Harvesting Energy from Ocean Current

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Abstract
Electricity is a need of greater necessity for the development of a civilization. Currently, the use of fossil fuels is the largest source of energy worldwide. This method of energy production is harmful because the carbon dioxide (CO_2) released by burning these fuels is largely the basis of global warming and climate change. Hence the necessity of producing energy in sustainable ways which are not harmful to the environment. The study presented in this paper aims to harvest energy from the ocean. The Acoustic Doppler Current Profiler (ADCP) data collected on the east coast of South Africa indicates that the Agulhas current has the potential of ocean current energy resources. This method is based on the training of turbines submerged in the ocean by the ocean current. This paper shows a review of different types of ocean current energy conversion and focuses on the horizontal axis marine current turbine. Results reveal that the method is suitable for big scale projects. This system does not produce any kind of pollution and proves to be a solution that will reduce the use of coal for electric generation in power plants. This is one of the best ways that will contribute to the country's electricity production and demand.
Keywords Harvesting energy, Agulhas current, ocean current energy conversion.

1. Introduction

The global energy demand is currently being met in most countries by an exhaustible resource of fossil fuels. This work is based on research of electrical energy production from the conversion of the freely flowing water energy into electricity power. South Africa is a large country located in Southern of the Africa continent. It has 2,798 km portion of its borders surrounded by water with the Indian Ocean to the southeast and the Atlantic Ocean to the west. According to statistics SA [1], the country has 50,586,757 people in 2011 and produces sufficient electricity power to meet the electricity demand. Presently, about 72.1% of the country's primary energy needs are provided by coal. An overview by Mbuseli [2] the main electrical company "Eskom" on the 25 March 2013 shows an installed capacity (total nominal capacity) of 44,145MW and usable capacity (total net maximum capacity) 41 194MW. This capacity does not seem to be sufficient for next high electricity demand soon. Eskom's system status bulletin which is released twice a week in line with its commitments to regular and

Transparent communication on the power system, the current capacity available on this period "April 2013" to meet the evening's peak demand "from 5pm to 9pm" is low. The Eskom's system status is available on their official web site. Therefore, the need to produce more energy in South Africa become high and the way to produce it must be clean. The potential that South Africa must produce electricity using one of the ocean's energy forms is to be considered. The study is to proof the concept of the generating power method in a flowing ocean current. Many components in a system using ocean current are to be analyzed. Data and measurement from the different sites where the system can be build are already done. Eskom states in a fact sheet published in January 2013: "In South Africa, coal has dominated the energy supply sector. It is not obvious to see a significant change in the next decade". As a member of the global community, South Africa has pledged its support for sustainable power generation to be produced by renewable energy sources. Nevertheless, ocean current power energy technology is a potential solution for a suitable alternative energy source [3].

The focus of this paper is on the kinetic energy of the ocean current and describes this resource for the energy conversion purposes which will contribute towards assisting the government in reaching its renewable energy goals.

2. South Africa Ocean current energy resources

Looking at the position of South Africa on Figure 1, two important boundary currents which are the Agulhas and the Benguela currents have been considered. Boundary currents are ocean currents with dynamics determined by the presence of a coastline and fall into two distinct categories: the Western boundary currents and the Eastern boundary currents. The Western boundary currents as warm, deep, narrow, and fast flowing currents that form on the west side of ocean basin due to western intensification. They carry warm water from the tropics pole ward.

Lutjeharms carried out research of the greater Agulhas current [4] that covers some aspects of the studies of the southern and northern parts of the Agulhas current. The study shows that Agulhas current is 100 Km wide and the two parts of this current have distinctly different trajectorial behaviors. The Northern Agulhas current is shown to be a Western boundary current with invariant path. The temperatures of the Agulhas current can be greater than 22°C, the speeds 1.3±0.3m/s and a volume flux estimated at about 72Sv (Sv=106 m^3/s) over the full depth of the current. The Southern Agulhas current is located downstream of Port Elizabeth. Its surface temperatures are 23 to 26°C and its surface speeds may be more than 2m/s. The Benguela currents is part of the Eastern boundary currents and are relatively shallow, broad and slow flowing. They are situated on the Eastern side of oceanic basins (adjacent to the western coasts of continents). Subtropical eastern boundary currents flow equator ward, transporting cold water from higher latitudes to lower latitude. The Benguela currents are cold, wide current flowing northward along the West coast of Southern Africa. It is 200 to 300 Km wide and as typical surface flow speeds of 0.2 to 0.5 m/s (therefore much slower than the Agulhas current). This paper focuses on Agulhas currents. Categories and criteria of ocean energy resources in the Western Indian Ocean are describe in Table 1.

