Direct Drive Contra-Rotating Generator (WEC- Direct)

WES Power Take Off
Stage 1 Project
Public Report

University of Strathclyde

This project has been supported by Wave Energy Scotland

1 Project Report

1.1 Project Introduction

Wave energy converters (WECs) produce a reciprocal motion which requires the inclusion of additional and sometimes complex power transfer and take-off systems to generate the rotary motion necessary to drive an electrical generator. These power transfer and take-off systems, as well as being expensive, are typically the primary cause of WEC failure. They can also introduce considerable power losses which further reduces the efficiency of the wave energy converter. The feasibility study undertaken in this PTO Stage 1 investigated the application of a direct drive contra-rotating generator (DD-CRG) to different WEC architectures to establish the impact this step changing technology can have on reducing both plant capital and operational costs.

The core team developing this project was formed by three members of the Energy Systems Research Unit at the University of Strathclyde: Cameron Johnstone, Kate Porter and Stephanie Ordonez. The team was complemented by an additional member of the tidal energy company, Nautricity, Ltd, Stephanie Conesa. When the project started the members of the team had already a vast experience related to the tidal energy field. The knowledge acquired throughout the duration of this project has widened up the experience of the team members in the wave energy field.

An important achievement during this project was the amount of information that was gathered and will be necessary if the project was selected to move on to Stage 2. The accomplishment of M1 was verified by cross-checking the objectives set at the beginning of the project and the deliverables. M1 presents the assessment undertaken for a wide variety of WEC technologies and the PTOs used by each of them. M1 also includes the generated variables required to assess the DD-CRG of three WEC technologies: a Point absorber, an Oscillating Water Column (OWC) and a Surge Converter at various wave climates. The project successfulness can be widely identified in Milestone 2, as at this stage, the team did an engineering analysis of the connection possibilities of the prime mover and the DD-CRG. M2 concluded with a list of components and linkage options to connect the DD-CRG to the Point absorber and OWC. Finally, a summary of the LCOE analysis was carried out at this stage with a list of potential manufacturing suppliers to be used at different TRLs of the DD-CRG.

1.2 Description of Project Technology

The principle of operation of the DD-CRG is that, unlike conventional generators which have a single unidirectional rotating section (rotor) which typically requires the use of a gearbox to increase the drive speed; the DD-CRG drive is applied to both the rotor and stator so that the stator rotates in the opposite direction, giving twice the speed of rotation without the use of a gearbox. Therefore, coping with the low speed and high torque requirements of tidal stream turbines. Compared to a conventional direct drive generator, the speed increase halves the size, weight and costs of the electo-magnetic components of the generator.

1.3 Scope of Work

To study the applicability of the DD-CRG, this feasibility study was divided into three main milestones. In Milestone 1, a full review of existent WEC technologies and the PTO options was undertaken and summarised. With that information, three WEC architectures were selected as candidates to be linked to the DD-CRG: a Point

Absorber, an Oscillating Water Column, and a Surge Converter. To finalised M1, a database of design parameters that include velocity, position, forces, pressures, etc. was generated for each of the selected WECs at different wave climates using open access methodologies, as described in M1. The main and secondary objectives of M1 are shown as follows.

A. Exclude the WEC architectures which are not entirely compatible with both the operational characteristics and capacity levels for the operational range of the DD CRG's available. This was done by assessing the power transfer and take-off characteristics, and the applicability of the power take off to a DD CRG of eight WEC devices according to existing literature.

B. The second main objective consisted of undertaking a technical engineering analysis to study the compatibility of DD CRG with the selected WEC designs. This section was divided into four secondary objective tasks:

- Identify applicable geometrical configurations for each of the selected WEC architectures
- Define a range of sea states these technologies operate within to study the response of the selected WEC designs.
- Identify appropriate analytical tools to analyse the selected WEC architectures.
- Quantify the engineering and physical parameters associated with the power transfer, to design linkages between the prime mover and the DD-CRG, which are fit for purpose.

The input generated in M1 was used in M2, which is considered the core product of this WEC–Direct project. M2 provided an engineering analysis of the power transmission required to link the prime movers to the DD-CRG. M2 did not only serve as guidance on what components can be used in the power transmission based on the design parameters obtained in M1; it also presents a section on how the scalability of the prime mover would affect the design of the DD-CRG. In M2 it was concluded that the current design of the DD-CRG is a viable option to be used in the generic Point absorber and OWC technologies explored; however, if it is selected to work on surge converters, a re-design of the generator will be required. The two main objectives proposed were:

A. To undertake an engineering system evaluation to identify the most efficient integration of a DD-CRG into the particular WEC architecture by:

- Evaluating and identifying the hardware options to establish an appropriate power transfer system from the prime mover to the DD-CRG.
- Analysing the hardware options with the input parameters obtained in Milestone 1.
- Selecting the components that will provide the best solution to connect the prime mover to the DD-CRG.
- Identifying the effects of PTO location on three WEC architectures.

