ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

IJARMATE
Your ult-MATE Research Paper !!!

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

A review of current tidal power technology: Optimization and improvement of mechanical design

Ahmad Syazwan Ramli [1], Firdaus Basrawi [1*], Shahrani Anuar [1], Thamir Khalil Ibrahim [1]

Energy Sustainability Focus Group (ESFG), Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia [1]

*email: mfirdausb@ump.edu.my

***Abstract*— One of the options that have the potential to supply enough energy to drive our modern world is tidal power. However, based on current trends, the adoption of this power source still remains slow as the power harnessing from this source is still not efficient enough and further improvement is needed especially in mechanical power conversion parts before it can be fully utilized for our daily energy consumption. One method to improve its efficiency is by introducing lightweight material such as carbon fiber reinforced plastic (CRFP) so that even small force from the wave can be harnessed and converted into electrical energy. Hence the design of tidal power plant which incorporates CRFP needs new design, further analysis and optimization to determine its suitability. This paper reviews the current technology of harnessing the tidal power, their advantages and disadvantages. Then, proposing any possibility of improving or optimizing its mechanical design.**

***Index Terms*— Tidal power, renewable energy, optimization, wave energy, tidal turbines.**

I. INTRODUCTION

Environmental issues have been taking the spotlight nowadays especially with the global warming theme. Global warming is the effect of greenhouse gasses especially carbon dioxide, CO_2 which traps solar radiation in form of heat from the sun by creating an insulation layer in atmosphere of the Earth [1]. In addition, sulfur dioxide emission SO_2 also can cause harmful acid rain that can erode building structures and destroy the ecosystem of the environment. The concentration of methane gas which is much worst greenhouse gas that has 20 times higher potential for global warming has double since 1850 [2].

In today's modern world, the main contributor of CO_2 and SO_2 emission is from everything that involves combustion process especially from combustion engines of conventional vehicles and energy generating power plants [3]. Most of the vehicles today rely on combustion engine to provide enough energy to drive them. Some vehicle company such as BMW with their i8 and i3 model, Hyundai with Ioniq, Volkswagen with E-Golf model and Tesla Motor with their Model S, X and 3 design for example have already developing green vehicles such as which fully utilize electric drive [4] [5] [6] [7]. Therefore, there has been a lot of effort to switch from the conventional fossil fuel to renewable energy resources such as tidal power, solar, biomass, geothermal and. Tidal energy is among the most promising energy sources which can be harness to feed the modern day energy consumption. Based on the Web of Science database, annual publications in tidal power technology shows an increasing trend in the last 15 years from 100 to a high of 500 [8]. Fig. 1 shows the published research on tidal power as a function of date from Web of Science. The search subjects are tidal power and tidal energy.

Figure 1: Number of published research on tidal power and tidal energy

This research reviews tidal power to understand the current technology used to harness this energy source, its limitation and what can still be done to improve the energy harnessing efficiency of the tidal power.

II. OVERVIEW OF TIDAL POWER

The source of tidal power comes from the dissipated energy of the ocean's tidal movements and these movements are the direct of the interaction between the sun, moon and earth's centrifugal and gravitational forces. The definition of tide is a cycle of the fall and rise of the ocean's water level which can be observed usually at the coastline which is caused by the sun and the moon's gravitational force. The rotation of the earth and the moon on their axis also produces the centrifugal force. The moon's gravitational force is 2.2 times greater than the

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

influence of the sun's gravitational force since the moon is much nearer to the earth thus having a greater effect of the tidal cycle of the ocean on earth [9]. A common cycle of a tide occurs two times for every 24 hours 50 minutes [10]. The moon gravitational pull will make the water on earth closer to moon to force a bulge. In addition, the rotation of the moon and the earth will cause another water bulge on the earth's side which is further from the moon. This phenomenon is explained in Fig. 2 graphically.

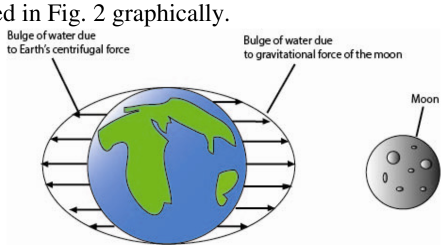

Figure 2: the moons gravitational force effects on earth

Therefore the place where the water bulge occurred will experience high tides and the other area without the bulge will experience low tides. This will cause the coastline to experience two low and high tides during one full rotation of earth on its axis. For every 29.5 days, the earth, sun and moon are in the same positions relative to each other and this is known as the lunar or synodic month [11]. Tidal currents on the other hand occurred in coastal area and also where the water needs to flow through certain narrow channels by the seabed. The current is going to flow in two different directions. The flood current is the one that moves in the direction of the coastline while the ebb current is the one that moves away from the coast. The speed of those two current also varies from the range from zero value to a maximum [12].

To utilize the power of the tidal energy, the potential energy generated during the high and low tides and the kinetic energy from the tidal need to be harness as much and as efficient as possible. The usual and simplest method of energy generation for barrages is ebb generation. Sluicing occurs when the tide floods and fills up the basin. Then the water is then contained until a certain point when the tide recedes creating a head. Then the water is passed through the turbines back to sea generating electricity. At the next tide, the process is repeated [13]. But the tidal technology has just only recently begun to attract serious investment and growing recognition since there is an urgent need to replace the fossil fuel source and the engineering challenges nowadays are becoming solvable in comparison with the engineering technology 25 years ago [14]. A few preliminary assessments of this kind of resource have gained interest of many parties and the allocation of public funding to kick starts the development of prototype for tidal current energy systems [15]. The assessment is usually depended on the kinetic energy flux extraction which is around 20% of at a certain site which is considered as the significant impact factor (SIF). SIF is used to represent the kinetic flux proportion available without disrupting any major flow of the water [16]. A lot of countries nowadays are considering government sponsored encouragement such as the UK for example which target energy harnessing from renewable energy around 10% by 2010 and 20% by 2020 [17]. A tidal harnessing facility in general can be divided into three main groups which are tidal barrage, tidal current turbines and wave energy converter.

