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Feasibility study and design of an ocean wave power generation station integrated with a decommissioned offshore oil platform in UK waters

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Abstract
Wave energy exploits the movement of the wind across the surface of the sea to provide an inexhaustible, carbon-free energy source for electricity generation. This can potentially provide a significant contribution to electricity generation supply in the UK, meeting up to 20% of the UK's electricity demand. This represents 30-50 MW capacity of electrical energy by 2020, and potentially 27 GW by 2050 as technology within the industry develops and matures. Studies show that developing marine energy resources in the UK can save 60 metric tons of carbon dioxide by 2025 and aid in the UK meeting 20-20-20 renewable energy objectives. In this paper the design of a wave power station integrated with a decommissioned offshore oil platform is proposed. This approach provides ideal conditions for the exploitation of wave energy for electricity generation. It not only saves the cost of decommissioning but also provides the offshore oil platform with new life, generating electrical energy from an inexhaustible source. The objective of this work was to conduct an extensive feasibility study to develop a proof of concept design for wave energy generation integrated with an offshore oil platform.

Keywords: Offshore structures; Offshore wave power; Decommissioned platform; Mechanical design of wave energy generation system.

1. Introduction

Marine energy harnesses the movement of the sea to provide an inexhaustible, non-carbon based source of energy for electricity generation and can potentially provide a significant contribution to the electricity supply in the UK. Developing marine energy resources in the UK can save around 60 metric tons (Mt) of carbon dioxide (CO_2) by 2025 (valued at an estimated £1.1 billion to the UK economy) and also aid the UK in meeting renewable energy objectives [1].

There are two main types of marine energy power generation; wave and tidal. Waves are formed as wind blows across the ocean and interacts with the water surface. Friction is created between the two fluids and kinetic energy from the air is transferred into the ocean. This energy can be exploited for work, e.g. electricity generation. The size of the waves formed depends on the wind speed at the ocean surface, duration of wave travel, fetch (distance traveled by the wave), and sea currents. The greater the wind speed and the larger the fetch, more energy a wave can hold. The energy in a wave is proportional to wave height squared. This mathematically could be described as

$$P = \frac{\rho g^2}{64\pi} H^2 T \approx \frac{1}{2} H^2 T \qquad kW/m \tag{1}$$

where, P is the wave energy flux per unit wave crest length (kW/m); ρ is the mass density of the water (kg/m^3); g is the gravitational acceleration (m/s^2); H is the wave height (m) and T is the wave time cycle (s). Due to the geographical location of the UK, it faces some of the highest wave power levels in the world, in particular the northwestern coast. Because of this, it is estimated that wave energy could deliver approximately 40-50 TWh/year of electricity [2].

Tidal energy harnesses the effect caused by gravitational pull of the moon and sun on the ocean. As a result, tides are formed, providing natural kinetic energy that is constant and predictable. It is estimated that tidal energy could deliver approximately 20-30 TWh/year of electricity [2]. Because of the geographical location of the UK, it naturally favors higher wave energy in comparison to tidal energy, with wave energy potentially producing almost double the amount of electricity over tidal energy.

This report will investigate the feasibility of exploiting a decommissioned offshore oil platform located in the North Sea for wave power generation. Offshore oil platforms can provide a good basis to build a marine wave power generation station. Since these platforms are located out at sea in deep waters, this would provide favorable conditions to exploit wave energy production, such as wind speed, fetch, duration of waves, sea currents and bathymetry of the sea floor (which can amplify or focus the energy of the waves) [3]. Repurposing a decommissioned platform for wave energy generation will not only cut decommissioning costs but also provide opportunities to generate revenue whilst contributing to renewable energy generation.

Although wave energy generation is currently still in the early stages of development, various concepts and technologies have been deployed with successful results. This paper will explore, compare and review current types of wave energy converters, assess various issues regarding wave energy technology and propose the design of the ocean wave energy generation station scalable to a decommissioned offshore oil platform along with the analysis in terms of power generation efficiency and life cycle.

2. Potential of wave energy in the UK

In efforts to reduce carbon emissions while also maintaining the supply of increased demand in energy consumption, the European Union (EU) committed to targets known as the “20-20-20” targets in 2007. These targets include reducing harmful greenhouse gas emissions by 20% from 1990 levels, increasing the share of energy consumption produced from renewable energy sources to 20% and improving energy efficiency by 20% [4]. Within the UK, electricity generation through clean, renewable, non-carbon based sources must increase to 30% to meet the targets set by the EU [5].

Marine energy has the potential to contribute heavily towards achieving these targets in the UK [6]. The UK Government Department of Energy and Climate Change claims that the UK is currently seen as a world leader and a focal point for the development of wave and tidal stream technologies [1]. The research and development of marine energy technology coupled with the geological location of the UK, facing some of the highest wave power levels in the world, makes marine energy for a source of renewable, clean, non-carbon based electricity generation a viable option. The Department of Energy and Climate Change in the Digest of United Kingdom Energy Statistics (DUKES), estimates approximately 40-50 TWh/year can be feasibly exploited from wave energy alone within the UK [2]. With an average energy consumption of 4227 KWh per household in 2012 [7] wave energy can potentially meet the annual electricity demand of roughly 11.8 million homes, approximately twice that of wind energy. This is supported by the geographical island characteristics which the UK possesses, being surrounded by vast distances of water including the North Atlantic Ocean and the North Sea. This provides a large fetch with large wind speeds, resulting in large waves throughout the year. The waves in the North Atlantic Ocean in the north-west of the UK on average can be up to 3-3.5m in height, whilst the waves in the North Sea in the north east of the UK on average can be up to 2.5-3m in height as shown in Figure 1. Exploitation of wave energy has many advantages over many other sources of renewable energy.

