波力発電装置用小型リニア発電機の設計研究

[課程博士・論文博士共通]

博士学位論文内容要旨
Abstract of Dissertation

専　攻 Major	応用環境システム学専攻	氏　名 Name	カンボ　　ペトルス
論文題目 Title	Design study of a compact linear generator for wave energy converter (波力発電装置用小型リニア発電機の設計研究)		

Renewable energy provides a clean and persistent form of energy. Ocean energy sources are renewable, have a high energy density, and could be more predictable than solar and wind energy. Wave energy is a type of ocean energy that offers the highest energy density among renewable energies. The global focus on the utilization of renewable energy in this century and the continued increase in energy demand place the development of power generation systems using ocean energy, especially wave energy, as an essential area of research and development for the next generation. For this reason, I have chosen wave power generation as my research subject. Wave energy is carried by seawater, which has a density of 840 times that of air. Seawater, a high-density working fluid with a large mass, exerts a large force on the generator. Not only that ocean waves exert a large force, but they also have a low frequency of oscillation, which slowly drives a power generation mechanism of a wave energy converter (WEC). This yields a slow-changing magnetic field through the induction coil. Almost generators produce power by electromagnetic induction, so the WEC outputs a low electromotive force due to this magnetic field change.

On the other hand, the stroke length obtained by wave power generation systems from near-shore with small wave heights is short, and together with their low frequency of oscillation, the output power is small. Therefore, a WEC device with improved output power despite its short stroke length is necessary to achieve practical application of ocean power generation systems. The above-mentioned high density of seawater also generates a large external force on the WEC, which places a significant load on the power-generating mechanism of a linear generator and could cause damage to the power-generating device. Consequently, damping the large loads from ocean waves in a practical WEC is desirable. To solve the problems mentioned above associated with the state-of-the-art technology of WEC, this research thesis aims to develop a compact linear generator suitable for the practical application of wave energy power generation. This is achieved by designing a new linear generator structure. The process of achieving the goal of this research will be addressed in the six chapters of the thesis.

Chapter 1 shows ocean power generation's global energy resource availability. Japan's overview of the demand for ocean power generation as related to the 13th goal of the SDGs and the need for energy self-sufficiency or energy security is presented. To determine the potential of ocean power generation for practical application in Japan, the current and projected cost of ocean energy generation in ¥/kWh is compared to other types of renewable energy. Finally, the objective and purpose of this research study are presented.

Chapter 2 is based on wave energy converters, whereby the working principle of wave energy conversion is presented. State-of-the-art power-generating technologies for wave energy converters from different countries are also introduced. We present the challenges of wave power generating technologies. The linear generators that have been realized for WEC application have been presented. These linear generators use permanent magnets (PMs) or superconducting materials for field poles. It further presents their developer, design specifications, and how different they operate, and we present their advantages and disadvantages.

In Chapter 3, we present field pole materials. Typical or commercially available PM types are shown with their demagnetization curves and magnetic properties. A particular focus was given to the neodymium type of PM as it was used later in the analysis study. Superconducting materials are also presented, whereby

the fundamentals of superconductivity, developments of HTS bulks, advantages, and applications of high-temperature superconducting (HTS) bulk magnets to power devices are presented.

Chapter 4 shows a compact linear generator for a wave energy converter. The concept design structure of the proposed device for WEC is demonstrated. It has a moving armature coil and REBaCuO HTS bulk field pole concept, which we call a dual translator power generation system. We also present the advantages of the proposed device. Finally, the cost estimation of the generated power by this generator machine is performed to determine its feasibility. Thus, the levelized cost of energy production (LCOE) or cost of power generation of the proposed dual translator linear power generator was found to be ¥38.3/kWh.

In Chapter 5, we analyzed the performance of a compact linear power generator's concept design structure using a finite-element electromagnetic field analysis method. Determining the main machine parameters for the dual translator HTS linear power generator was conducted. Simulation results were compared between our dual translator HTS linear generator structure and the use of PMs for the field poles of that structure. It was found that the EMFs, electromagnetic forces, and output power of the dual translator HTS linear power generator structure are 1.67, 2.63, and 2.60 times superior to those of the dual translator PM linear generator structure, respectively.

Chapter 6 compares the finite-element electromagnetic field analysis results of a dual translator HTS linear generator structure to that of a single translator HTS linear power generator structure. The maximum electromagnetic force and the average output power of the dual translator HTS generator are around 5 % and 11 % higher than that of the single translator HTS generator. We further present the results of the analysis regarding the influence of reducing the stroke length of the linear generator translator on the output power, where the output power of the dual translator HTS system increased up to a factor of two, in comparison to the single translator HTS counterpart, for the same reduction of stroke length.

This research is concluded as follows. A novel design structure of a compact linear power generator for WEC has been developed. It has a dual translator power generation system and uses HTS bulks for field poles. The developed linear generator machine increases the strength of the magnetic field in the airgap and the changing magnetic field through the induction coil. A combination of the dual translator and HTS bulks has the potential to help us to achieve higher torque and higher output power despite the low frequency of oscillation of ocean waves and short strokes. This is a prerequisite for a WEC to achieve practical application, essential for commercializing ocean energy power generation systems.