A

Seminar report

On

# Underwater Windmill

Submitted in partial fulfillment of the requirement for the award of degree
Of Civil

***SUBMITTED TO:***



***SUBMITTED BY:***

# Acknowledgement

I would like to thank respected Mr…….. and Mr. ……..for giving me such a wonderful opportunity to expand my knowledge for my own branch and giving me guidelines to present a seminar report. It helped me a lot to realize of what we study for.

Secondly, I would like to thank my parents who patiently helped me as i went through my work and helped to modify and eliminate some of the irrelevant or un-necessary stuffs.

Thirdly, I would like to thank my friends who helped me to make my work more organized and well-stacked till the end.

Next, I would thank Microsoft for developing such a wonderful tool like MS Word. It helped my work a lot to remain error-free.

Last but clearly not the least, I would thank The Almighty for giving me strength to complete my report on time.

# Preface

I have made this report file on the topic **Underwater Windmill;** I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to ……..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

# CHAPTER 1

## INTRODUCTION

I just did a Search here for "underwater" and "windmill" and it came up blank, so if this idea really has been posted here using some other verbiage,

Anyway, this Idea should be somewhat obvious in hindsight. We build ordinary windmills to extract useful power from wind energy. We put turbines in rivers (usually accompanied by dams) to extract useful power from downhill water flow. The second is more "energy intensive" than the first, which is why we all know that dams are great sources of electrical power, while electric-generator windmills spent decades in the economic doldrums (return on investment --ROI-- is relatively tiny, and only recently proved viable on a large scale).

Anyway, putting the equivalent of a windmill in a steady ocean current, say the Gulf Stream, should have an automatically-viable ROI that is intermediate between windmills and ordinary hydropower. This is because water is something like a thousand times denser than air, so a volume of flowing water contains a thousand times the energy of an equal volume of equally-flowing air.

Do note that the ocean has different currents at different depths. I once read somewhere that near the seafloor underneath the Gulf Stream is another current going the opposite direction. If true, then we can build towers on the seafloor, just like ordinary windmills, to extract power. Being so deep will protect them from ships, and most sea life is found at other depths, so they won't be bothered. Also, another thing that protects sea life is the fact that underwater windmills will have a SLOW rotation rate, due to that same greater density of water over air. This means we can also put windmills in the rich-life upper ocean currents; animals will have time to dodge the blades. (Some life forms, like barnacles, need to be discouraged; probably everything needs to be coated with Teflon or something even more slippery.)

Consider buoyant windmill modules can be anchored by cables to the bottom. They float up to perhaps fifty meters beneath the surface, in the midst of the ocean current. There they stay and generate power (which flows down those same anchor cables, and then toward shore).

Finally, it may be necessary to build all underwater windmill modules in counter rotating pairs. Again, this is because the water is denser than air; and for every unit of force that tries to rotate the blade, there will be reactive force against the generator assembly, Counter rotating blades will let such forces be canceled.

Tidal currents are being recognized as a resource to be exploited for the sustainable generation of electrical power. The high load factors resulting from the fluid proper- ties and the predictable resource characteristics make marine currents particularly attractive for power generation. These two factors makes electricity generation from marine currents much more appealing when compared to other renewables. Marine current turbine (MCT) installations could also provide base grid power especially if two separate arrays had offset peak flow periods. This characteristic dispels the myth that renewable energy generation is unsuitable on a large scale.

The global strive to combat global warming will necessitate more reliance on clean energy production. This is particularly important for electricity generation which is currently heavily reliant on the use of fossil fuel. Both the UK Government and the EU have committed themselves to internationally negotiated agreements designed to combat global warming. In order to achieve the target set by such agreements, large scale increase in electricity generation from renewable resources will be required.

Marine currents have the potential to supply a significant fraction of future electricity needs. A study of 106 possible locations in the EU for tidal turbines showed that these sites could generate power in the order of 50 TWh/year. If this resource is to be successfully utilized, the technology required could form the basis of a major new industry to produce clean power for the 21st century.

Although the energy in marine currents is generally diffuse it is concentrated at a number of sites. In the UK, for example, tidal races which exist in the waters around the Channel Islands and the 'Sounds' off the Scottish west coast are well known amongst sailors for their fast flowing waters and treacherous whirlpools. The energy density at such sites is high and arrays of turbines could generate as much as 3000 MW in the spring tides.

In spite of the advantages offered by MCTs, it is rather surprising that such technology has not received much attention in terms of research and development. There are many fundamental issues of research and various key aspects of system design that would require investigation. A major research effort is needed in order to expedite the application of the marine current kinetic energy converters. Virtually no work has been done to determine the characteristics of turbines running in water for electricity production even though relevant work has been carried out on wind turbines and on high speed ship's propellers and hydro turbines. None of these three well established areas of technology completely overlap with this new field so that gaps remain in the state of knowledge. This paper reviews the fundamental issues that likely to play a major role in implementation of MCT systems. It also highlights research areas to be encountered in this new area and reports on issues such as the harsh marine environment, the phenomenon of cavitation and the high stresses encountered by such structures.

Fig.1 Consuming and harnessing the power generated under the oceans.

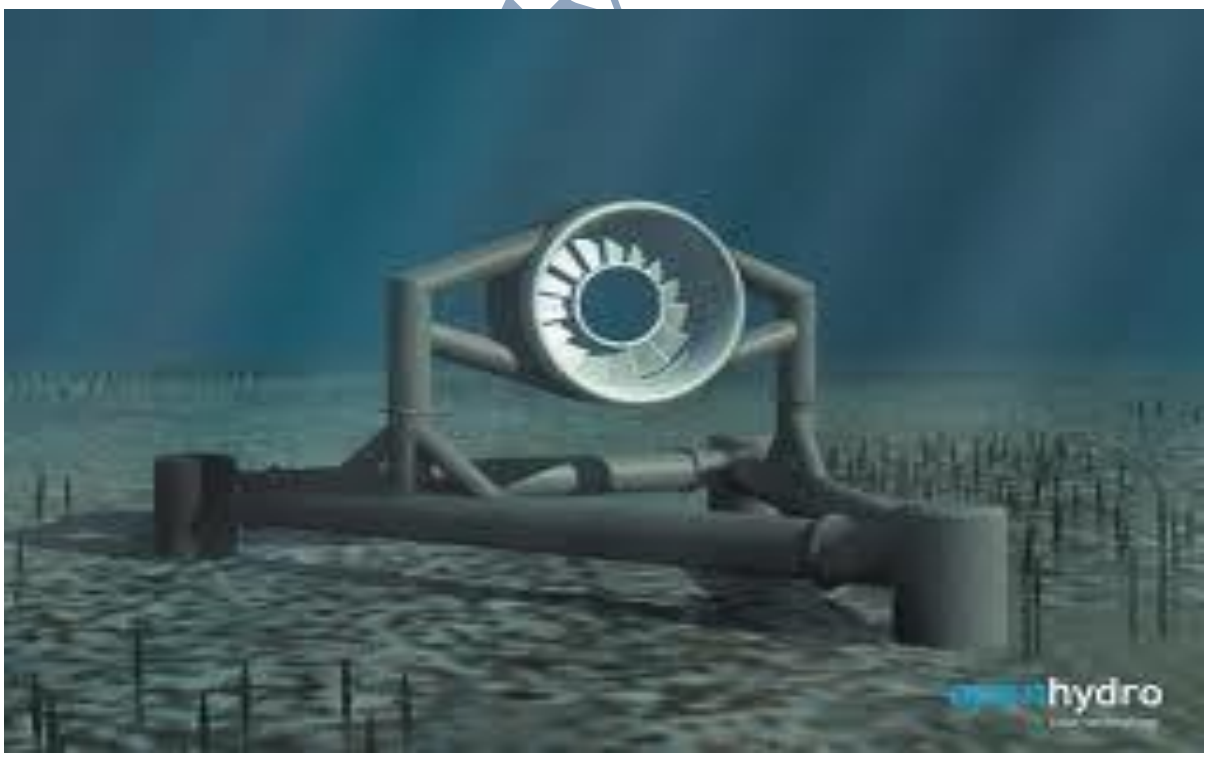


Fig.2 Turbine placed under water to consume ocean power.

CHAPTER 2

## HISTORY

Two British consultants have developed an underwater pump that can irrigate riverside fields without using fuel or causing pollution. The prize-winning turbine is easy to construct and can work continuously

Originally designed to harness the energy of the Nile to irrigate the desert areas of Sudan, the pump has a three-blade rotor that utilizes the energy of moving water, just as a windmill uses wind. The underwater pump can be operated by a single person with little training.



Fig.3 Two blade fins placed under water and generating energy.

