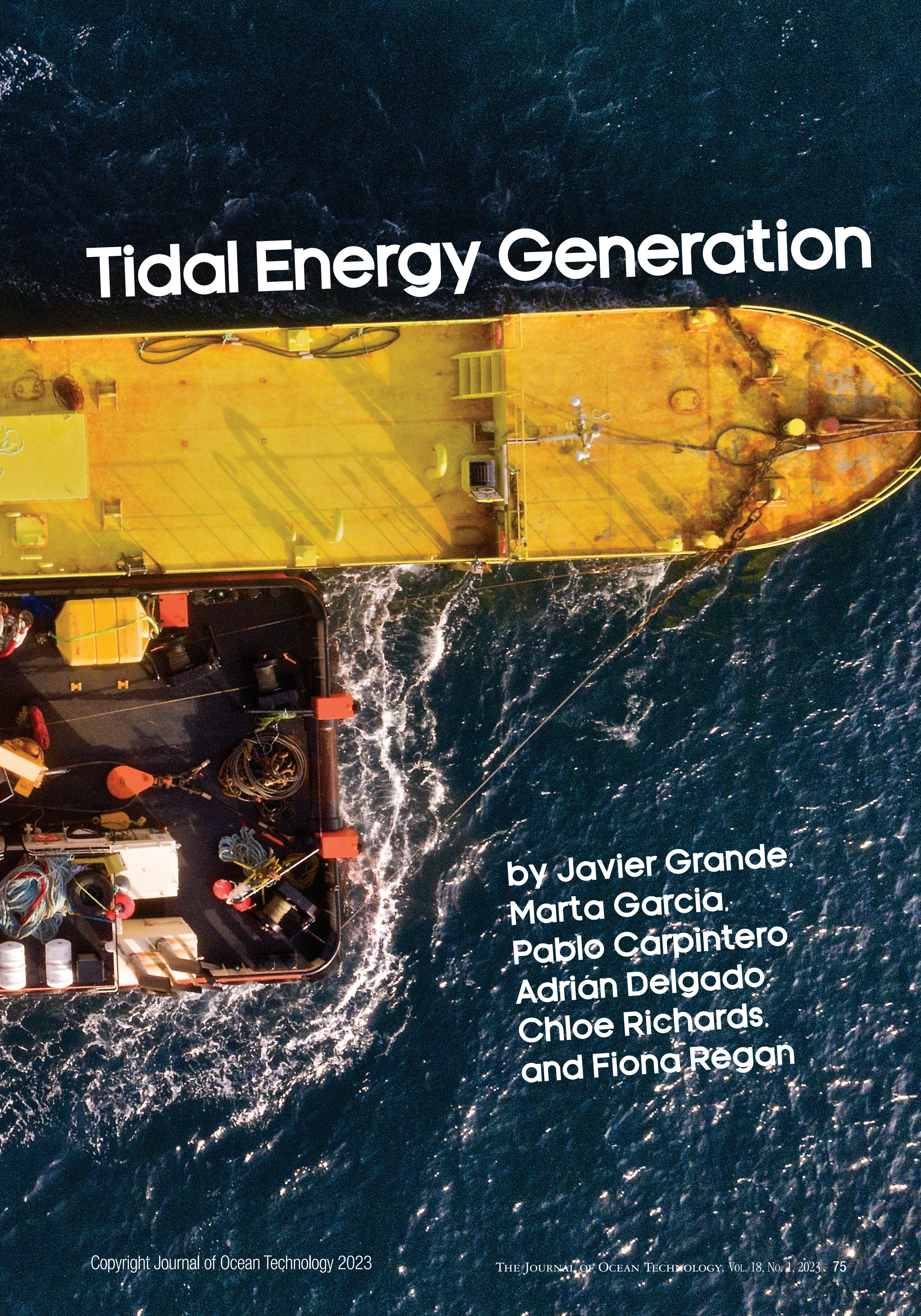
Making Better Blades for

MAGALLANES RENOVABLES



Tidal Energy Generation

by Javier Grande, Marta Garcia, Pablo Carpintero, Adrián Delgado, Chloe Richards, and Fiona Regan

Figure 1: Blade maintenance by diver.