A. Tidal barrage

A tidal barrage is type of dam, constructed across an estuary or a bay which can collect seawater during the high tide and then release it back during the low tide. The difference between a tidal barrage and a conventional hydropower dam is that hydropower dam typically uses an axial propeller turbine whereas a tidal barrage uses horizontal propeller much like the wind turbine [18]. During the high tide, the seawater will flow into the basin enclosed by the dam or barrage and turbines are placed in the tunnel across the barrage where the seawater will flow into the barrage. The water stored behind the dam possesses potential energy and this energy will then be harnessed when water is released during the low tide and again the water flow through the tunnels and turn the turbines to generate electricity. This means that it uses the same principle as a hydroelectric power generation but also enables power generation from two different directions. In order to obtain enough potential energy for this kind of method to works, the tide difference between low and high tide must be a minimum of 5 m high [19]. The highest tides in the world are recorded at Bay of Fundy, Canada. The recorded tidal range is about 16.27 m measured at Burntcoat Head, Minas Basin making it a good spot to build a plant for tidal power [20]. Unfortunately another important factor is the proximity of the site to an area in demand for power. Therefore the Minas Basin has the disadvantage for being far away from major population areas with high power demand and therefore is not seen as being as successful of a scheme as La Rance in France due to the very small population to which it serves [21].

This type of energy generation is clean with zero emission of greenhouse gases in comparison with conventional energy generation from fossil fuel. A tidal power plant in La Rance for example can generate a clean 240 MW for example [22].The world's largest plant for tidal power is held currently by Shihwa Lake tidal power station in South Korea which capacity of 254 MW of power and can generate 552 million kWh per year [23]. That amount of energy is enough to supply 500,000 houses with the total construction cost of around $US 293 million [24] [25]. However the adoption of this tidal power still remains low mainly due to its high negative environmental impact and the total cost of construction since the barrage changed the landscape and the ecology of the coastal area [26]. The high construction cost mostly is spent on the building of barrage because many construction materials are needed to build a barrage structure which is strong enough not only to contain the high pressure of seawater that stores high potential energy but also to withstand the beating and pounding of ocean wave so that the wave will not erode the barrage so easily. So far, this remains as the deciding factor in the decision whether a tidal barrage is worth to be built or not based on the return of investment (ROI) it can offer.

In terms of environmental effect, the construction of barrage at a coastal area can alter the natural tidal current flow. As the result, some coastal area nearby may experience severe soil erosion. The change of the tidal flow can also change the location of the sediment deposited on the ocean floor and this will affect the ecology of the marine life of that area. The imbalance of the marine ecology may lead to a migration of some local species or worst it may lead to extinction of them.

B. Tidal current turbines

A tidal current turbine works by harnessing the kinetic energy of tidal current flow. There are only a few different parameters that need to be considered for marine environment such as Reynold's number, various stall characteristics and the possibility of cavitation [27]. Many tidal current turbine developers proposed using technology which resembles the wind turbines since both are moved by a flowing fluid [28]. However a tidal current turbine can harness more energy due to the higher water density which is 832 times denser than the air if both work at the same current speed [1]. Since the force acting on a tidal turbine is higher in comparison with a wind turbine, more substantial supporting structure is needed to handle this condition and this will lead to a higher construction cost [29]. A tidal current turbine also experience both flood and ebb current and therefore it is usually design to harness energy and able to generate electricity when the current flow in any of those direction. In general there are two types of tidal current turbines which are commonly used which are vertical axis tidal current (VATC) turbine and horizontal axis tidal current (HATC) turbine. A HATC turbine has its turbine blades rotating in parallel to the water flow direction. A VATC turbine on the other hand has turbine blades that rotate in perpendicular to the direction of the water flow.

In both cases those turbines blades will harness the kinetic energy from the current of the tide and they will be rotated by the water flow. The turbine blades are linked to a gearbox that will convert the blades rotation into the desired speed that will then turn a generator that will generate electricity. One clear advantage of tidal stream turbines is that its size and dimensions can be designed to suit the local environment, such as coastal limitation, tidal flow or its range, seabed topography, etc. It also can be placed as either an individual or 'farm' configuration [30]. In comparison to a tidal barrage, tidal turbine option is much cheaper and cost efficient to deploy since it uses less construction material. The majority of the cost would goes to the installation and the maintenance of this facility since it needs to be fixed at the seabed and this process requires special and costly skills and technology. The maintenance of the facility is also an issue since the whole system is submerged underwater. Hence the new generation of tidal current turbines is equipped with special power train mechanism that can lift the submerged turbine above the water level for maintenance purpose such as the Seaflow facility installed off Lynmouth as shown in fig. 3 below [31].

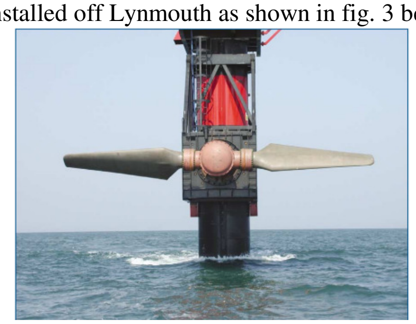

Figure 3: The 300kW Seaflow system installed off Lynmouth [31]

In theory, harnessing the tidal current kinetic energy is based on the speed and the flow's cross-section which is able to be covered by the radius of the turbine blades. The basic power generated by the current flow equation is as equation (1) [32]:

$$P = \frac{1}{2}\rho A V^3 \qquad (1)$$

where P = power generated, ρ = water density, A = cross-sectional area that can be covered by the turbine blades and V is the free stream velocity of current that flow through the turbine. Based on this equation, we can conclude that the amount of power generated by a current turbine depends on the A and V since the water density will always remain almost constant. However in a free stream, 59.3% is the only maximum amount of theoretical efficiency of an ideal kinetic energy that can be converted is if we assume the flow is uniformed based on the conclusion made by a German aerodynamicist named Albert Betz. The conclusion is based on the logic that if the device took out 100% of the energy, the flow would definitely stop. Therefore, there must be a sufficient residual kinetic energy to take the flow away after it passes through the device. It is known as Betz limit and it defines the optimum value which the flow downstream of the rotor is reduced to 1/3 from the initial flow velocity at certain point where energy conversion is maximized [33]. However in reality, the conversion of energy is much lower than the Betz-limit anticipated since the some of the energy will be dissipated into friction and drag in the fluid.

In addition, the design of the turbine blades is usually refer to the Blade element momentum (BEM) theory. The momentum theory part is used to derive the circumferential and axial inflow factors which include the foundation of a tip loss factor to determine the finite number of rotor blades. The blade element theory on the other hand is used to model the

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

section torque and drag by separating the rotor blade into a number of elemental sections. This combination means that the rotor power loadings and thrust loading are deduced by matching the changes of fluid momentum to blade forces which depend on lift C_L and drag coefficient C_D at working angles of attack of the blade sections at each blade radius [34]. These conditions based on BEM theory are usually defined in computer software to calculate the most optimized turbine rotor design to harness the kinetic energy of the tidal stream as efficient as possible. At each time step, the BEM is able to determine the load on the blade section for given constant blade axial stream velocity and rotational velocity [35]. Other than that, a phenomenon known as cavitation often occurs in marine propellers. Cavitation is considered to one of the constraint in propeller design and it can cause unwanted noise, vibration and erosion that will damage the propeller [36]. Therefore, a calculation to predict cavitation flow is crucial in order to avoid damage to the propeller and this has to be taken into account when choosing the suitable propeller design.