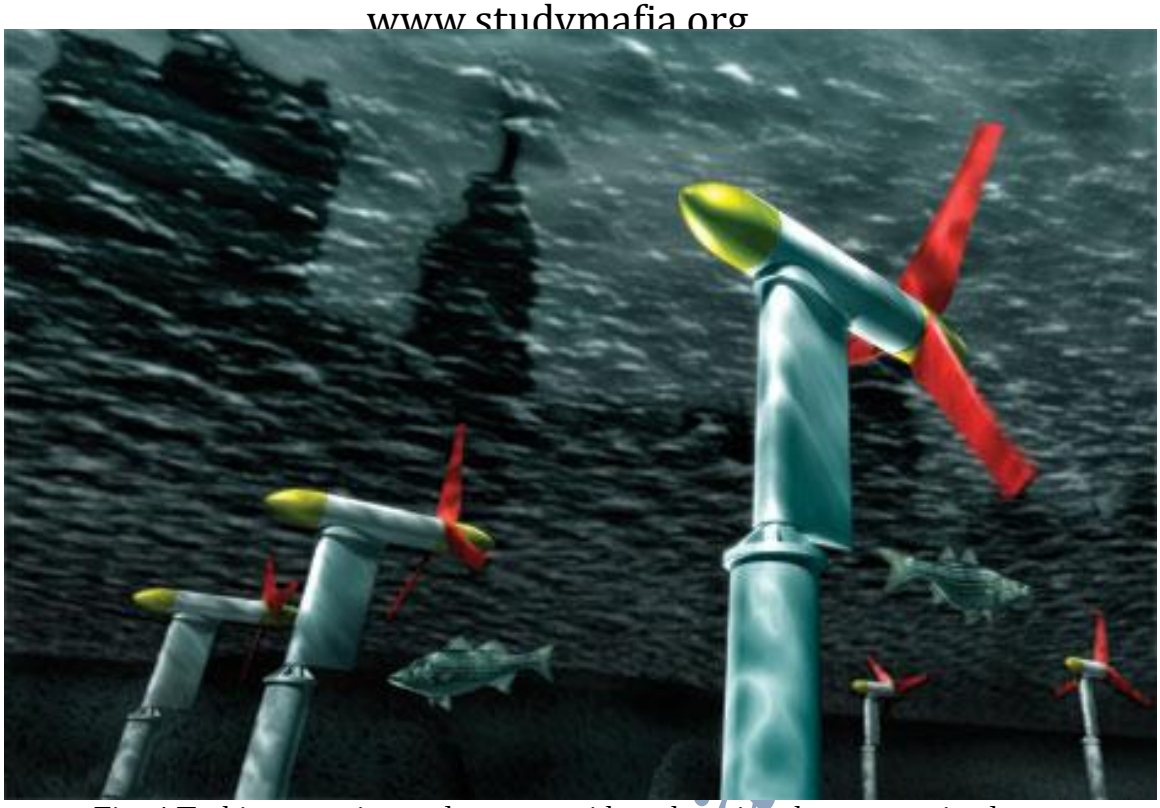

Fig. 4 Turbines running under water without harming the water animals.

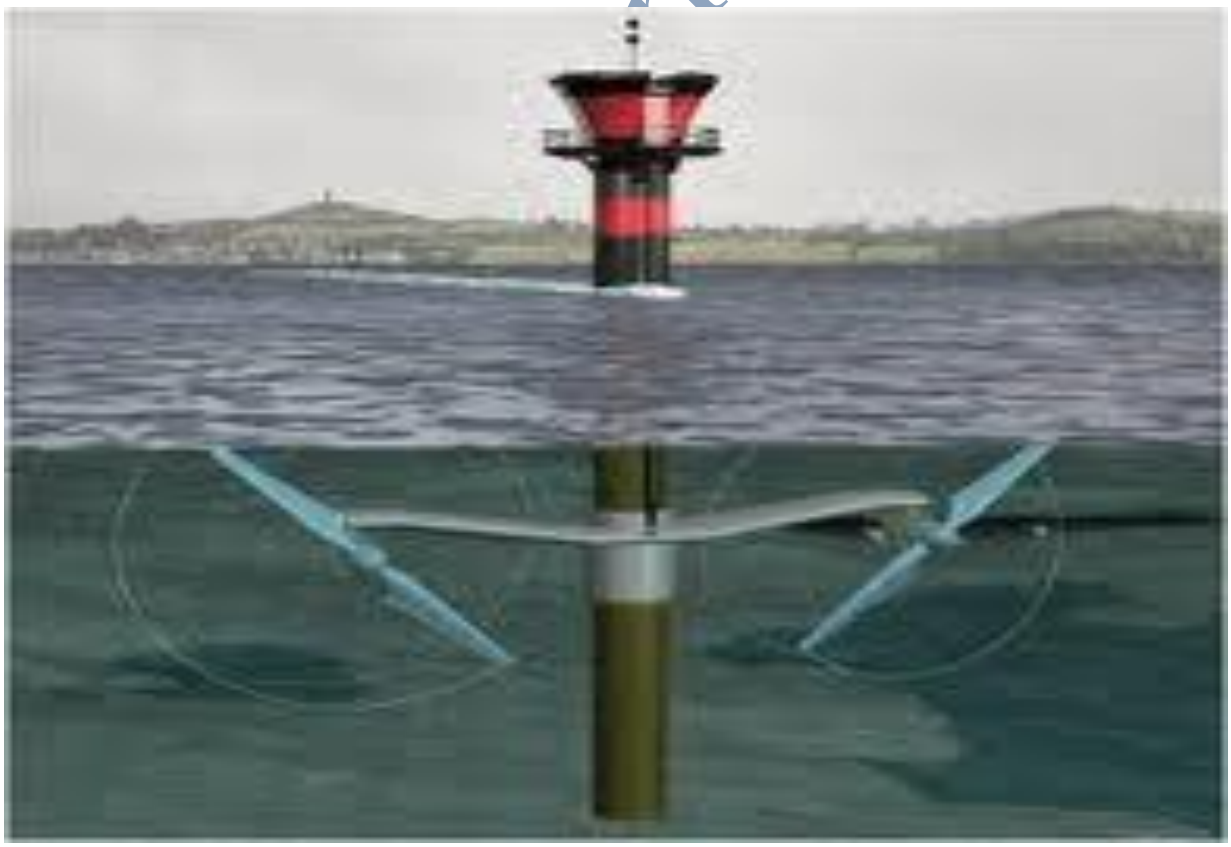

Fig.5 huge turbine placed under the sea and rotating in the direction of flow.

Researchers launched the first offshore tidal energy turbine on Monday. The rotor on the English coast uses the power of the tides to generate electricity. Just the beginning: The first "farm" of tidal turbines could spring up off the English coast within years.

Imagine taking a windmill, turning it on its side and sinking it in the ocean. That, in effect, is what engineers have done in the Bristol Channel in England. The aim is to harness the energy the tide produces day in, day out. On Monday, the world's first prototype tidal energy turbine was launched.

The "Sea flow" installation was built into the seabed about one and a half kilometers (one mile) off the Devon coast. Above the surface, only a white and red-striped tower is visible. Beneath, 20 meters down, the single 11-meter long rotor turns up to 17 and a half times a minute at a maximum speed of 12 meters per second, drawing energy from the water's current.

The €6 million ($7 million) project's supporters -- which include the British and German governments and the European Union -- hope that tidal turbines may one day be a further source of energy. Unlike sun and wind energy, tidal energy is reliable, since it's not affected by the weather.

"As long as the earth turns and the moon circles it, this energy is a sure thing," Jochen Bard from ISET, a German solar energy institute involved in the project, told the dpa news agency.

The red dots show locations where tidal energy turbines could be employed in Britain and northern France.

Sea flow can generate around 300 kilowatts, while rotors developed in the future should be able to produce a megawatt. The new facility is pegged to be linked to Britain's national grid in August, and a second rotor is to be added by the end of 2004. Marine Current Turbines (MCT), which operates Seaflow, estimates that 20 to 30 percent of British electricity needs could be provided by the new technology.

CHAPTER 3

## Renewable Energy

We can divide renewable energy sources into two main categories: traditional renewable energy sources like biomass and large hydropower installations, and the "new renewable energy sources" like solar energy, wind energy, geothermal energy, etc. Renewable energy sources provide 18% of overall world energy (2006), but most of this energy is energy from traditional use of biomass for cooking and heating - 13 of 18%. In large hydropower installations is another three percent. So, when we exclude conventional biomass and large hydropower installations it is easy to calculate that so called "new renewable energy sources" produce only 2.4% of overall world energy. 1.3% are water heating solutions, 0.8% are different power generation methods, and 0.3% are biofuels. In the future this portion should be significantly increased because the availability of non-renewable sources is decreasing with time, and their damaging influence has significantly increased in the last couple of decades. Sun delivers 15 thousand times more energy to Earth than humanity really needs in this stage, but despite this some people on Earth are still freezing. This fact shows us that we should exploit renewable sources much more and that we do not have to worry about the energy after fossil fuels cease to exist. Development of renewable energy sources (especially from wind, water, sun and biomass) is important because a couple of reasons:

- Renewable energy sources have major role in decreasing of emissions of the carbon dioxide ($CO_2$) into atmosphere.
- Increased proportion of renewable energy sources enhances energetic viability of the energy system. It also helps to enhance energy delivery security by decreasing dependency on importing energetic raw materials and electrical energy.
- It is expected that renewable energy sources will become economically competitive to conventional energy sources in middle till longer period.

Fig.6 Different types of renewable energy.

Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished). About 16% of global final energy consumption comes from renewables, with 10% coming from traditional biomass, which is mainly used for heating, and 3.4% from hydroelectricity. New renewables (small hydro, modern biomass, wind, solar, geothermal, and biofuels) accounted for another 3% and are growing very rapidly. The share of renewables in electricity generation is around 19%, with 16% of global electricity coming from hydroelectricity and 3% from new renewables.

## 3.1 SOLAR ENERGY

Solar energy is the energy derived from the sun through the form of solar radiation. Solar powered electrical generation relies on photovoltaic and heat engines. A partial list of other solar applications includes space heating and cooling through solar architecture, day

lighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes.

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Fig.7 Nellis Solar Power Plant, 14 MW power plant installed 2007 in Nevada, USA.

## 3.2 BIO MASS

Biomass (plant material) is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, plants capture the sun's energy. When the plants are burnt, they release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably, with only as much used as is grown, the battery will last indefinitely.

