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Design and feasibility study of a performance evaluation system for a large-scale HTS generator under short-circuit conditions

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CAPTA

1 Introduction

Generally, in a high temperature superconducting (HTS) generator, a large magnetic air gap exists because of needed space for a cryostat or non-magnetic cores in the HTS generators. Consequently, the inductance becomes lower than conventional genera-tors. As a result, the short circuit current and torque becomes as high as more than 10 times the rated torque. It would be very challenging to design the mechanical structure of a generator to withstand a high torque at the HTS field coils. Therefore, a performance evaluation system (PES) is required to test the HTS field coil and support structures of the generator. In this paper, the design and feasibility study of a PES for a large-scale HTS generator under short-circuit conditions are presented. The 10 MW class HTS generator and PES was designed based on the electromagnetic analysis results obtained using the finite element method. The torque and force of the HTS field coil were analyzed under normal and short-circuit conditions. As a result, the HTS field coil can be practically tested using the proposed PES whether the structure of the coil can withstand the high torque and force of the generator under normal and short-circuit conditions. The proposed PES design and analysis results can be effectively used for the development of large-scale HTS wind power generation systems.

2 Design of a 10 MW class HTS generator

A. Design and electromagnetic analysis of the 10 MW HTS 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
Turns of field coil	310
Number of layers	4
Operating current	221 A
Operating temperature	35 K
Mechanical / Electrical air gap	15 / 60 mm
Generator weight	120 ton
Total length of a 1 pole HTS wire	2.9 km