2.1 Wave energy and reliability

As fossil fuels deplete with demand, alternative sources for energy generation are required to meet high energy demands. Wave energy is very reliable compared to other alternative sources of renewable energy. Begard et al. [8] identified wave energy sources to be the sun and wind. As long as the sun is there, waves will be formed through the transfer of energy between the wind and the sea surface. As a result, wave energy will never run out. Alternative sources of renewable energy such as wind and solar require the presence of wind and the sun respectively for energy generation. When there is no wind, there is no working fluid to drive wind farms for energy generation. Likewise, when there is no sun, there is no energy to drive work for solar power generation. However, waves on the ocean can be described as perpetual, continuously present.

The reliability of wave energy can also be attributed to its predictability. From Table 1, Begard et al. [8] estimated the predictability of various renewable energy sources. Compared to wind and solar energy, waves can be predicted days before they occur. This means wave energy converters can be deployed or relocated to obtain maximum energy generation in preparation for large wave days before they occur.

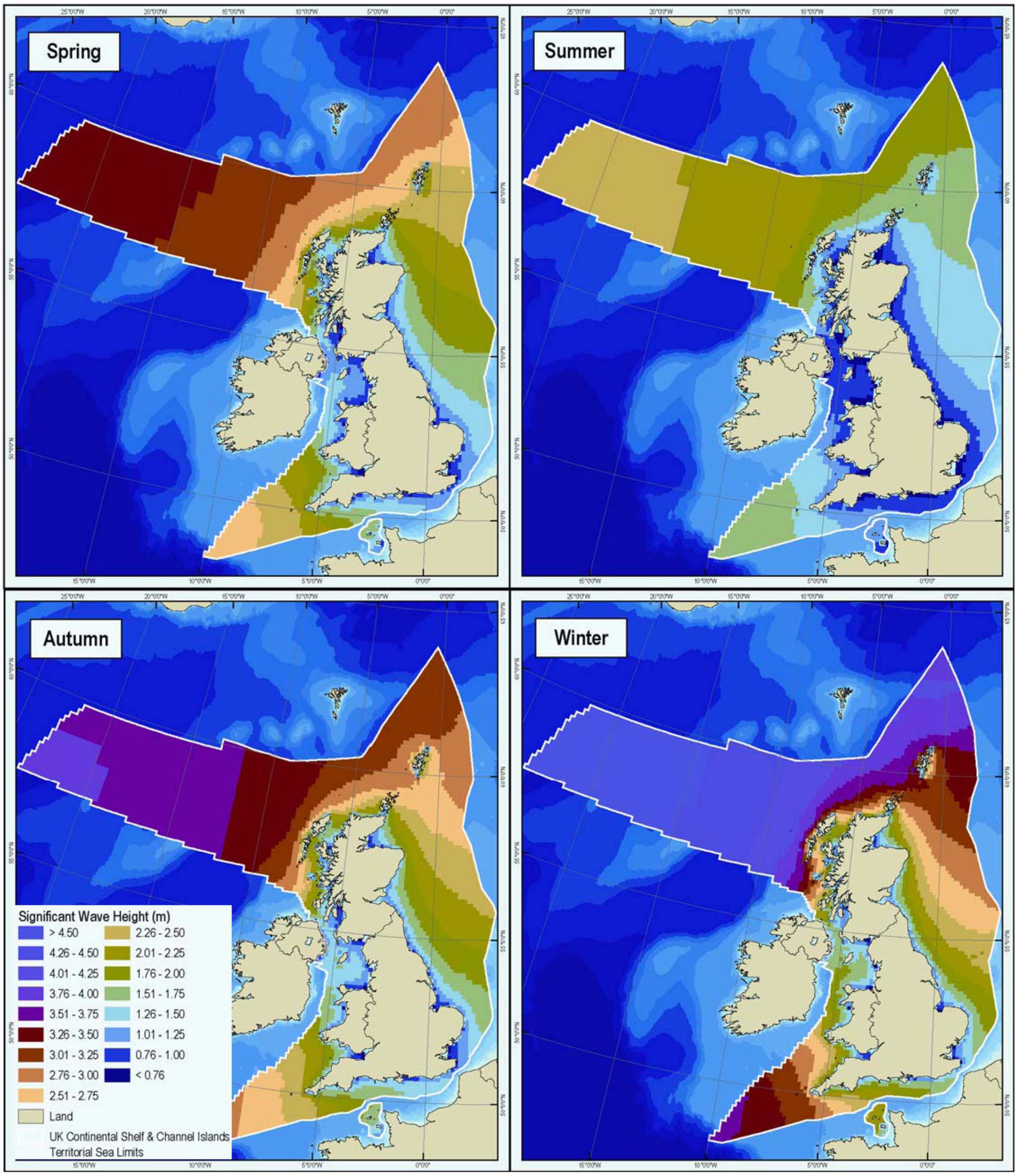

Figure 1. Maps showing seasonal mean wave heights in the UK territorial waters [7].

Table 1. Renewable Energy Resource Attributes [8].

	Solar PV	Wind	Wave	Tidal Flow
Development status	Early commercial	Commercial	Pre Commercial	Pre Commercial
Power Density	1 kW/m^2 at peak solar insolation	1 kW/m^2 at 12m/s (GE 1.5MW machine)	25 kW/m^2 at San Francisco average annual power flux	5 kW/m^2 at 3 m/s water flow rating
Hourly Variability	Daily cycles-clouds	When it blows	24-7 and highly variable	Diurnal cycles
Predictability	Poor	Hours	Days	Centuries

Aside from the manufacturing and maintenance of wave energy converters, the process of electricity generation from wave energy is completely environmentally friendly. The process releases no gaseous or polluting byproducts as most, if not all, wave energy converters only rely upon the energy and motion of waves through various methods. Being both renewable and environmentally friendly gives wave energy an advantage over un-environmentally friendly renewable sources such as biofuel.