In general there are two main approaches to using plants for energy production: growing plants specifically for energy use (known as first and third-generation biomass), and using the residues (known as second-generation biomass) from plants that are used for

other things. See bio based economy. The best approaches vary from region to region according to climate, soils and geography.

## 3.3 BIO FUEL

Biofuels include a wide range of fuels which are derived from biomass. The term covers solid biomass, liquid fuels and various biogases. Liquid biofuels include bio alcohols, such as bioethanol, and oils, such as biodiesel. Gaseous biofuels include biogas, landfill gas and synthetic gas.

Bioethanol is an alcohol made by fermenting the sugar components of plant materials and it is made mostly from sugar and starch crops. With advanced technology being developed, cellulosic biomass, such as trees and grasses, are also used as feedstock's for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil.

Biodiesel is made from vegetable oils, animal fats or recycled greases. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using trans esterification and is the most common biofuel in Europe.

Biofuels provided 2.7% of the world's transport fuel in 2010.

## 3.4 GEOTHERMAL ENERGY

Geothermal energy is thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. Earth's geothermal energy originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%). The geothermal gradient, which is the difference in temperature between

the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. The adjective *geothermal* originates from the Greek roots *geo*, meaning earth, and *thermos*, meaning heat.

The heat that is used for geothermal energy can be stored deep within the Earth, all the way down to Earth's core – 4,000 miles down. At the core, temperatures may reach over 9,000 degrees Fahrenheit. Heat conducts from the core to surrounding rock. Extremely high temperature and pressure cause some rock to melt, which is commonly known as magma. Magma convicts upward since it is lighter than the solid rock. This magma then heats rock and water in the crust, sometimes up to 700 degrees Fahrenheit.

From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation.

Fig. 8 Steam rising from the Nesjavellir Geothermal Power Station in Iceland.



## 3.5 WIND ENERGY

Airflows can be used to run wind turbines. Modern wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5–3 MW have

become the most common for commercial use; the power output of a turbine is a function of the cube of the wind speed, so as wind speed increases, power output increases dramatically. Areas where winds are stronger and more constant, such as offshore and high altitude sites, are preferred locations for wind farms. Typical capacity factors are 20-40%, with values at the upper end of the range in particularly favorable sites.

Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand. This could require wind turbines to be installed over large areas, particularly in areas of higher wind resources. Offshore resources experience average wind speeds of ~90% greater than that of land, so offshore resources could contribute substantially more energy.

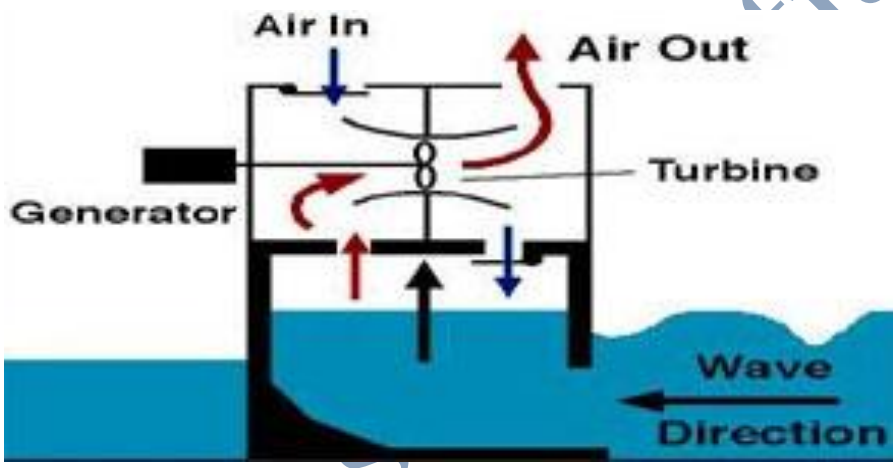


Fig.9 Wave power principle. You can see from this picture that huge wave amplitude is needed in order to achieve efficient transformation.

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## 3.6 HYDRO ENERGY

Energy in water can be harnessed and used. Since water is about 800 times denser than air, even a slow flowing stream of water, or moderate sea swell, can yield considerable amounts of energy. There are many forms of water energy:

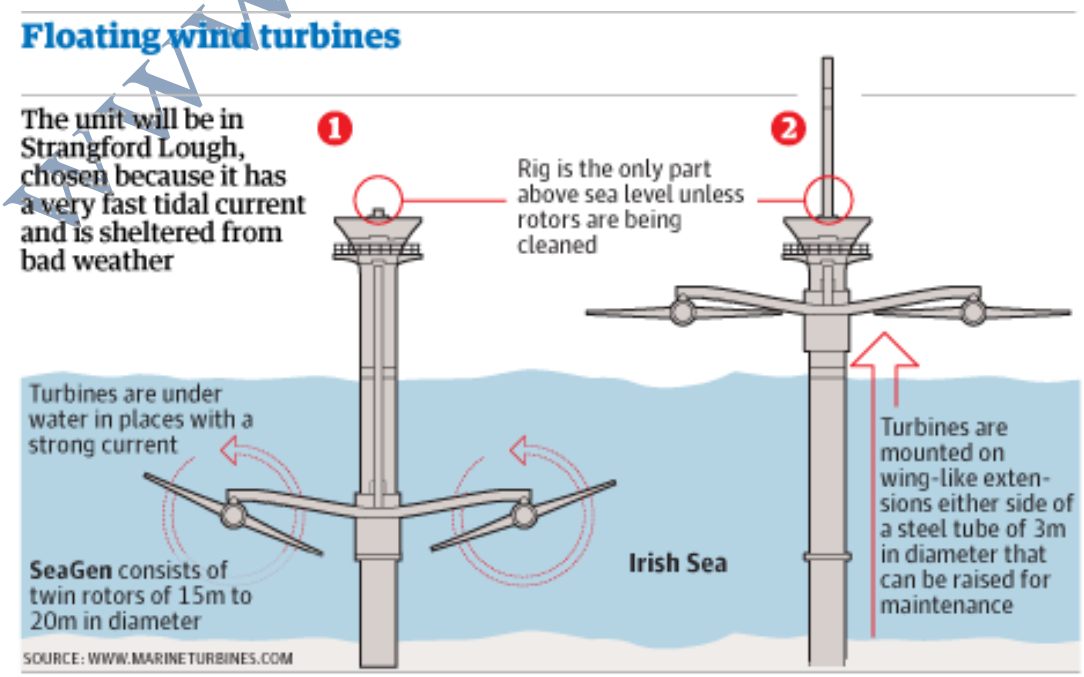
- Hydroelectric energy is a term usually reserved for large-scale hydroelectric dams. Examples are the Grand Coulee Dam in Washington State and the Akosombo Dam in Ghana.
- Micro hydro systems are hydroelectric power installations that typically produce up to 100 kW of power. They are often used in water rich areas as a remote-area power supply (RAPS).
- Run-of-the-river hydroelectricity systems derive kinetic energy from rivers and oceans without using a dam.

## 3.7 TIDAL ENERGY

Tidal power is a consequence of Sun's and Moon's gravity forces. For now, there is no major commercial exploitation of this energy, despite of its big potential. This energy can be gained in places where sea changes are extremely emphasized (for instance some places have difference between high tide and low tide bigger then 10 meters). The principle is quite simple and very similar to the one of the water power plant. On the entrance to some gulf, escarpment is built and when the level of the water rises, water leaks across the turbine in to a gulf. When gulf is filled with the water escarpment is sealed and after the level of the water falls the same principle is being used to direct water out of the gulf. In more simple case water leaks through turbines in only one direction, and in this case turbines are less complicated (unilateral, not bilateral). The biggest problems of this use of energy are vicissitude of tidal power (wait the sufficient level of the water to rise enough, or to fall enough) and small number of places suitable for using this energy source. The most famous power plant is the one on the river Rance delta in France (picture) built in 1960 and still functional. Russia has build small power plant near city of Murmansk, Canada in gulf Fundy, China small number of them, but neither of this countries has made any significant progress. Alternative method of use relates to the location of power plants in sea ravines where due to a canalizing tidal wave,

its energy increases, and underwater turbines similar as the ones of the wind power plants would be used as the generator machinery. Energy of the sea currents is also planned to be used in the same way, but this technology is still in very early phase.

Fig. 10 most famous tidal power plant is the one on the river Rance delta in France built in 1960 and still function



CHAPTER 4

# UNDERWATER WINDMILL

## 4.1 DEFINITION

Tidal stream turbines are often described as underwater windmills. They are driven by the kinetic energy of moving water in a similar way that wind turbines use moving air. The generator is placed into a marine current that typically results when water being moved by tidal forces comes up against, or moves around, an obstacle or through a constriction such as a passage between two masses of land. There are sufficient numbers of such fast-flowing underwater currents around the world to make this form of marine renewable energy worth pursuing. In figure 1, the areas between the coasts of Ireland and Scotland that are colored magenta would merit the application of tidal current capturing systems. Harnessing the marine currents could also help fulfill the Climate Change Committee's recent request in 2010 that calls for an almost complete.

decarburization of the UK's electricity supply by 2030. In their report, *Future Marine Energy*, published in 2006, the Carbon Trust estimated that tidal stream energy could meet 5% of the UK's electrical energy needs, reducing the country's dependence upon carbon intensive imported fossil fuels. Other studies have predicted that tidal generators could produce up to 10% of the UK's electrical energy needs. A point not lost on the UK government and the devolved administrations who see the industrial growth opportunities that tidal and wave energy could offer. Tidal flows have the advantage of being as predictable as the tides that cause them; both in terms of timing and in judging their maximum velocity. This long-term predictability helps greatly in electricity generation, enabling more efficient grid management and thus reducing the total amount of power that needs to be generated.

