Electromechanical Design of a MW Class Wave Energy Converter with a HTS Tubular Linear Generator

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Abstract

We have proposed a direct-drive wave energy converter (**WEC**) device with a high-temperature superconducting tubular linear generator (**HTS-TLG**) adopted, and compared the design results of the HTS-TLG to the conventional TLGs, which suggests clear advantages of the HTS-TLG.

In this paper, we focus on the mechanical structure of the WEC, the cryogenic cooling system of the HTS-TLG, and the relation between maximum output power and size of the heaving buoy. Besides, design results of a 2 MW HTS-TLG are compared to those of another counterpart, which verified that the proposed HTS-TLG has higher power density. In the end, induced voltage waveforms of the 2 MW HTS-TLG are plotted.

Conceptual Structure

Overall structure and working principle:

- Buoy-I is used to extract power from ocean waves, and is directly coupled to the translator of the HTS-TLG.
- Buoy-II is surrounded the outer armature part of the HTS-TLG to float the armature part in sea water, which is moored to seabed.

As wave moves, the buoy-I heaves up and down, driving the translator of the HTS-TLG, so the voltage is induced.

Cryogenic cooling system:

Input power of the cryocooler comes from the output power of the HTS-TLG. The output power also provides the exciting current to HTS coils.

Configuration of cryostat:

The ring-shaped HTS coils are arranged as three layers. Between the inner and the outer shells, there are GFRP pins with length of 6 mm.

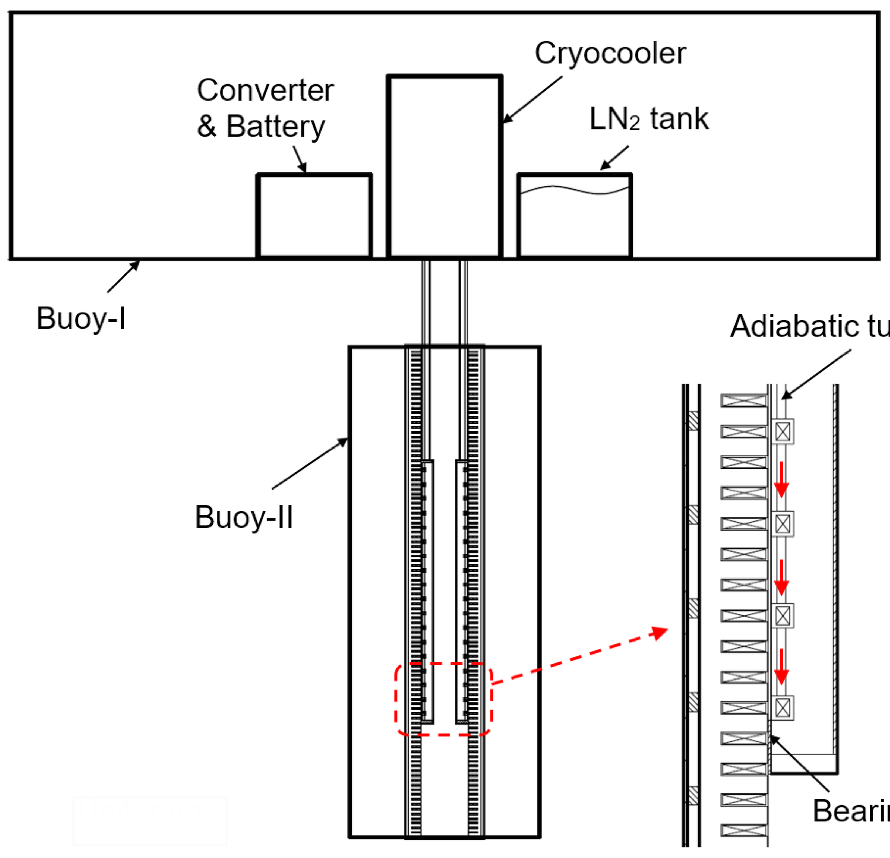

Fig. 1. Conceptual structure of the WEC.