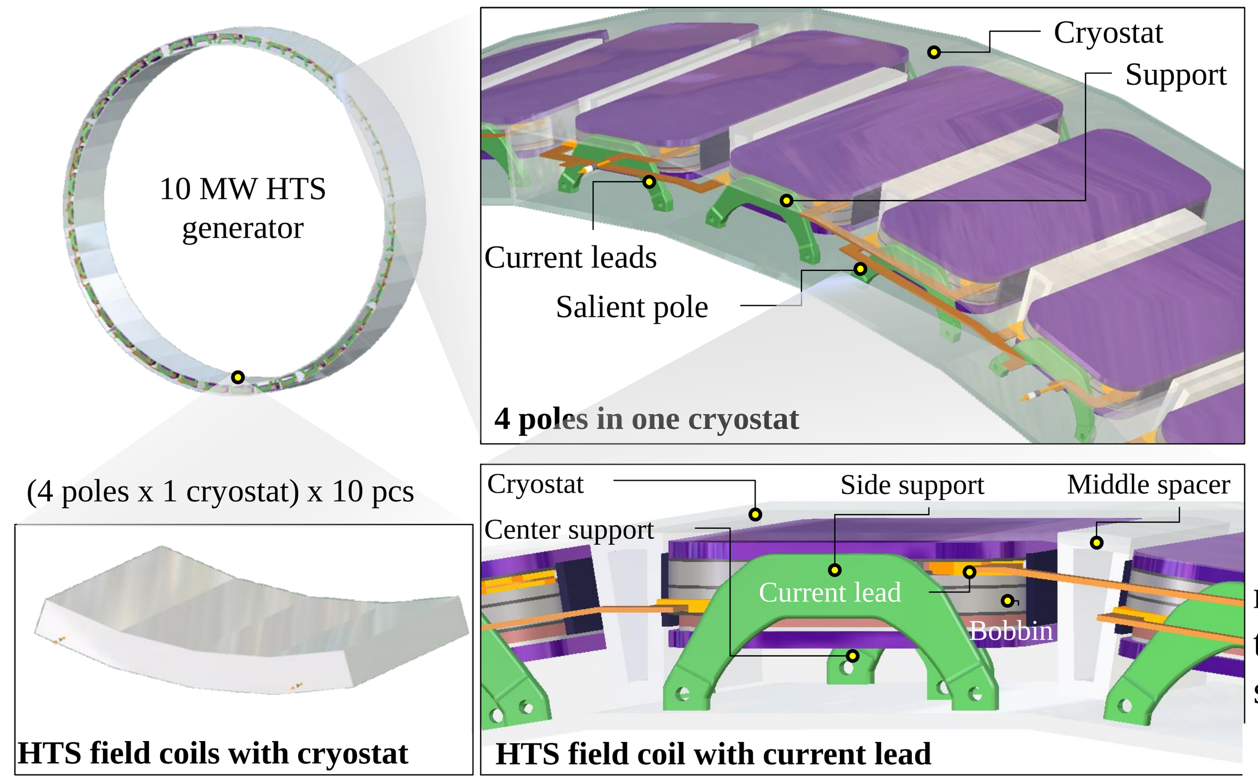

Fig. 1. Designed structure of the 10 MW class HTS generator

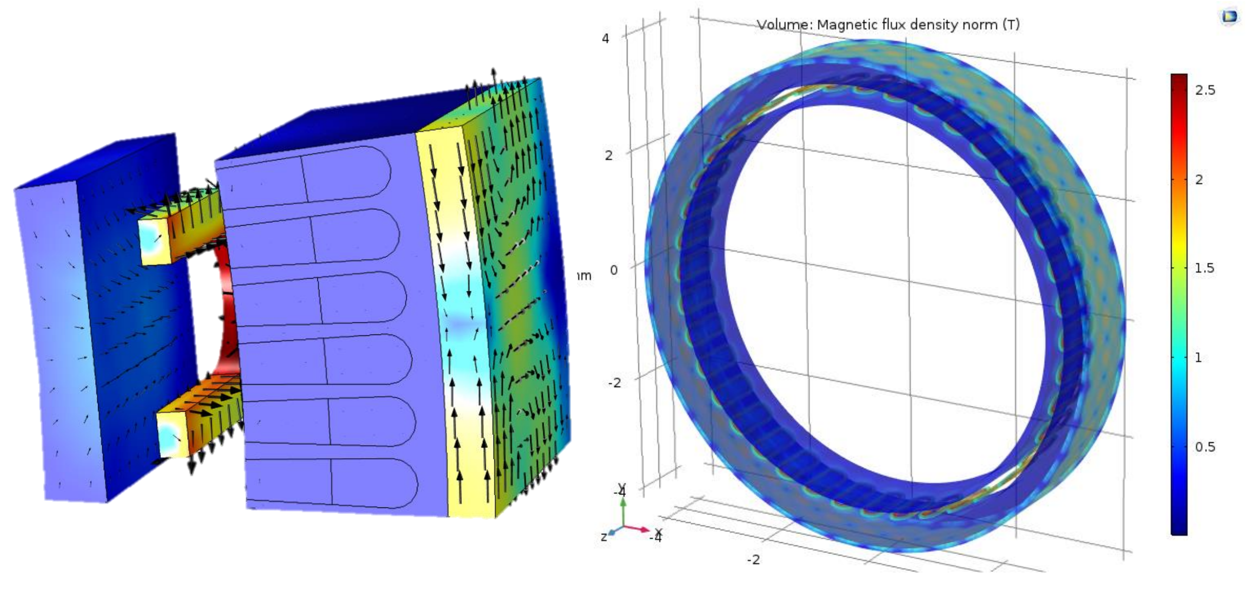

Fig. 2. Magnetic field distribution of the 10 MW HTS generator

Fig. 1 and Fig. 2 show the designed structure and magnetic field distribution of the 10 MW class HTS generator. The structures of the HTS field coil must be analyzed and tested for their ability to withstand the torque and force prior to installation on the HTS generators.