As for vertical axis current turbine, the concept of Darrieus turbine is implemented. This kind of turbine harnesses the flow current's kinetic energy in direction perpendicular to the flow. This type of turbine was named after its inventor's name, G.J. Darrieus [37]. The application of cross-flow turbine allows the possibility to place the turbine part submerged underwater and let the other parts such as gear system and energy converting generator to be located above the water level. This will allow the maintenance process to be easily conducted thus reducing the cost of operating the tidal power plant facility. This kind of turbine also enables the kinetic energy harnessing process to be harnessed in any direction unlike its counterpart of the horizontal current turbine which needs to be yawed parallel to the direction of the flow in order for it to be able to harness the kinetic energy. It can also be used at a location where the current flow is very slow since it is able to rotate and harness the kinetic energy even at the speed as low as 15 rpm [22].

However even the most optimized Darrieus turbine is reported to be only able to achieve around 30 to 35% energy harnessing efficiency. Fig. 4 [32] summarized the rotor efficiency for wind turbine and this data can be translated in efficiency prediction of water kinetic energy turbine as well. Due to the poor power harnessing efficiency, this kind of turbine is not favorable to be used in comparison with its horizontal axis turbine counterpart. In addition this type of turbine cannot start and rotate on its own. It needs to be driven to about 2 times the speed of the current before it can produce net torque [32]. There is also an issue of vibration and shaking of the Darrieus turbine especially with fixed pitch Darrieus turbine because of to the varying angle of attack cyclically on the turbine blades and therefore each blade is going to experienced two peaks in tangential and also radial force per revolution for roughly around 180º apart [38]. Therefore horizontal axis turbine concept is highly unlikely to be adopted by the investors and energy industry in comparison with vertical axis turbine concept. However, for this technology to be accepted, the design, installation and maintenance cost crucially need to be reduced [39].

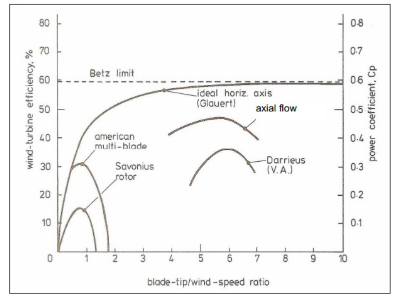

Figure 4: A Summary of rotor efficiency of wind turbine which can be used to predict water kinetic energy turbines' efficiency [32]

C. Wave energy converter

In principle, a wave energy converter (WEC) is machinery which has a mechanism that can convert ocean current wave's mechanical energy wave into electrical power. It harnesses the oscillating behavior of ocean wave and translates it into rotational mechanical movement which in turns will rotate a generator that will produce electricity. By definition wave energy resource is usually deduced as the wave power which crosses into 1 m circumference of circle. In early 1970s, it has been recognized that these devices have a narrow bandwidth. During early research, mechanical impedance is used to match schemes to maximize the velocity and hence the absorbed power from sinusoidal (or regular) waves [40]. To derive optimal amplitude and phase conditions on the velocity of the device, simple frequency domain analysis was used with respect to a sinusoidal wave excitation force [41]. However, the definition may have changed because most of the available wave data is not directionally resolved and therefore the direction of wave propagation remains unknown [42]. Wave energy is assumed to be a solar energy in concentrated form. The winds generation is influenced by the differential heating of the earth and as the blowing wind pass over open area of water, some of their energy are transferred to form waves. Both potential energy and kinetic energy are stored in waves [43]. The development of WEC has been going on for almost 39 years. Most WEC machines developed or designed up until now, the electrical energy generated is going to be supplied to a grid [44]. However, nearly 1000 of wave energy harnessing designs has been patented in Europe, Japan and North America [45]. Even though there is a large variation of concept designs, the WEC can be divided into three main groups as follows:

1) Attenuator

An attenuator is placed to be parallel to the direction of the wave and floats on the water surface. With the help of hydraulics mechanism, the oscillating ocean wave will be

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

IJARMATE

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

converted into electrical energy [46]. The Pelamis is an example of this type of WEC which is constructed by Ocean Power Delivery Ltd (see fig. 5) [47]. Based on a research by Danish Wave Energy Research program, it was concluded that only Pelamis was the best design to be chosen among 8 WEC devices at that time in 2002 [48].

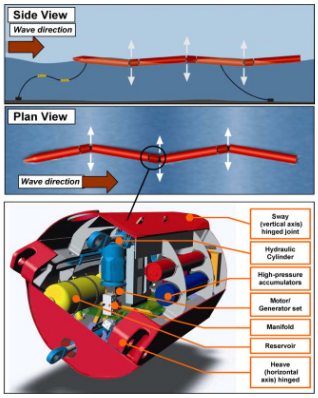

Figure 5: Diagram depicts how Pelamis harness wave energy and its physical layout [46]

