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ANALYTICAL MODEL OF AN IMPROVED LINEAR GENERATOR FOR SEAWAVE ENERGY HARVESTING

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Abstract

This paper describes an improved topology of a linear permanent magnet generator for sea wave energy harvesting and presents an electrical model for analysis of this generator. The electrical model is established based on the magnetic equivalent circuit of the machine. This model can be used to design a power electronic interface for capturing maximum power at the resonant frequency of a sea wave. Validity of the model is verified via comparing the calculated inductance of the machine with that of obtained from numerical analysis based on finite element method.

1 Introduction

Sea waves are among renewable sources of mechanical energy oscillating at variable low frequencies, ranging from a fraction of *Hz* up to a few *Hz*. Capturing and converting the energy of a sea wave to electricity at low frequencies requires a suitable generator and mechanical structures. Among various suggested topologies for oscillation-to-electricity energy conversion, the combination of linear generators connected to point absorbers has been recognized as an efficient and viable structure for sea wave energy harvesting [1,2]. In this structure, a floating object (buoy) is connected to the translator of a linear generator and the mechanical energy of the translator is converted to electrical energy often by using a variable reluctance energy conversion mechanism. Several linear machine topologies including transverse flux permanent magnet machines (TFPMs) [3,4], hybrid vernier [5,6], and switched reluctance machines[7] have been suggested as suitable linear generators for sea waves energy harvesting [1,8]. One of the main challenges with linear TFPMs is high shear stress at the translator of the generators. This paper describes an improved structure for a linear generator which reduces the shear stress by using a rigid stator axis at the centre of the machine.

To capture the maximum power from the sea waves, mechanical structure of the generator and the connected point absorber should resonant at the sea wave frequency. This resonance frequency must be able to adaptively follow the sea wave frequencies. This can be achieved mechanically using latching, breaking and clutching mechanisms which in turn add to the complexity of the wave energy convertors [9]. An alternative solution is to achieve resonant condition via electric loading of the machine [10-12]. A power electronic circuit can statically match an electric load with the electrical model of the machine and the resonance frequency of the mechanical part can be adaptively adjusted by tuning the electrical damping and stiffness. Design of electrically matching circuit requires an accurate electrical model of the generator. This paper also deals with an analytical modelling approach based on the concept of magnetic equivalent circuit. Using a few simplifying assumptions, a magnetic equivalent circuit has been obtained for the machine and the electrical model of the machine has been developed using the equivalent circuit. Finally, the paper verifies the validity of the model assumptions via comparing the analytical model parameters with those of obtained through numerical (finite element) analysis of the machine.

2 Existing Generator Topologies for Sea wave Energy Harvesting

In high torque and low speed (frequency) applications, direct-drive energy converter topology has been recognized as a suitable topology due to eliminating gear box and therefore improving the efficiency of the machine. Electric motors for the thrusters of the ships and drive-drive (gearless) wind turbine-generators are two examples of direct-drive energy conversions in motor and generator modes. In sea wave energy harvesting applications, also high torque (force) and low frequency generators are required as the oscillation frequencies of the sea-waves range from a fraction of Hz up to a few Hz. For this application, linear machines suggest a more appropriate topology compared to rotational ones.

The operation principle of linear generators is the same as rotational machine: mechanical oscillation results in a variable flux which induces voltage in the machine coils. The flux vibration can be also created via a variable reluctance mechanism. In so far existing machining, linear movement of a translator in presence of a permanent magnet (PM) flux creates a variable flux linkage. A linear machine without permanent magnet requires an external electric source to provide sufficient flux for energy conversion which is often impractical for marine applications. The weak point of PM machine is the volatile cost permanent magnetic which limits the power rating of the machine.

Variable reluctance permanent magnet (VRPM) machines are well known generators for sea wave energy harvesting in which the PM's flux is changed via variation of reluctance