The UK has many schemes which fund the development of marine energy technologies. The Marine Energy Array Demonstrator scheme pledges £20 million towards developing marine technology, and the government's Department of Energy and Climate Change has a budget of £200 million to help fund various low-carbon technologies [1]. These funding schemes will help push the design and development of wave energy technology towards commercialization.

2.2 Types of Wave Energy Converters (WEC)

Despite development of wave technology still being in its early stages, there already exists a number of methods in which energy is extracted from the ocean through waves. Figure 2 shows the main types of WEC's used in industry. They can be identified through their infrastructure configuration in relation to the shoreline and also by their placement, whether floating or affixed. WEC's located at shoreline have an advantage of being closer to various grids and networks meaning less equipment is required to connect, they are easier to access for maintenance and servicing, and, because they are closer to the shore, the waves exploited for electricity generation are smaller in size, reducing the likelihood of damage to WEC's.

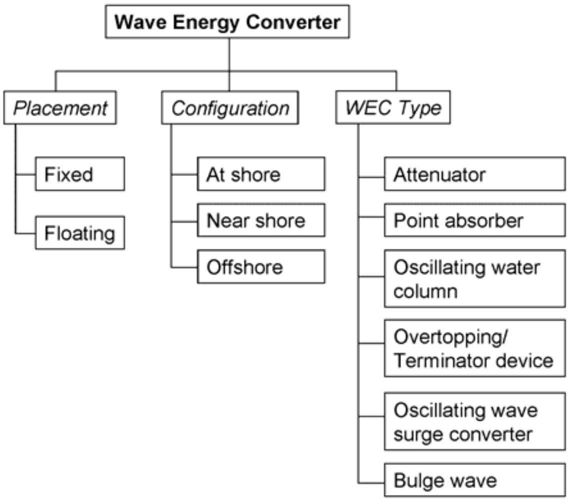

Figure 2. A diagram outlining Wave Energy Converters.

Because electricity generation is directly correlated to wave size, this means WEC's located at the shoreline generate less power [9]. WEC's located near shoreline are those located in shallow waters. Near-shore devices are often attached to the seabed, giving stability through an anchoring point which can be used as a base in which an oscillating body, e.g. a piston can work. Point absorbers are a prime example [9]. Near-shore devices face small waves, reducing generated power. On the contrary, WEC's located offshore are located in deep waters. These devices face large waves and can generate the most power, however because of their distance in relation to the shoreline, maintenance, servicing, installation and decommissioning is more difficult. They also need to be designed to withstand extreme conditions. There are currently many UK-based wave energy converter research and development centers which are both in commercial operation and development as shown in Table 2.

Table 2. UK-based wave energy converter technology developers.

Company	Device Name	Device Type	Reference
AlbaTERN	Squid	Attenuator	[10]
Aquamarine Power	Oyster 800	Oscillating Wave Surge Converter	[11]
AWS Ocean Energy	AWS III	Overtopping/Terminator Device	[12]
Checkmate Seaenergy UK Ltd	Anaconda	Bulge Wave	[13]
Ecotricity	Searaser	Point Absorber	[14]
Embley Energy Limited	Sperboy	Point Absorber	[15]
Greencat Renewables	Wave Turbine	Attenuator	[16]
Greenheat Systems Ltd	Gentec WaTS	Other	[17]
Lancaster University	PS Frog	Point Absorber	[18]
Marine Power Systems	WaveSub	Point Absorber	[19]
Nodding Beam	Nodding Beam	Other	[20]
Ocean Hydropower Systems Ltd	OHS Wave Energy Array	Point Absorber	[21]
Offshore Wave Energy Ltd (OWEL)	OWEL WEC	Oscillating Wave Surge Converter	[22]
PAULEY (Phil Pauley Innovation)	Solar Marine Cells	Other	[23]
Pelamis Wave Power	Pelamis	Attenuator	[24]
Polygen Ltd	Volta WaveFlex	Oscillating Wave Surge Converter	[25]
Portsmouth Innovation Limited	WAVESTORE	Overtopping/ Terminator Device	[26]
Sea Wave Energy Ltd (SWEL)	Waveline Magnet	Other	[27]
SEEWEC Consortium	FO3	Point Absorber	[29]
Snapper Consortium	Snapper	Point Absorber	[30]
Trident Energy Ltd	PowerPod linear generator power take-off system and wave energy converter	Point Absorber	[31]
University of Edinburgh	Salter's Duck	Attenuator	[32]
Voith Hydro Wavegen	Limpet	Oscillating Water Column	[33]
Caley Ocean Systems	Wave Plane	Other	[34]
BOLT (Fred Olson)	Lifesaver	Other	[35]
VERT Labs	--	Other	[36]
Ocean Power Technologies	Power Buoy	Point Absorber	[37]

2.3 Economical implications of wave energy

Begard et al [8] discovered that wave energy has the highest power density compared to alternative sources of renewable energy, with approximately 25 kW/m^2 in comparison to 1 kW/m^2 produced by wind or solar. This suggests that for the same amount of power generated, wave energy will be the cheapest. Despite having a high cost for development and deployment, in the long run it will be the most economically feasible technology.