2) Point absorber

Point absorbers come in a variety of forms, but can generally be defined as linear, small a damped oscillator which is moved by ocean waves [49]. In relative to the incident wavelength, a point absorber has small dimensions and heaving point absorbers are one of the most potential concepts. The system concept utilized hydraulic power take-off (PTO) systems which include a double-acting cylinder, two or more accumulators and a hydraulic motor [50]. Usually it a floating structure which moves up and down along the ocean wave and it works by using the application of pressure differential. The air passage is made to be as short and smooth as possible to avoid changes in flow direction and also to prevent inefficient flow distribution at the turbine inlet section which could lead to reduction in turbine efficiency [51]. Direct drive energy converters with a linear generator for electrical generation provides an alternative to the hydraulic systems [52]. Permanent magnet linear generator is used for the conversion of the relative linear motion of the buoy and the spar into electricity [53]. By using these kinds of generators, the complexity and the number of movable parts can be reduced hence leads to less maintenance required [54]. This means that the need for a mechanical gearbox can eliminated and thus reducing the maintenance cost and the risk of damage. To increases the flux change and also to increase the induced voltage, a large number of magnetic poles are placed on the generator piston on the order of 1500 [55]. However, this would lead to more complicated transmission to grid because the voltage will differ in both amplitude and frequency [56]. Voltage and frequency deviation issues may arise if the WEC is connected to a weak grid [57]. One method of electricity conversion is by using diode rectifiers first to rectify the voltages from the WECs. A common busbar is then interconnected in parallel with the WECs so that the dc-voltage can be stabilized to different voltage levels for different states of the sea [58]. The wave cycle is converted into reciprocal motion which in induced voltage in the coil. The frequency of the piston will differ each time due to the irregular motion of the wave. Therefore the voltage and current output of the generator is going differ over time. Hence two generators cannot be connected together if their frequencies differ from one another. One solution to this problem is to rectify the electrical output into a direct current, DC first [59]. Therefore the needed energy storage can be omitted and the capacitor cost can be substantially reduced by connecting several generators on the dc bus [60]. As simplification of the drive train, a direct-drive topology is therefore favored in some conditions. But this implies for a lower speed for the generator [61]. Powerbuoy is one example of a point absorber type of WEC which is developed by Ocean Power Technology (see fig. 6) [46]. Current technology uses an oil hydraulic system in the secondary step in energy conversion for a heaving wave energy absorber. On average the typical peak velocity of WEC is around of 2m/s [62]. This kind of low speed but with high force regime of wave energy conversion is very suitable for the application for high-pressure hydraulics [47]. However, the downside of using this system is that a leaking rod seal can cause operational problems and environmental pollution [63]. In addition the common hydraulic systems are still very expensive and their seals are generally made to work at lower velocities than a typical WEC [62].

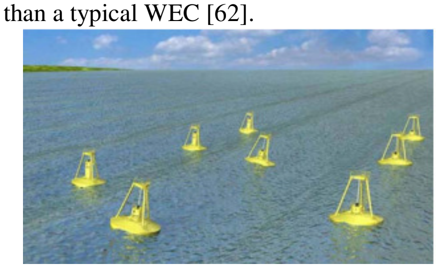

Figure 6: Illustration that depicts the Powerbuoy as an example of point absorber device [45]

3) Terminator

A terminator is a WEC device with its principal axis in parallel to the wave direction and physically intercepts the oscillating wave [46]. A simplest design of a terminator is by using piezoelectric polymers (PVDF) which can harness the wave kinetic and potential energy straight forward into electrical energy. The fluid and viscous pressure from the motion of the wave is going to bend the polymer. The undulation resulted by the motion of the polymer is similar to the movement of sea plant on the ocean floor [64]. Another example of this device is Salter's Duck which is developed by the researchers at University of Edinburgh (see fig. 7). This device would convert the oscillating movement of the wave

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

into rotary movement that will turn the generator with the help of hydraulics system. The system was said to be as cost effective as nuclear power generation and a single device can generate up to 6 MW of electricity which can supply up to 4000 homes [65]. However the overall power captured by this type of WEC can be influenced by the water depth. A research by Folley et. al. found that there is an increase in overall energy captured when the WEC is sited in a 10 m of water depth in comparison to deeper water depths. It is also showed that for typical sea-states the power captured by incident wave energy from 10 m water depth contour is much higher than the power capture at the 22 m contour [66]. This means that in water depths of around 10m, there is an amplification of the fluid particle motion in in horizontal direction in comparison to that in deeper water. This condition is best to be exploited by surging devices such as terminator type WEC [67].

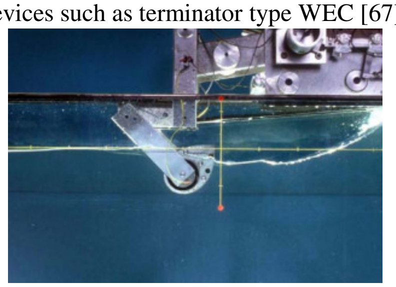

Figure 7: Salter's Duck developed at University of Edinburgh [45]

According to Hals et. al. the optimal wave-energy captured in irregular motion waves might be much better than the corresponding optimal absorption in regular waves under certain circumstances such as for the same wave-power level and energy period. It was shown how this phenomenon is connected to the shape of the limiting curves for the possible absorbed power [68]. However, if compared to WEC with variable pitch Wells turbine based on Nunes et. al., it was demonstrated that it is possible to increase energy absorption by using this kind of control for a regular wave. However the controller used showed that it is not to be effective when experimentation with irregular waves were done because of the decrease in energy absorption in comparison with the uncontrolled device [69]. Murray et. al. for example has concluded that a WEC system using supercapasitor and sea-state data could be adjusted to reduce and smooth out the grid peak power for a 570-kW (peak) system. The peak-to-average grid power is enhanced to 2.3 in comparison to 6.8 for the turbine input of mechanical power [70].

III. Improvement of Tidal Power Plant

The implementation of tidal power in most locations is still not favorable mainly because of the limited financial resources and suitable tidal power plant location. Hence the adoption of tidal barrage is not recommended in this case. It is estimated that a suitable capital cost for tidal power generation should have to be less than € 510,000 per MW installed for it to be a viable option [3]. The option of using tidal current turbine is much better than tidal barrage but the tidal current speed on average is less than 1 m/s on average which is not enough speed to rotate the turbine for energy harnessing purpose [71]. Plus there is also a power loss in generators and for a given type of generator, the iron losses depend on the rotor speed and the flux linkage, the copper losses is due to the currents, the friction and windage losses only depend on the generator speed whereas the stray losses can be considered as constant [72]. This factor will further reduce the efficiency of the turbine thus making this choice not preferable. Darrieus turbine may work with such low current speed but due to the other limitation and low power generating efficiency of that kind of turbine, it also ruled out as the preferable choice of tidal power generating method.

Other than that there is a choice of improving the design of the tidal current turbine by using optimization option. Before optimization process can take place, the design of the turbine need to be analyzed for its performance. The most popular computational method for this kind of analysis is the Blade element momentum theory BEMT. In this theory assumes that the work done by the flow passing through the rotor is going to create pressure loss in the rotor. Using this theory, the induced velocity due to the momentum lost in the flow in the axial and tangential directions can be calculated. The blade element theory is the second part of the theory where the prediction of the forces on a blade by the drag and lift forces generated at various spanwise blade sections. Based on this theory, the sum of forces and moments exerted on the turbine can be calculated [73]. By using this computational method, the amount of force exerted on the blade can be determined in 2D characteristic. After that the blade needs to undergo a CFD simulation analysis to verify the flow effect on the blade and which angle of attack is most suitable for the blade.