B. Torque and force of the HTS field coil

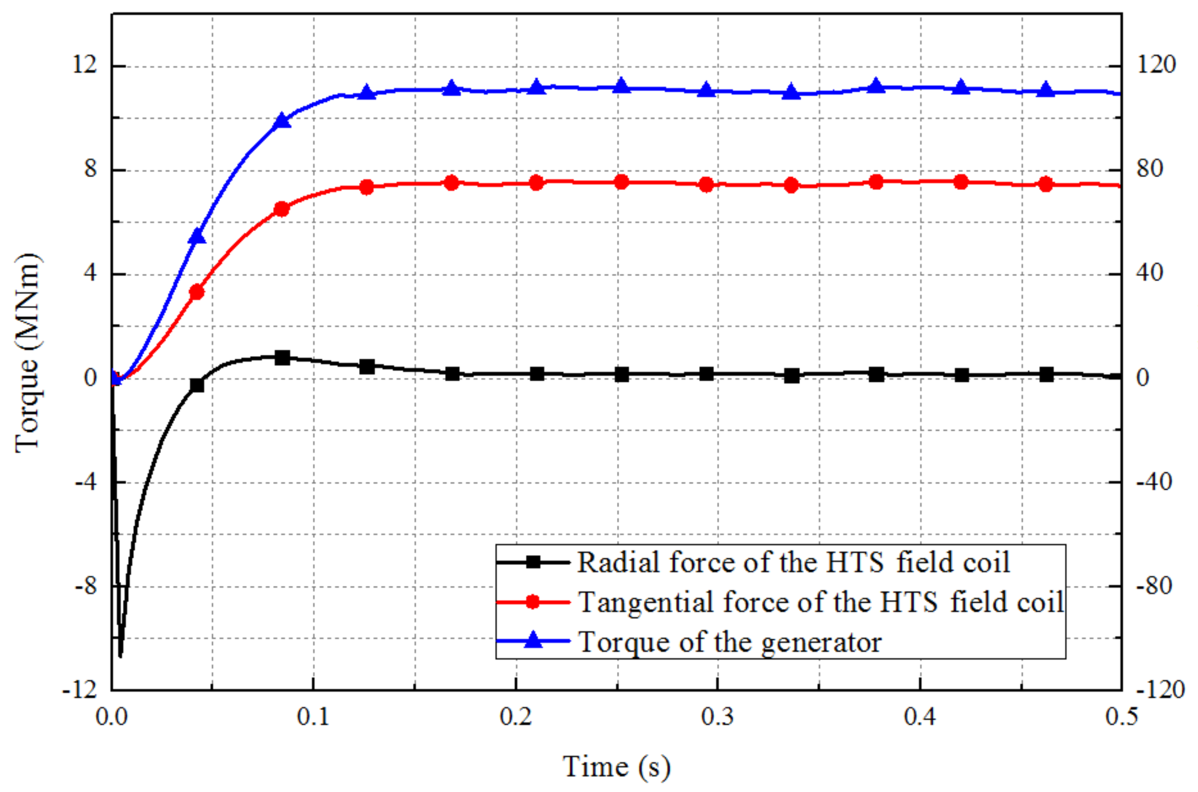

Fig. 3. Radial and tangential forces of the HTS field coil and torque of the designed 10 MW class HTS generator

Fig. 3 shows the radial and tangential force of the HTS field coil, and torque of the 10 MW class HTS generator. The radial and tangential force of the HTS field coil were 73.5 kN and 1 kN, respectively. The output torque of the generator is 10.6 MN·m. The tangential force can be calculated by following equation.

$$F_{tan} = \frac{\tau\ (torque)}{r\ (radius\ of\ rotor\ coil)}$$

3 Short circuit analysis results of 10 MW HTS generator

Generally, a three-phase short-circuit in a synchronous generator is very rare in the stator, but it is essential to understand the characteristics of the transient current. A three-phase short-circuit is considered to be the most stressful fault that a generator must endure.