Introduction

Tidal energy is an essential part of Europe's energy future. It is a clean, predictable energy source, and the potential tidal resource is huge. The European Union (EU) has set an ambitious goal to reach 100 gigawatts of installed capacity for wave and tidal energy by 2050.

Tidal currents are caused by the gravitational forces of the sun and the moon, and are particularly concentrated in narrow bodies of water, such as around islands or inlets. With an estimated global resource of 800-1,200 terawatt-hours, tidal stream energy can contribute significantly to the decarbonization of our energy systems.

Tidal currents are not influenced by weather conditions, and it is possible to predict tidal energy production hundreds of years in advance. This long-term predictability makes tidal energy one of the most reliable sources of renewable energy available. It has a crucial role to play in a 100% renewables-powered Europe, as it is instrumental in guaranteeing an electricity baseload and balancing the grid.

The design of tidal turbine blades is crucial to the performance and efficiency of the device, and has a major impact on the upscaling of tidal turbines (Figure 1). A strong, well-designed set of blades can increase annual energy production and reduce operating costs and project downtime. Blade edges can erode rapidly, causing leaks, accelerating fatigue, and increasing the risk of failure. Improving the seaworthiness of blades will reduce the likelihood of this type of failure. There is also a need for further technology investigation and demonstration of improved reliability and efficiency of tidal turbine blades and rotor, including pitch and yaw control.

The European Strategic Energy Technology Plan (SET Plan) has established cost targets for tidal energy equivalent to C$0.22 (15 c€)/kWh by 2025 and $0.15 (10c€)/kWh by 2030. Technological advances in areas such as blade design are an integral part of bringing down the levelized cost of energy (LCOE) in line with these targets.

Magallanes Renovables

Founded in 2009 by Alejandro Marques, Magallanes Renovables is a Spanish tidal energy developer, focused on the commercialization of floating tidal energy systems. The company aims to open and lead a new worldwide industry based on the exploitation of tidal energy – an unexploited and uniquely predictable renewable energy.

In 2017, Magallanes built its first full-scale tidal energy platform, the ATIR, equipped with

Figure 2: (top) Launching of Magallanes' full-scale prototype, the ATIR. (bottom) The ATIR in a dry dock for maintenance.

two tidal turbines (Figure 2). The ATIR is 45 metres long and 15 metres deep, with a total power production capacity of 2 megawatts (MW). The launch was followed by several months of electrical construction and towing tests, after which it was ready for action. Two years later, the ATIR was connected to the Scottish energy grid, successfully generating energy from tidal currents.

The NEMMO Project

The EU-funded NEMMO (Next Evolution in Materials and Models for Ocean Energy) project aims to create a larger and more durable composite blade for floating tidal turbines, enabling devices to reach capacities of over 2 MW. The innovative blade prototypes produced by the project will be used on Magallanes' tidal turbines, mounted on its ATIR device.

This will boost the competitiveness of tidal energy by reducing its LCOE and increasing the yield of tidal turbines.

These dual goals will be achieved by optimizing the tidal turbine blade design and performance. To do so, the project team has designed a geometry to improve the fluid dynamic performance of the blade. To increase the useful lifespan of tidal blades, it has also made changes to reduce cavitation, improved resistance to fatigue, and reduced the cleaning needs of the blade by using innovative antifouling surfaces. Finally, the project will optimize the blade's structural design to reduce mass production costs, and will also reduce the need for mechanical pitch changes to make this system cheaper to run, and to facilitate its installation in the marine environment.

Computer Modelling and Experimental Testing

The project work started with extensive computer modelling (Figure 3A), carried out by NEMMO project partner Technion (Israel Institute of Technology). The work studied potential cavitation effects on scaled-down versions of the blades and were used to predict the performance coefficient of the turbines. This study encourages accurate and affordable simulations of multi-rotor devices in the future.

Tailor-made testing procedures were developed to carry out a sizeable experimental test program in a cavitation tunnel at the SSPA facilities in Sweden, with the aim of validating the computer simulation models carried out by Technion (Figure 3B). These testing procedures for integrated harsh marine stresses enable the replication and modelling of composite blade lifespan, cavitation wear rates, bio-fouling growth, aging in a harsh marine environment, and hydrodynamic performance.