One thing that needs to be considered as well is the strength and the integrity of the turbine blade will be reduced when less material is used to construct the optimized blade shape. Therefore another simulation with higher safety factor needs to done in order to prove strength and integrity of the turbine under tensile stress and bending moment especially during heavy storm where the tidal current is much higher than the usual. Pengfei Liu and Brian Veitch for example has simulated a turbine which is subjected to 6.2 m/s of current speed which is 2 times higher than the normal peak current speed needs a safety factor of 1.29 to avoid any mechanical failure during its operation. The optimization process also managed to reduce the weight of nickel-aluminum-bronze turbine from 229 tonnes up to 143 tonnes. That is a reduction of total 86 tonnes (37%) of material consumption saving worth up to $17 million at a cost of $200/kg [74]. It can be concluded that turbines do not demonstrate high efficiencies over a wide speed range and also very expensive to construct [62].

There is also an option to replace the common metal material used by marine propeller to fiber reinforced plastic

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

(FRP) due to its lightweight, high strength and corrosion resistance characteristics [75]. Carbon fiber reinforced plastic (CFRP) is one the most recommended material to be used in tidal power application since it has the highest strength to weight ratio [76]. That is why CFRP is the main material used in the construction of Airbus A380 which is about 25% and 50% for Boeing Dreamliner 787 airplane [77] [78]. By implementing CFRP both aircraft are able to carry more passengers and at the same time uses less jet fuel due to its lightweight characteristic. If CFRP is used in tidal power system especially on wave energy converter, it can harness more energy because the mechanism is still can be move with even by small amplitude wave with limited pushing force. However, the downside of using CFRP at the moment the high material and production cost in comparison with conventional construction metal [78]. That is why there is a need for design optimization so that the material and production can be reduced as much as possible without jeopardizing the design's strength and rigidity. There is also an option to implement sandwich construction which means that 2 layers of CFRPs is couple together which soft material such as foam which can increase its strength without increasing it weight. Fig 8 is an example of constructing a sandwich CFRP beam [79].

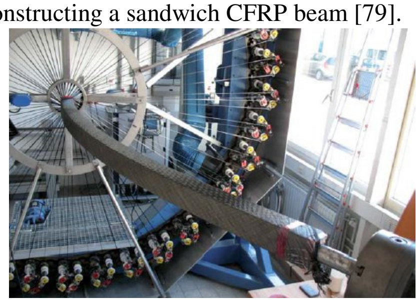

Figure 8: Construction of CFRP sandwich beam [78]

Another option for further optimization is the wave energy converter. This device is much cheaper to manufacture in comparison with other option and still be able to work with low current speed. Since the point absorber type of WEC is considered to be the most promising technology, it is recommended that this choice should be chosen for further optimization. The point absorber is described by the equation (2) by assuming the chosen frame of reference to be inertial; the time domain equation of motion, according Newton's second law of motion, is [49]:

$$m\ddot{z}(t) = f_h(t) + f_e(t) + f_r(t) + f_{PTO}(t) \qquad (2)$$

Where t denotes time, m is the structural mass of the point absorber; z is the vertical displacement of the float with respect to its position at rest and f_{PTO} the force exerted by the PTO system on the floating body. The other three forces, f_h, f_e, f_r follow from linear wave theory (Newman, 1977) where f_h is the hydrostatic restoring force, expressed in terms of the hydrostatic stiffness k_h and z in equation 3, the spring-like effect of the fluid surrounding the body is reflected [49]:

$$f_h = -k_h z(t) \qquad (3)$$

The wave-excitation force, f_e on the other hand reflects the interactions between incident waves and the body held fixed at its position of equilibrium whereas the radiation force, f_r is related with the waves which are radiated by the body oscillating in calm water. Therefore based on equation (2), the structural mass of the WEC needs to be kept as minimal as possible since the vertical displacement, z is small so that less amount of forces needed to oscillate the point absorber WEC. Large motion amplitudes are produced when the oscillation is in resonance with the wave frequency. Therefore to encourage resonance behavior, advanced control strategies such as amplitude control or optimal phase are implemented to increase power capture. Hence WECs' numerical models with advanced control should consider the non-linear effects such as non-linear hydrodynamic forces which happened at large motion amplitudes. However Zurkinden et.al. concluded that linear assumption is still an acceptable estimation of the physical model even though a flow regime analysis suggests that the wave excitation force is influenced by a small drag term. The hydrostatic characteristic of the float was defined in the numerical scheme as a cubic function of the float's effective draft [80]. According to Ringwood et. al. it is also stated that the device's wave frequency need to be placed where the wave frequency is dominant. In addition, adjustments to optimize the power harnessed by the machine in the damping condition may be made by attempting to get the incident wave force in phase with the velocity profile [81].

Green Ocean Energy Ltd from Scotland for example has optimized a wave energy converter with the help of ANSYS AQWA simulation software (see fig. 9) [82]. The reason they need to optimize the design is to reduce the weight so that it can increase the energy harnessing efficiency but at the same time balance its structural strength. But this prototype alone costs around $3 million dollars and months to construct just to generate up to 500 kW of electricity [82]. In general the cost of building a WEC is still high because they deal with large force moving slowly [83]. Therefore, there is a need for further optimization so that this kind of cost can be further reduced. According to Leijon et.al. it is suggested that the large waves define the costs while the small and medium waves provide the incomes from an economical point of view. This means that it must have large safety margins if a WEC is to survive the peak powers in the ocean. This factor increases the total costs for the whole system without the ability to increase the income accordingly [84]. Schoen et al. for example suggested a hybrid control as an improvement for the energy conversion while also having the ability to withstand modeling errors [85]. The robust controller attempts to minimize the modeling errors whereas the short-term tuning of the converter is done by a fuzzy logic controller. Then there

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

IJARMATE
International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

is also an introduction of Model Predictive Control (MPC) algorithm which has the ability to control the power potential of a WEC fully and also respecting the constraints on motions and forces on the at the same time [86]. Other than that, there is also a proposal by Temeevet. al. for an integrated system of WEC with electrolytic hydrogen producer. However there is still a problem with their storage and delivery to the places of consumption as well as the problem to set up a large-scale hydrogen and oxygen electrolysis production [87]. It is however undeniable that implementation of a lot of the WECs developed in small scale and being tested worldwide is still far from being considered a reality as construction, operation and maintenance costs compared to the economic recovery times make them unaffordable [88].

