Gator – a compliant seal free hydraulic PTO

WES Power Take Off Stage 2 Public Report

Exceedence Ltd.

This project has been supported by Wave Energy Scotland

Project Introduction

The innovative Gator PTO is a polymer 'spring pump' capable of pumping significant quantities of water at moderate pressures (~10 bar) through a conventional hydroelectric turbine, delivering enhanced reliability at reduced cost. Hydro-electric technology is highly efficient, cost effective and well established but suffers as a PTO option due to poor seal lifetimes and reliability issues around pumping pressurised water to shore. Gator PTO overcomes both these issues by using seal-less polymer pumps and converting the water to power locally. Not needing seals gives the Gator PTO significant cost advantages in both operating and capital costs, over alternative systems. Other advantages include increased availability, performance and affordability.

The Gator team consists of Exceedence Ltd, Technology from Ideas, Pelagic Innovation, University of Strathclyde and University College Cork.

- Exceedence are lead contractors with WES and have project managed both Stage 1 and Stage 2 as well as provided the LCOE analysis for the project. They specialise in innovative financial modelling and analytics software tool for the renewable energy sector as well as providing LCOE analysis services, project management and leadership services.

- Technology from Ideas have undertaken design and engineering work on the PTO during Stage 1 and Stage 2. They identified the opportunity for the polymer springs to be used as stand alone PTO components. They specialise in polymer based mooring technology and load protection components for the aid to the navigation market, aquaculture and marine energy companies.

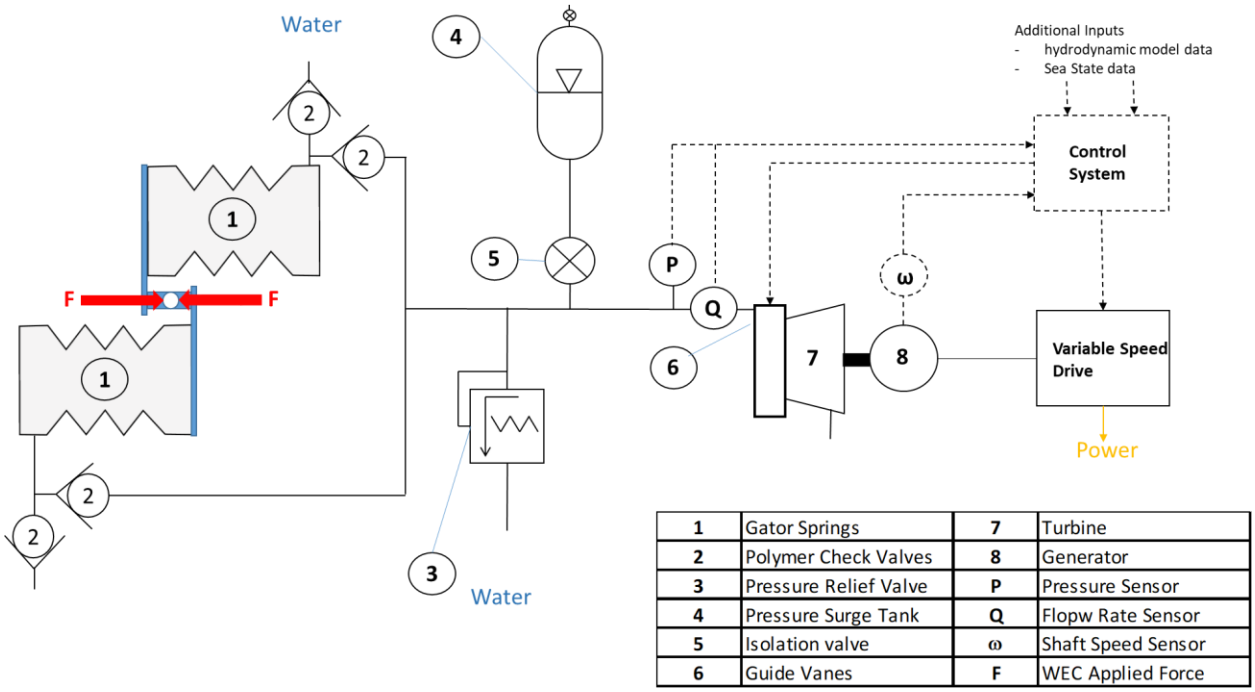
- Pelagic Innovation have led several of the engineering work packages in Stage 2. Having previously worked for Aquamarine Power, they offer 'real world' engineering services to the marine renewables sector. They provide consultancy in the areas of engineering management, system engineering studies, concept and detailed design to the Wave and Tidal sectors.