3. Challenges

The questions in this research are as follows:

- How can we produce more electrical energy to supply the country?
- Eskom Ltd which is the country's electricity supply utility responsible for generating, transmitting, and distributing electricity seems to be saturated [2].
- How can we produce electricity avoiding the negative effect of the carbon dioxide (CO_2) in atmosphere which can compromise the ability of our future generations?
- In 2007 Eskom was the second largest utility emitter of carbon dioxide globally [5]. Coal intensity has increased at a time while a commitment was made to reduce coal reliance at the World Summit on Sustainable Development (WSSD).
- How can we capture the ocean currents surrounding South-Africa as the Agulhas current and convert them in electrical energy?

Many different technologies have been developed to convert natural energy into electricity. To solve the problem considering the questions above, the ocean current energy conversion seems to be one of the ways that contributes to the sustainable development and produce more electricity to supply the country.

The above challenges have been addressed in the paper.

4. Ocean energy technology

Ocean renewable energy system has different forms, which can be: encompassing tides, ocean circulation, surface waves, salinity and thermal gradients [6]. These different forms can easily be classified in three options which are: wave energy conversion, ocean thermal energy conversion (OTEC) and ocean current energy conversion. The common point with ocean current energy and tidal energy is the fact that tidal energy is a current that occurs when the tide is moving in or out. The study of harvesting energy from moving water is the same with the one for ocean current energy conversion. These three different forms extract energy from the oceans and convert it into clean, green electricity. The technology is not the same and for every form, we find many different methods of conversion. Different aspects like the speed of water, the depth, the strength of waves, the difference in temperature between cool deep water and warm shallow water… should be considered before deciding which technology to be used at any particular site for better performance.

4.1. Wave energy conversion

Wave energy is the result that comes from conversion of kinetic energy capturing from ocean's oscillation into electricity. The conversion is realized by capturing in the ocean water the vertical oscillation and the linear motion of waves. Deep water ocean waves give large energy fluxes under predictable conditions. Figures 2 and 3 show some devices converting wave ocean energy into electricity. The Pelamis is an offshore wave energy converter that uses the motion of waves to generate electricity. The machine operates in water depths greater than 50m and is typically installed 2-10km from the coast. The machine is rated at 750kW with a target capacity factor of 25-40%, depending on the conditions at the chosen project site.

On average one machine will provide sufficient power to meet the annual electricity demand of approximately 500 homes. The Lilypad twin membrane wave energy converter on Figure 4 is another device. It consists of an upper floating flexible membrane following the wave motion, provided on its underside with load distributing flanges taking upward loads to several linearly disposed fixation points to which are attached arrays of hose pumps. Hose pumps operate on the principle that as they are elastically elongated from their original large diameter cylindrical shape, they gradually reduce in volume, pressurizing the working fluid within them. At their base, the hose pumps are fixed to load distribution cables which are in turn fixed to the bottom membrane, which is both weighted and valved, so that it will resists upward movement as it is pulled up by the passing wave, flexible flaps closing against a mesh below them. After the wave has passed, the bottom weighted membrane sinks downwards by gravity, the valves opening upwards, and returns to its initial position, ready for the next cycle. The hose pumps extend as the wave passes, expelling working fluid, normally seawater that runs to and along high-pressure pipes to a hydraulic generator. Electricity is generated typically at 65% efficiency by a hydraulic turbogenerator. This mode prevails till the hose pump is partially or fully extended by the wave crest. As the wave passes, the upper membrane descends, gradually releasing pressure on the hose pump, which elastically returns to its shorter and larger cylindrical shape, drawing in seawater through a one-way valve. This allows the lower membrane to descend to its original position, ready for the next upward stroke. The membranes run perpendicularly to prevailing significant wave direction, the size and length of hose pumps being related to wavelength and amplitude spacing of hose pumps and width of marine platform structure. The energy E (Wh), per unit wavelength in the direction of the wave, per unit width of wave front is given by:

$$E = \frac{\rho g^2}{16\,\pi}(H^2 T) \qquad (1)$$

where:

ρ Density of ocean water (Kg/m3)
g Acceleration due to gravity (m/s)
H Wave crest height (m)
T Wave period (s-1)