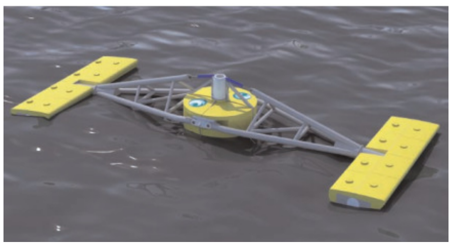

Figure 9: A wave energy converter developed by Green Ocean Energy Ltd. [81]

IV. Conclusion

Based on the options reviewed, the most viable for tidal power generation is by using the wave energy converter system. The construction cost of this kind of device is much cheaper and easier to manufacture. Moreover, such device can also work in a location with slow tidal current. What needs to be done at this stage is to further improve the WEC design so that its efficiency can be increased and making it much more cost effective. This means that the device needs to be further optimized so that we have a much lighter design to harness even the slightest wave oscillation. New lightweight materials such as CFRP designed in a sandwich structure may offer a better solution for this device. The shape and the overall design need to be improved as well so that the drag or any friction that may have reduced the energy harnessing efficiency of the device can be reduced. Finally, a hybrid renewable energy system such a tidal power harnessing system coup up with a solar photovoltaic system can be introduced so that the lack of power generating consistency of one system can be compensated by the others.

References

[1] Fergal Boyle, Anthony Reynolds Fergal O Rourke, "Tidal energy update 2009," *Applied Energy 87*, pp. 398–409, 2009.

[2] IPCC, "Climate Change 2001: the scientific basis.," Intergovernmental Panel on Climate Change, Cambridge, UK, Cambridge University Press 2001.

[3] Eleanor Denny, "The economics of tidal energy," *Energy Policy 37*, pp. 1914–1924, 2009.

[4] (2016, August) BMW. [Online]. HYPERLINK "http://www.bmw.com/com/en/newvehicles/i/i8/2014/showroom/" http://www.bmw.com/com/en/newvehicles/i/i8/2014/showroom/

[5] Tesla Motor. (2016, October) Tesla. [Online]. HYPERLINK "https://www.tesla.com/models/design" https://www.tesla.com/models/design

[6] Hyundai Motor Company. (2016, October) Hyundai. [Online]. HYPERLINK "https://www.hyundaiusa.com/ioniq/" https://www.hyundaiusa.com/ioniq/

[7] Volkswagen. (2016, October) Volkswagen. [Online]. HYPERLINK "https://www.vw.com/models/e-golf/" https://www.vw.com/models/e-golf/

[8] Thomson Reuters. (2017) Web of Science. [Online]. HYPERLINK "http://wcs.webofknowledge.com/RA/analyze.do" http://wcs.webofknowledge.com/RA/analyze.do

[9] Bernhard Haurwitz, "Atmospheric tides," *Possible Responses of Weather Phenomena to Variable Extra-Terrestrial Influences*, p. 107, 1964.

[10] Clark RH, *Elements of tidal-electric engineering*.: John Wiley and Sons, 2007.

[11] Robert Montgomery McDowall, "Lunar rhythms in aquatic animals: a general review," Marine Department, 1970.

[12] Boyle G, *Renewable energy power for a sustainable future*.: 2nd ed. Berlin: Oxford University Press, 2004.

[13] Keith Tovey. (2010-11) Tidal Power. [Online]. HYPERLINK "www2.env.uea.ac.uk/gmmc/env/energy.htm" www2.env.uea.ac.uk/gmmc/env/energy.htm

[14] PETER L FRAENKEL, "Tidal Current Energy Technologies," Bristol, UK, 2006.

[15] J.P. Chick, I.G. Bryden X. Sun, "Laboratory-scale simulation of energy extraction from tidal currents," *Renewable Energy 33*, pp. 1267–1274, 2008.

[16] Scott J. Couch Ian G. Bryden, "How much energy can be extracted from moving water with a free surface: A question of importance in the field of tidal current energy?," *Renewable Energy 32*, pp. 1961–1966, 2007.

[17] A.S. Bahaja, A.F. Mollandb, J.R. Chaplin W.M.J. Battena, "Experimentally validated numerical method for the hydrodynamic design of horizontal axis tidal turbines," *Ocean Engineering 34*, pp. 1013–1020, 2007.

[18] M Koller2, M Gauthier1 and C Deschênes T C Vu1, "Flow simulation and efficiency hill chart prediction for a Propeller turbine," in *25th IAHR Symposium on Hydraulic Machinery and Systems*, Pointe Claire, Canada, 2010.

[19] The institute of engineering and technology, I. Tidal power, 2007.

[20] Natasha Barker, "Managing Tidal Change," School of Earth & Ocean Sciences, Cardiff University, UK, Panda House, Weyside Park, Godalming, Surrey, UK, Final Project Report of Winston Churchill Memorial Trust Travelling Fellowship Award 2006.

[21] Peter Clark, Rebecca Klossner, Lauren Kologe, "Tidal Energy," CAUSE 2003: Final Project 2003.

[22] M.E.H. Benbouzid, J.F. Charpentier, S.E. Ben Elghali, "Marine Tidal Current Electric Power Generation Technology: State of the Art and Current Status," *IEEE*, 2007.

[23] Koea Energy. "World's Largest Tidal Power Plant-Shihwa Lake in Korea". [Online]. HYPERLINK "http://energy.korea.com/archives/6887" http://energy.korea.com/archives/6887

[24] Margaux Chanal, "How is 100% Renewable Energy Possible in South Korea by 2020?," South Korea by 2020?, 2012.

[25] Han Soo Lee, "Ocean renewable energy: Tidal power in the Yellow

] Sea," *Journal of International Development and Cooperation*, vol. 17, no. 3, pp. 29–44, 2011.

[26] Andrew B Gill, "Offshore renewable energy: ecological implications of generating electricity in the coastal zone," *Journal of Applied Ecology*, vol. 42, no. 4, pp. 605-615, 2005.

[27] A.F. Mollandb, J.R. Chaplina, W.M.J. Batten A.S. Bahaj, "Power and thrust measurements of marine current turbines under various hydrodynamic flow conditions in a cavitation tunnel and a towing tank," *Renewable Energy 32*, pp. 407–426, 2007.

[28] Scott J. Couch Ian G. Bryden, "ME1—marine energy extraction: tidal resource analysis," *Renewable Energy 31*, pp. 133–139, 2005.

[29] Patrick Cummins Chris Garretta, "Limits to tidal current power," *Renewable Energy 33*, pp. 2485–2490, 2008.

[30] A Mason-Jones1, D M O'Doherty1, C B Byrne, I Owen2 and Y X Wang T O'Doherty1, "Experimental and Computational Analysis of a Model Horizontal Axis Tidal Turbine," in *Proceedings of the 8th European Wave and Tidal Energy Conference*, Uppsala, Sweden, 2009, pp. 833 - 841.

[31] Peter Fraenkel, "Windmills below the sea: a commercial reality soon?," *Refocus*, vol. 5, no. 2, pp. 46-50, 2004.