Energy derived from the moon now trickles into an Artic tip of Norway via a novel underwater windmill like device powered by the rhythmic slosh of the tides. The tidal turbine is bolted to the floor of the Kvalsund channel and is connected to the nearby town

of Hammerfest's power grid on September 20th. This is the first time in the world that electricity directly from a tidal current has been feed into a power grid. The gravitational tug of the moon produces a swift tidal current there that cause though the channel at about 8 feet (2.5 meters) per second and spins the 33-foot (10 meters) long blades of the turbine. The blades automatically turn and rotate at a pace of seven revolutions per minute, which is sufficient to produce 700,000 kilowatt hours of non-polluting energy per year- enough to power about 35 Norwegian homes (70 U.S homes).

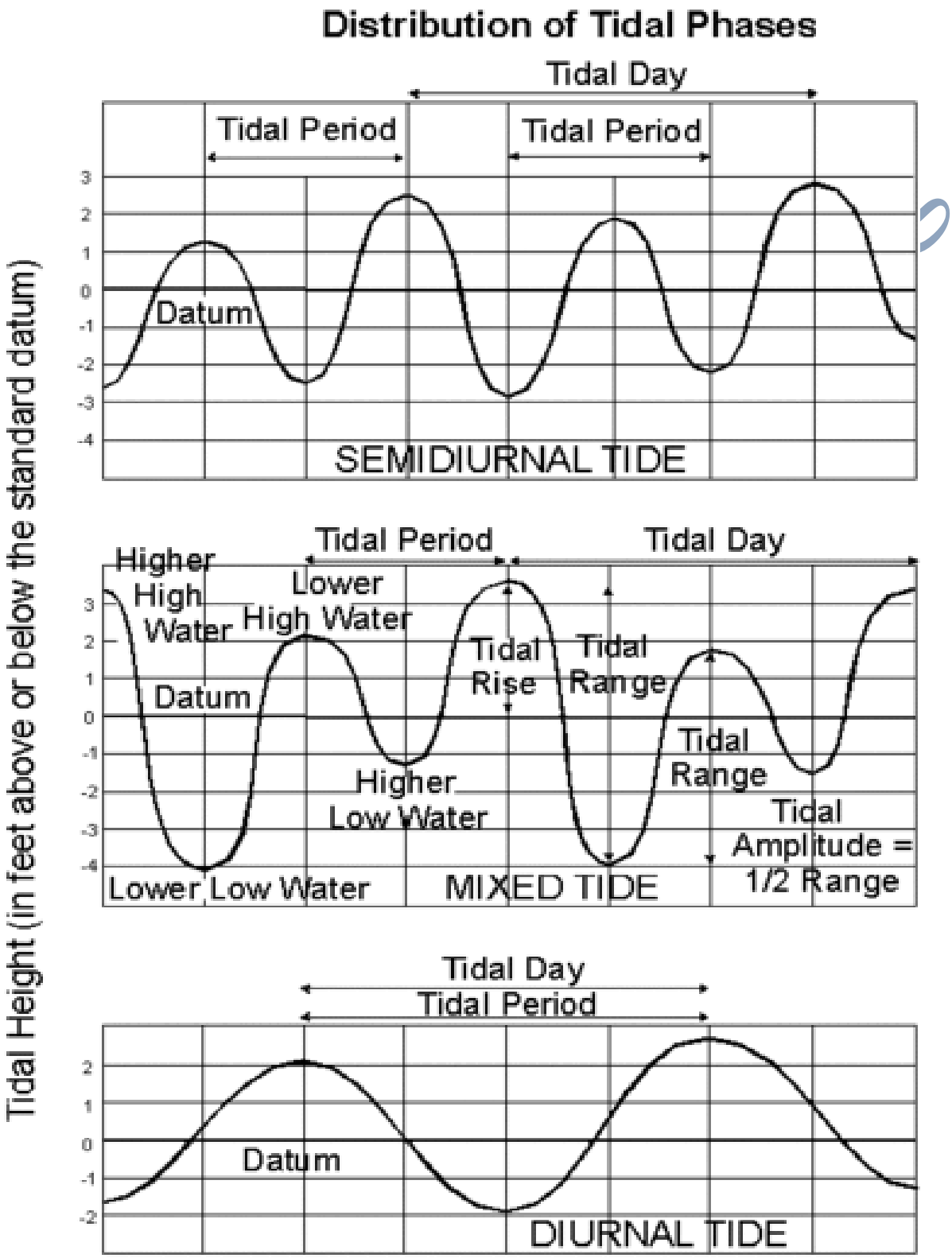
It can also be defined as, Energy derived from the moon that now helps to power a small arctic village. An Underwater windmill-like device gets power from the tides. The gravitational pull of the moon produces a swift tidal current, which courses through the channel and spins the long blades of the turbine.

## 4.2 PRINCIPLES

Underwater turbines operate on the same principles that wind turbines use; a flow of fluid moves a set of blades creating mechanical energy which is then converted to electrical energy. They are equally troublesome for environmentalists, as wind turbines interrupt bird flights just as water turbines can disturb underwater life. One advantage water turbines enjoy over other sources of renewable energy is a predictable tide table.

MCT's ocean energy device works on the same principles as a windmill, where large underwater rotors, shaped like propellers, are driven by the huge mass of flowing water to be found at certain places in the sea. The technology consists of rotors mounted on steel piles (tubular steel columns) set into a socket drilled in the seabed. The rotors are driven by the flow of water in much the same way that windmill rotors are driven by the wind, the main difference being that water is more than 800 times as dense as air, so quite slow velocities in water will generate significant amounts of power. The energy generated, being derived from tides has the added significant advantage of being predictable

TABLE BASED ON THE FORMATION OF TIDES



## 4.3 WORKING

Underwater turbines rely on tides to push water against angled blades, causing them to spin. These turbines can be placed in natural bodies of water, such as harbors and lagoons that naturally feature fast-moving flows of water. These turbines must be able to swivel 180 degrees to accommodate the ebb and flow of tides, as demonstrated by the SeaGen prototype turbine in Ireland. As the blades spin, a gearbox turns an induction generator, which produces an electric current. Other devices can be tethered and attached to a float, such as the Evopod in England. This design allows the face of the turbine to always face the direction of the current, much like a moored boat does.

Many wave power machines are designed to capture the energy of the wave's motions through a bobbing buoy-like device. Another approach is a Pelamis wave generator, now being tested in Scotland and in Portugal, which transfers the motion of surface waves to a hydraulic pump connected to a generator.

Tidal power typically uses underwater spinning blades to turn a generator, similar to how a wind turbine works. Because water is far more dense than air, spinning blades can potentially be more productive than off-shore wind turbines for the same amount of space.

In addition to being renewable, another key advantage of ocean power is that it's reliable and predictable, said Daniel Englander, an analyst at Greentech Media.

Although they can't generate power on-demand like a coal-fired plant, the tides and wave movements are well understood, giving planners a good idea of energy production over the course of year.

There are only a few underwater turbines in operation today and they all operate like underwater windmills, with their blades turning at right angles to the flow of the water. In contrast, the Oxford team's device is built around a cylindrical rotor, which rolls around its long axis as the tide ebbs and flows. As a result, it can use more of the incoming water than a standard underwater windmill

## 4.4 TECHNOLOGY

### Types of Technology

Ocean energy refers to a range of technologies that utilize the oceans or ocean Resources to generate electricity. Many ocean technologies are also adaptable to no impoundment uses in other water bodies such as lakes or rivers. These technologies can be separated into three main categories:

**Wave Energy Converters:** These systems extract the power of ocean waves and convert it into electricity. Typically, these systems use either a water column or some type of surface or just-below-surface buoy to capture the wave power. In addition to oceans, some lakes may offer sufficient wave activity to support wave energy converter technology.

**Tidal/Current:** These systems capture the energy of ocean currents below the wave surface and convert them into electricity. Typically, these systems rely on underwater turbines, either horizontal or vertical, which rotate in either the ocean current or changing tide (either one way or bi-directionally), almost like an underwater windmill or paddle wheel. These technologies can be sized or adapted for ocean or for use in lakes or noni pounded river sites.

**Ocean Thermal Energy Conversion (OTEC):** OTEC generates electricity through the temperature differential in warmer surface water and colder deep water. Of ocean technologies, OTEC has the most limited applicability in the United States because it requires a 40-degree temperature differential that is typically available in locations like Hawaii and other more tropical climates.

**Offshore Wind:** Offshore wind projects take advantage of the vast wind resources available across oceans and large water bodies. Out at sea, winds blow freely, unobstructed by any buildings or other structures. Moreover, winds over oceans are

stronger than most onshore, thus allowing for wind projects with capacity factors of as much as 65 percent, in contrast to the 35-40 percent achieved onshore.

**Other:** Marine biomass to generate fuel from marine plants or other organic materials, hydrogen generated from a variety of ocean renewables and marine geothermal power. There are also opportunities for hybrid projects, such as combination offshore wind and wave or even wind and natural gas.

## 4.5 Design and Challenges

There are three factors that govern the energy capture by any water current kinetic energy converter: the swept area of the rotor(s); the speed of the flow (kinetic energy is proportional to the velocity cubed) and the overall efficiency of the system. There have been many challenges to make tidal turbines commercially viable, among these has been the need to place the systems in the right locations where the water depth, current flow patterns and distance to the grid make a project economically viable, and to make units efficient and easy to maintain.

Perhaps the greatest challenge relates to creating an underwater structure with foundations capable of withstanding extremely hostile conditions. The drag from a 4.5 m/s current such as MCT's SeaGen experiences at the peak of a spring tide at Strangford is equivalent to designing a wind turbine to survive wind speeds of 400 km/h (250 mph).

