ALTERNATIVE GENERATION IN WAVE ENERGY

WAVE ENERGY SCOTLAND

Technical note

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Wave Energy Scotland has investigated some alternative methods of electricity generation from the motion of the waves. This technical note highlights the motivation for this, what the opportunities are and what challenges remain.

1. What is the opportunity?

Wave energy technology is currently being demonstrated around the world and it is anticipated that the first pre-commercial arrays will be deployed over the next five years. The global market for wave energy is vast with estimates of more than 200GW by 2050. The UK is a leading nation in the race to develop wave energy and has a well-developed supply chain with estimates showing that the UK could retain 70% of the supply chain on future UK projects. This contrasts with other leading low carbon technologies where the technology supply chain is almost exclusively outside the UK. Analysis by ORE Catapult suggests that wave energy could have a net positive contribution to the UK economy of £4 billion and support 8,100 jobs by 2040[1].

There is an opportunity with alternative generation techniques to realise step-changes in cost and performance that could hasten wave energy's path to cost competitiveness and subsequent widespread deployment. There are challenges that need to be addressed with these technologies, and at this early stage of development this will require a collaborative effort involving materials research, development of cost-effective power electronics, systems integration and wave energy expertise.

Key findings

- *Electricity generation from the waves typically involves highly complex systems*
- *A step change in cost and performance is required*
- *Alternative generation methods such as DEGs and TENGs could simplify WECs*
- *Applications of DEGs and TENGs have been demonstrated at small scale for various types of mechanical energy harvesting systems. The challenge in the wave energy context is to scale up for cost effective energy production*
- *A number of technology specific challenges were identified*
- *Cross-sector collaboration could help resolve these issues*

2. Why consider alternative methods of generation?

Within the wave energy sector, electrical generation subsystems have primarily focused on power take-off (PTO) systems which utilise permanent magnet generators. These are heavy devices with many moving parts and ongoing maintenance requirements. They have to be integrated into a wave energy converter (WEC) which transfers the motion of the waves into a suitable input for the generator. This results in a highly complex system.

While more traditional solutions are rapidly maturing and reducing costs, recent years have brought growing interest in alternatives technologies.

Prototype methods of generation have been demonstrated which exploit the electromechanical behavioural characteristics of certain types of material to directly generate electricity from WEC motions. This provides the potential to reduce the mass, volume and cost associated with a traditional PTO within a WEC.

1 https://s3-eu-west-1.amazonaws.com/media.newore.catapult/app/uploads/2018/05/04120736/Tidal-Stream-and-Wave-Energy-Cost-Reduction-and-Ind-Benefit-FINAL-v03.02.pdf

In the right application, these technologies could provide the step-change cost and performance improvements required to accelerate wave energy to market competitiveness.

3. What methods are considered?

In late 2018 WES commissioned a consultant to carry out a landscaping study into the different alternative generation technologies that could be used in wave energy[2]. Dielectric Elastomer Generators (**DEGs**) and Triboelectric Nanogenerators (**TENGs**) were highlighted in the study as having sufficient potential to merit further research.

DEGs

DEGs use an electroactive polymer (EAP), sandwiched between two electrodes, to generate electricity when the EAP is cyclically stretched and relaxed. The deformation causes an increase in the capacitance of the material, which is then charged while fully stretched. As the charged elastomer relaxes, electrostatic energy is produced and stored in the DEG electric field, this energy is then harvested when the device reaches its minimum capacitance configuration. The amount of electricity generated is the difference between the energy harvested and the energy applied at maximum deformation. This sequence is then repeated.

DEG technology may provide cost reduction by eliminating the need for a separate PTO, with the power conversion function being integrated into the WEC structure[3]. The flexibility of the elastomeric material can help tune the natural frequency of the WEC with the incoming waves helping to optimise the amount of power that can be captured and also help the structure of the WEC to withstand extreme loads through compliance of the material.

Wave Energy Scotland (WES) was formed in 2014 at the request of the Scottish Government and is a subsidiary of Highlands and Islands Enterprise. WES' aim is to ensure that Scotland maintains a leading role in the development of wave energy. WES is driving the search for innovative solutions to the technical challenges facing the wave energy sector. Through our competitive procurement programme, we support a range of projects focused on the key systems and sub-systems of Wave Energy Converters (WECs).