From the future of Marine Renewables in the UK published by the House of Commons, it is estimated that by 2050 the global market for marine energy could be worth £340 billion, with the UK share worth approximately £76 billion, providing 68,000 jobs based in the UK [38]. In addition, electricity generation from wave energy will reduce the UK’s dependency on foreign companies for import of fossil fuels, whilst providing opportunity for the export of energy. As interest in marine technology increases around the world, with markets emerging in USA, Canada and Asia, the export of technology, skill and expertise can also be feasible. As the UK is seen as the world leader and focal point for development of marine technology due to its geographical location and expertise based on offshore oil and gas exploration, capitalizing on its advantage in the marine technology industry will bring much benefit for the UK economy and also for global research. However, along with the advantageous implications wave energy technology also poses some disadvantages.

2.4 Disadvantages of wave energy technology

One of the main disadvantages of many, if not all, energy infrastructure projects is the ‘Not In My Backyard’ issue. Complaints regarding the visibility of wind turbines or power generation stations from urban or communal areas described as a ‘scar on the landscape’ may halt the deployment of various technologies. For onshore and near shore devices, the ‘Not In My Backyard’ issue may exist as machinery may be unpleasant to those who live in coastal areas. Machinery may disturb sightseeing by the coast through noise and visual appearance. For offshore devices, they will be distant enough not to be visible from the shoreline. Because wave energy is out at sea, WEC’s are also located out at sea. This will minimize complaints of the general population as the visibility of such offshore or near-shore devices will be minimal. However, they still require safety hazard lights for times of haze or fog. In addition, sound signals, radar reflectors and highly contrasting day-markers are required for safety purposes.

The main disadvantage of wave energy is the localization of WEC’s. Each device is designed to be deployed at a certain location, meaning, although parts can be mass produced, each device is unique. This will increase costs per unit for initial manufacturing. Because the devices are designed to be deployed at certain locations, this requires extensive research into each one during the planning stages. Identification of wave height, extreme conditions throughout the year, wind speeds etc. are required and as each site is unique, this requires first hand research. As a result, the initial cost of WEC devices is high. This is because WEC devices are not readily available and require research and development for each site. WEC devices several kilometers from shoreline may need extra infrastructure installation to connect generated electricity to the grid. Besides, marine space may be occupied with protected areas for commercial and private use through shipping, fishing, military, telecommunications etc. If WEC devices are to be deployed to certain locations, these issues must be addressed during location selection. As WEC devices are deployed at sea, this may create a hazard for the marine ecosystem, including marine life and sea birds. During installation, if the devices require anchoring to the seabed then this would result in disturbance to creatures living on the sea bed. During operation, if sea life disrupts moving parts, it may cause damage to the machinery or to the creatures themselves. Risk of fluid leakage from faulty or damaged machinery will also be an issue to wildlife.

WEC devices are located out at sea, therefore during the process of installation, transportation of equipment is required. These devices vary in size, but most of which are so large that they require assembly on site. As a result, several transportation ships and vessels are required to carry these parts several kilometers offshore to site to deploy or assemble. This increases cost not only through fuel and transportation but also man hours. Maintenance is also difficult as the occasional unpredicted storms may cause damage to the machinery. Therefore, WEC devices must be designed to withstand high levels of extreme conditions. Addressing all these challenges mentioned above, the most feasible and effective solution could be to integrate a wave power generation station with a decommissioned offshore oil platform.

3. Decommissioned offshore oil platforms as a basis for wave power stations

The UK has much resources and expertise in oil and gas exploration. There are over 570 offshore oilrigs in the North Sea alone, many of which provide ideal wave and sea conditions for the deployment of WEC devices for electricity generation, whether for the grid or for various novel applications. Redeveloping and converting a decommissioned offshore oil platform into a wave energy generation station will:

- Save millions of pounds in decommissioning costs [39],
- Save waste in the form of decommissioned material,
- Restore use to a decommissioned offshore platform,
- Provide further revenue and jobs to help support the economy,
- Provide clean, renewable energy which will contribute to various targets and help the UK towards more sustainable green energy generation and production,

- Be less harmful to the marine environment (conversion rather than dismantling which may upset wildlife).

As a case study, one offshore platform was identified from the many which exist, whether in commissioned and decommissioned form, within the North Sea. This platform will be the basis on which the wave power station will be designed. To achieve this, there were three criteria which the platform must meet:

1. To be in the state of decommissioning or have been decommissioned within the past ten years
2. To have a suitable steel platform infrastructure
3. To be in a location of large wave height

Figure 3 shows two superimposed maps: a map showing annual mean wave height in UK territorial waters [7], and a UKCS infrastructure wall map showing oil and gas activity (last updated 3rd March 2014) [40]. The resultant map clearly shows UK's offshore platform infrastructure, in circles, with corresponding wave height in colours.