MCT's most recent turbine installation is located in Strangford Narrows, Northern Ireland. Known as 'SeaGen', it became operational in 2008 using twin 16 m diameter rotors each sweeping over 200 m2 of flow that develop a rated power of 1.2 MW at a current velocity of 2.4 m/s. It is accredited by Ofgem as a UK power station and is the largest and most powerful water current turbine in the world, by a significant margin, with the capacity to deliver about 10 MWh per tide, adding up to 6,000 MWh a year. Its

distinctive shape and functions have been developed by years of trials of locating and operating underwater systems

An in-stream tidal turbine, also called a tidal current turbine, works a lot like an underwater windmill. In-stream technology is designed to use the flow of the tides to turn an impellor, just like a windmill uses the flow of air to turn its blades. Each turbine technology deals with this challenge differently, but each uses the rotation of a turbine to turn an electrical generator.

Open Hydro and ALSTOM/Clean Current both house their impellors in a shroud or duct, to accelerate the flow of water over the blades, and improve the efficiency of the units. Marine Current Turbines uses two reversing pitch propellers, just like a conventional wind turbine, and uses the design of their blades to maximize efficiency.

**Operation**

The turbines are designed to operate in the open flow of water. In the Minas Passage, they must operate in a range of speeds from zero to 8 knots, depending on where they are sited and how deep they are positioned. Water speed is fastest at the surface and slowest near the sea floor. Tidal power output is very sensitive to water speed, just as windmills are to wind speed. For example, if the water speed doubles, the turbine will produce eight times more power!

The potential of electric power generation from marine tidal currents is enormous. Tidal currents are being recognised as a resource to be exploited for the sustainable generation of electrical power. The high load factors resulting from the fluid properties and the predictable resource characteristics make marine currents particularly attractive for power generation and advantageous when compared to other renewables. There is a paucity of information regarding various key aspects of system design encountered in this new area of research. Virtually no work has been done to determine the characteristics of turbines running in water for kinetic energy conversion even though relevant work has been carried out on ship's propellers, wind turbines and on hydro turbines. None of these three well established areas of technology completely

overlap with this new field so that gaps remain in the state of knowledge. This paper reviews the fundamental issues that are likely to play a major role in implementation of MCT systems. It also highlights research areas to be encountered in this new area. The paper reports issues such as the harsh marine environment, the phenomenon of cavitation, and the high stresses encountered by such structures are likely to play a major role on the work currently being undertaken in this field.

CHAPTER 5

## Power Generation by Underwater Windmill And Cost

Energy derived from the moon now trickles into an Artic tip of Norway via a novel underwater windmill like device powered by the rhythmic slosh of the tides. The tidal turbine is bolted to the floor of the Kvalsund channel and is connected to the nearby town of Hammerfest's power grid on September 20th. This is the first time in the world that electricity directly from a tidal current has been feed into a power grid. The gravitational tug of the moon produces a swift tidal current there that cause though the channel at about 8 feet (2.5 meters) per second and spins the 33-foot (10 meters) long blades of the turbine. The blades automatically turn and rotate at a pace of seven revolutions per minute, which is sufficient to produce 700,000 kilowatt hours of non-polluting energy per year- enough to power about 35 Norwegian homes (70 U.S homes



An underwater turbine that generates electricity from tidal streams was plugged into the UK's national grid today. It marks the first time a commercial-scale underwater turbine has fed power into the network and the start of a new source of renewable energy for the UK Tidal streams are seen by many as a plentiful and predictable supply of clean energy. The most conservative estimates suggest there is at least five gigawatts of power in tidal flows around the country, but there could be as much as 15GW.

The trial at Strangford Lough, in Northern Ireland, uses a device called SeaGen and generates power at 150kW. However, engineers have plans to increase power to 300kW by the end of the summer. When it is eventually running at full power SeaGen will have an output of 1,200 kW, enough for about 1,000 homes.

SeaGen was designed and built by the Bristol-based tidal energy company Marine Current Turbines (MCT), which also installed the test device at Strangford in May.

"The best way to think of it is an underwater windmill," said Martin Wright, managing director of MCT. "There are big masses of water moving on the Earth's surface as a result of the gravitational attraction of the moon. Therefore you have streams occurring where you have accelerated flow."

Tidal generators harvest the energy of these moving streams with the added advantage that the resource is, unlike wind, predictable.

The secretary of state for business, John Hutton, said: "This kind of world-first technology and innovation is key to helping the UK reduce its dependency on fossil fuels and secure its future energy supplies.

"Marine power has the potential to play an important role in helping us meet our challenging targets for a massive increase in the amount of energy generated from renewables."

The Department for Business, Enterprise and Regulatory Reform supported Seagen with a £5.2m grant, helping take its plans from the drawing board to the first demonstrator.

The cost of installing the marine turbines is £3m for every megawatt they eventually generate, which compares to £2.3m per megawatt for offshore wind. The costs will drop if the technology is more widely adopted.

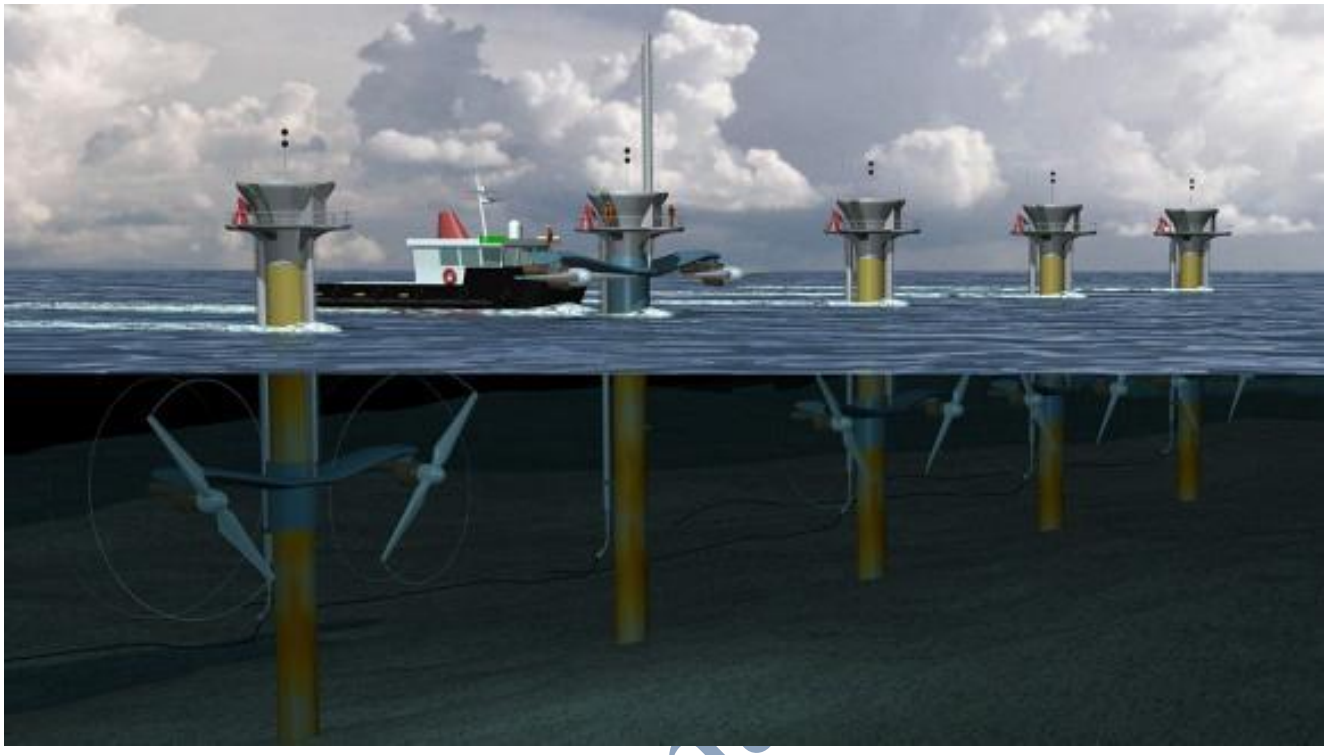
Robin Oakley, head of Greenpeace UK's climate and energy campaign, welcomed the SeaGen trial: "Britain should be at the forefront of marine renewable energy development. Our windswept island has huge renewable resources and we should seize the opportunities to secure energy from around our coasts.

"Clean reliable tidal stream power can make a massive contribution to Britain, cutting CO2 and fuel consumption. But it also offers a chance for us to be world leaders in a new and potentially huge industry."

After SeaGen starts operating at full capacity, MCT plans to build a farm of turbines before 2011. "Our next site will be off the coast of Anglesey, the initial farm is about 10.5MW," said Wright. "The resource up there is around 350MW."

The Pentland Firth, the Channel Islands and the Severn estuary are also potential hotspots for tidal energy.

Wright said: "I hope it makes people believe that tidal power isn't 20 to 30 years away and a dream, but it is something that, if we get the right resources around it, could become a significant reality and contributor much quicker than that.



Marine Current Turbines Ltd (MCT), in partnership with RWE npower renewables, has today submitted a consent application to install a 10MW array of tidal stream turbines off the North West coast of Anglesey in 2015. The array, consisting of seven twin rotor turbines arranged across an area of 0.56km², will harness the power of the tidal waters, generating enough power for over 10,000 homes on the island. It will be the first tidal array to be deployed in Wales.