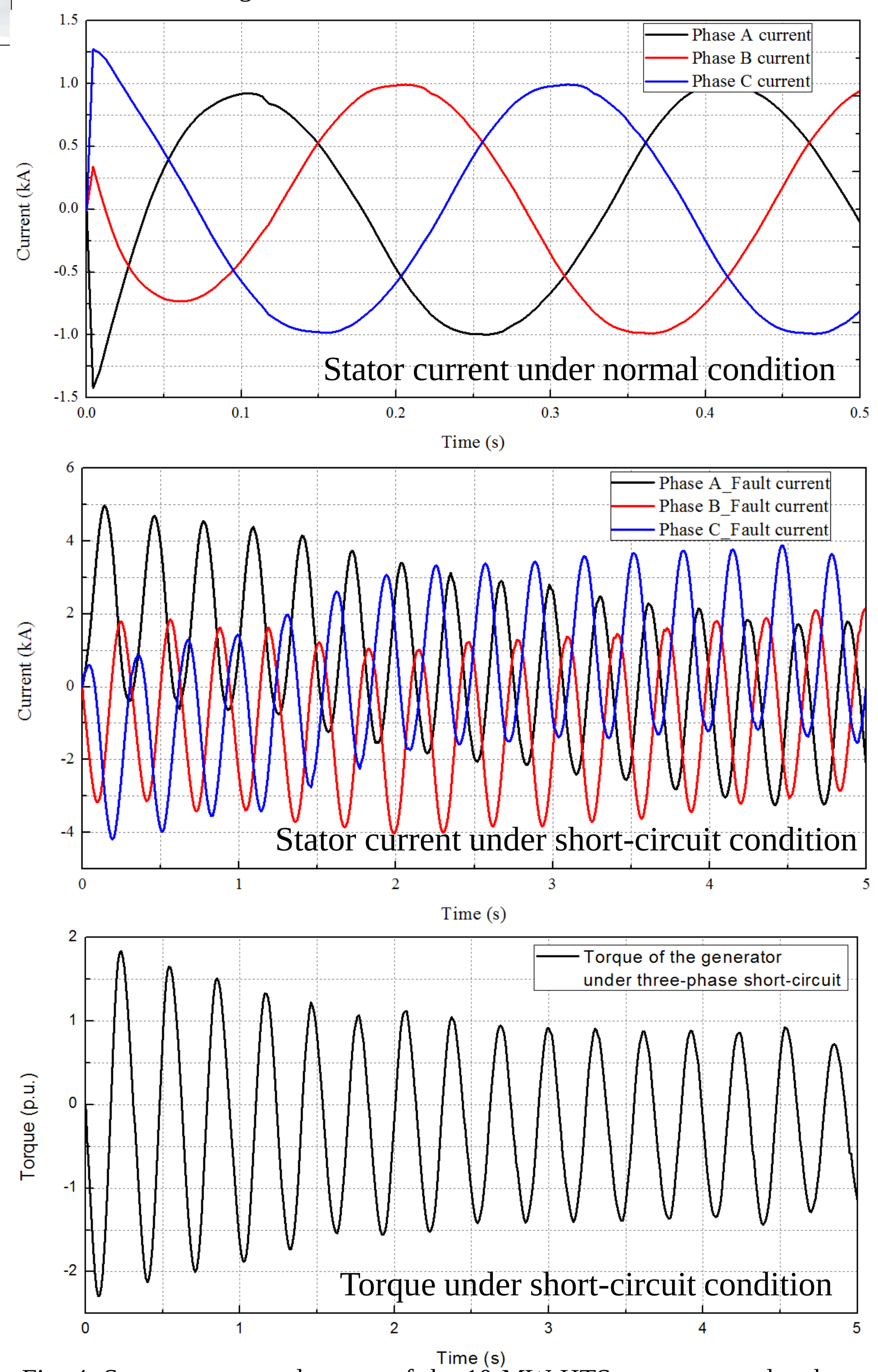

Fig. 4. Stator current and torque of the 10 MW HTS generator under short-circuit conditions

Fig. 4 shows the stator current and torque of the 10 MW HTS generator under short-circuit conditions. The lower reactance of the HTS generator will tend to result in larger fault currents than those that would occur in the case of a similarly-rated conventional generator. Such high stator currents and fault torques pose a great challenge to the generator. For instance, the insulation of the stator winding might get burnt due to intense heating during short circuits or the generator mechanical component could collapse. Moreover, the tangential and radial forces of the HTS field coils tend to overload the support parts and decrease the current carrying capacity of the field winding.