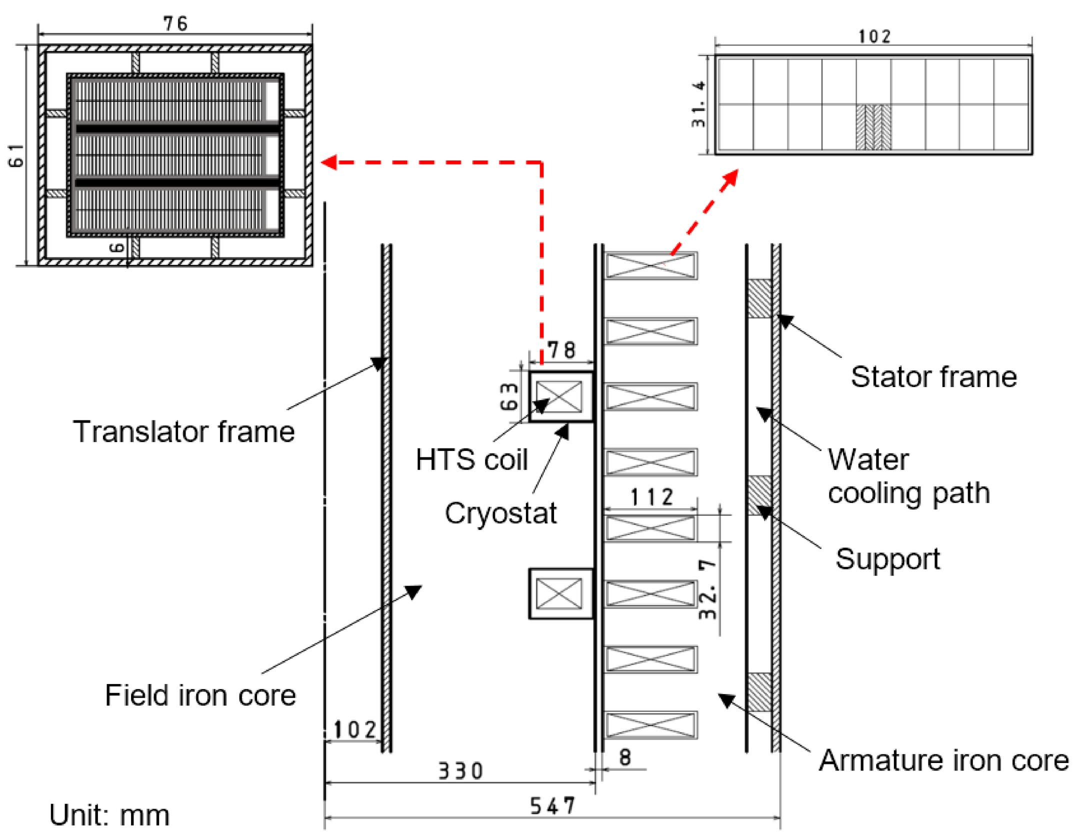

Fig. 2. Cross sectional view of a 1 MW HTS-TLG.

Maximum output power

The relation of maximum output power and the radius of buoy-I :

$$P_m = \pi^2 \rho g f_0 A^2 r^2 \cdot \sin 2\alpha$$

where P_m is maximum output power of the HTS-TLG, ρ mass density of sea water, g gravitational acceleration, f_0 wave frequency, A wave amplitude, and r is radius of the buoy-I.

$$\cos\alpha = v_{bm} / v_{sm}$$

where v_{bm} and v_{sm} are peak velocities of the buoy-I and waves, respectively.