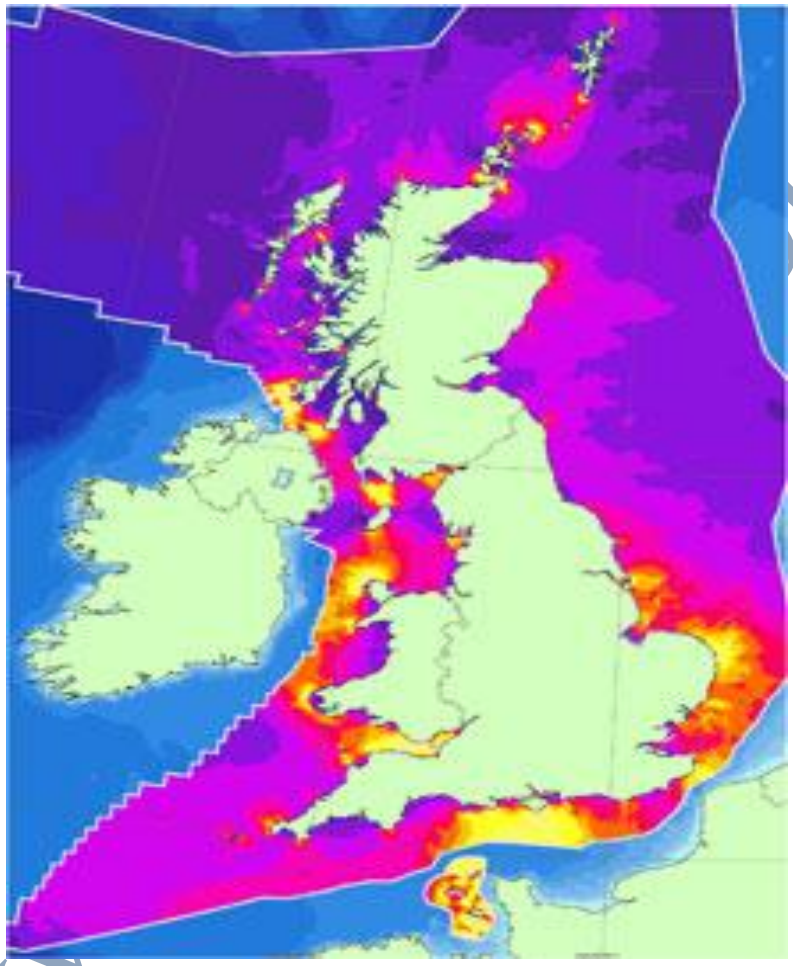
This tidal farm, using the fast moving and predictable flow of the tides, will use MCT's proven and award-winning tidal energy technology (known as SeaGen and which works in principle like an underwater windmill) to generate enough power to supply electricity to up to 10,000 homes. The array will be situated between the Skerries islands and Carmel Head, about 1km off the Anglesey coast. SeaGen is a proven technology, the first 1.2MW unit having been successfully operated in Strangford Narrows, Northern Ireland since 2008, and it is officially accredited by OFGEM as the UK's first and only tidal current power plant.

If the planning consent is granted to SeaGeneration Wales Ltd, the MCT / RWE npower renewables project company, it will be the first tidal array in Wales demonstrating the commercial viability of this technology. This project will help to demonstrate that the deployment of tidal generation can be recognised as a viable means of securing renewable generation, lower carbon emissions whilst simultaneously creating a new industry and many jobs.

The project will cost approximately £70 million to develop and, where possible, local businesses will be contracted for the assembly, installation, operation and maintenance of the tidal array. It will generate jobs that use skills ranging from advanced blacksmithing through to sophisticated control systems management. The project will also stimulate the supply chain to support the emerging marine renewable energy sector in the UK and Wales.Martin Wright, CEO and founder of MCT said: "Tidal power is a predictable and reliable source of renewable energy and our technology can play an important part in helping Wales realise its renewable energy targets as set out in the Welsh Assembly Government (WAG) Energy Policy statement. It aims to capture 10% of the tidal stream and wave energy off the Welsh coast by 2025, making Wales a UK low carbon economic area for tidal energy. The proposed project would represent a significant step in meeting both of these targets and furthermore, will see the creation of many new green jobs."

CHAPTER 6

## NEXT GENERATION UNDERWATER WINDMILL



**(UK tides ... stronger tides are yellow and red. Image.)**

Harnessing the vast energy of the UK's coastal tides could become much simpler and cheaper with a new design for the next generation of underwater turbines. The device, unveiled by a team of engineers from Oxford University, re-thinks the way power is generated underwater and the inventors believe it will be more robust, more efficient and cheaper to build and maintain than anything in operation today.

There is an immense potential resource of clean energy from the tidal flows around the UK: conservative estimates suggest there is at least five gigawatts of power, but there

could be as much as 15GW, equivalent to 15 million average family homes. Tidal generators can harvest the energy of these moving streams, with the added advantage that the resource is, unlike wind, predictable.

There are only a few underwater turbines in operation today and they all operate like underwater windmills, with their blades turning at right angles to the flow of the water. In contrast, the Oxford team's device is built around a cylindrical rotor, which rolls around its long axis as the tide ebbs and flows. As a result, it can use more of the incoming water than a standard underwater windmill.

At full size, a Transverse Horizontal Axis Water Turbine (Thawt) rotor would be 10m in diameter and 60m long. Connecting two of these together with a generator in the middle could produce around 12MW of power, enough for 12,000 average family homes.

"To do that, you only need three foundations and one generator," said Martin Oldfield, senior research fellow of engineering science at Oxford University. "To do that with a [windmill] would require five foundations and 10 generators."

The Thawt device is mechanically far less complicated than anything available today, meaning it would cost less to build and maintain. "The manufacturing costs are about 60% lower, the maintenance costs are about 40% lower," said Malcolm McCulloch, head of the electrical power group at Oxford's engineering department.

So far, the researchers have successfully tested a version of Thawt that is 1m in diameter and 6m long. They are now planning to build a 5m-diameter test device that could generate electricity for the grid. By 2009 the team wants to carry out sea trials to test the device's durability in open water.

Scaling up the power at a coastal site would involve connecting together a series of Thawt rotors across the sea floor. The engineers said that, if all went well, farms of Thawt devices could be built starting around 2013. "If you have a tidal site of 20km, you could build 20km of these turbines going across [the sea floor] and then you would be

into the gigawatt class," said Oldfield. This would make the farm equivalent to a small coal-fired power station.

McCulloch said that their economic analysis of the Thawt device showed that, at farm scale, the Thawt devices could be installed at around £1.7m per MW. That compares with around £3m per MW for modern marine turbine technology and just over £2m per MW for wind power.

Doug Parr, chief scientist at Greenpeace said the UK is a potential global leader in wave power. But he noted: "Many good ideas for wave power generation suffer from a lack of finance, lack of assured market and lack of access to business expertise.

"Some of these bottlenecks need to be addressed by the industry - others need government to play a boosting role rather than hoping that the rules and organisations that got us into the climate problem are going to be the ones that get us out."

In July, Bristol-based company Marine Current Turbines installed the SeaGen device, an underwater windmill device, at Strangford Lough in Northern Ireland. It is the first commercial-scale tidal device to generate power for the grid. When it is eventually running at full power, MCT said it will have an output of 1,200 kW, enough for about 1,000 homes.

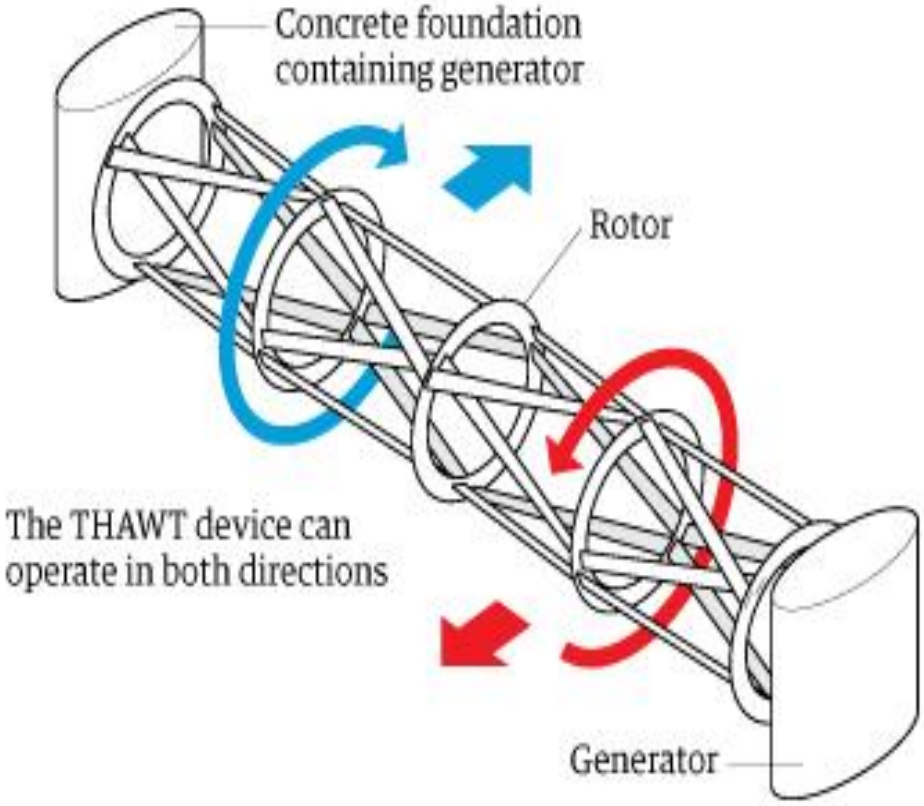
"There are presently tidal devices undergoing testing – we regard those as first generation device and we regard ours as a second generation," said Oldfield. "To some extent we admire them for being pioneers of the technology but we think what we've got will end up being better."