This is the total excess energy in continuous wave motion in deep water (kinetic + potential) in a dynamic ocean [7]. The power, P per unit width of a wave front is given by:

$$P = \frac{1}{64}\frac{\rho g^2}{\pi(H_S^2 T_e)} \qquad (2)$$

where:

P Power per unit width (W/m)
Hs Significant wave height (m)
Te Wave period (s-1)

4.2. Ocean thermal energy conversion (OTEC)

Ocean thermal energy conversion (OTEC) takes advantage of ocean temperature gradients greater than 20 degrees Celsius. Where such gradients exist between surface waters and waters no more than 1,000 meters deep, they can be used to extract thermal energy stored in the ocean, and convert it to electricity (and often, desalinated water). OTEC uses the natural difference in temperatures between the cool deep water and warm surface water to produce electricity. There are different cycle types of OTEC systems, but the prototype plant on Figure 5 of a project for a pilot plant of ocean thermal energy conversion to be built off the coast of southern China is likely to be a closed-cycle system like the one on Figure 6. This sees warm surface seawater pumped through a heat exchanger to vaporize a fluid with a low boiling point, such as ammonia. This expanding vapor is used to drive a turbine to generate electricity with cold seawater then used to condense the vapor so it can be recycled through the system. Tropical regions are considered the only viable locations for OTEC plants due to the greater temperature differential between the shallow and deep water. Unlike wind and solar power, OTEC can produce electricity around the clock, 365 days a year to supply base load power. OTEC plants also produce cold water as a by-product that can be used for air conditioning and refrigeration at locations near the plant.

4.3. Ocean current energy conversion

As indicated earlier, ocean current is a form of kinetic energy. Although this energy is generally diffused, it is concentrated at several sites where sea flows are channeled around or through constraining topographies such as islands and straits. There are many potential sites around the world that could be explored and utilized. The tides which drive such currents are highly predictable, being a consequence of the gravitational effects of the planetary motion of the earth, the moon and the sun. As the resource is highly predictable albeit variable in intensity, its conversion to useable energy offers an advantage over other renewable energy resources such as wind or wave energy [8]. Projects that relay on ocean currents will have quantifiable and firmly foreseeable output profiles which can be plan for and managed appropriately within utility grid. In addition, long term energy yields can be accurately estimated which offer a particular advantage to a project developer to negotiating, with utilities, a better power purchasing agreement compare with other renewables. The ocean energy which produces a current coming from tide is a vast energy resource. It was used in France on the estuary of the river Rance for a 240 MW tidal barrage [9] and is working until now. Utilizing ocean currents does not require water-impounding structures such as dams used in conventional hydropower but some sort of anchoring system within the flow stream. There are three factors that determine how much power any turbine can produce. The first one is the speed or velocity of the moving water. This factor shows us that the faster the water moves the more energy in the water that can be harvested. Then comes the size of the turbine rotor. The bigger the turbine rotor is the more energy it can harvest from the moving water. Finally, we look at the efficiency of the turbine rotor or the ability of the turbine to convert the energy in the moving water into mechanical energy in the form of a rotating shaft with the ability to do useful work: drive a gearbox and generator or pump water etc. In most cases, the fundamental understanding needed has similar basis as those used to predict the conversion of the kinetic energy of a moving fluid to provide useful work as employed in wind energy conversion. Hence its technology variants are somehow similar or related to those of wind energy conversion although other unique design philosophies are being pursued.

4.3.1. Energy extraction from marine currents conversion

Marine currents offer an analogous energy resource to wind, i.e. the kinetic energy of the moving fluid can similarly be extracted and applied using a suitable type of turbine rotor. Many studies have been done in this field.

Grabbe [10] carried out a study on Marine Current Energy Conversion. They design a prototype variable speed generator. The construction of this system was based on previous finite element simulations. The experiments show that the generator is well balanced and there is agreement between measurements and corresponding simulations, both at nominal load and under variable speed operation. It also shows that the generator can accommodate fixed tip speed ratio operation with different fixed pitch vertical axis turbines in current velocities in range 0.5 – 2.5m/s. Şen [11] undertook some studies on Energy generation possibility from ocean currents. The study focused on the current speed data measured during different sorties across the Bosphorus. The current power generation in accord with the speed probability distribution of the water has been developed and a simple numerical sample was presented. With a continuous current from the black sea in the north towards the Marmara Sea in the south due to a 30-40cm level difference between the two seas, current power estimation formulation is developed parametrically and by considering the cut-in low current speed as 1.0m/s.