4 Design and analysis results of the PES

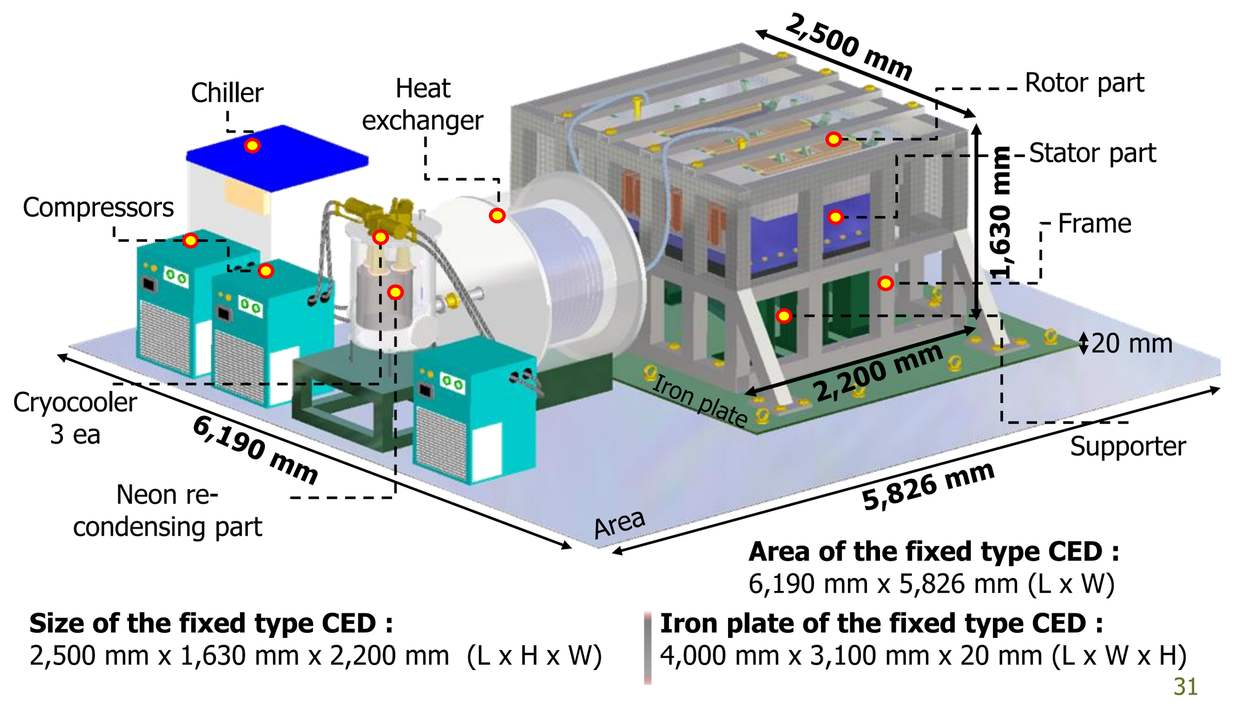

Fig. 5. Designed structure of the PES with cryo-cooling system

The PES can be used to evaluate and verify the HTS coils before mounting at the full generator. The PES for a 10 MW HTS generator was designed. The Fig. 5 shows the designed structure of the PES with cryo-cooling system. The PESs consist of a three-HTS field coil to make the pole-pair considering the interaction of the mutual inductance and magnetic field distribution between the HTS field coils. The torque and the force were generated by the magnetic field reaction between the rotor and the stator coils.