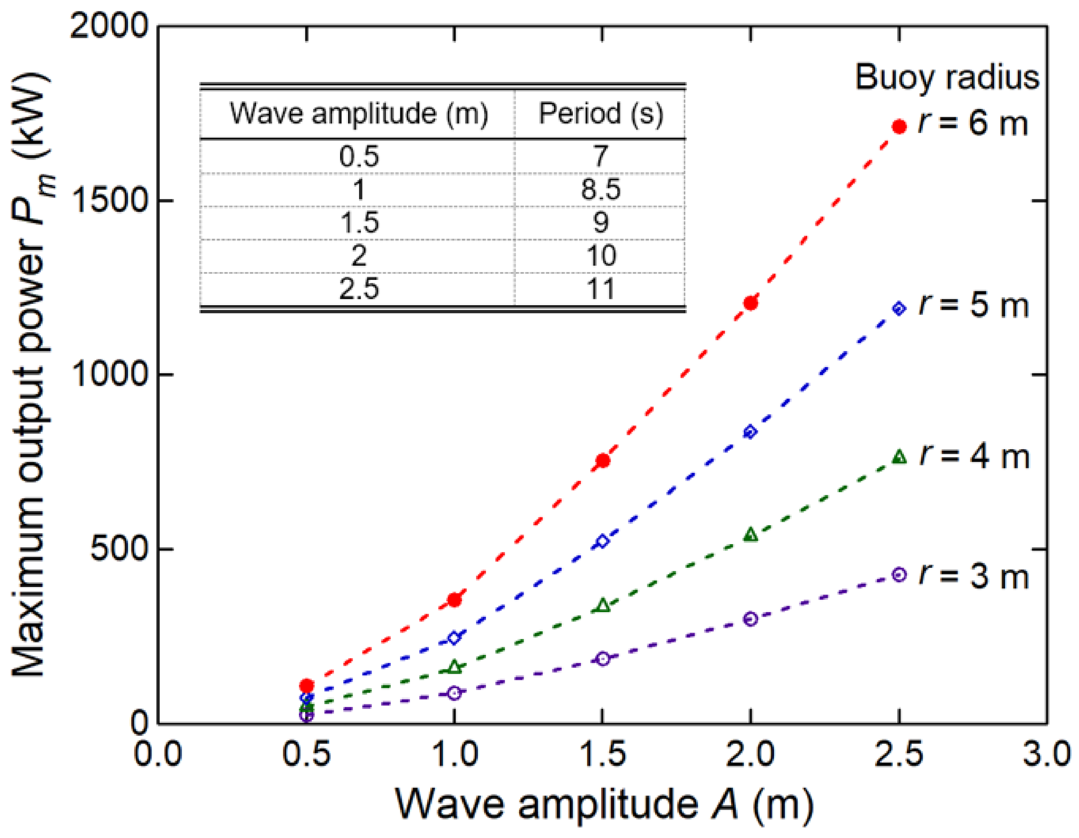

Fig. 3. Variation of maximum output power with wave amplitude under different buoy radii.

Design Results

Table I
Performance Comparison of a 2 MW HTS-TLG with a SCLG Proposed in [1].

Item	HTS-TLG	SCLG
Rated output power P_m (kW)	1000	640
Terminal voltage (V)	660	1010
Line current (A)	1750	732
Wave frequency f_0 (Hz)	0.4	0.3
Maximum stroke (m)	2.0	2.4
Maximum linear speed (m/s)	2.5	2.2
Generator length (m)	9.3	9.6
Length of SC wire (km)	17.5	27.4
Stator weight (ton)	20.4	18.5
Translator weight (ton)	6.8	3.0
Weight of generator with cryocooler W_g (ton)	28.2	21.5
P_m / W_g (kW/ton)	71	60

Features:

- Rated output power of the HTS-TLG is more than 1.5 times than that of the SCLG.
- Length of these two linear generators is almost the same.
- The SCLG has a much lighter translator than the HTS-TLG. And the total weight of SCLG is about 3/4 that of the HTS-TLG.
- Power density (P_m / W_g) of the HTS-TLG is 18% higher than that of the SCLG.
- The HTS-TLG uses 17.5 km × 5 mm × 0.2 mm AMSC's HTS wires, much less amount of expensive HTS wires than the SCLG (less than 1/2), implying a substantial reduction of costs..

[1] O. Keysan, and M. Mueller, "A linear superconducting generator for wave energy converters," *in IET International Conf. on PEMD*, pp. 134, 2012.