Aditya and Estiko [12] studied ocean current energy conversion system in Wallacea region using variable speed control approach. The research and development of ocean current energy conversion systems had to be implemented in the Wallacea region. They reviewed four types of green energy conversion systems extracted from ocean. Their advantages and disadvantages were also discussed. The types of turbines used and selected to be implemented in the Wallacea region was one objective. The control strategy was finally proposed for the region. The work reported in their research concluded that it is appropriate to implement ocean current energy conversion systems using axial flow water turbines in the Wallacea region, and that to maximize energy conversion variable speed control approach is selected together with control of mechanism to move the turbine vertically as well as to rotate the turbine in yaw direction. Grabbe [13] made an analyze on Marine current energy device: Current status and possible future applications in Ireland. The world's first tidal current-powered experimental turbine was realized by Marine Current Turbines Ltd. The company designed, developed, installed and tested the Sea flow in May 2003. It is the first offshore tidal current turbine. Installed in Lynmouth in Bristol Channel (United Kingdom) the turbine has a rotor of 11 meters and rate at 300kW. The basic concept on this prototype was the axial flow rotor, marine drive train, surface breaking monopole, structural integrity, low coast intervention, no significant environmental intervention. The analysis offered for consideration of wind turbines can be extended for marine current turbines. The power Po (W) available from a stream of water (in the absence of significant changes in depth or elevation) is given by:

$$P_o = \frac{1}{2}\rho A v_o^3 \quad (3)$$

where:

Po Power available from a stream of water (W),
ρ Density of fluid (Kg/m^3).
A Cross-sectional area of the rotor under consideration (m^2) and
νo Unperturbed fluid speed (m/s)

In equation (3), Po is proportional to the velocity to the power 3. Hence the power and the energy are sensitive to the variation in the velocity of the fluid. Additionally, the power in the flow is also promotional to the fluid density, which for water, is about 829 times greater than that of air. This indicates that the power density or flux (kW/m^2) for marine current energy converters will be appreciably higher than that produced by wind energy converters when considered at appropriately rated speeds for both technologies [14]. The consequence of this is that smaller and hence more manageable converters can be installed to exploit local conditions, such as water depth or bathymetry where they are favorable. However, water depth in practice places a constraint on the maximum rated power of a marine current turbine. Such a constraint does not exist with wind turbines. Considering power extraction using the case of a horizontal axis turbine, the theory of which stems from the classic analysis of power extraction from the wind by an actuator disk [15] is normally used. This states that the maximum power that can be extracted by a single turbine in an unconstrained flow is the fraction (16/27 = 0.59) of the kinetic energy flux through the rotor disk area and in the case of no extraction this is given by Equation (3). In general, this fraction is known as the power coefficient Cp, defined by:

$$C_p = \frac{P}{P_o} = \frac{P}{\left(\frac{1}{2}\right)\rho A \upsilon_o^3} \quad (4)$$

where:

Cp Power coefficient
P Power developed by the generator
(W)

For all wind turbines currently in operation, Cp<0.59; however, more sophisticated design methods allowing for the effects of finite numbers of blades predict for typical designs, maximum values of Cp in the range 0.4–0.5 [9]. Such analysis also applies to the case of similar turbines in a marine current site or tidal stream channels, providing these are wide and deep compared to the rotor disk diameter and that there is only a small change in free surface elevation across the turbine location [16]. The power coefficient as given in [6] represents the effectiveness of a device in generating power, regardless of flow speed or capture area of the device. Cp can also be determined experimentally from the consideration of the relationship between the fluid speed and the rotational speed of the turbine blades. This known as the tip speed ratio TSR, given by:

$$\mathrm{TSR} = \frac{\omega R}{\upsilon_0} \qquad (5)$$

where:

R Radius of the turbine (m)
ω Rotational speed of blade tip (rad/s)

Another important parameter for ocean current turbines is the thrust T encountered by the hydrodynamic subsystem. This is normally quantified in terms of the thrust coefficient Ct and is given by:

$$C_t = \frac{T}{\left(\frac{1}{2}\right)\rho A v_0^2} \qquad (6)$$

where Ct is the loading of the subsystem, independent of scale and is also a function of TSR.

