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Design of full scale wave simulator for testing Power Take Off systems for wave energy converters

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ABSTRACT

For wave energy to become a major future contributor of renewable energy it is a requirement that the efficiency and reliability of the Power Take-Off (PTO) systems is significantly improved. However, the cost of installing and testing PTO-systems at sea is very high. The focus of the current paper is therefore on the design and commissioning of a full scale wave simulator for testing PTO-systems for point absorbers. The challenge is to be able to design a system, which mimics the behavior of a wave when interacting with a given PTO-system – especially when considering discrete type PTO-systems. The paper presents the designed system, including the major design considerations. A model of the complete system is presented and controllers for the system are developed. These enable the system to emulate the wave behavior and the wave–float interaction. Finally both simulation and experimental results are presented, showing that the system is able to emulate real waves up to three meters in height and with a resulting force of more than 800 kN.

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1. Introduction

Today, wave energy is at a stage, where several principles have passed the proof-of-concept stage, showing that it is possible to produce electricity from the waves. Despite this achievement, the produced energy is far from price competitive when compared to e.g. wind turbines. This is partly due to the Power Take-Off (PTO) systems used, which have been characterized by extremely poor efficiencies and reliability. The poor efficiency results from the wave energy companies being forced to use standard solutions and of the shelf components. One of the challenges for making wave power price competitive is therefore to improve the PTO-system.

The challenges in developing a PTO system are touched upon by [3,27]. Based on these references, the main challenges for the low PTO-efficiency may be outlined as:

- The wave motions are irregular. This results in slow irregular oscillating movements with varying frequency and amplitude and extreme high torques/forces. Fluid power is the most realistic technology available for handling the large reversing torques/forces, cf. [27] and the evaluation in [15]. However, fluid power components in this power class are very limited and have extremely poor efficiencies and durability under these operating conditions. The majority of electrical solutions are only considered for relatively small torques/ forces and no realistic design yet exist in the high power range. An overview comparison and overview of all the different technologies may be found in [15].
- The PTO system has to deal with large power scales and a very high peak-to-mean power ratio. The peaks, however, contain a large portion of the available energy – easily up to 40% of the available energy.
- Power smoothing is difficult due to the large variations in the wave power (both frequency and amplitude) while maintaining a high efficiency from wave power to generator.
- Both high dynamic performance of the PTO system an advanced control strategy is required to optimize the amount of energy extracted from the waves. Coordinated control of all sub-systems is also required to ensure a stable, safe and efficient energy production.
- Reliability and lifespan is important as maintenance at sea is expensive. Strategies for surviving extreme wave conditions are therefore necessary.

The use of standard solutions and off the shelf components is one of the barriers for developing better PTO-systems. However, research activities have also almost entirely disregarded the PTO system development. Instead, research has focused on two areas: (1) hydrodynamics and the mechanical capture of wave motion see e.g. [28,8], and (2) power extraction algorithms assuming an ideal unlimited PTO system see e.g. [8,5]. In references where the PTO system is mentioned, this is generally a simple non-optimized fluid power transmissions with very limited efficiency, see e.g. [5,17,4]. Overviews of the different type of possible PTO-systems may be found in [7,27,15]. Salter et al. [26] also describes the potential in using digital hydraulics. This includes the very promising digital displacement pump (DDP) technology, developed by Artemis Ltd., is also described in Payne et al., [25,24]. DDP is still not in a commercial stage where it may be directly utilized in wave energy converters. Nor does it solve the problems of e.g. power smoothing. Similarly research in electrical direct drives are treated in e.g. [21], but is still in an early state and not applicable for full scale wave energy converters.

It is first within the last decade that the PTO-system efficiency been taken into account, see [19,14,12,13,2,11,10,16,9,6,22]. Still, the research has mainly been limited to simulation results, based on assumed and approximated efficiencies of the components. The newest work in this area include the work by Diessler et al. which presents models for a number of components for the WavePOD concept. The results are, however, still limited to single component validated models. Experimental validation of a pneumatically based PTO system may be found in Liermann et al. [22], which shows good resemblance between measured and modeled efficiencies. However, this system is in a completely different power range (approx. power output 13.7 W) and primarily designed for learning purposes. Similarly Cargo, [2], developed a scaled PTO-system to experimentally validate his models and develop control strategies. Again this was in a power range, where more suited components are available. There is hence

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