

Tidal Energy: Formation and Electric Energy generation

Sara Gamal El-Den

Abstract— Environmental pollution is increasing enormously, the main reason for it is the harmful gases emitted from excessive usage of fossil fuels. To solve this problem, Alternative energies are used instead of fossil fuels. Almost all alternative energies are renewable except nuclear energy. Tidal energy is one of the renewable alternative energies. It's produced from two main factors related mainly to the Earth-Moon system: the gravitational attraction and the centrifugal forces. Although the Sun's gravitational attraction affects the tide, its effect is only 44% of the Moon's effect. It's resulted as the closeness of the Moon to the Earth. There are different types of tides and also different characteristics. A lot of methods are used by oceanographers to predict and analyze the tides and to calculate its energy output. This resembles a great advantage for the tidal power among the other types of alternative energies, that it's predictable. Unlike wind power, tidal power can produce energy at very slow speeds because of the high density of the water compared to the air's density. The disadvantages of the tidal power are few and studies are being done to reduce and solve them. The most important disadvantage is the environmental impact on the marine creatures during the construction and operation of the tidal generators. Researches proved that generators' designs are developed to decrease the harm on the marine creatures and that new process of constructing will be applied to keep them safe. On the other hand, tidal power generators differ in cost and efficiencies. They are made accurately to be suitable for the types of tides they will face, and it's done according to the scientific predictions of the tidal power. Turbines are the main type of generators, build alone or combined in bigger structures, generating a massive amount of energy.

Index Terms— Alternative Energy, Generating Electricity, Tidal Power, Tides

1 INTRODUCTION

Total global electricity consumption approached 21,000 terawatt-hours in 2016 (one terawatt [TW] = one trillion watts)" (Selin, 2019). The usage of energy is increasing enormously daily worldwide and the old energy sources as coal and oil are running out in addition to their harmful disadvantages on the environment. Alternative energies are the new global concern especially renewable ones as they have a lot of advantages and are permanent. Tidal energy is an important type of alternative renewable energies. It's produced from the tides of the ocean and the sea. Many different classifications are used to classify the tides from their directions to their frequencies and their intensities. The amount of produced tidal power is massive. Selin (2019) continued, "energy experts speculate that fully built-out tidal power systems could supply much of this demand in the future."

Many processes are used by scientists to analyze the tides as graphs, tables, and classifications having a strong relation to our studies. In PH.1.08 fluids, pressure, and pressure gauge are explained which have a strong relation to the types of the tides low and high. Low tides are tides with higher pressure while high tides are with a lower one. To present the type and the intensity of tides using graphs and tables, parabolas are used by oceanographers accurately by different methods. In MA.1.07 quadratic functions and parabolas and representing them on graphs are studied informatively. In ME.1.06 resultant forces and how to represent them using vectors are studied. They are also used

by scientists to represent the directions of the tides in a rose diagram or a force diagram. In Big lakes and seas are the smallest amount of water that the Moon's gravitational force can affect and so there are no tides in rivers and small lakes. It's similar to the limiting reagent of the reactors needed to make a chemical reaction which is studied in CH.1.10 as well. In BI.1.09 plant tissues are studied; sclerenchyma is one of them responsible for supporting the plant by fibers and sclerids which play an important role in restoring the plants' stem to their original positions in case they were bent or pulled. The Earth's gravitational force plays the same role to the ocean's water during the tides, it's responsible for restoring the water into its original position after it's attracted by the Moon's gravitational force. In BI.1.10 photosynthesis process is explained as an energy-producing process, as the light energy is converted into chemical energy through it. Similar to the photosynthesis process, tides are energy-producing processes, they produce mechanical energy which is converted into electricity using the tidal power plants. Tides are sources of alternative renewable energy that is proved to have the priority to be used rather than the other types of energy sources even the renewable ones; because of its numerous advantages, negligible flaws and the disadvantage that don't affect the operation nor the quality of the produced energy and are to be solved too.

2 LITERATURE REVIEW AND THEORETICAL ANALYSIS

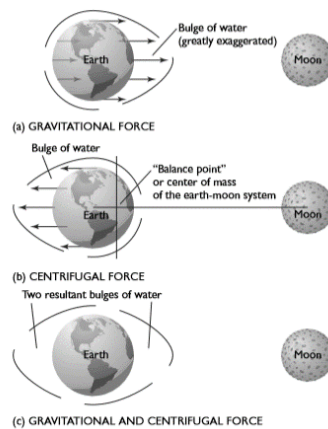
According to the energy map published by Student Energy organization, there are two types of energy which are: alternative energy and fossil fuels. Fossil fuels are non-renewable sources, a great source of pollution for the

• Sara Gamal El-Den is currently a High-School Senior in Gharbiya STEM School, Egypt.
PH-+201201196632.
E-mail: sara.1919134@stemgharbiya.moe.edu.eg

environment. On the other hand, the alternative energy divides into two types which are renewable and non-renewable energy. Unlike fossil fuels, the non-renewable alternative energy, resembled in nuclear energy, don't pollute the environment and presented in massive amounts in nature. The renewable alternative energies are the cleanest, safest and most efficient like solar, wind and geothermal energies and many others. Tidal power is renewable energy produced from the tides of the ocean. (ENERGY SYSTEMS MAP, n.d.). Comparing to other energies from the same type, Tidal power isn't famous enough even it's been used for more than 50 years.