[32] Peter Fraenkel, "Practical tidal turbine design considerations: a review of technical alternatives and key design decisions leading to the development of the SeaGen 1.2MW tidal turbine," in *Ocean Power Fluid Machinery Seminar*, London, 2010.

[33] M Ragheb, "Wind Energy Conversion Theory. Betz Equation," *Wind Energie*, 2004.

[34] A.S. Bahaj, A.F. Mollandb, J.R. Chaplin W.M.J. Battena, "The prediction of the hydrodynamic performance of marine current turbines," *Renewable Energy 33 (2008)*, pp. 1085–1096, 2008.

[35] Ole Gunnar Dahlhaug Céline Faudota, "Prediction of Wave Loads on Tidal Turbine Blades," *Energy Procedia 20* , pp. 116 – 133, 2012.

[36] Göran Bark Rickard E. Bensow, "Implicit LES Predictions of the Cavitating Flow on a Propeller," *Journal of Fluids Engineering*, 2010.

[37] M.Shiono and K. Suzuki SKiho, "THE POWER GENERATION FROM TIDAL CURRENTS BY DARRIEUS TURBINE," in *WREC*, Tokyo, 1996, pp. 1242-1245.

[38] L. Lazauskas B.K. Kirke, "Limitations of fixed pitch Darrieus hydrokinetic turbines and the challenge of variable pitch," *Renewable Energy 36*, p. 893e897, 2011.

[39] W.M.J. Battena, G. McCann A.S. Bahaj, "Experimental verifications of numerical predictions for the hydrodynamic performance of horizontal axis marine current turbines," *Renewable Energy 32*, pp. 2479–2490, 2007.

[40] J. Falnes, "Ocean Waves and Oscillating Systems: Linear Interaction Including Wave-Energy Extraction," Cambridge Univ. Press, Cambridge, U.K., 2002.

[41] Edo Abraham, Eric C. Kerrigan, "Optimal Active Control and Optimization of a Wave Energy Converter," *IEEE TRANSACTIONS ON SUSTAINABLE ENERGY*, vol. 4, no. 2, 2013.

[42] M. Folley, T.J.T. Whittaker, "Analysis of the nearshore wave energy resource," *Renewable Energy* , no. 34, pp. 1709–1715, 2009.

[43] James Brooke, *Wave Energy Conversion*, 6th ed., Michael E. McCormick Rameswar Bhattacharyya, Ed. Fddlington, Oxford, UK: Elsevier Science Ltd, 2003.

[44] K.K. Ahn, D.Q. Truong, Hoang Huu Tien, Jong Il Yoon, "An innovative design of wave energy converter," *Renewable Energy* , vol. 31, pp. 186 - 194, 2012.

[45] A., McCullen, P., Falcˇao, A., Fiorentino, A.,Gardner, F., Hammarlund, K., Lemonis, G., Lewis, T.,Nielsen, K., Petroncini, S., Pontes, M.-T., Schild, B.-O.,Sjöström, P., Søresen, H. C., and Thorpe, T. Clément, "Wave energyin Europe: current status and perspectives," *Renew. Sust. Energy Rev*, no. 6, pp. 405-431, 2006.

[46] A R Plummer, and M N Sahinkaya B Drew∗, "A review of wave energy converter technology," *Power and Energy*, pp. 887-902, 2009.

[47] Ross Henderson, "Design, simulation, and testing of a novel hydraulic power take-off system for the Pelamis wave energy converter," *Renewable Energy 31*, pp. 271–283, 2006.

[48] A. Babarit, J. Hals, M.J. Muliawan, A. Kurniawan, T. Moan, J. Krokstad, "Numerical benchmarking study of a selection of wave energy converters," *Renewable Energy*, no. 41, pp. 44-63, 2012.

[49] J. A. M. Cretel. G. Lightbody, G. P. Thomas. A. W. Lewis, "Maximisation of Energy Capture by a Wave-Energy Point Absorber using Model Predictive Control," in *18th World Congress The International Federation of Automatic Control*, Milano (Italy), 2011, pp. 3714 - 3721.

[50] P. Ricci, J. Lopez, M. Santos, P. Ruiz-Minguela, J.L. Villate, F. Salcedo, A.F.deO. Falcao, "Control strategies for a wave energy converter connected to a hydraulic power take-off," *IET Renewable Power Generation*, vol. 5, no. 3, pp. 234–244, 2011.

[51] J.M. Paixa˜o Conde, L.M.C. Gato, "Numerical study of the air-flow in an oscillating water column wave energy converter," *Renewable Energy* , no. 33, pp. 2637– 2644, 2008.

[52] N. J. Baker, M.A. Mueller, "Direct drive wave energy converters," *Reviews in Energy Renewable: Power Engineering*, pp. 1-7, 2001.

[53] David Elwood, Solomon C. Yim, Joe Prudell, Chad Stillinger, Annette von Jouanne, Ted Brekken, Adam Brown, Robert Paasch , "Design, construction, and ocean testing of a taut-moored dual-body wave energy converter with a linear generator power take-off," *Renewable Energy*, no. 35, pp. 348–354, 2010.

[54] E. Spooner, M.A. Mueller, "Comparative study of linear generators and hydraulic systems for wave energy conversion," School of engineering, University of Durham, ETSU Report V/06/00189/REP, 2001.

[55] Irina A. Ivanova, Olov Ågren, Hans Bernhoff, and Mats Leijon, "Simulation of Wave-Energy Converter With Octagonal Linear Generator," *IEEE JOURNAL OF OCEANIC ENGINEERING*, vol. 30, no. 3, July 2005.

[56] M. Eriksson, J. Isberg, M. Leijon, "Hydrodynamic modelling of a direct drive wave energy converter," *International Journal of Engineering Science*, no. 43, pp. 1377–1387, 2005.

[57] H. Polinder and M. Scuotto, "Wave energy converters and their impact on power systems," Amsterdam, DOI: 10.1109/FPS.2005.204210, 2005.

[58] C. Bostrom, M. Leijon, "Operation analysis of a wave energy converter under different load conditions," *IET Renewable Power Generation*, vol. 5, no. 3, pp. 245-250, 2010.

[59] Karin Thorburn, Hans Bernhoff, Mats Leijon, "Wave energy transmission system concepts for linear generator arrays," *Ocean Engineering* , no. 31, pp. 1339–1349, 2004.

[60] Cecilia Boström, Rafael Waters, Erik Lejerskog, Olle Svensson, Magnus Stålberg, Erland Strömstedt, and Mats Leijon, "Study of a Wave Energy Converter Connected to a Nonlinear Load," *IEEE JOURNAL OF OCEANIC ENGINEERING*, vol. 34, no. 2, 2009.

