Oscilla Power Ltd

WES Power Take-Off

Stage 2
Public Report

This project has been supported by Wave Energy Scotland

1 Project Introduction

The overall objective of this Stage 2 PTO project was to develop a novel linear hybrid drivetrain (LHDT) in a wave energy convertor (WEC). This will allow the wave generated forces from the marine system to be manipulated and adjusted for application to a linear generator so that the generator can operate at maximum efficiency and with high reliability, while simultaneously allowing the float to displace as needed to capture energy from the waves at maximum efficiency or at sufficient reliability as determined by the specific wave state.

During Stage 2, the LHDT has been demonstrated successfully at 1:10 scale with a laboratory unit. The performance of this prototype is described in detail within our Stage 2 reporting. We have shown full functionality of the system at this scale, and these results have been 3rd party validated by EMEC.

2 Description of Project Technology

The LHDT comprises a linear hydraulic gearbox (LHG) coupled to a high-power density and high efficiency Vernier linear generator.

The operation is somewhat analogous to that performed by a rotary gearbox, which converts rotary energy at one RPM into a different (usually higher) RPM that is more suitable for optimal performance of a rotary generator. The simple, nearly hydrostatic operation of OPI's linear gearbox is similar to that of a hydraulic press, in which a compressive force on one cylinder is transferred directly to another cylinder with a different piston area, resulting in an amplification ratio that is dependent upon the ratio of the piston areas. With tandem cylinders and appropriate valving, this ratio can be adjusted during operation.

The coupling of the linear gearbox with a linear generator offers many drivetrain options with trade-offs between technical risk and maintenance cost. At the one end of this scale is a conventional multi-pole linear generator. In this combination, the linear gearbox provides an effective spring and damping coefficient that is optimized for the wave environment, and the captured mechanical energy can be transferred to conventional linear generators with an appropriately amplified displacement/velocity. This approach could reduce required generator mass and cost substantially, to the point where the generator only employs components suitable for high-volume manufacturing.

At the other end of the spectrum, variable reluctance generators offer the possibility for significantly more reliable performance relative to that which can be achieved with conventional linear generators. This is due to the significantly lower travel needed on bearings and shafts that are expected to control the maintenance and scheduled schedule. Integration of a variable reluctance generator with a linear gearbox enables this advantage to be maximized.

This project has explored two approaches to variable reluctance;

- A variable reluctance design, which is driven by the elastic extension of components that control a variable air gap within a magnetic circuit,
- A hybrid approach by changing the stress on magnetostrictive components of the magnetic flux.

In both of these designs, it was proposed that a key advantage would be high reliability, due both to the low displacements delivered by the linear gearbox and to their limited reliance on end stops or return springs. In effect, the return spring is built into the system from the elastic deflection of the generator itself.

The highest perceived level of applicability is to Attenuator and Point Absorber WEC types.

For Attenuators, the motions of the WEC provide low displacements and velocities at the joints, which could be easily applied to hydraulic cylinders (as in the Pelamis) and would see advantage from the amplifications that the LHDT can provide. The controllability provided by the LHDT could allow better wave to wire performance than a conventional PTO.

For Point Absorbers, either single or multi-mode (i.e. one or two body concepts) are ideal for the LHDT and is what the LHDT was originally developed for. These types of WEC device provide a linear input that can be applied directly to a hydraulic cylinder. The return spring and power dissipation functionality of the LHDT in particular, can enable significantly greater power performance than current PTO solutions. The Oscilla Power Innovations (OPI) Triton was the application that the LHDT focused on in Stage 2.

Technology Opportunities

The novel drivetrain has to potential to improve the efficiency of the power take off (PTO) for a variety of wave energy convertor (WEC) architectures.

- The nearly-hydrostatic gearbox modifies and decouples the highly variable input energy from the marine system into loads and speeds that enable high-efficiency operation of the generator.
- The LHG also provides for variable damping, spring constant and generator displacement, resulting in improved power capture and increased system efficiencies in low waves. In larger waves, the system provides the ability to shed power, limiting peak energy transferred to the generator and improving survivability.
- Full system modelling in a wide range of irregular wave environments has shown the potential for achieving system mechanical to electrical efficiencies in excess of 86% for all normal operating conditions, and median efficiencies of 89%.
- Incorporation of this hybrid drivetrain into WECs can help to both reduce capital expenditures (CAPEX) and increase annual energy production (AEP), leading to a substantial reduction in the WEC's levelized cost of electricity (LCOE).
- CAPEX is reduced through an improved efficiency, which allows a smaller prime mover to be used for the same power level, and the power shedding ability, which enables a significant reduction in peak loads.
- AEP is increased by independently tuning the system displacement/damping and the speed of the translator in the linear generator, allowing both high efficiency energy capture from waves and high efficiency conversion of the captured mechanical energy into electrical energy.
- Further, the LHDT has features and functionality that makes it ideal both for passive sea-state by sea state control, as well as for active wave-by-wave control through latching and reactive power supply to drive the WEC motion.