It is important to note that despite the analogy indicated above with wind turbines, there are major differences in the engineering of ocean current turbines. This is particularly due to the higher density of water compared with air, the closer proximity of the free surface and the much slower speed of flow and cavitation. Hence, marine current turbines will encounter larger forces than wind turbines and the design of marine current converters will need to consider the overall thrust from the kinetic energy of the flowing water. Installations of such converters in fast flowing seas will clearly present structural engineering challenges for both system integrity and foundations or anchorage of the submerged structure. Such structural designs will need to consider the marine environment and the complex dynamic loadings that are present due wave/structure interactions, turbulence, velocity shear and pressure variations across a vertically moving rotor within the bathymetry (water column) of the flow regime.

4.3.2. Types of ocean current turbines

There are different types of ocean current turbines which according to the design can be classified as follows:

- Horizontal axis turbine like the SeaGen tidal energy convertor installed in Strangford Lough shown on Figure 7 and Figure 8: It extracts energy from moving water in much the same way as wind turbines extract energy from moving air. The ocean current stream causes the rotors to rotate around the horizontal axis and generate power.
- Vertical axis turbines: It extracts energy from the tides in a similar manner to the above, however the turbine is mounted on a vertical axis. The ocean current stream causes the rotors to rotate around the vertical axis and generate power.

- Oscillating hydrofoil (Figure 10): It is attached to an oscillating arm. The ocean current flowing either side of a wing results in lift. This motion then drives fluid in a hydraulic system to be converted into electricity. Enclosed tips "Venturi": The venture effect devices house the device in a duct which concentrates the water flow passing through the turbines. The funnel-like collecting device sits submerged in the ocean current. The flow of water can drive a turbine directly or the induced pressure differential in the system can drive an air-turbine.
- Archimedes screw: It is a helical corkscrew-shaped device (a helical surface surrounding a central cylindrical shaft). The device draws power from the ocean current stream as the water moves up/through the spiral turning the turbines. Tidal kite: a tidal kite is tethered to the seabed and carries a turbine below the wing. The kite "flies" in the tidal stream, swooping in a figure-of-eight shape to increase the speed of the water flowing through the turbine.

5. Energy harnessing from Agulhas current

For the last 6 years, Eskom research, testing and development business unit has been recording measurements of the Agulhas current in the Indian Ocean. The results show that its velocity depends on variations in the equatorial current velocity, which in turn change with location, depth, and season. One of the fastest-flowing currents in any ocean, it reaches an estimated top speed of 2.58 m/s off the southeast coast of South Africa. Its average velocity can be estimated to be 1.3±0.3 m/s. most of the ocean current turbines are design for water current with an average speed of 2.5 m/s. However, some companies manufacture turbines that can operate with a low-speed marine current. For example, Tocardo International BV is a company with its head office in the Netherlands. They design turbines for potential site where water speed flow must be at least 2 m/s. We can find a section on their web site allowing a quick evaluation of the power output of their turbines when we know data on our site. The section is linked on the tocardo website [17]. Another company named Tidal Energy Pty Ltd designs the Davidson-Hill venture turbine. The device can be installed anywhere there is a fast-moving body of water where the water is moving at 2m/s (walking speed) or more. If there is minimum turbulence in a fast-flowing river, the efficiency of the turbine will be reduced. Table 2 shows the performance of different turbines according to 3 factors which are the speed velocity of the moving water, the size of the turbine rotor, the efficiency of the turbine rotor. The company Hale-turbine uses the Side Drive concept for tidal turbine. This technology however adds new innovative ideas to improve output and potential use of the turbine with much larger blade areas and can operate successfully in water flows between 1 and 2 m/s, these lower speed water flows are found in a great many tidal areas of the world and includes several ocean currents, making the possibility of local energy extraction a reality. Many other companies designing ocean current turbine can be found in the sector. With these turbines able to produce electricity with a small water speed, we can now focus on other important aspects. Besides tidal flow velocity, the two most important variables for construction, operational and maintenance cost are farm size and offshore distance. Operational and maintenance costs per unit energy production are minimized by building farms with larger numbers of turbines closer to shore. All these variables help us in this study, and we are going to estimate the power output from different site according to the data recorded during the observation period.

6. Estimation of the power output for different site

The power output depends to the data of designated sites, the power input for the turbine and the power coefficient C_p which determine the power that can be extracted from a site by the hydrodynamic system. We are going to calculate the power output using the formula above and the tocardo power calculator while assuming the size of different rotor, velocity of the water, depth and width of the site. For a simple estimation, we can use the following link to evaluate the power according to Tocardo turbines [17]. The tool gives options for different aspect of the site. For location type we can choose if it is a constant river, a seasonal river, an in-shore tidal (optimum), an in-shore tidal (moderate), an off-shore tidal (optimum) or an off-shore tidal (moderate). For the velocity we have 2 m/s, 2.5 m/s, 3 m/s, 3.5 m/s, 4 m/s and 4.5 m/s, the minimum depth and width required to fit the blade is 7.6 m. In this paper we are using 2 m/s and 2.5 m/s because they are the peak velocities Agulhas current can reach. For ρ = 1000 Kg/m^3, we calculate the power of potential sites and the power output with Tocardo tool by assuming different cross-sections area A. Results are shown in Table 3.