Regarding the performance of the turbine blade, an investigation of the influence of cavitation and translation due to the yaw of the turbine was performed at four different yaw angles between 0° and 19.5° and four pitch angles in different tip speed ratios. As the initial results showed no influence of cavitation, the pressure for the first tests was at atmospheric pressure. The remaining tests were completed at overpressure, which was the actual hydrostatic full condition for the turbine.

Novel Materials and Nanotechnology

Developing novel materials and coatings for tidal turbine blades is one of the main objectives of the NEMMO project to increase their aging, fouling, impact, and cavitation resistance (Figure 4). To enhance blade material performance, three parallel approaches were carried out, namely: improving the fatigue and impact resistance of the new nano-enhanced composite materials, controlling biofouling by means of blade surface micro-texturing, and developing novel non-leaching anti-fouling coatings with permanent cavitation resistance.

The latter is achieved through the design and synthesis of polymers bearing different functionalities within its chemical backbone and the incorporation of functionalized nanoparticles into such polymer formulations. Functionalized silica nanoparticles and carbon nanocomplexes were also added to the coatings.

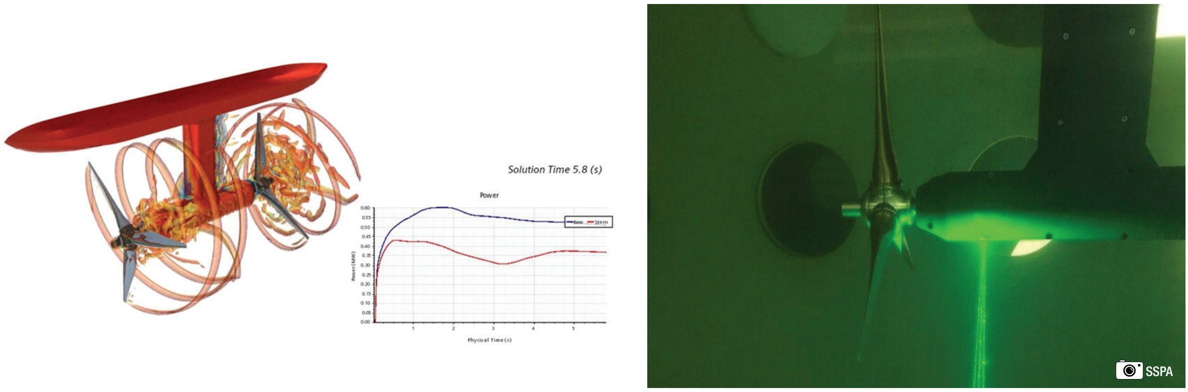


Figure 3: (left) High fidelity fluid dynamic simulation animation. (right) Cavitation tunnel tests with 1:38 model.

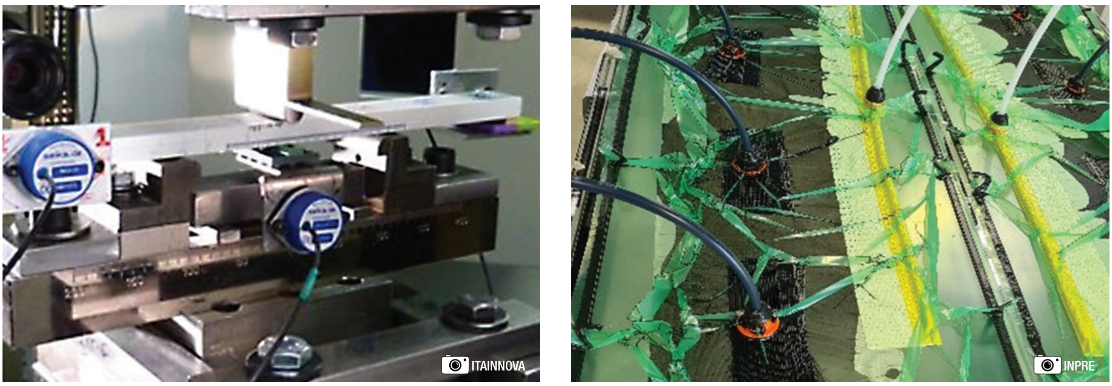


Figure 4: (left) Static test bench installed at ITAINNOVA. (right) Additive infusion process to fibreglass laminates.