B. To determine any limitations in size and capacity of a specific WEC, which is a suitable receptor for the DD-CRG.

With the information obtained in M1 and M2, the parameters required to carry out an LCOE analysis were obtained. The data of M1 aid to quantify the energy capture of both devices while the information obtained in M2 was utilised to get initial costs of the components required for the power transmission and comparative analysis of similar technology. Even though the LCOE analysis undertaken in this project consider the costs of various parameters that are unrelated to the manufacturing and development of the DD-CRG, it served as evidence on the problematic arising when developing WEC technology. The two main objectives proposed in this Milestone were:

A. To identify a potential supply chain for the relevant power transfer system and any gaps in it.

B. To undertake an LCOE analysis for each of the WEC architecture incorporating DD-CRG.

An additional objective of the overall project was to propose an initial small scale prototype to be tested in laboratory environments.

1.4 Project Achievements

The study undertaken during M1 was very useful to the project; we learned that the DD-CRG is not completely compatible with all types of wave energy conversion. Several PTOs designers who may believe that their designs are completely transferable to any WEC, which at least in this project we have proved contrarily. Using available open-source tools in M1 gave the capability to explore the forces, torques, velocities, etc. developed by two types of WECs. With such data, we were able to demonstrate that the DD-CRG was able to work with its current design on a generic point absorber application.

The use of experimental data of small scale OWC also gave a good insight on what pressures/flow rates the turbines and PTOs have to work with. Similar to the tidal energy conversion, a dual twin rotor can be applicable for OWCs to use it as a unidirectional turbine in the same axis. A re-design of the DD-CRG was inevitable for this WEC application. However, this was a good outcome as due to the torque and speeds developed by the turbine; the manufacturing costs of the DD-CRG proved to be lower than those for a 500kW DD-CRG used in tidal energy applications (or on the generic point absorber).

The project would have been even better if a partner specialised on the generator/power systems side had been very beneficial in M2 as we could have included a more detailed calculation on the power transfer system. At the moment using a constant damping did not give a realistic insight into the PTO system and the annual energy output. Also, a strategic partner with advanced knowledge in wave energy conversion would have been beneficial. The help of an expert would have accelerated the delivery of some of the objectives, specifically on M1. Finally, the work packages would be rearranged differently on the second part of the project. It was hard to undertake the scalability and the location of the DD-CRG without contemplating the power transfer system.

1.5 Applicability to WEC Device Types

When undertaking the design analysis of the power transmission system between the DD-CRG and the three WEC technologies identified in M1, it was evident, as presented in the report, that the Point absorber and the OWC devices can be directly connected to the DD-CRG without the need to make radical changes on the DD-CRG. For the Point Absorber, a good match between the torque and RPM requirements of the generator compared to the force and velocity of the point absorber system under a range of wave conditions was observed. The generator mass and dimensions are such that it is unlikely to have much impact on device performance and can easily be integrated within the existing WEC geometry. A simple system for converting the linear motion into rotary motion has been proposed using off-the-shelf, low-cost components. It was demonstrated that the contra-rotating feature of the generator could be used to reduce the forces transferred to the components of the generator while at the same time enabling both the up and down strokes of the point absorber to be utilised regarding power absorption. Potential partners can be CorPower Ocean AB.

For the OWC, the applicability of the DD-CRG was evident from the initial stages of the analysis. The capabilities of the DD-CRG are currently too high for the requirements of OWC PTO systems. A slight re-design of the DD-CRG should be undertaken to cover the demands of the air turbines selected in the project. The re-design of a DD-CRG with lower torque and higher speed rates will implicate a smaller and lighter machine. Therefore, costs will be lower and the effect on performance according to PTO location will be minimal, even if a floating structure is considered. Off the shelf components are difficult to obtain at this stage for OWCs as the turbines are designed for specific purposes, similar to a tidal energy device; however, even if the turbine design changes, the DD-CRG could be used as a ‘plug and play device’. Any developer using pneumatic or hydraulic turbines in the OWC design can be a potential partner.

The surge converter was rejected from the engineering analysis at initial stages due to high forces and low velocities generated by the flap used in this project. However, additional studies which will involve other types of surge converters can be undertaken in the future. The applicability of the DD-CRG to other technologies was not fully explored in this project due to the complexity of the systems (e.g. attenuator devices similar to the Pelamis technology). However, the team is convinced that once the DD-CRG is fully developed for wave energy applications, there is no reason to limit its applicability to only a few devices.

1.6 Summary of Performance against Target Outcome Metrics

The attractions associated with the DD-CRG are as summarised as follows:

Affordability- Using proven mechanical, 'off-the-shelf' power transfer components and minimising the number and complexity of drive train and power transfer conversion stages within the WEC system, considerably reduces the CapEx and OpEx associated with device operation. The use of the DD-CRG reduces the size and mass of the WEC, this facilitates lower cost manufacturing, transportation and handling using inexpensive vehicles and cranage, and cheaper and quicker installation enabling lower cost vessels to be used in the installation and maintenance of the WEC.