Using different assumption for the Agulhas current, the following results are the maximum power that can be extracted from a site: For:

v = 0.5 m/s; $P_o = \frac{1}{2} * 1000 * A * 0.5^3 [W]$

v = 1.0 m/s; $P_o = \frac{1}{2} * 1000 * A * 1.0^3 [W]$

v = 1.5 m/s; $P_o = \frac{1}{2} * 1000 * A * 1.5^3 [W]$

v = 2.0 m/s; $P_o = \frac{1}{2} * 1000 * A * 2.0^3 [W]$

v = 2.5 m/s; $P_o = \frac{1}{2} * 1000 * A * 2.5^3 \quad [W]$

These results depend on the velocity and size of the blade. Table 4 gives the results of P_o for different cross-section A. The loss of power in the system due to the gear and other mechanism depends to the design of the turbine. People who manufacture turbine know about the fraction of loss and provide the C_t coefficient for their turbine.

7. Figures, Tables and Equations

7.1. Tables

Table 1: Categories and criteria of ocean energy resources in the Western Indian Ocean. Temporal variability, predictability, and ranking criteria refer to annual means if not specified otherwise.

	Wave power	**OTEC**	**Tidal barrages**	**Tidal current turbines**	**Ocean current power**
Temporal variability	Daily & seasonal	Seasonal	Hourly & weekly	Hourly & weekly	Seasonal
Predictability	Moderate	High	High	High	High
Ranking criteria					
High	≥ 5kWm-1	≥20 ΔT, ≤ 5 km	≥ 5 m mean tidal range	≥ 2 ms^{-1} peak speed	≥ 1.5 ms^{-1} seasonal average speed
Conditional	15-25kWm^{-1}	≥20 ΔT, ≤ 10 km	2.4 - 5 m mean tidal range	≥ 1.5 ms^{-1} peak speed	1-1.5 ms^{-1} seasonal average speed

Table 2: Performances of Davidson-Hill Venturi turbines.

Turbine Size Diameter	**Water Speed 2m/s**	**Water Speed 3m/s**	**Water Speed 4m/s**	**Water Speed 5m/s**	**Water Speed 6m/s**
1.5 m rotor	4.6 kW	15 kW	35 kW	70 kW	120 kW
2.4 m rotor	10 kW	40 kW	90 kW	180 kW	300 kW
5 m rotor	50 kW	170 kW	400 kW	800 kW	1.35 MW
7 m rotor	100 kW	340 kW	800 kW	1.6 MW	2.7 MW
10 m rotor	200 kW	680 kW	1.6 MW	3.2 MW	5.5 MW

Table 3: Power output from Tocardo turbines inshore and offshore tidal using

Location type	**Velocity (m/s)**	**Turbine type**	**Blade size (m)**	**Power grid (KW)**
Offshore tidal (optimum)	2.0	T 100	06.30	042.0
Offshore tidal (optimum)	2.0	T 200	09.00	087.0
Offshore tidal (optimum)	2.0	T 500	14.20	232.0
Offshore tidal (optimum)	2.5	T 200	07.30	112.0
Offshore tidal (optimum)	2.5	T 500	11.50	300.0
Offshore tidal (moderate)	2.0	T 100	06.30	042.0
Offshore tidal (moderate)	2.0	T 200	09.00	087.0
Offshore tidal (moderate)	2.0	T 500	14.20	232.0