TENGs

TENGs generate electric charges through friction when two dielectric materials come into contact with each other. These charges are then used to create a current flow through electrodes. The charges can be generated by separating surfaces or sliding surfaces and can therefore be incorporated into different existing WEC types.

[2]https://library.waveenergyscotland.co.uk/other-activities/project-landscaping/phase-2/alternative-generation/wes_ls08_er_alternative/

[3] Integration in such a way isn't a requirement for use of DEGs in wave energy though: use of a DEG PTO which is a separate subsystem could also be a cost-effective option.

4. What are the challenges?

In 2020 WES undertook a study to identify areas and methods to improve DEGs and TENGs that could benefit the application of these technologies in the wave energy generator. The study reviewed the current status of these technologies, methodologies for improvement, applications of these methodologies and any gaps that exist. This review considered a number of critical target characteristics of ocean energy technologies, such as performance, reliability and survivability.

The following aspects were considered to be important in general when considering the application of alternative generation technologies:

- Maximising the energy yield by an energy harvesting system depends on how the generator interacts with the system and in turn how it interacts with the energy source. This will be different depending on the application. An optimal generator for one application may be sub-optimal for another.
- The influence of wear during the lifetime of the material needs further investigation. What happens to generator performance during its lifetime and what strategies can be employed to prolong life appears to need further investigation (e.g. operating at lower charging voltages as the elastomer ages, in the case of DEGs).
- Control is an important consideration for optimising power output and respecting operating constraints in many WEC types. For DEGs and TENGs the timing of the charging and discharging presents an additional challenge for maximising power output.
- Fabrication and application of effective and reliable electrodes which may have to survive continuous contact with water.
- Impact on performance, reliability and survivability of power electronics in energy harvesting systems operating in a highly energetic and random energy source need to be better understood and minimised.
- Interdependencies between different criteria are important to consider e.g. a good energy capture device with a short fatigue life may be less effective than a less good energy capture device with a better fatigue life.

More specifically for each of the technologies considered:

DEGs

- Manufacture of rubber based electroactive polymers needs to improve to make it durable enough for use as a generator.
- Methods of manufacture for larger EAPs are not clear. Is it best to weld smaller sections together or make a larger monolithic section?
- In spite of the clear similarities, the characteristics that make a good dielectric elastomer actuator may not make for the best DEG. As a result, there would seem to be an R&D opportunity for development of EAPs for generator applications as most material development work to date has focused on EAP materials for actuator applications.

- Systematic estimation of theoretical power capture limits for potential DEG membranes is required.
- Better understanding of load-elongation hysteresis effects of electroactive polymers used in DEGs and how to model them is required to enable more accurate numerical modelling of energy harvesting systems (including WECs) that would use them.
- The effects of creep[4] of electroactive polymers on power production and lifetime needs to be understood.
- The effect of mechanical loading (energy capture in a wave application) combined with the charging effect needs to be better understood.
- The effects of scale do not seem to be well understood. Froude scaling is the most widely employed method of scaling in wave energy however some key DEG characteristics don't scale in this way.
- The application of more realistic reliability tests is required (e.g. most reliability analysis focuses on sinusoidal loading whereas in reality most energy harvesting systems will experience highly irregular loading .)

TENGs

- Power capture performance needs to be better understood. More rigorous assessment, taking account of the actual resource where WECs using TENGs would be deployed, is required to better demonstrate the impact that use of TENGs could have in wave energy.
- Control of the damping force a TENG PTO exerts on WEC motions merits consideration as often this is a key driver in optimising energy yield of a WEC.
- What longer term side effects are there from the friction of the TENG materials? e.g. heat and abrasion.
- A broad consideration of the engineering aspects of the use of TENGs in a wave energy context is required particularly in respect of understanding the impact on the levelised cost of energy that generators of this kind can have.

5. What next?

These novel energy capture technologies show potential, however further work is required if they are to be part of the solution. The relevant expertise is likely in a different sector such as material science, power systems engineering, chemical engineering or soft robotics or automotive or aerospace. Wave Energy Scotland is keen to facilitate cross-sector collaboration that could unlock an exciting new chapter in the wave energy story.

[4] Creep is the permanent deformation of a material due to long-term exposure to mechanical stresses.

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