Performance- Simplification of the mechanical drive train, minimising the complexity and number of stages in the energy conversion process eliminates losses in the power transfer system ensuring maximum efficiency. The ability to vary the load on the generator through field weakening linked to a direct drive system coupling the power capture interface to the generator enables the immediate application of load control on the power capture interface. This enables the WEC's power capture interface to be controlled to ensure operation at optimum performance. These combine to ensure maximum power production performance can be maintained through all states of wave climates the WEC is exposed to.

Power quality can be maintained due to the inherent inertial capacities inherent within the contra rotating generator ensuring a smoother power output. With the power take off unit integrated within the WEC, this eliminates long pipelines/ ducts of pressurised fluids which deteriorate with time.

Availability- due to reduced complexity in the power transfer and conversion process in the DD-CRG and the use of proven 'off the shelf' mechanical rack and pinion based power transfer components connecting the power capture interface to the input shafts of the contra-rotating generator results in reduced necessity for frequent

maintenance and reduced risk of drive train failure. The use of field weakening of stator currents using proven and widely available pulse width modulation power conditioning electronics enables the generator to operate at its most efficient levels over a wide spectrum of wave climates. These parameters combine to ensure high availability.

Survivability- The ability of the generator to vary its load through field weakening allows for the load on the power transfer system to be controlled and/ or eliminated in response to extreme conditions. This facilitates the alleviation of potential damage to the power transfer system during extreme conditions. The resulting loads on the contra-rotating generator during extreme conditions will be less than the technology has been designed to withstand within the tidal environment. This results in the generator system being able to withstand the loads it may experience during extreme conditions/ events. The combination of these factors indicate this novel PTO will have high survivability during extreme events.

1.7 Communications and Publicity Activity

The DD-CRG has been widely promoted due to its applicability to tidal energy conversion. The production of several papers were presented during its development in the tidal energy field. Those outcomes are referenced as follows:

- Clarke, J., Connor, G., Grant, A., Johnstone, C., 2005. Developments of a contra-rotating tidal current turbine and analysis of performance. In: Proceedings of the 7th European Wave and Tidal Energy Conference. Porto, Potrugal.
- Clarke, J., Connor, G., Grant, A., Johnstone, C., Mackenzie, D., 2007a. Development of a contra-rotating tidal current turbine and analysis of performance. In: Proceedings 7th European Wave and Tidal Energy Conference (EWTEC). Porto, Portugal.
- Clarke, J. A., Connor, G., Grant, A. D., Johnstone, C. M., Jan. 2007b. Design and testing of a contra-rotating tidal current turbine. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 221 (2), 171–179.
- Clarke, J., Connor, G., Grant, A., Johnstone, C., Ordonez-Sanchez, S., 2008. Contra-rotating marine current turbines: Performance in field trials and power train developments. In: Proceedings of the 10th World Renewable Energy Congress.
- Clarke, J., Connor, G., Grant, A., Johnstone, C., Ordonez-Sanchez, S. E., 2010. Analysis of a single point tensioned mooring system for station keeping of a contra-rotating marine current turbine. IET Renewable Power Generation 4, 473–487, iSSN 1752
- Ordonez, S., Johnstone, C., Pratt, D., Grant, A., Gracie, C. 2012. Dynamic Response Analysis of the CoRMaT Turbine when Deployed within a Working River Environment. In: Proceedings of the 1st Asian Wave and Tidal Energy Conference. Jeju Island, South Korea.

Additionally, the generator has been widely promoted along with tidal turbine design in various marine energy workshops, seminars and conferences by the team members of Nautricity, Ltd. Some examples of these are:

- All Energy Conference, 2011
- All Energy Conference, 2012

Additional material including the applicability of the DD-CRG in wave energy conversion is planned to be released in the future.

1.8 Recommendations for Further Work

A preliminary insight on the physical parameters to study PTOs is necessary as from our experience not all the wave energy converters have the same requirements, and thus, a PTO systems may not be successful in all the wave energy applications. A PTO cannot be transferred from one device to another as it could be done with the wind or tidal energy converters. Similarly, wave energy converters are highly complex systems because of the number of parameters, interactions and feedback between parameters. Some parameters inevitable will be unknown or set arbitrarily during initial analyses to focus on specific components of the system. However, it will be crucial to study the hydrodynamic, structural, mechanical, electrical and electronic aspects of the problem in an integrated way. In the future, a model that includes full feedback between the prime mover, drive train mechanical linkage, generator and control system will be developed, as it is not possible to optimise one aspect without consideration of the others.

Open source models developed by NREL and ECN provide an efficient way to conduct preliminary modelling of some types of wave energy converters, including point absorbers and oscillating surge converters. There is potential to extend these open source models to include more components including the novel generator, the moorings, the control system and the mechanics of the drive train. Moreover, this model can be used at different stages of development which will be useful for further stages of development.

Although the team has increased their knowledge in wave energy conversion, to accelerate the achievement of the future development stages, the consortium will be expanded. The core ESRU team will incorporate experts in the wave energy field, power conversion and manufacture to help on the specifications of device design, production, testing and data processing. This will also help in the process of finding a more suitable supply chain and also reducing the uncertainties when calculating the LCOE.