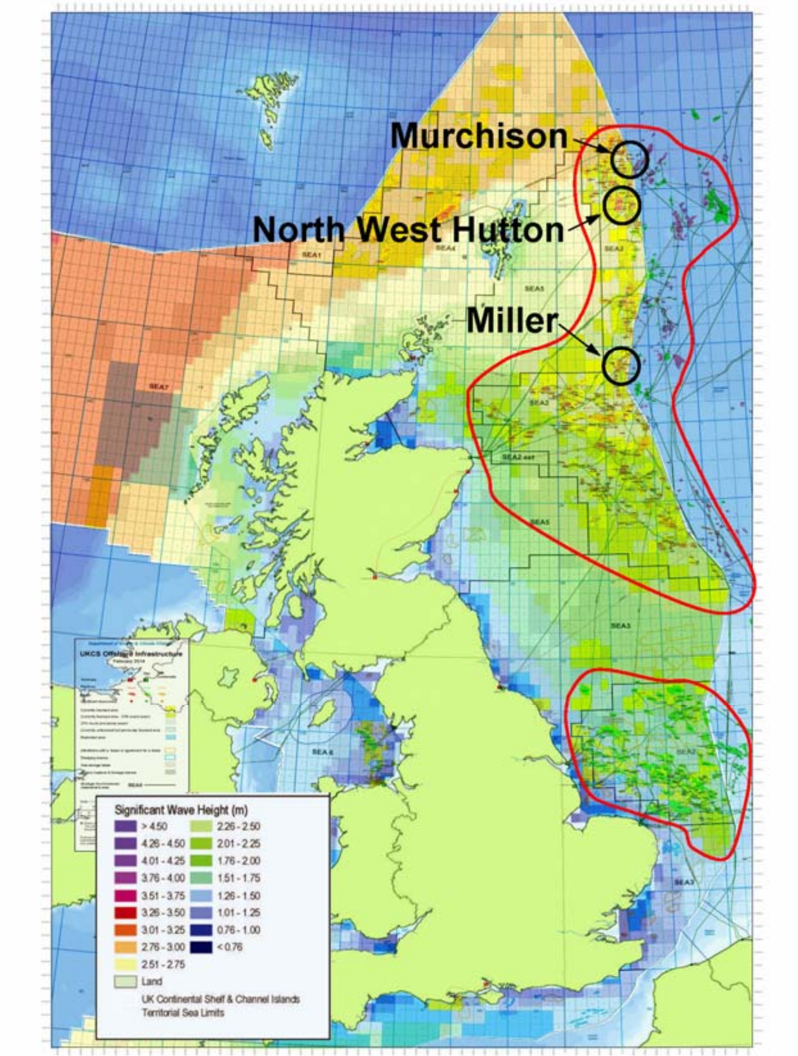

Figure 3. Location of UK offshore platforms and wave height.

Offshore infrastructure decommissioning programmes are available to the public from the UK government's department of energy and climate [41]. With this data, three suitable offshore platforms from the past ten years were identified, as shown in Table 3. Two of these platforms are already decommissioned and one is in the process of decommissioning. A ten year period was identified to be the most ideal time frame because the majority of decommissioned offshore platform infrastructures older than ten years were completely removed, including topside steel platforms and the entire jacket assembly.

Table 3. Suitable decommissioning platforms [41-43].

Field name	Field Operator	Status	Main points of the programme	Year of approval
North West Hutton	Amoco (UK) Exploration Company – now a subsidiary of BP plc	Large Steel Platform Pipelines	Footings to remain in place, steel topsides and jacket to top of footings to be removed to shore. Decommissioned in situ	2006
Miller	BP Exploration (Alpha) Limited	Large Steel Platform	Footings to remain in place, steel topsides and jacket to top of footings to be removed to shore	2013
Murchison	CNR International (UK) Limited	Draft programme under consideration	Topsides and steel jacket to top of footings to be removed to shore. Proposal to leave jacket footings in place.	2014

Figure 4 shows the typical life cycle of an offshore marine platform. After a certain number of years within their production life, they are typically decommissioned, costing companies hundreds of millions of pounds to decommission, dismantle and recycle. However, since the existing infrastructure will still be installed after production, alternative uses for the offshore platforms can be explored. Redevelopment and conversion into the offshore power stations exploiting wave energy resources not only gives the infrastructure a new use but also, the platform will continue to provide power and revenue without depletion of natural energy sources. Although technologies of the WEC devices are relatively high cost, once the technology has become developed and mass produced for mainstream power generation, the costs of manufacture and installation will decrease. However, installation of the devices onto the platform will still require offshore transportation and installation which may cause the cost to rise.

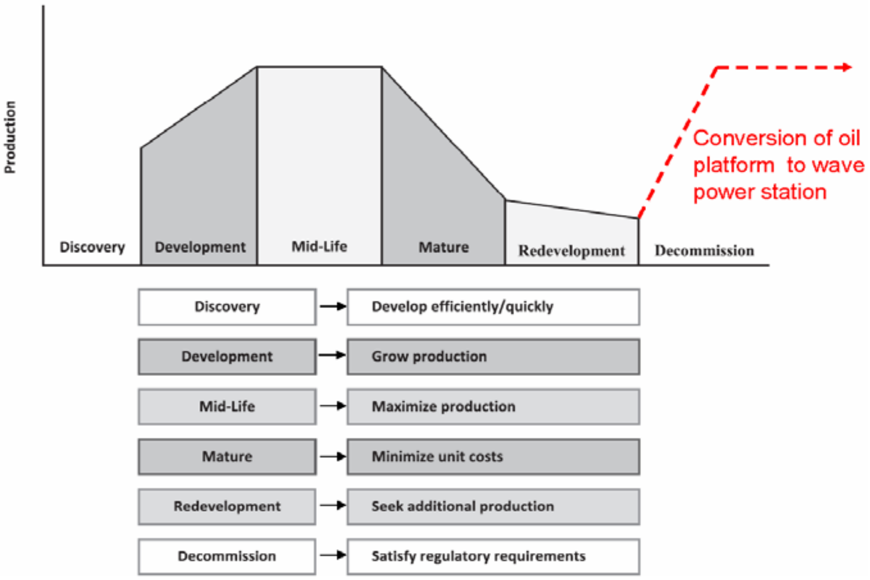

Figure 4. Life cycle of offshore platform converted to wave power station [39].