- Finally, the permanent magnet (PM) Vernier linear generator provides a high flux switching frequency, resulting in much better low speed performance relative to other generators, resulting in increased power density and lower cost/kW.

3 Scope of Work

Within Stage 2, a number of activities were completed which can be summarised as:

- Conceptual design ideation
- Development and analysis of a linear generator numerical model, which was coupled to a WEC model
- Engineering conceptual development of the PTO system
- FEED for a mid-scale prototype for the next stage of development
- Construction and testing in a controled environment of a 1:10 scale prototype of the drvietrain
- Review of the market opportunites, and the proposed market entry plan

The PTO technology developed through this program is currently at TRL 4. This view is support by the work completed in Stage 2, whereby:

- An iterative design approach let to a detailed concept design for the full-scale system being developed, which enabled an optimal technology to be identified and thoroughly expanded into the current concept. The design includes consideration of the variants for sub-components, such as the generator. Many settings and configurations for the system were explored by varying factors (for example, amplification ratio of the linear hydraulic gearbox, load shedding settings under high waves, spring and damping coefficients of the system, etc.).
- The hydraulic front end of the hybrid drivetrain will be built up entirely of off-the shelf components from major vendors, resulting in this sub-system having a higher TRL than the drivetrain as a whole. While some level of customization may help to improve performance, the variations in the design to achieve this are expected to be minimal.
- The system loads expected to be imposed on the PTO have been modelled and studied in detail through both drivetrain and coupled WEC modelling in representative irregular wave environments. Features that can maximize efficiency in small waves, and allow for load shedding in high waves have been identified. Key, life-limiting components (such as generator bearings and hydraulic seals) have been identified, and solutions specified that are likely to meet the required overall requirement for system design life of 20 years, or 60+ million load cycles in actual operation.

4 Recommendations for Further Work

There are a number of key uncertainties and future development needs which would be addressed through further work that will be completed by the project team.

Sealing and Bearings

The drivetrain functionality has been successfully demonstrated and proven out through the Stage 2 numerical modelling work and a 1/10 scale small demonstration unit. However, during this Stage 2 work, challenges were identified which include achieving good hydraulic seal performance and identifying linear generator bearings with suitable performance. Both of these challenges will be addressed and resolved early in the next stage of the PTO development.

More accurate information on seal performance will inform better predictions on the efficiency of the hydraulic system and on the anticipated maintenance intervals, and therefore OPEX. Generator bearing performance will also inform OPEX and will dictate if solutions can be found for the proposed generator solution, or if this has shall remain single-sided.

Scale

Other aspects of the technology, such as the hydraulic subsystems, need to be proven at a larger scale to continue to demonstrate functionality and further characterise performance and efficiency. In particular, it will be important to demonstrate the power dissipation at a larger scale.

Active Control

The active control functionality has only been evaluated numerically, and although this subsystem is somewhat straightforward, there is uncertainty in the practical response time and maximum reactive forces achievable. Demonstrating this active control with larger scale components at higher flow rates will be important to identify if there are practical constraints to the system. This is particularly the case with high flows and large diameter pipes, where there is the possible issue of cavitation around valves which can cause additional losses. Understanding these issues is important to the full-scale system.

5 Communications and Publicity Activity

To the best of our knowledge, a linear Vernier generator is novel and we have taken steps to protect this arising IP from our Stage 2 project in the WES PTO pgroamme by filing a provisional application in April 2016. In addition, a provisional application was filed prior to entry into Stage 2 on the concept of combining the front end hydraulic system with a linear generator. This was converted to a utility application in 2017 and recently published as US 20170002789. The combination of these two patents should provide Oscilla with excellent patent protection on the new concepts developed through the WES program.

6 Useful References and Additional Data

Publicity Material

Filename	Media Type	Description