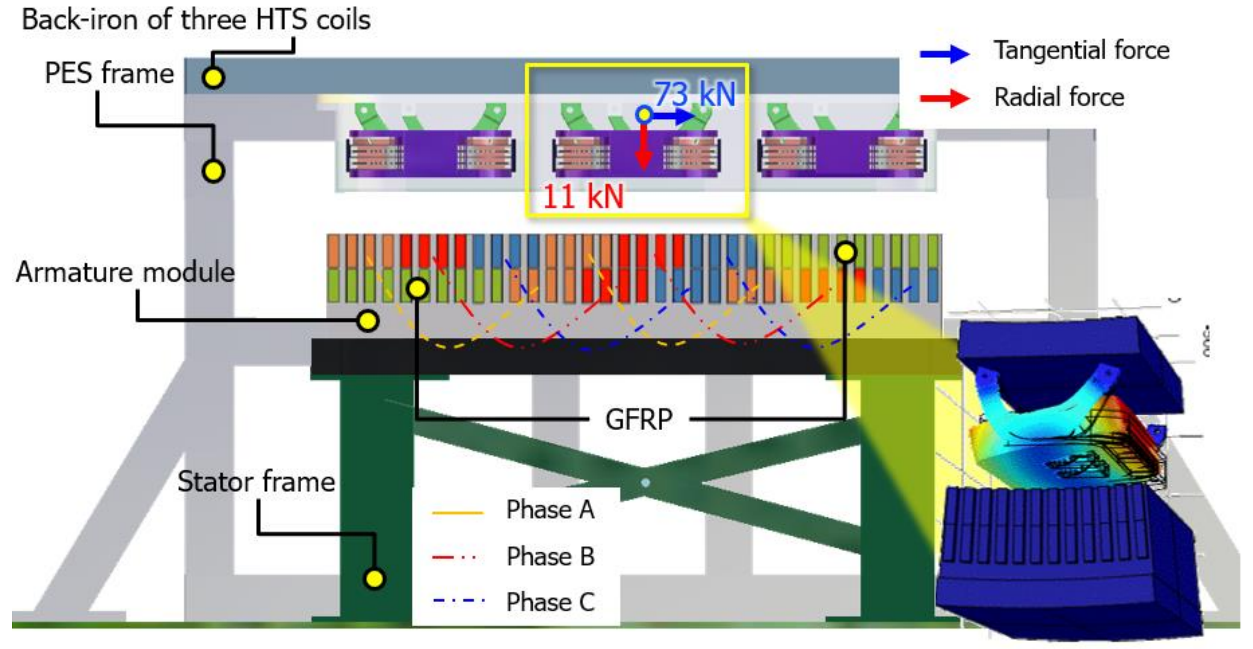

Fig. 8. Force values and directions of the HTS coil depending on the stator current

5 Conclusions

In this paper, the authors propose a real-scale PES as a way to evaluate the mechanical and electrical stability of a large HTS wind turbine generator. The distribution of magnetic fields in the 10 MW HTS generator and the PES were analyzed using 3D FEM. The 10 MW HTS generator and the PES were compared with each other with a focus on tangential, radial forces and magnetic flux density. The tangential forces of the 10 MW HTS generator and the PES were 73.2 kN and 73.0 kN, respectively. The radial forces of the 10 MW HTS generator and the PES were 11.2 kN and 10.7 kN, respectively. As a result, it was found that the PES produced the same force as the field coils of the HTS generator.

Next step is to build PES hardware and test its overall performances. The advantage of hardware-based PES that the authors want to implement is that it can physically check the characteristics of the generator before producing the actual generator.

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