2.1 Tides

"The tides are formed as a result of two main factors: gravitational attraction and centrifugal force" (Pinet, 2008, p. 267). Earth is exposed to gravitational attractions from the Moon and the Sun. "The oceans cover 71 percent of the Earth's surface" (Aqua Facts, n.d.), the largest part of the Earth to be affected by the external gravitational attractions is the oceans. Big lakes are the smallest amount of water that the gravitational attractions can affect, similar to the limiting reagent in CH.1.10, which is: "the reactant that runs out first and thus limits the amount of products that can form is called the limiting reactant" (Zumdahl & Zumdahl, 2010, p. 117)



(Fig. 1) Formation of The Earth's bulges producing Tides

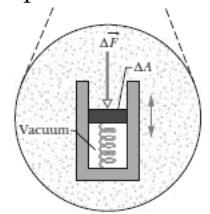
"The Moon, because of its closeness to the Earth, is the main regulator of the planet's tides. It exerts about twice the tide-raising force on the Earth as that of the Sun." (Pinet, 2008, p. 267). There are two bulges of the ocean's water formed around the Earth as a result of the two main factors of tides as Fig.1 explains, (a) is the Moon's gravitational bulge, (b) the centrifugal bulge from Earth and Moon's rotations and (c) is the real form of bulges around the Earth.

Connecting tides to the living organisms, In BI.1.10, sclerenchyma is a plant tissue responsible for supporting the plant by fibers and sclerids which play an important role in restoring the plants to their original positions in case they were bent "The walls of sclerenchyma cells are very thick... providing support for the plant." (NationalGeographicOrganization, 2004, p. 606). The Earth's gravitational force plays the same role to the ocean's water during the tides, it's responsible for restoring it into its original position after it's attracted by the Moon

Other characteristics are used to describe tides as diurnal, semi-diurnal and mixed tides, which are used to describe the frequency of tide in one lunar day. Although these

characteristics are different from each other, some places are characterized by all of them at the same time, "Generally, the tides at Rosetta promontory are mixed but are mainly of semi-diurnal type and the tidal ranges" (AbdAllah, El-Gindy, & Debes, 2006, p. 41), besides all the important information provided, the weakness is that all the figures are grouped in two pages, understanding is harder while moving along pages. "in Alexandria, 35 tidal harmonic constituents, have been produced. Each of these constituents has its own frequency, period, amplitude and phase..., which specifies the mixed mainly semi-diurnal tidal type in the area of investigation." (El-Geziry & Radwan, 2013, p. 4), this paper is so informative and well organized, with few language mistakes, proving that tides can be high and low at the same place which is the Mediterranean Sea. "In an investigation of the basin properties of the tides at the two harbors, it may be sufficient to refer to the harmonic constituents for this area, Alexandria and Port Said... .This means that the tide is semi-diurnal in character." (Moursy, 1998, p. 21), This paper is professionally made and revised resulting in a great source of information about the tidal characteristics in the harbors of Alexandria and Port Said. Also, the sea levels differ during the daily hours not only from day to another ... "There is a significant hourly sea level variation off Port Said during the day reaches its maximum values 6 cm..., minimum values -6 cm..., This indicates that the sea level off Port Said has a semidiurnal tidal cycle." (Tonbol & Shaltout, 2013, p. 73).

On the other hand, In the Red Sea, "the semidiurnal tidal waves play a major role in the region except in the central part of the Red Sea." (Madah, Mayerle, Bruss, & Bento, 2015), this study is characterized by the well-visualized papers depending on Delft3D modelling system, but from the weaknesses is that the excessive focus on the visualities affected negatively on explaining the information, most of them are referred to maps without enough explanations.



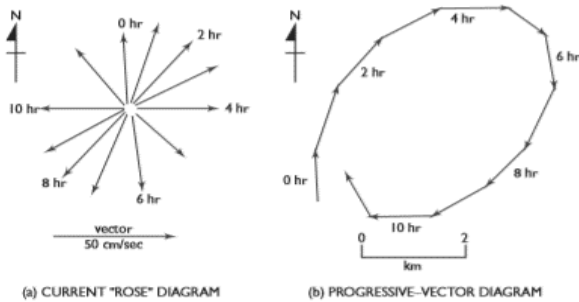
2.2 Measuring Tides

Different methods used to measure tides; the currently used method depends on pressure sensors. As studied in PH.08.1,

$$Pressure = (\Delta Force)/(\Delta Area) = Atmospheric pressure + pressure gauge,$$

$$P = \Delta F/\Delta A = P_o + (\rho g \Delta h)$$

the pressure is directly proportioned to the height, this law is used to measure the tide's height and from getting it, the tidal type can be determined. The operation of the pressure sensor, as shown in Fig.2, "The sensor (Fig. 2) Tidal Pressure Sensor consists of a piston of surface area riding in a close-fitting cylinder and resting against a spring. A readout arrangement records the amount by which the spring is compressed by the surrounding fluid, thus indicating the magnitude of the force that acts normal to the piston." (Halliday, Resnick, & Walker, 2010, p. 360), pressure sensors are used to measure tides from the amount of



pressure exerted on them, "the variations of pressure over time reflect the actual fluctuations of the tide." (Pinet, 2008, p. 264).