- University of Strathclyde have undertaken the modelling and simulation works as well as the small scale 1kW rig tested during the project. The Naval Architecture, Ocean and Marine Engineering Department provide simulation and engineering services.

- University College Cork along with TFI have have undertaken small scale physical testing of the spring pump during Stage 1 and early on in Stage 2 to further the design development, by using an already existing purpose built PTO rig. UCC also operate the Irish National Ocean Test Facility (NOTF)

Description of Project Technology

Gator pumps can be configured in a multitude of ways to provide the damping profile and to fit the space constraints of a specific WEC. A typical bi-directional Gator system is shown schematically in Figure 1. This system consists of two spring pumps working in opposite directions, check valves, a pressure relief valve, a pressure surge tank with an isolation valve, a turbine, generator and power electronics. The bi-directional Gator uses an approximate to Coulomb damping, which means it provides a force resisting the motion of the prime mover that is approximately constant.



1	Gator Springs	7	Turbine
2	Polymer Check Valves	8	Generator
3	Pressure Relief Valve	P	Pressure Sensor
4	Pressure Surge Tank	Q	Flopw Rate Sensor
5	Isolation valve	ω	Shaft Speed Sensor
6	Guide Vanes	F	WEC Applied Force

Figure 1: Schematic of the bi-directional Gator system

The Gator PTO uses water as a working fluid, which is much more environmentally friendly than alternative hydraulic systems. The majority of the PTO force is used to pump the water rather than compress the spring. However, in extreme seas, the spring force dominates the overall PTO force, so more energy is required to compress the spring rather than pump the water, naturally protecting the PTO components from damage. The spring has a passive response and so is always protecting the system, whether from a rogue wave in normal seas or a series of extreme waves in high sea states.

The Gator, manufactured using existing processes and equipment from a high performance-marine compatible polymer, offers a contamination tolerant pumping device (e.g. sand infiltration does not interfere with the device function). A thermoplastic rather than a rubber polymer allows for higher water pressures to be pumped and the spring response can be tailored in a non-linear manner to increase performance and efficiency. The pump is closely coupled to existing proven hydroelectric turbine solutions using polymer valves, reducing the flow losses and the transient pipeline effects that have plagued previous shore based systems. Mature accumulator system solutions can be used to reduce flow variations. The non-linear response and robustness of the Gator enables novel control strategies relying on the natural response of the spring to deliver inbuilt survivability in extreme conditions.

Scope of Work

The work undertaken during this Stage 2 project can be divided into the following five headings: Idea and Design Development, Simulation, Engineering, Testing, and Market.

- Idea and Design Development

The work undertaken with the Idea and Design development task have been to better understand each of the components that make up the Gator PTO. The main components are the spring pump, the different valves, the surge tank, and the hydroelectric turbine. Most of these components have been sourced through mature water network and small hydropower industries. Other topics of interest have been contamination and blockages, corrosion, marine growth, open and closed loop systems including water cleanliness requirements. Furthermore, work has been conducted to understand the different requirements for submerged versus surface access as well as design life assessments. These studies have helped inform decisions on major topological and component options and have helped inform technological solutions.

- Simulation

  The modelling and simulation work has been undertaken to support the other work during this Stage 2 Project. A 'wave to wire' model built in Matlab Simulink of a utility scale PTO activated by a heaving buoy has been used as a design tool to assess component sizing, function and performance in regular and irregular sea conditions. Separate studies have considered different Gator configurations (e.g. bi-directional versus uni-directional systems) and applicability to different WEC types. Simulation has been used to support the interpretation of test results.

- Engineering

  The engineering work provided system specifications and detailed designs for the 1kW testing, as well as the specifications for the full scale PTO. Engagement with WEC developers has informed the WEC integration work as well as FEED studies for a potential Stage 3 device. Stage 2 has given a better understanding of what the full-scale PTO may look like, and therefore has allowed the team to also better understand the CAPEX costs of said system.

- Testing

  The Gator system was physically tested at a 1kW scale. The reason for this scale was because the team had identified a potential early adopter market for this scale in, among others, the aquaculture market. By testing at this scale, it allows the team to not only learn more about the system as a stepping stone to a full scale prototype PTO to be integrated with a WEC in the near future, but also to be able to continue the work on the 1kW system for the early adopter markets. Characterisation testing was conducted on the Gator spring pump, and the turbine to inform loading, reliability and survivability. The system was then connected and was tested to validate and optimise the system topology, functionality, behaviour and performance. Testing has built confidence and informed the next scale of testing to be conducted in Stage 3.