Steph Merry, head of marine renewable energy at the Renewable Energy Association welcomed the Oxford team's work but said that, in terms of backing a technology to harness tide power, nothing can be ruled in or out. "We've got this 15% renewables target for 2020 to achieve, which equates to 40% electricity, so you have to look at all possible options of generating it."

Merry added that, technology aside, there were other stumbling blocks in building tidal projects around the UK, including what she sees as an excessive need to monitor the environmental impact of turbines. "We have to get it in proportion, you can't have an unlimited budget for environmental monitoring when every engineering company has to work to a budget for any project. At the moment, there is no limit to the monitoring that can be imposed."

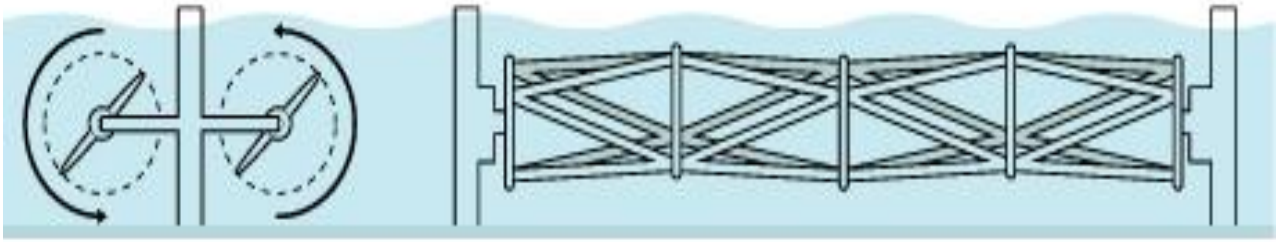
She said that the industry had to sit down with environmental groups and government to find a balance between the need to tackle climate change and the requirements to safeguard the ecology of tidal areas.

## Next generation marine turbine

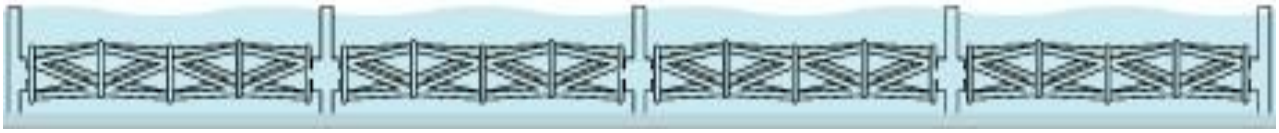



**Conventional tidal turbines** (below left) operate like windmills and must be turned with the tides

The **THAWT** device (below right) is more robust and so can be larger, harnessing more of the energy of the flow



Multiple THAWT rotors can be chained together across the width of channel



CHAPTER 7

## Research & Development of Underwater Windmill

Advances in a number of other sectors have benefited the marine renewable industry sector including advanced materials, turbine design, and offshore construction. Listed below are the present day R&D requirements to support the development of marine and hydrokinetic technologies in the United States.

**R&D Needs for the Ocean Renewable Energy Sector**

- Developing and demonstrating marine and hydrokinetic renewable energy technologies;
- Reducing the manufacturing and operation costs of marine and hydrokinetic renewable energy technologies;
- Increasing the reliability and survivability of marine and hydrokinetic renewable energy facilities.
- Integrating marine and hydrokinetic renewable energy into electric grids.
- Identifying opportunities for cross fertilization and development of economies of scale between offshore wind and marine and hydrokinetic renewable energy sources.
- identifying the environmental impacts of marine and hydrokinetic renewable energy technologies and ways to address adverse impacts, and providing public information concerning technologies and other means available for monitoring and determining environmental impacts and,
- Standards development, demonstration, and technology transfer for advanced systems engineering and system integration methods to identify critical interfaces.

**Specific R&D tasks**

**Wave Power**

1. Technology road mapping

2. Resource characterization – Data and models to identify "hot spots"

3. Hydrodynamics – mathematical and physical modeling including arrays (especially non linear and real fluid effects)

4. Control systems and methods for optimum performance (while ensuring survivability)

5. Power take off systems/smoothing especially direct drive

6. Materials – low cost

7. Materials, corrosion and biofouling

8. Construction methods – low cost

9. Performance specification standardization and test verification

10. Low cost moorings/deployment/installation/recovery methods

11. Ultra high reliability components (for minimum maintenance cost)

12. Electrical grid connection

13. System configuration evaluations (which are best under what circumstances)

14. Module size versus cost of electricity sensitivity

15. Results from pilot tests (especially to reduce cost and environmental impacts uncertainty)

**Tidal Power**

1. Technology road mapping

2. Resource characterization – Data and models to identify "hot spots" given complex bathymetry and turbulence

3. Hydrodynamics – mathematical and physical modeling including arrays (especially nonlinear and real fluid effects) and an evaluation of the efficacy of diffusers (i.e., ducted water turbine)

4. Control systems and methods for optimum performance

5. Power take off systems/smoothing especially direct drive

6. Materials – low cost

7. Materials, corrosion and biofouling

8. Construction methods – low cost

9. Performance specification standardization and test verification

10. Low cost moorings/deployment/installation/recovery methods

11. Ultra high reliability components (for minimum maintenance cost)

12. Electrical grid connection

13. System configuration evaluations (which are best under what circumstances)

14. Module size versus cost of electricity sensitivity

15. Results from pilot tests (especially to reduce cost and environmental impacts uncertainty)

**More funding for R&D and technology development:** Wind energy has benefited from substantial government investment. Thirty years ago, wind cost 30 cents/kWH to generate; today, that cost stands at 3 to 7 cents/kWH. And even today, DOE continues to invest in wind. Just a few months ago, DOE announced a $27 million partnership with GE to develop large-scale turbines and also issued a $750,000 SBIR to Northern Power for offshore wind technology development. Private developers have borne the costs of bringing the ocean energy technology forward for the past thirty years, but they need government support. Government funding will also give confidence to private investors and help attract private capital.

**Resource Assessment:** At present, we do not even know the full potential of offshore renewables, because no agency has ever mapped the resource comprehensively. The Energy Policy Act of 2005 directed the Secretary of DOE to inventory our renewable resources but that work has never been funded. And even as MMS moves forward with a rulemaking for offshore renewables on the OCS, it has not received appropriations to map the resource. Preliminary studies done by EPRI and private companies show that we have substantial ocean resources. But we will not know the full scope without further mapping and study.

**Incentives for Private Investment:** Offshore renewables are compatible with other large industries in our country, such as oil and maritime industry. These industries, with the right tax incentives, can provide substantial support to offshore renewable development. Incentives could include investment tax credits for investment in offshore renewables and incentive to use abandoned shipyards and decommissioned platforms for prototypes and demonstration projects.

**Incentives for coastal communities:** Coastal municipalities stand to gain tremendously from installation of offshore renewables. They need to be stakeholders in the process with a voice in development that takes place off their shores. Government can support this by

continuing to authorize Clean Renewable Energy Bonds (CREBS) and the Renewable Energy Portfolio Incentives (REPI) for coastal projects.

**Reduced regulatory barriers:** Until companies get projects in the water, we will not learn about the environmental impacts or true costs of offshore renewables. Unfortunately, developers face onerous barriers to siting small, experimental projects. We should establish streamlined regulation and permitting for offshore renewables, with maximum cooperation between state and federal agencies.

CHAPTER 8

## FUTURE DEVELOPMEN

MCT is now concerned not only with ensuring that its SeaGen type device is installed in other locations, but also with the conception of new forms of this technology that are both more powerful (to gain further economies of scale) and viable in shallower and in deeper water than the 20 m to 40 m range that suits the current design. In shallower water the existing twin rotor system would provide too small a swept rotor area to be cost-effective, while deeper water brings concers about taller tower structure cost and strength.

A potential solution under consideration and already patented is a buoyant support tethered to the seabed by rigid but hinged struts. This system, which is based on the same rotors, control systems and power-trains as the existing SeaGen, has been labeled SeaGen "U" and is already under development. A 2 MW at 2.4 m/s version with three rotors is planned for installation in the Minas Straits of the Bay of Fundy in Nova Scotia, Canada by 2012-3. Systems rated at over 5 MW with up to six rotors are expected to follow. The wind industry has improved the cost-effectiveness and efficiency of windturbines by gradually enlarging them – a few years ago 1 MW was the norm but today up to 5 MW systems are preferred. There is a similar pressure to develop larger in order to improve their cost-effectiveness and generate electricity more cheaply.

Peter Fraenkel thinks that as with all new technologies, tidal turbines will be initially too expensive to be immediately competitive. They will need to benefit from economies of scale and learning curve effects to get their costs down. As a result he believes this new renewable energy technology market needs government subsidies such as ROCs (Renewable Obligation Certificates) to help finance early stage small projects, and to see the technology through the stage between R&D and full commercial competitiveness. Fraenkel is confident that tidal turbine technology will become competitive reasonably quickly but the first projects will need support to leverage the necessary investment.

The potential market for green power generation is significant. A Carbon Trust survey, published in January 2011, noted that the environmental and low carbon market is worth over £112 bn a year in the UK and employs over 900,000 people. It is forecast to grow by 25% over the next four years. Marine current technology now has a clutch of companies that are set to make a substantial impact on renewable power generation and add to these figures.

In the face of Global Warming and Peak Oil, there is an urgent need to prove and bring on stream new clean energy technologies such as tidal turbines. The technology under development by Marine Current Turbines Ltd has the potential to be commercially viable well within the next 5 years and it is hoped that it will be effectively demonstrated through the Seagen project in less than a year from now. The key to arriving at this result is to gain the operational experience to develop the reliability of the systems, to value eng ineer them in order to get costs down and to ensure they can reliably deliver electricity from the seas with minimal environmental impact.