3.1 North West Hutton patform

The platform was located 130km north east of the Shetland Islands with a water depth of approximately 140m. The multipurpose platform was supported by an eight legged steel jacket, installed in the early 1980's [42]. The decommissioning of the North West Hutton platform began from planning in 2003, approval in 2006 to completion in 2010, with decommissioning of the entire platform from jacket, topside, pipelines and drill cutting piles.

The decommissioning posed many risks. According to a Danish engineering consultant, the risk of project failure was 45%, and eventually, it was accomplished through splitting the programme into three phases: decommissioning of the platform and equipment costing £154 million, decommissioning of the gas pipeline costing £3 million, and decommissioning of the oil pipeline costing £3 million, a total of

£160 million. There were also social impacts as there were many fishing activities around the area. This was seen as a positive impact as removal restored a 0.75 km^2 area for fishing.

3.2 Miller platform

The Miller platform is an integrated multipurpose oil and gas platform for drilling, production, processing and accommodation. The platform was installed in the Miller Field in 1991 by BP Exploration Limited. Water depths are approximately 103 meters. The topsides are supported by an eight-legged steel jacket and had an installed weight of 28,732 tonnes [43]. Planning for decommissioning began in 2007, it was approved in 2013 and is expected to be completed in 2019. Decommissioning and removal of the platform is expected to have various environmental impacts including noise, waste, upsetting the sedimentary seabed composition with sand and clay content, altering the seabed chemistry with hydrocarbon and metal particulates from the cutting of metal, upsetting plankton, benthic communities, fish population, seabirds and marine animals. Although risk assessments and consultations were carried out, many issues still remain from decommissioning. The cost of decommissioning for the Miller Programme is expected to be in the order of £300 million. This covers the decommissioning of the entire platform including removal and transportation of infrastructure, topside, jacket, project management, engineering and the removal of 22 well conductors [43].

3.3 Murchison platform

The Murchison platform is currently in the drafting process of decommissioning and is expected to be completed in 2021. It is approximately 150km North East from Shetland and the platform is located in waters of 156m depth. It is supported by an eight legged steel jacket and in total weighs 27,584 tonnes. Contact with the company was attempted to acquire decommissioning cost data, however it was classified information, as also stated in the draft decommissioning programme. However, it can be estimated that the costs would be approximately £300 million due to the size of the platform [44, 45].

4. Design of a wave power generation station integrated with the murchison platform

For this analysis the Murchison platform was chosen as the basis for the design as it was located at the site with the largest waves. Theoretically, the larger the waves, the larger the power generated from the waves. The size of the platform is shown below in Figure 5. Design criteria were chosen to be considered for feasibility and optimization such as materials and manufacture, maturity of the technology, ethical and environmental issues and sustainability.

Materials and manufacture is important to the overall feasibility of the design as this will determine other factors such as cost of manufacture, assembly, durability, failure, repair, replacement, maintenance and the ability to withstand extreme conditions. It has to be designed around the existing infrastructure of the platform. Maturity of the technology will affect the cost of the general parts, the availability of the parts and the efficiency. Because WEC technology is relatively new, maturity of the principles and technology are vital. Ethical and environmental issues are also taken into consideration during the development of conceptual design as installation into a marine environment will affect a vast ecosystem. Sustainability is taken into account for assembly, disassembly, recycling, servicing and modularity to prolong the life cycle of the concept. Finally, the area of the Murchison platform was aimed to be utilized as much as possible including area under and around the platform as there will no longer be wells and drills after decommissioning.

The wave energy generation device for the purpose of integration into a decommissioned offshore power generation station is purely a conceptual design. Therefore, as a proof of concept, the primary objective for feasibility of the concept will be theoretical power output. The secondary objective will be calculated revenue. To decide which types of WEC principles were the most ideal as the basis of the design, eight types of WEC devices which are currently on the market were compared for maturity of the technology and power generation output.

For the context of an offshore platform with integrated WEC devices, adapted to build an offshore power generation station, two principles of WEC were identified to be the most suitable: floating point absorber and oscillating water column. Technologies for both principles are relatively mature with commercialization such as Ocean Power Technologies' point absorber and Voith Hydro Wavegen's oscillating water column. They also have relatively high power output. A combination of the two technologies will not only result in higher power generation but also the reliability to cover both high and low wave heights.

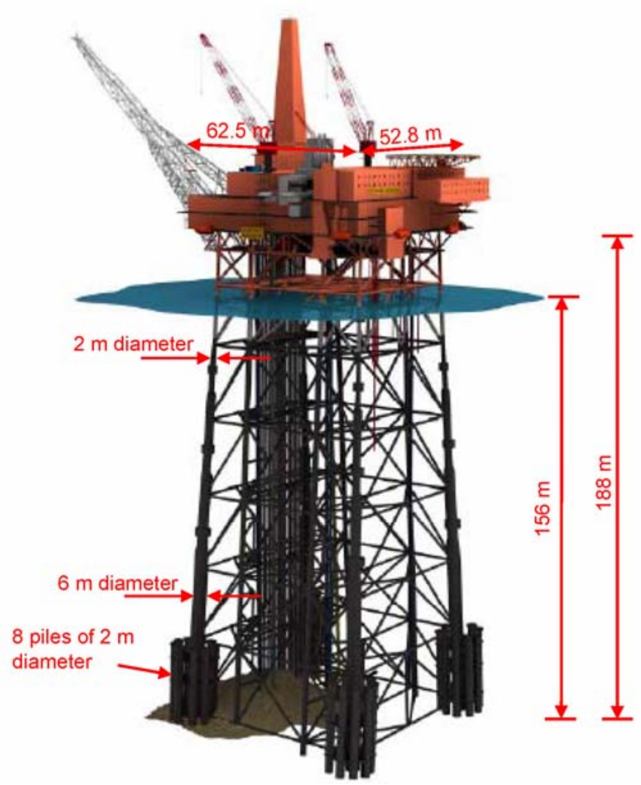

Figure 5. Dimensions of the Murchison platform [44, 45].