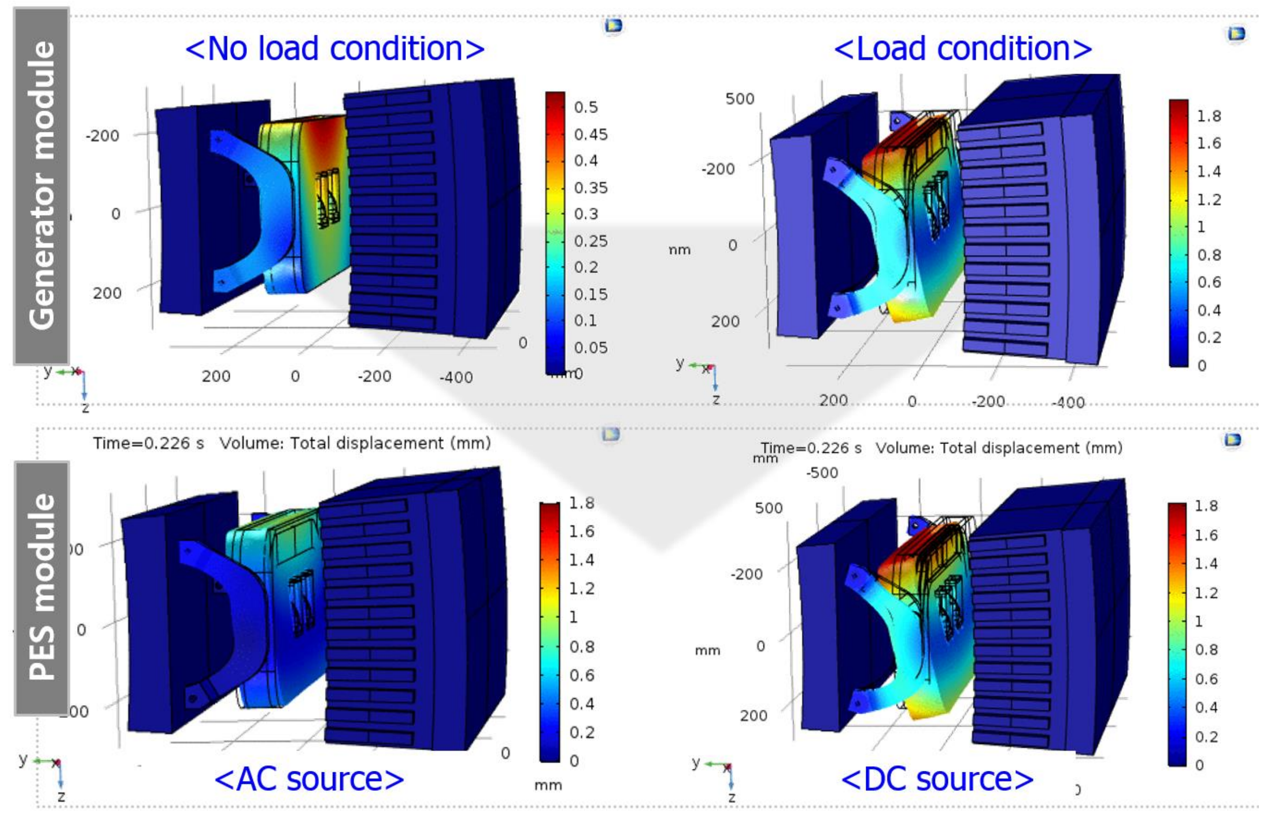

Fig. 6. Force analysis results of the HTS generator and PES under no-load and load conditions

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

Items	Radial force	Tangential force	Air-gap
10 MW HTS generator	1.0 kN	73.5 kN	15 mm
PES	0.9 kN	73.5 kN	19 mm

Table II represents the comparison results of the force acting on the generator and the PES. As a result, the radial and tangential force of the PESs were about 0.9 kN·m and 73.5 kN, which is identical to the designed specifications and the calculation results of the HTS generator.