CHAPTER 9

## EFFECT ON ENVIRONMENT

"I think we have invented one of the least offensive energy methods," MCT technical director Peter Fraenkel told Deutsche Welle. He explained that the effect on marine life would be minimal. "Any kind of higher marine mammals is as likely to run into it as a human begin is to walk into a brick wall." Not only do marine creatures mainly move faster than the rotor, water spirals through it in such a way that even jellyfish would be likely to go right through without being harmed.

Greenpeace climate and energy campaigner Robin Oakley told Deutsche Welle he didn't expect negative impacts from Seaflow either. When it comes to environmental impact, "there's a very big positive that has to be taken into account," Oakley said. "You have to weigh the effects carefully, he said. "That can't be allowed to slow down the development of green energy."

It is the first of a kind SeaGen serves as a testbed for tidal power generation. To date, it has not yet had a full year of operation unconstrained by other research considerations. From installation until November 2009 the system could only be operated when two marine mammal observers were on board, and able to look out for seals that might be in danger from the rotors (which rotate at about 14 rpm). Further seal monitoring restraints continued to reduce operation to daylight hours until March 2010, so energy yield was significantly reduced. There is great concern to avoid sanctioning anything that could cause negative environmental impact at the Strangford site. After two years of independent environmental monitoring no sign of a detrimental effect has so far been detected. At the time of writing, seal movements near the turbine still have to be monitored in real time using sonar by an operator onshore who can shut the turbines down within five seconds if they feel a seal might be in danger. It is expected that this requirement may soon also be relaxed as there are no signs yet of seals having so far been harmed. The environmental monitoring programme which will run for five years in total will cost some £2 million by the time it concludes. It has been very useful in terms of

environmental data acquisition and giving new insights on the behaviour of seals and other marine wild-life endemic to this environmentally significant location.

The common seal, which despite the name suggests, are in decline and need to be protected from harm. This one at Strangford has a cell-phone frequency transponder attached to the back of its head to allow it to be tracked. Its movements can be plotted by a computer as part of the major environmental monitoring programme being conducted primarily by Queen's University Belfast and the Sea Mammal Research Unit of the University of St Andrews to ensure that SeaGen is not causing any environmental harm.

CHAPTER 10

# ADVANTAGES AND DISADVANTAGES OF UNDERWATER WINDMILL

## 10.1 Advantage:

- One of the most important and highly significant benefits of using the power of the tides is that there are no fuel costs. The energy is fueled by the reliable and sustainable force of the ocean. Although initial construction costs are high, the overall maintenance of the equipment and the return of power in the form of electricity can help offset this expense.
- Tidal power is also an emission free source of power, providing clean energy by harnessing this natural resource. It can be used to displace other electricity-producing methods that rely on the burning of fossil fuels. Burning fossil fuels like coal, contribute to the greenhouse effect because they release poisons into the atmosphere like carbon dioxide. Sulfur is also a result of burning fossil fuels and contributes to the cause of acid rain in our environment.
- Tidal power can also provide secondary benefits because transportation corridors can be built above the tidal generators. These can support roadways, water mains, rail lines, or communication lines, which again can offset the expense of installing the tidal equipment.
- And, unlike renewable resources such as wind power, the ebb and flow of the ocean tides are entirely predictable and consistent and aren't affected by outside forces such as the weather.
- Tides are predictable and go in and out twice a day, making it easy to manage positive spikes.
- Its predictability makes it easy to integrate into existing power grids.
- Tidal energy is completely renewable.
- Tidal energy produces no emissions.

- Energy output is a 100 % reliable , as tides are as sure as the moon.
- Hidden beneath the water.
- When the tides go out gravity sucks the water through the turbines to generate electricity
- Tidal energy reduces dependency on oil reserves from other countries.
- Dams built can double as protective cover for coastline during rough weather.
- While the use of tidal energy must be considered as a future source of energy, environmental and cost concerns will have to be addressed. As technology advances, there is no reason not to believe that engineers, scientists, biologists and other related professionals will develop a way to harness the tide more effectively.

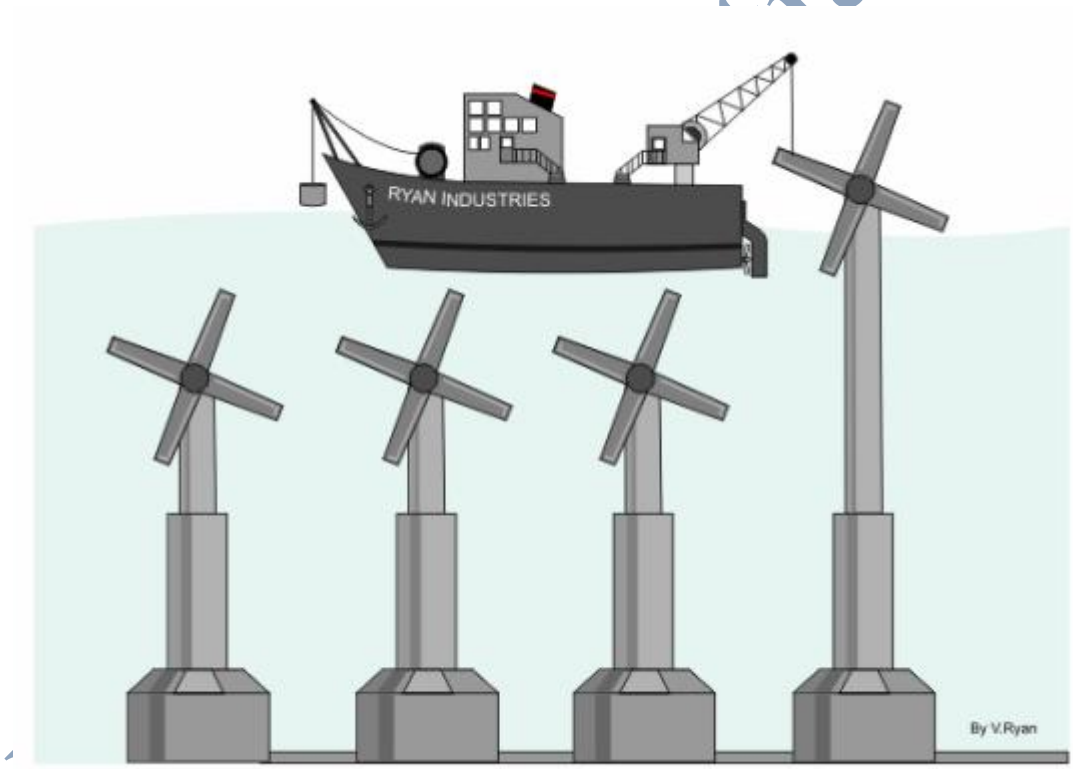
## 10.2 DISADVANTAGE

- The major difficulties with this type of system is that the off shore turbines cost more money than land / wind based turbines.
- They are also more expensive to maintain as they function under water. Furthermore, sea water is corrosive to steel and other metals because of the salt content.
- Fishing has to be restricted in the areas of the power plant.
- Damages habitat up to 500km away

CHAPTER 11

## MAINTENANCE OF UNDERWATER WINDMILL

Maintenance of the device while it is submerged in fast currents would be exceptionally challenging and expensive, so a key patented feature of the technology is that the rotor and drive train (i.e. gearbox and generator) can be raised completely above the surface. Once raised, any maintenance or repairs can readily be carried out from the structure attended by a surface vessel.




Maintenance done to underwater windmills.


Underwater windmill under maintenance process.

CHAPTER 12

## CONCLUSION

Ocean energy can play a significant role in our nation's renewable energy portfolio. With the right support, the ocean energy industry can be competitive internationally. With the right encouragement, ocean renewable energy technologies can help us reduce our reliance on foreign oil – fossil fuels, in general – and provide clean energy alternatives to conventional power generating systems. And with the right public awareness, our coastline communities can use ocean renewables as a springboard for coastal planning that reflects the principles of marine biodiversity.

In conclusion, we believe that the intense and predictable marine current resource offers the possibility of clean energy at a cost that will ultimately be competitive not only with the other renewables, but in the long run we believe we can compete head on with most forms of fossil fuelled power generation at present-day costs. We think that, given appropriate government support to help the technology through its early and immature stages, it can play a significant role in producing clean energy.

Tidal energy has potential to become a viable option for large scale, base load generation in Scotland. Tidal Streams are the most attractive method, having reduced environmental and ecological impacts and being cheaper and quicker installed.

Development of a robust offshore renewables industry can:

- Reduce reliance on foreign oil.
- Rely upon ocean terrain for power generation as opposed to onshore land resources.
- Revitalize shipyards, coastal industrial parks and shuttered naval bases.
- Create jobs in coastal communities.

- Allow the US to transfer technology to other countries, just as a country like Scotland is exporting its marine renewables.
- Provide low cost power for niche or distributed uses like desalination plants, aquaculture, naval and military bases, powering stations for hybrid vehicles and for offshore oil and gas platforms.
- Provide use for decommissioned oil platforms through "rigs to reefs program".
- Promote coastal planning that reflects the goals of bio-diversity, that maximize best comprehensive use of resources and capitalizes on synergies between offshore industries
- The resource is located near highly populated areas on the coast, placing fewer demands on already taxed transmission infrastructure.
- Ocean renewables can help diversify our energy portfolio and improve our environment. With the proper support, these resources will become a robust part of a reliable, affordable, clean electric supply portfolio.

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