4.1 Point absorber design

The point absorber part of the design was adapted from the principle of a floating buoy in which the resultant motion incurred by the waves will move/flex mechanical parts in relation to an anchor point to generate electricity. Floating buoys rests on the ocean surface. As waves pass, this causes the buoy to bob up and down. The resultant movement from the buoy will cause a movement on the arm about a pivot point which is hinged to the base of the device. The movement on the arm drives a piston that drives a working hydraulic fluid through pipes which then drives a typical pelton wheel turbine that drives a generator to produce electricity. The working hydraulic fluid is then pumped back through the piston and the cycle continues. Rack and pinion integration will allow the device to be moved up and down the platform leg according to ocean surface level, or lifted above the waters when extreme conditions occur.

As point absorbers require the floating buoy to be in direct contact with the ocean, the most feasible approach is to be attached to the offshore platform jacket legs. Alternative solutions were to be hung below the platform which will allow the device to be reeled back when not deployed. However, the distance is 30 m from the ocean surface and the bottom surface of the Murchison platform and strong winds will cause the device to be unstable.

The point absorber design should accommodate for wave heights of approximately 2.76-3.0 meters, which occur around the Murchison platform. One of the highlighted design qualities is materials and manufacture. For the device to be ocean-friendly, it must be resistant to corrosion from the saline waters, strong enough to withstand extreme marine conditions and environmentally friendly to the marine ecosystem. As the design is very modular, this will, in effect, contribute to sustainable and cheaper manufacturing and assembly. As a result, should any part be damaged during deployment and require replacement or repair, they are able to be easily replaced.

The point absorber device, as shown in Figure 6, will have to be assembled on-site, therefore requiring transportation 150 km offshore and manned assembly around the offshore platform jacket legs. Once the base is assembled around the platform leg, the internal components can be installed. This makes transportation more cost effective and the parts easier to transport.

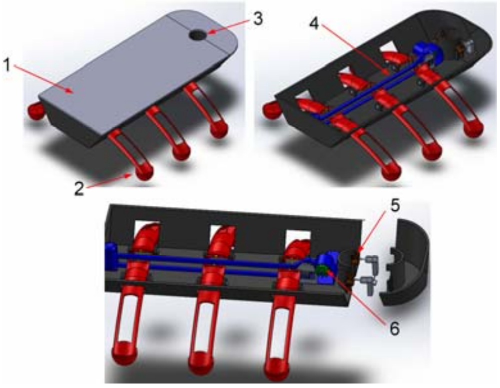

Figure 6. Point absorber system design: 1. Cover, 2. Point absorber, 3. Liner, 4. Pipes, 5. Rack and pinion mechanism, 6. Pelton wheel turbine.

Modularity of design also results in the possibility to increase the number of devices as required for desired energy output. The mechanisms of a pivoting point driving a hydraulic piston are relatively simple and have been in many applications for a very long time. As a result, the technology is very mature and developed, increasing reliability and efficiency of various components.

As proof of concept, assumptions of 1 MW per buoy can be estimated, resulting in a total rating of 6 MW of energy per point absorber WEC device. Simple calculations can be made to calculate how many homes it will supply per year:

Maximum Electricity generated per year (kWh) = 6000 (kW) * 8760 (hours in a year)
= 52560000 kWh per year

Assuming 45% total efficiency of turbine and mechanical parts,

Electricity generated per year (kWh) = 52560000 kWh * 0.45 = 23652000 kWh per year

Assuming the average annual household consumption as 4227 kWh [6],

Number of Homes = 23652000 / 4227 = 5596 homes per year

4.2 Oscillating water column design

Oscillating Water Columns (OWC) are generally located onshore. However, within recent years, several concepts for offshore oscillating water columns have been developed and patented to exploit larger wave height. The principle of the OWC is based on the rise and fall of the wave (change in wave height), with a large area submerged in the ocean, as shown in Figure 7. As a result, the air trapped in the upper chambers is compressed and decompressed due to the motion of the waves. This compression and decompression of the air can be channeled through to a bi-directional Wells turbine which spins the same direction despite the direction of air flow.

Because the column is partially submerged into the sea, it must be made out of a material which is not only robust and strong enough to withstand extreme marine climate conditions but also resistant to the saline conditions of the water. Some type of reinforced concrete may be suitable for such infrastructure. The principle behind oscillating water columns means there aren’t many moving parts, besides the Wells turbine driving the generator, as the whole column assembly acts as one hydraulic column. It is arguable that the compression and decompression of the air within the chamber may be minimal due to the mass of air within the chamber. However, Okuhara, et al. [46] researched into the use of Wells turbines for wave energy conversion and found that their efficiency is maximized at low velocity. As a result, despite the rise and drop of the waves being only approximately 3 meters, this will still cause sufficient compression and decompression of air to drive the Wells turbine. Submerging a large infrastructure into the ocean may pose some ethical and environmental issues such as trapped sea life within the column. This may be overcome by adding some sort of filter or netting at the bottom of the column to prevent marine life entering the device. This will also prevent debris from within the device from entering the ocean.

