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Optimisation of a clutch-rectified power take off system for a heaving wave energy device in irregular waves with experimental comparison

K.S. Lok [a,b,*], T.J. Stallard [b], P.K. Stansby [b], N. Jenkins [c]

[a] Perkins Engine Ltd., Mail Drop 42, Frank Perkins Parkway, Peterborough, UK
[b] School of Mechanical, Aerospace and Civil Engineering, University of Manchester, UK
[c] Institute of Energy, Cardiff School of Engineering, Cardiff University, UK

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ABSTRACT

Many devices have been proposed for generating electricity from the oscillatory motion of a floating body in waves which are generally irregular. This study undertakes numerical modelling and small-scale experimental testing of a power take-off system for a heaving float. A power take off system is employed to provide high speed rotational input to a standard induction generator. A numerical model of the coupled hydrodynamic and electrical system is described with particular focus on the effect of generator control strategy on the time-varying response and power output of the system. The numerical model with three empirical hydrodynamic coefficients is calibrated against experimental measurements in regular waves. The control method includes a static characteristic and a proportional integral (PI) controller to maximise average power output whilst reducing the peak rate of change of torque in the driveshaft compared to a system with no control applied. The control strategy is implemented within a model drive-train with a geometric scale of 1:67. Experimental tests are reported and model predictions of time-varying response have a form similar to the measured response. Average power output from irregular waves is predicted within 11% for frequencies less than 1.3 Hz (periods greater than 6.3 s full scale) and wave heights greater than 30 mm (2 m full scale).

* Corresponding author.

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Nomenclature

I_{fr}	assist current
I_{gen}	generator current
I_{net}	net applied current
I_{ref}	reference current
K_i	integral gain
K_p	proportional gain
V_{torq}	generator torque current voltage
ϕ_d	drive-train displacement
ϕ_p	pulley displacement
$k\tau$	torque constant of the DC motor
τ_{fr}	assist torque
τ_{gen}	generator torque
τ_{net}	net applied torque
τ_{rate}	rated torque
ω_d	drive-train velocity
ω_{min}	minimum velocity
ω_p	pulley velocity

1. Introduction

Electricity generated from ocean waves represents a significant renewable energy resource. According to [1], there were 31 wave energy converters (WECs) under development in the UK in 2007. At present, a handful of systems are approaching commercial viability but none are yet commercially viable without financial subsidy. One of the design difficulties is how to efficiently convert the irregular and oscillatory motion of a float into the high-speed rotation that is desirable for electricity generation. Typical wave conditions of interest for electricity generation are characterised by periods in the range of 4–12 s and significant wave heights of the order of 1–3 m. To maximise power capture of a float it is necessary to oscillate with an amplitude greater than the wave amplitude. However, the response amplitude of a heaving float is typically less than double the incident wave amplitude due to mechanical constraints. The float velocity is oscillatory and typically less than 4 m/s. The power take off (PTO) approach considered here is based on a standard variable speed induction generator as widely used in wind turbines. Such generators are available with rated speeds in the range of 1500–2000 rpm and rated powers in the range of 0.5–5 MW [2]. In the present design the generator shaft drives a flywheel which is accelerated through clutch engagement as the float descends. During ascent of the float, flywheel rotation is retarded by the generator as the clutch is disengaged and the float motion is unconstrained.

For some WECs, the oscillatory motion is directly coupled to a linear generator for direct conversion into electricity [3,4]. This system structure is relatively simple with low maintenance. The efficiency is reasonably high for a wide operating range. However, the cost of linear generator remains high [5].

A numerical model of a coupled electro-mechanical system has been developed, by the authors [6], to simulate the time-variation of power output and generator loading due to irregular forcing of a heaving float. The model was applied to a range of force-time histories to evaluate appropriate PTO characteristics. It has been provisionally demonstrated that a "static characteristic" control strategy is able to enhance the power output significantly [7]. However, this enhancement was only achieved with a high rate of change of electromagnetic torque which could be damaging to the drive-train. This rate of change was reduced, with only a very small drop in power output, by tuning the proportional integral (PI) controller in the control system. This study develops this further with experimental validation.

The electro-mechanical system, its static characteristic, and the selection of the ramping rate value are described in System description. The PI controller is also presented and the effect on mean power