Induced voltage

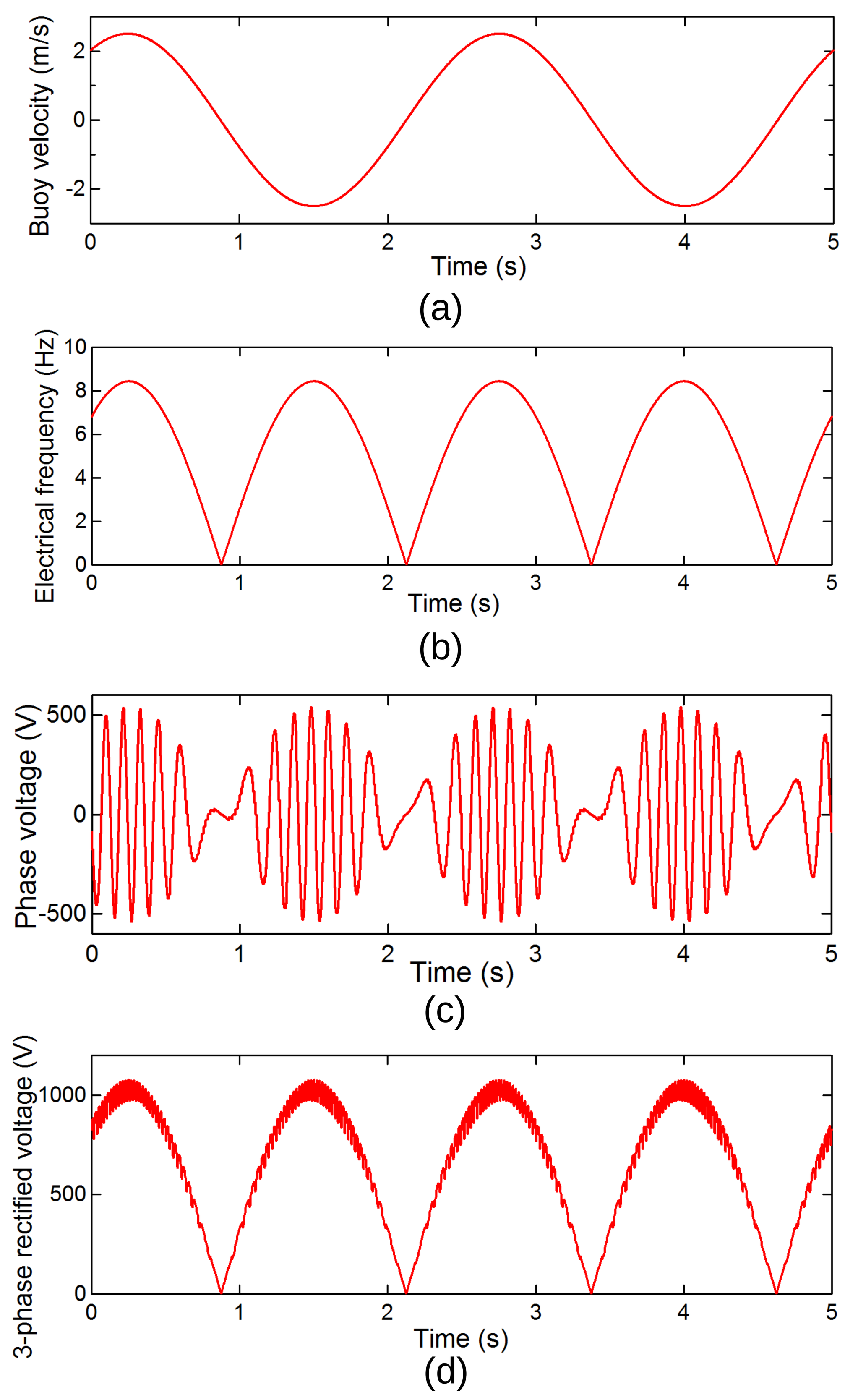

Fig.4. Time dependence of (a) buoy velocity; (b) electrical frequency of the HTS-TLG; (c) induced phase voltage under no-load condition; (d) 3-phase rectified voltage under no-load condition.

Conclusion

1) Conceptual structure is considered in the viewpoint of industrial application, including the cryogenic cooling system proposed.
2) The relation between maximum output power and size of the heaving buoy shows a reference to decide the output power and the buoy size.
3) Comparisons between the 2 MW HTS-TLG and a counterpart demonstrate advantages of the former in power density and reduction of HTS wires.