Table 4: The power Po (W) available from a stream of water with different velocity and cross-section

v=0.5 m/s		***v=1.0 m/s***		***v=2.0 m/s***		***v=2.0 m/s***		***v=2.5 m/s***	
***A* (m^2)**	**P_o (W)**	***A* (m^2)**	**P_o (W)**	***A* (m^2)**	**P_o (W)**	***A* (m^2)**	**P_o (W)**	***A* (m^2)**	**P_o (W)**
5	312.5	5	2500	5	8437.5	5	20000	5	39062.5
10	625	10	5000	10	16875	10	40000	10	78125
20	1250	20	10000	20	33750	20	80000	20	156250
30	1875	30	15000	30	50625	30	120000	30	234375
40	2500	40	20000	40	67500	40	160000	40	312500
50	3125	50	25000	50	84375	50	200000	50	390625
60	3750	60	30000	60	101250	60	240000	60	468750
70	4375	70	35000	70	118125	70	280000	70	546875
80	5000	80	40000	80	135000	80	320000	80	625000
90	5625	90	45000	90	151875	90	360000	90	703125
100	6250	100	50000	100	168750	100	400000	100	781250
110	6875	110	55000	110	185625	110	440000	110	859375
120	7500	120	60000	120	202500	120	480000	120	937500
130	8125	130	65000	130	219375	130	520000	130	1015625
140	8750	140	70000	140	236250	140	560000	140	1093750
150	9375	150	75000	150	253125	150	600000	150	1171875
160	10000	160	80000	160	270000	160	640000	160	1250000
170	10625	170	85000	170	286875	170	680000	170	1328125
180	11250	180	90000	180	303750	180	720000	180	1406250
190	11875	190	95000	190	320625	190	760000	190	1484375
200	12500	200	100000	200	337500	200	800000	200	1562500

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7.2. Figures

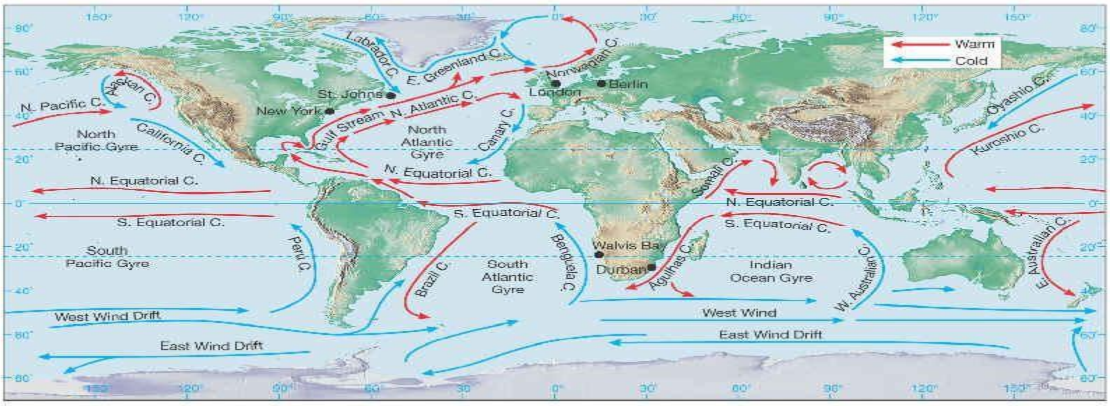


Figure 1: Schematic showing the major ocean current systems in the world.

Figure2: Scottish Power Renewables machine operating in Orkney

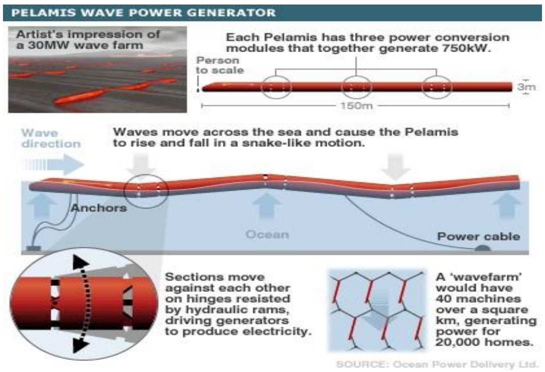


Figure3: Pelamis wave power generation

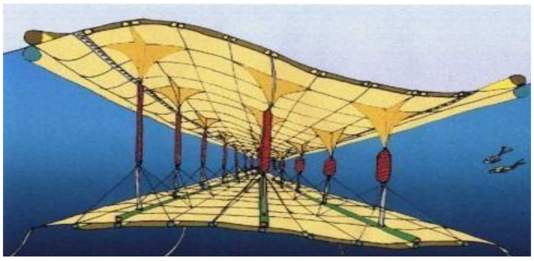
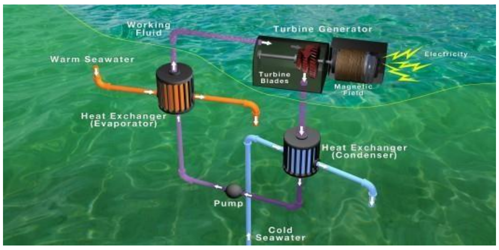