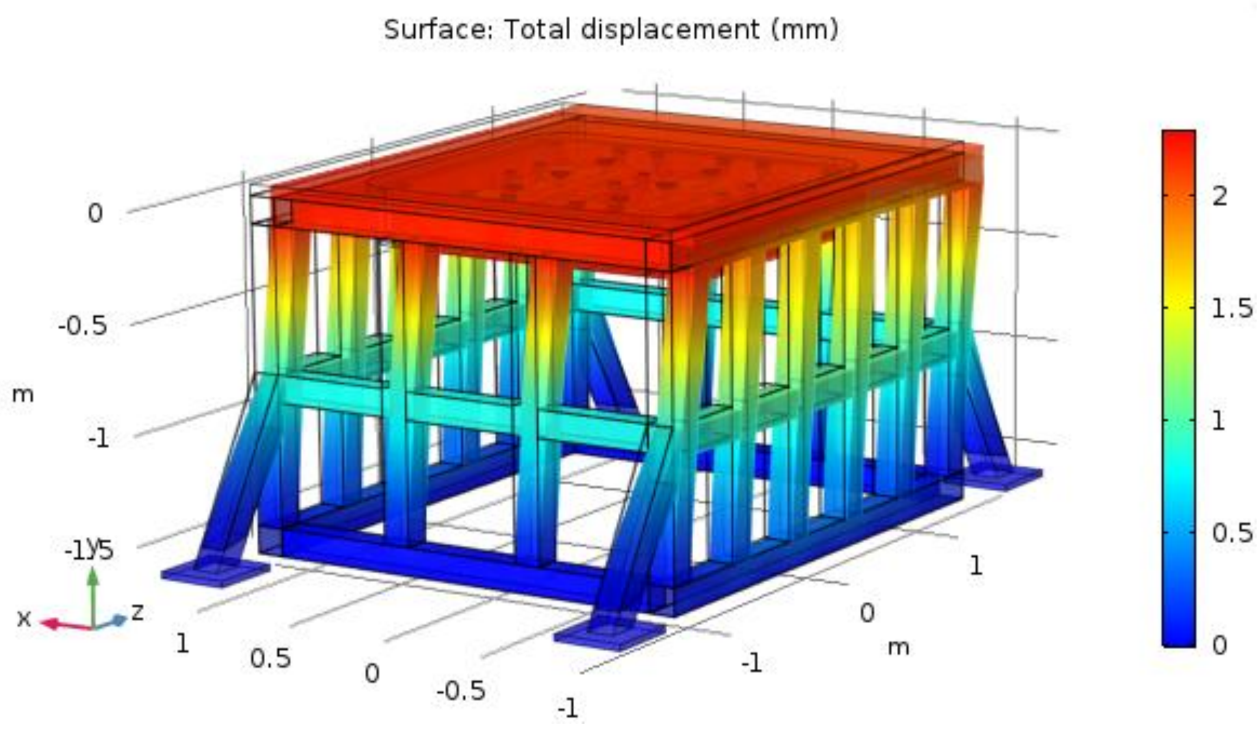

Fig. 7. Structural analysis results of the PES with a main frame

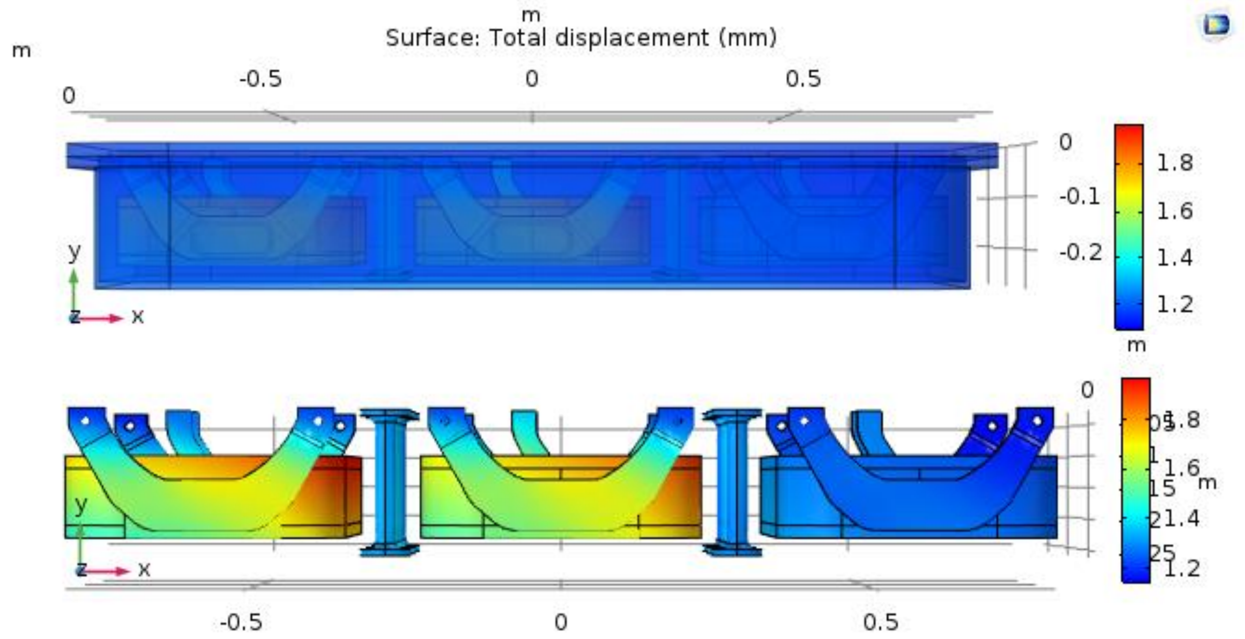

Fig. 8. Structural analysis results of the PES with HTS field coil and cryostat

Fig. 7 and 8 show the structural analysis results of the HTS field coil and overall PES system. The von Mises stress and displacement of designed structures can withstand the torque and force of the generator under normal condition. After that, we will build the PES in the near future considering the torque and forces under short-circuit conditions.

5 Conclusions

In this paper, the design and feasibility study of a PES for a large-scale HTS generator under short-circuit conditions are presented. Based on the specifications of the 10 MW class HTS generators, the stator and field current, torque, and force of the HTS coil were analyzed under normal and short-circuit conditions. The PES was designed based on the results of electromagnetic analysis using FEM program. We conclude that the proposed PES can test the high torque and force of the generator under normal and short-circuit conditions through stator and field current control. The proposed PES design and analysis results can be effectively used for the development of large-scale HTS wind power generation systems.

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