Furthermore, several formulations of the reference resin have been tested. Composite plates of glass fibre resin have been successfully manufactured for each formulation. Mechanical properties seem to be similar whatever the formulation, but new formulations are still under development. Characterization of the failure (adhesive or cohesive) and ongoing humid aging to assess moisture effect onto formulated materials is currently underway at the Spanish technological institute ITAINNOVA.

Reducing Biofouling with Biomimicry

Biofouling, the development of nuisance or unwanted biofilms on surfaces, is a major problem due to accumulation of biomass causing reduced efficiency, contamination, corrosion, and failure of engineered components. Fouling in the marine environment has been an issue that has reduced the lifespan of structures, increased the fuel consumption of vessels, increased maintenance frequency, and spread invasive species for as long as humankind has been placing objects in the water. Biofilm formation is most readily recognized in marine and freshwater environments where a cursory glance at a surface, such as a ship's hull immersed for even a short period (weeks), reveals a multitude of organisms attached to and populating surfaces.

The study of surface topographical features has become increasing popular in recent years, with several investigations reporting sophisticated natural topographies found on many organisms that are known to have antifouling properties. The replication of artificial surfaces inspired by nature – known as biomimicry – has produced many promising results.

Studies have shown a mixture of attachment, depending on the size and shape of the organism and the specific micro-texture used as a fouling-resistant mechanism (Figure 5). However, the explanation behind this attachment is still not well known. Numerous theoretical models have been proposed through the years in order to understand this attachment behaviour. One of these models is the attachment point theory.

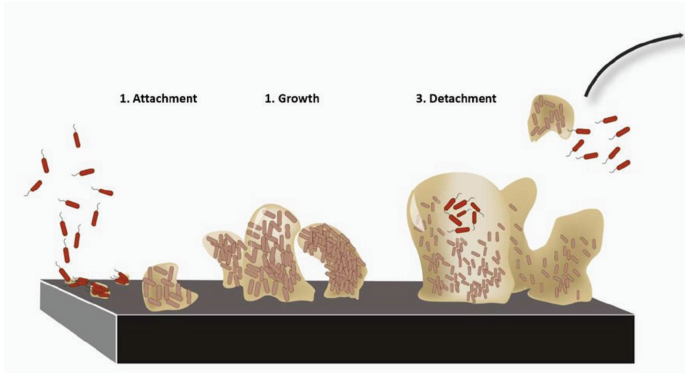


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Figure 5: Biofouling growth mechanism.

In this model, the fouling organism experiences increased attachment where there are multiple attachment points and reduced attachment when the number of attachment points are decreased. This can often be related to micro-texture, in the sense that highly intricate topographies (i.e., whereby the micro-texture is smaller than that of the organism) will not be favourable for attachment. On the other hand, where the micro-texture is larger than the organism, settlement does occur.

An application of the micro-texture discussed here is for the control of antifouling on advanced tidal turbine blades. The successful incorporation of antifouling technology onto tidal turbine blades could unlock significant potential for the use of ocean energy, reducing cleaning costs and allowing the extraction of energy from the blade system. Surface texturing has been shown here to be effective under static immersion. Field tests under dynamic conditions are ongoing as part of the project to assess the impact of hydrodynamic stresses under real sea conditions.

The testing of micro-textured surfaces showed that the cluster of biofouling organisms covered all candidate textures. The best results were obtained with sharp edge, raised, rectangular bars, leading to a 13% decrease in the cell coverage, a 42% decrease in the colony size, and a notable reduction in the nearest neighbour distance. If feasible, more significant reductions could also be achieved with narrower gaps between neighbouring structures.

Fatigue and Full-scale Ocean Testing

One full-size blade will undergo resonance fatigue testing at the Blaest Blade Test Centre (Figure 6). Innovations are also being made in the fatigue test processes of the blade bed, which in the tidal energy sector has not yet reached the same level of development as in the wind sector.

