Published in IET Electric Power Applications
Received on 31st August 2012
Revised on 18th December 2012
Accepted on 2nd January 2013
doi: 10.1049/iet-epa.2012.0247

ISSN 1751-8660

Rim-drive marine thruster using a multiple-can induction motor

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Abstract: This study presents the development, analysis, manufacture and testing of a demonstrator multiple-can line-start rim-drive induction motor for use as a bi-directional electric thruster on-board a tidal stream turbine. A simple 'canned' rotor construction was used to eliminate the requirement for a conventional squirrel-cage rotor, to minimise the rotor size and weight and improve reliability, all the while providing compatibility with the sub-sea operating environment. The experimental test results on a demonstrator 30 kW rim-drive motor show good agreement with finite-element analysis predicted results.

1 Introduction

With generally rising energy costs and environmental concerns from burning fossil fuels, there is a growing demand to generate cleaner energy [1]. One of the potential sources of this cleaner energy is from renewable energy resources and technologies that exploit them [2]. Consequently, Rolls-Royce, through its subsidiary Tidal Generation Ltd., is developing tidal stream turbines to generate power from tidal currents, as illustrated in Fig. 1.

The tidal stream turbine shown in Fig. 1 is a fully submersible machine designed to operate at sea depths typically about 30–50 m. A demonstrator tidal stream turbine, DeepGen 3, capable of generating up to 500 kW has been successfully installed and operated at the European Marine Energy Centre (EMEC) in Orkney, Scotland.

1.1 Requirements for a bi-directional thruster

The tidal stream turbine is fixed to the sea floor using a secure tripod base which supports the 'nacelle', as illustrated in Fig. 1. The nacelle is buoyant so that it can be removed easily from the tripod and floated to the surface, then shipped to a facility for maintenance or repair. To maximise the capture of useful tidal stream energy and avoid turbulence from the support structure, the turbine is steered (yawed) into the direction of the tide. A bi-directional thruster mounted at the rear of the nacelle, as illustrated in Fig. 2, is therefore needed to yaw the nacelle through 180° when the tide reverses.

On-board the DeepGen 3 tidal stream turbine, yawing is undertaken using a hydraulically driven thruster. Hydraulic thrusters have a number of disadvantages, however, including the need for an appropriately rated hydraulic power pack (pump and accumulators) and the requirement to pass high pressure hoses through the nacelle wall. An equivalent electric thruster capable of performing the yawing duty would improve the operation of the turbine by increasing its safety and reliability, reducing maintenance costs and saving valuable space within the nacelle.

1.2 Operational requirements of the bi-directional electric thruster

In applications where high speed is not required, there is the potential for electric machines to be directly coupled to the load. These are referred to as 'direct-drive' machines. Direct-drive machines offer several advantages including reduced through-life costs, reduced weight, and reduced noise and vibration. Direct-drive machines are presently being used in a number of industrial applications including renewable energy wind turbines [3–7] marine propulsion systems [8–13] and elevators [14, 15].

The mode of operation for the bi-directional direct-drive electric thruster is to carry out yawing during the slack period between the end of one tidal phase and the start of the subsequent phase, that is, when the tidal stream velocities are at their lowest. Approximately 2 min of operation of the electric thruster is sufficient to rotate the turbine nacelle through 180° during the tidal slack period. Since the tide changes direction approximately every six and one quarter hours, the electric thruster only operates roughly four times per day, totaling less than 10 min. This ultra-low duty-cycle requirement means that the electric thruster can be designed to make use of the intermittent rating to minimise the size and cost of the motor. Also, high operating efficiencies can be compromised in order to achieve other technical objectives since the lost energy cost is low.