[61] L. Ran, P. J. Tavner, M. A. Muller, N. J. Baker, S. McDonald, "Power Conversion and Control for a Low Speed, Permanent Magnet, Direct-Drive, Wave Energy Converter," *Power Electronics, Machines and Drives*, pp. 17-21, 2006.

[62] M.A. Mueller, "Electrical generators for direct drive wave energy converters," *IEE Proc.-Gener. Transm. Distribution*, vol. 149, no. 4, July 2002.

ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

IJARMATE
International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 3, Issue 2, February 2017

[63] L. M. Yang, J. Hals and T. Moan, "A wear model for assessing the reliability of wave energy converter in heave with hydraulic power take-off," in *8th European Wave and Tidal Energy Conference*, Uppsala, Sweden, 2009, pp. 874 - 881.

[64] A.S. Zurkinden, F. Campanile, L. Martinelli, "Wave Energy Converter through Piezoelectric Polymers," in *COMSOL Users Conference* , Grenoble, 2007.

[65] (2008, June) The Economist. [Online]. HYPERLINK "http://www.economist.com/node/11482565" http://www.economist.com/node/11482565

[66] M. Folley, T.J.T. Whittaker, A. Henry, "The effect of water depth on the performance of a small surging wave energy converter," *Ocean Engineering*, no. 34, pp. 1265–1274, 2007.

[67] Trevor Whittaker, David Collier, Matt Folley, Max Osterried, Alan Henry, "The development of Oyster – A shallow water surging wave energy converter," in *Proceedings of the 7th European Wave and Tidal Energy Conference*, Porto, Portugal, 2007, pp. 11-14.

[68] Jørgen Hals, Johannes Falnes, Torgeir Moan, "Constrained Optimal Control of a Heaving Buoy Wave-Energy Converter," *Offshore Mechanics and Arctic Engineering*, vol. 133, February 2011.

[69] Guilherme Nunes, Duarte Valério, Pedro Beirão, José Sá da Costa, "Modelling and control of a wave energy converter," *Renewable Energy*, no. 36, pp. 1913-1921, 2011.

[70] Donal B. Murray, John G. Hayes, Dara L. O'Sullivan, Michael G. Egan, "Supercapacitor Testing for Power Smoothing in a Variable Speed Offshore Wave Energy Converter," *IEEE JOURNAL OF OCEANIC ENGINEERING*, vol. 37, no. 2, April 2012.

[71] L.Y. Seng K.S. Lee, "Simulation Studies on the Electrical Power Potential Harnessed by Tidal Current Turbines," *Journal of Energy & Environment*, pp. 18-23, 2009.

[72] Yan Du, Xiangzhen Yang, "Efficiency of Kinetic Hydropower System," in *2nd IEEE International Symposium on Power Electronics for Distributed Generation Systems*, Hefei, China, 2010.

[73] Sunho Park a, Dong Hwan Kim a, Shin Hyung Rhee b, Moon-Chan Kim Ju Hyun Lee, "Computational methods for performance analysis of horizontal axis tidal stream turbines," *Applied Energy 98*, pp. 512–523, 2012.

[74] Brian Veitch Pengfei Liu, "Design and optimization for strength and integrity of tidal turbine rotor blades," *Energy 46*, p. 393e404, 2012.

[75] Ya-Jung Lee b, Chu-Sung Hung Ching-Chieh Lin a, "Optimization and experiment of composite marine propellers," *Composite Structures 89* , pp. 206–215, 2009.

[76] K.. Chawla, *Composite Material*. New York: Springer Science + Bussiness Media, 2012.

[77] Airbus. (2016, October) Airbus. [Online]. HYPERLINK "http://www.airbus.com/innovation/eco-efficiency/design/" http://www.airbus.com/innovation/eco-efficiency/design/

[78] Boeing. (2008) Boeing. [Online]. HYPERLINK "http://www.boeing.com/commercial/aeromagazine/articles/qtr_4_06/article_04_2.html" http://www.boeing.com/commercial/aeromagazine/articles/qtr_4_06/article_04_2.html

[79] Commision European. (2014) European Commision's Research and Innovation. [Online]. HYPERLINK "http://ec.europa.eu/research/transport/projects/items/imac_pro_en.htm" http://ec.europa.eu/research/transport/projects/items/imac_pro_en.htm

[80] A.S. Zurkinden, F. Ferri, S. Beatty, J.P. Kofoed, M.M. Kramer, "Non-linear numerical modeling and experimental testing of a point absorber wave energy converter," *Ocean Engineering*, no. 78, pp. 11-21, 2014.

[81] John Ringwood, Shane Butler, "OPTIMISATION OF A WAVE ENERGY CONVERTER," *IFAC*, 2004.

[82] Tamas Bodai George Smith, "Harnessing the Power of Ocean Waves," Aberdeen, Scotland, 2009.

[83] M J French, "On the difficulty of inventing an economical sea wave energy converter: A personal view," *Enfineering for Maritime Environment*, vol. 220, pp. 149-155, 2006.

[84] M. Leijon, O. Danielsson, M. Eriksson, K. Thorburn, H. Bernhoff, J. Isberg, J. Sundberg, I. Ivanova, E. Sjo¨stedt, O. A˚gren, K.E. Karlsson, A. Wolfbrandt, "An electrical approach to wave energy conversion," *Renewable Energy*, vol. 31, pp. 1309–1319, 2006.

[85] M. Schoen, J. Hals, and T. Moan, "Wave prediction and robust control of heaving wave energy devices for irregular waves," *IEEE Trans. Energy Convers.*, vol. 26, no. 2, pp. 627–638, June 2011.

[86] Markus Richter, Mario E. Magaña, Oliver Sawodny, and Ted K. A. Brekken, Member, "Nonlinear Model Predictive Control of a Point Absorber Wave Energy Converter," *IEEE TRANSACTIONS ON SUSTAINABLE ENERGY*, vol. 4, pp. 118-126, January 2004.

[87] Alexander A. Temeev, Victor P. Belokopytov, Sergey A. Temeev, "An integrated system of the floating wave energy converter and electrolytic hydrogen producer," *Renewable Energy*, vol. 31, pp. 225–239, 2006.

[88] Edgar Mendoza, Rodolfo Silva, Barbara Zanuttigh, Elisa Angelelli, Thomas Lykke Andersen, "Beach response to wave energy converter farms acting as coastal defence," *Coastal Engineering* , no. 87, pp. 97–111, 2014.