Figure4: Lilypad Twin Membrane Wave Energy Converter



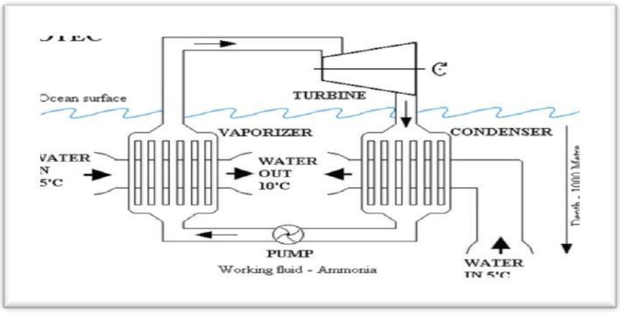


Figure6: Operating principle of an OTEC plant

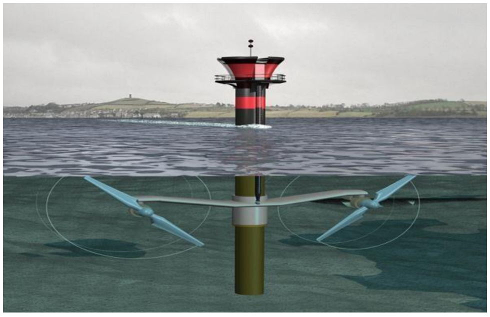


Figure 7: SeaGen, the1.2MW tidal energy convertor installed in Strangford Lough, Northern Ireland.

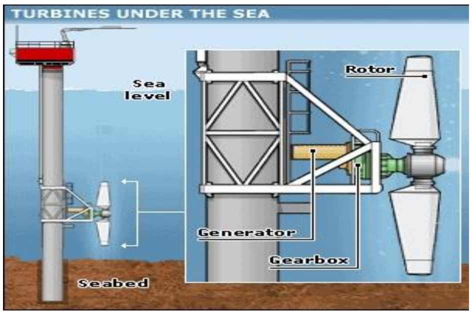


Figure 8: description of a horizontal axis turbine system

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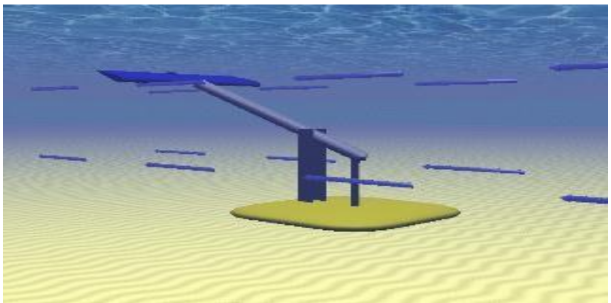

Figure 9: A hydrofoil is attached to an oscillating arm

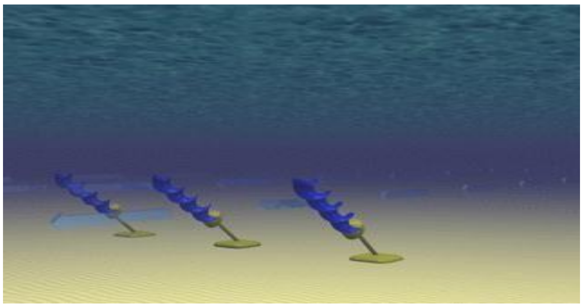

Figure 10: The device draws power from the tidal stream as the water moves up/through the spiral turning the turbines.

7.3. Equations

$$E = \frac{\rho g^2}{16\pi}(H^2 T) \quad (1)$$

$$P = \frac{1}{64}\frac{\rho g^2}{\pi(H_S^2 T_e)} \quad (2)$$

$$P_O = \frac{1}{2}\rho A v_O^3 \quad (3)$$

$$C_p = \frac{P}{P_o} = \frac{P}{\left(\frac{1}{2}\right)\rho A v_O^3} \quad (4)$$

$$TSR = \frac{\omega R}{v_O} \quad (5)$$

$$C_t = \frac{T}{\left(\frac{1}{2}\right)\rho A v_O^2} \quad (6)$$

8. Conclusions

This paper was focus on harvesting energy from the Agulhas current by the Ocean Current Energy Conversion System using a horizontal axis turbine. The result shows that the potential of the Agulhas current can be used for greater project. New generation of marine current turbine are designed and run with low speed like the one in Agulhas. The distance offshore and the scale of the project are to be evaluated for construction and commercialization.

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