At the end of the NEMMO project, the blades will also be installed on the ATIR, Magallanes Renovables' full-scale platform. Full-scale testing is necessary to test the operation and control, to enable verification of all aspects of the device performance. This kind of testing is usually carried out at the European Marine Energy Centre's offshore site. The data collated from the real scale demonstrator will be used for the validation of the simulation results and the optimized blades performance evaluation during a complete tidal cycle.

Due to the floating nature of Magallanes' platform and its dimensions, it is foreseen that waves' effect will be secondary. Besides, the variable pitch system can control blade orientation to reduce the potential impact of waves in the blades. The effects of waves, tides, and other unexpected fluctuating loads will be considered in the project during the load definition.

The difference with respect to the smaller diameters tested so far not only affects the maximum achievable power, but also the energy production at low tidal speeds, which significantly affects the annual energy

Figure 6: Blade breakage test.

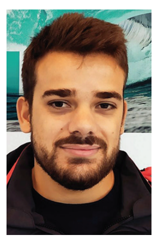
production, an evident improvement in the income derived from the sale of energy. The counterpart is that the bending moments transmitted to the hub by the blades increase with their length. This important milestone will serve to measure these static and fatigue loads to validate the fluid dynamic simulations and drive the structural design of the new generation of tidal energy generators.

This project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement 815278.

Javier Grande graduated with a M.Sc. in industrial engineering in 2014 from the University of Vigo, where he specialized in electronics and automation. Since then, he has worked at Magallanes Renovables where he has performed various functions, initially working on the tests of the 1:10 scale prototype. In 2019, he led the ATIR (Magallanes Renovables tidal energy converter) energy generation test campaign. In 2021, he was involved in the design of new innovative blades for a tidal turbine for the NEMMO project. At the same time, he has actively been working on the performance assessment of new locations of tidal currents potentially usable by the Magallanes Renovables tidal energy converter ATIR. His current role at Magallanes is instrumentation and control software manager.

Marta Garcia, a mining engineer with over 10 years of experience in renewable energy, oversees the naval-mechanical department at Magallanes Renovables. She is responsible for the development and growth of the company since its very early stages.

Pablo Carpintero has a B.Sc. in industrial electronics and automation engineering and a M.Sc. in mechatronics from the University of Vigo; and has three years' of experience in renewable energy. At Magallanes Renovables, he is in charge of digital twin modelling and data analysis of Magallanes prototype and has previous experience in control design and automation for machinery of automotive and pharmaceutical sectors.



Adrián Delgado is a researcher with the Dublin City University (DCU) Water Institute. He completed a B.Sc. in biology at Universidad Autónoma de Madrid (UAM) in 2017; a M.Sc. in water quality and microbiology in 2018 from Interdisciplinary Centre of Marine and Environmental Research and UAM; and is currently finishing his PhD in analytical chemistry at DCU. Mr. Delgado investigates how biofouling adheres to the surfaces of different materials, coatings, and bio-inspired micro-textured materials using techniques based on image segmentation in combination with machine learning in order to create growth models to understand their behaviour and thus select the best compounds for use in the marine tidal energy industry.

Dr. Chloe Richards is a researcher with the Dublin City University (DCU) Water Institute. She completed a B.Sc. in analytical science at DCU in 2017 and finished her PhD in analytical chemistry in 2022. Dr. Richards' PhD investigated the hypothesis that bio-inspired micro-textured materials can disrupt marine biofouling. She is currently working as a postdoctoral researcher on the I-SECURE project that aims to evaluate the sources and occurrence of contaminants of emerging concern in the marine coastal and transitional waters.

Fiona Regan is founder and director of the Dublin City University (DCU) Water Institute and is a full professor in chemistry at the School of Chemical Sciences in DCU. Prof. Regan's research focuses on analytical chemistry in the field of environmental monitoring, and she has special interest in priority and emerging chemicals as well as the establishment of decision support tools for environmental monitoring using novel technologies and data management tools. Her work includes the areas of separations and sensors (including microfluidics), materials for sensing, and antifouling applications on aquatic deployed systems.