Summarizing this section it should be noted that an Oceanlinx offshore oscillating water column has been deployed in Australia since 2005 and is currently rated at 1.5 MW per unit [47] using a 450 kW induction motor to generate electricity from a bi-directional Wells turbine. Using this as a basis of our calculations we can estimate the amount of electricity that can be generated using this technology as follows:

Maximum Electricity generated per year (kWh) = 1500 (kW) * 8760 (hours per year)
= 13140000 kWh per year
Assuming 45% total efficiency of mechanical parts,
Electricity generated per year (kWh) = 13140000 kWh * 0.45 = 5913000 kWh
Assuming the average annual household consumption as 4227 kWh [6],
Number of Homes = 5913000 / 4227 = 1398 homes per year
The design of WEC devices are integrated onto a complete scale model of the Murchison offshore platform to build the offshore power generation station, as shown in Figure 8.

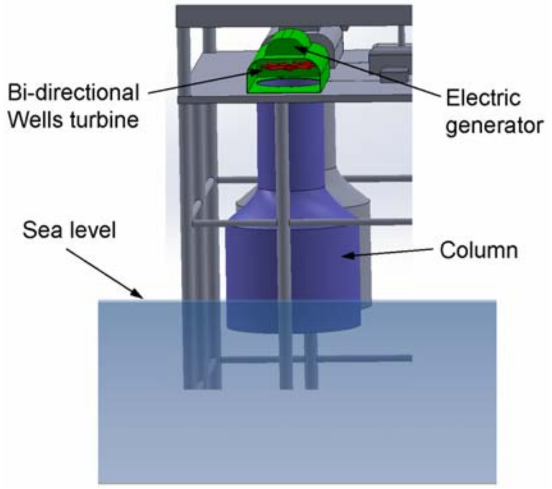

Figure 7. Oscillating Water Column integrated with offshore platform.

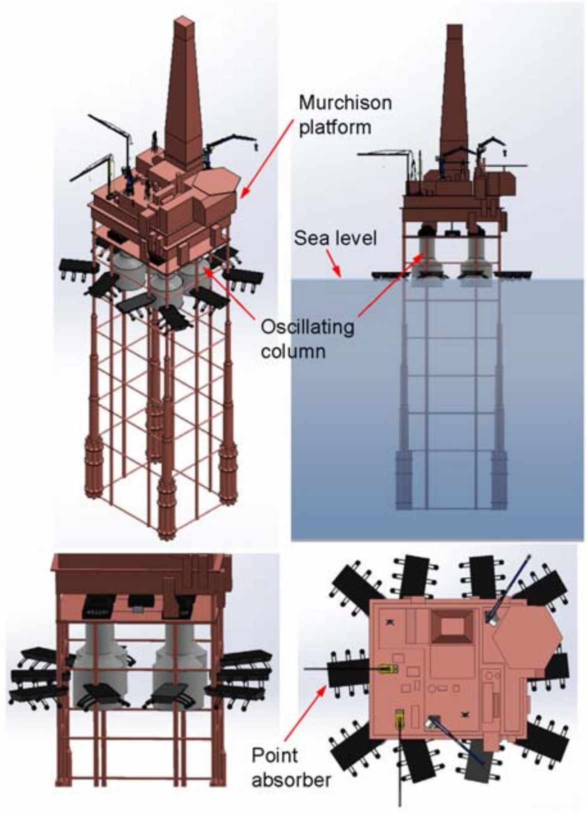

Figure 8. Complete assembly of wave power station integrated to the offshore platform.

4.3 Power output and total income

For the final generation station, ten point absorber devices were attached to each leg of the Murchison platform, and four oscillating water columns beneath the platform to maximize the area usage of the platform. As a result, the total power output of the platform is calculated to be 66 MW, estimated to provide power to 61,360 homes annually at 45% efficiency. Total income can be calculated using a simple economic model:

- 66 MW power station at 45% efficiency is 260172 MWh per annum,
- Basic power price at £55.00/MWh [44],
- Renewable Obligation Certificate (ROC) £50.00/MWh [44],
- ROC band 2.0 [44],
- Levy Exemption Certificate (LEC) £4.30/MWh [44],

Total income = 260172 MWh * (£55 + £50*2.0 + £4.30) = £44,047,119.60 pa.

The future work on this project will address the structural integrity of the system. The mechanical feasibility will be carried out through model testing using Fluid-Structure Interaction to ensure that the design will be able to withstand extreme conditions. As the project explores a relatively new research area, legal issues regarding the reuse and conversion of existing infrastructure will also be considered. Further post-installation site analysis will be carried out to recognize environmental and social implications. WEC technology cost reduction, improvement in efficiency & reliability will be carried out.

5. Conclusion

Wave energy is an inexhaustible source of clean, renewable energy. It can be exploited to provide for much of the UK's energy generation, reducing the dependency on importation of fossil fuels and cutting costs. The UK possesses favorable qualities for the development of wave energy. It is an island facing some of the world's highest potential wave energy and it is seen as the world's leader in wave energy technology development. This work has shown that integrating wave energy conversion devices with offshore decommissioned platforms can help to solve many issues of renewable energy implementation. An extensive qualitative feasibility study was used as a basis throughout this project, from the conceptual design stage to the complete offshore power generation station. Using various design qualities, two WEC technology principles were identified to be the most suited for integration onto an offshore platform and further developed for proof of concept. Finally, the concept design was integrated onto a modeled Murchison platform, chosen for its ideal location and decommissioning status. As well as giving a new life to the offshore platform it was shown to have the potential to provide the UK with enough electricity to power more than 60,000 homes per annum. Furthermore, the conversion of the platform would provide continuous, inexhaustible revenue to the industry, providing the economy with approximately £44 million per annum.

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