Cost

An OPEX analysis was conducted early on in Stage 2 based on the main components that were being considered for the Gator PTO. Based on key findings in terms of risk in increasing maintenance requirements, the engineering and design work were further informed. Two separate LCOE analyses were carried out during the course of the Project: one on the 1kW system, and the other on the 1MW system.

As the Gator system is mainly composed of off-the-shelf components, list prices can be found which gives confidence to the final CAPEX of the Gator system. Both systems showed very promising LCOE results.

- Market

  During Stage 2 dialogue has been initiated with WEC developers to understand their needs for preliminary engineering and integration studies. FEED studies have also been drawn up, one to inform the Stage 3 medium scale testing, and the others to inform the full scale WEC integration. Increased engagement is envisaged during Stage 3. The market assessment, as well as the commercialisation roadmap has been refined to better reflect the new knowledge gained during Stage 2, both in terms of early adopters but also the WEC market status.

Project Achievements

What went well

- The Gator team indentifed mature industries that can supply most of the needed components, driving the cost down for the Gator system, giving confidence in the calculated CAPEX cost.
- Communication between the geographically dispersed project partners were effective and professional. Bi-weekly call meetings, physical project team meetings after each Milestone, and an action list after each meeting has helped the team to stay connected and focused
- The 1kW Gator PTO functioned as intended and has provided a significant set of data that can be used to inform technology and design developments.

What can be improved

- Start the procurement process as early as possible as this can add significant delays to the project. Also, ideally go directly to the manufacturer rather than through a supplier.
- Plan the project in so far as possible so that a vital resource in the project is not needed on several different aspects of the project at the same time. This can cause delays as decision on priorities may need to be taken.
- Be aware that some tasks may take longer than anticipated, which may cause delay.
- Add more time between writing reports, and delivery to allow for more review of results and what they mean for the project as a whole.

Applicability to WEC Device Types

The Gator PTO is compatible with a wide range of WECs. Standardised Gator PTO components are assembled with the desired design functionality to meet each WEC's needs. Figure 2 illustrates how the Gator PTO could be

configured with various WEC types including Point Absorbers, Submerged Pressure Differential devices, Attenuators and Oscillating Wave Surge Converters. This group of 4 types of WECs accounts for over 80% of the total of WECs in development, demonstrating the high applicability of the system, as well as the significant advantage the Gator PTO system has over those PTO systems that are developed and customised to a single (i.e. proprietary) type WEC.

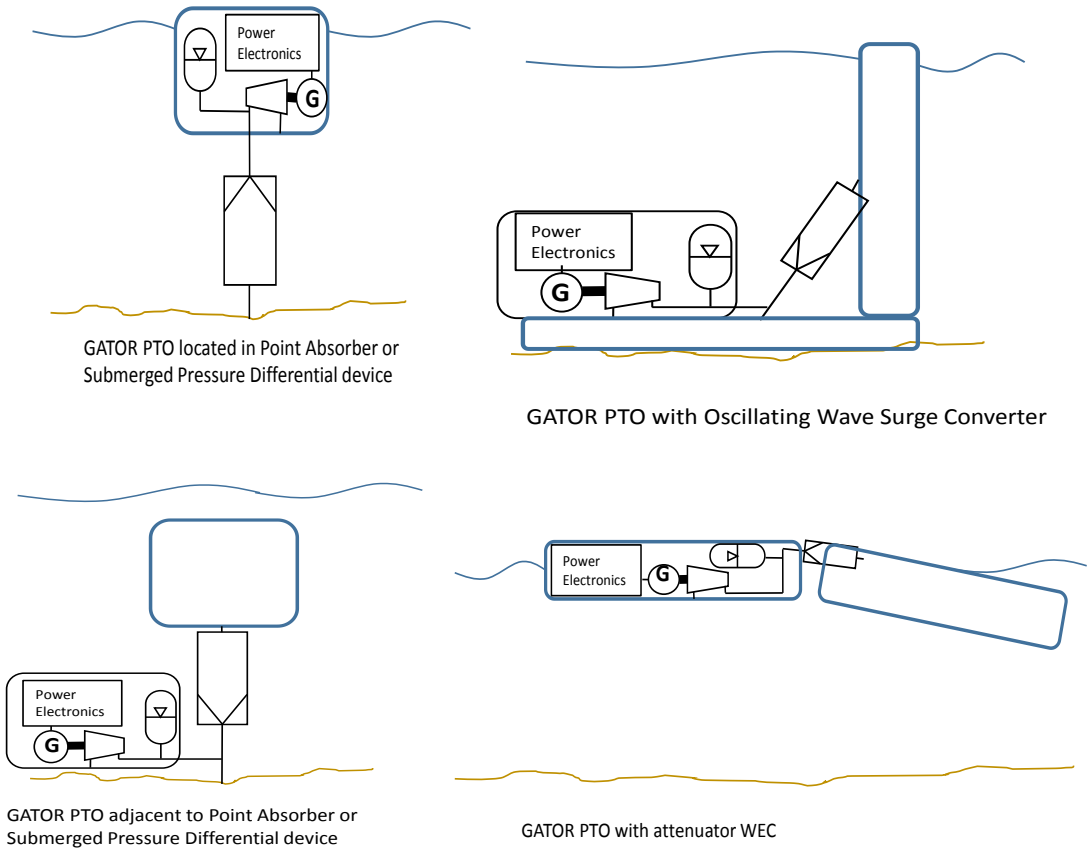


Figure 2: Wide Application - WEC Types Gator PTO is Compatible

Summary of Performance against Target Outcome Metrics

Metric	Expected Target Outcome (Qualitative)	Actual Project Outcome (Quantitative)
Affordability	Stage 1 LCOE analysis (incl CAPEX and OPEX) was relative. The expected outcome for Stage 2 was that absolute CAPEX costs could be made and that this cost will enable the WES target of less than £150/MWh	As most of the components of the Gator PTO are off the shelf, suitable suppliers were found who could give list prices and expected bulk reductions. The CAPEX cost was therefore calculated with high confidence for a one-off PTO unit as well as in the multi-MW at full scale (1MW). The resulting LCOE analysis showed promising reductions.

Performance	The purpose of the small scale testing was to validate the assumption made around the Gator PTO performance and identify any additional design issues which need addressing. To achieve this a 5L Gator PTO pump operating at 1-10bar pressure, with flow rates >1L/s, and a max 1kW of power was designed.	While some issues with spring manufacture quality and the test rig drive system limited the maximum performance, a full set of tests were successfully completed, providing valuable performance data on the Gator PTO system. A >5L volume pump was tested, with flow rates >1.6L/s, and pressures up to 4bar. The issues have been addressed moving forward and confidence in the Gator PTO performance has been achieved.
Availability	Stage 2 will look at a ground up LCOE model and identify the MTBF for individual components. It will also look at maintenance requriements and undertake long term fatigue testing. Minimum Gator PTO maintenance interval - 12 months. Ii. Modular design of the balance of the PTO	Design changes to the pump assembly allowed for ease of spring replacement, and these worked well. The polymer components obviously showed no corrosion issues. No other components needed servicing or replacement during the testing, as mature water network and hydro-power components were used throughout.
Survivability	Stage 2 will investigate this further with long term fatigue tested and high load survivability testing. The simulation work will also investigate the feedback response on a real WEC device and show the enhanced survivability	Simulation work showed how the built-in end stop behaviour of the springs would enhance survivability. Testing of individual spring convolutes also showed this end stop load behaving as expected.

Communications and Publicity Activity

The Gator PTO team have presented the Gator project at the following events:

- 2 minute Elevator Pitch of the Gator Project at the Wes Annual Conference November 2016
- Poster presentation at the Structure and Materials WES event in April 2017
- 3 minute pitch at the WES event as part of the EWTEC Conference in August 2017
- 15 minute presentations at EWTEC Conference in August 2017 on the ‘Development of a Polymer Spring Pump Based PTO’

Recommendations for Further Work

The project team is preparing a Stage 3 application Some of the key areas that are being proposed are:

- Ongoing Technology Development (supported by testing at small scale using existing 1kW system)
- Component Development (primarily focussed on ongoing polymer spring development and adaption of existing small hydro-power turbine/generators at >10kW scales)
- Simulation and Modelling (enhanced wave to wire model for developers to assess Gator PTO on their devices)
- Engineering (of a medium scale demonstrator and full scale FEED studies)
- Testing and Demonstration (of the medium scale demonstrator in a laboratory and representative environments)
- Market and Commercialisation
- Certification and IP Management

Useful References and Additional Data

- D13 1MW LCOE and Market Update Report - CONFIDENTIAL
- D19 Technical Confidential report - CONFIDENTIAL
- D20 Commercialisation report - CONFIDENTIAL