2.3 Converting Tidal Energy into Electric Energy

"Although not yet widely used, tidal power has the potential for future electricity generation. Tides are more predictable than wind energy and solar power." (Tousif & Taslim, 2011, p. 1). The tidal energy is converted into electric energy by converting the mechanical energy produced from the tidal movements into electric energy by generators in different technologies. In ME.1.06 resultant forces and how to represent them using vectors are studied. (Fig. 3) "When three or more vectors are added, their sum is independent how the individual vectors are grouped together." (Serway & Jewett, 2009, p. 58). They are also used by scientists to represent the directions of the tides in a rose diagram Fig.3 (a) or a force diagram Fig.3 (b) which helps in determining the best places to construct generators. (See next page)

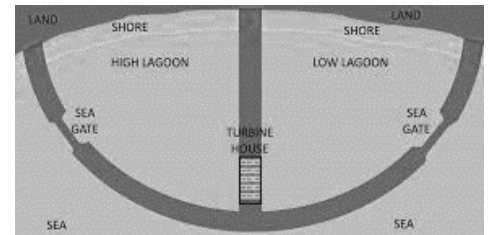
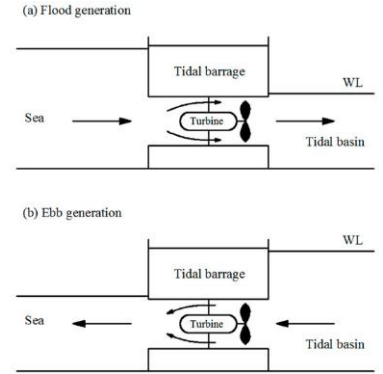


and electricity is generated. "Various turbine designs have varying efficiencies and therefore varying power output." (Tousif & Taslim, 2011, p. 2), according to this research, knowing the efficiency of the generator, the power output of a turbine can be determined by using this equation:

$$P = (\xi \rho A V^3) / 2$$

The second method used in generating electricity from tides is the tidal barrages systems,

shown in Fig.6, "Turbines inside the barrage harness the power of tides the same way a river dam harnesses the power of a river." (NationalGeographicSociety, 2012), the barrage gates are opened during the Flooding tide as in Fig.6 (a) till it becomes a high tide the gates are closed, forming a temporary tidal basin, during the Ebb tide shown in Fig.6 (b) the gates are opened letting the water to flow through the turbines for another time and generating more electricity; this is why tidal energy is called double-current energy. "A proposal for the Severn Barrage, if built, has been projected to save 18 million tons of coal per year of operation." (Rashid, Mohamed, & Hashim, 2012, p. 113).



Three main methods of generating electricity from tidal power are applied, each one of them has its types of generators. First, the tidal stream, (Fig. 4) Tidal Fence used in tidal stream which is scientifically defined as "A tidal stream is a fast-flowing body of water created by tides." (NationalGeographicSociety, 2012). Tidal fences shown in Fig.4 and tidal turbines Fig.5 are the types of generators used in a tidal stream, "The turbines are similar to designs used for wind turbines... Furthermore, they have to withstand greater forces and movements than wind turbines." (Kempener & Neumann, 2014, p. 11).

The tidal turbine as shown in Fig.5 is similar to a wind turbine but its blades are much smaller. The blades are designed with accurate sizes to be suitable for the water-dense and to help the marine creatures to swim safely. As the water flows through the shaft, it rotates

(Fig. 5) Tidal Turbine used in tidal stream

(Fig. 6) Tidal Barrages used in generating electricity

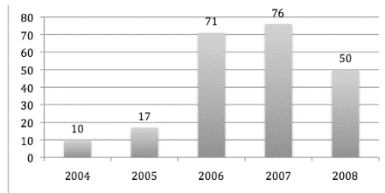
(Fig. 7) Tidal Lagoon Used in Electricity Generating

The third type is the tidal lagoon, Fig.7, "A tidal lagoon is a body of ocean water that is partly enclosed by a natural or manmade barrier. might also be estuaries and have freshwater emptying into them." (NationalGeographicSociety, 2012). According to National Geographic Society, the tidal lagoon can work as a continuous power generator, during the filling and the releasing of water; but in a tidal power journal, it's mentioned that the lagoons can't work as barrages, "Two lagoons operating at different time intervals can guarantee continuous power output." (Tousif & Taslim, 2011, p. 3). This journal is very informative and direct to the point, also the National Geographic Society is revised by experts in the scientific society, but both of them mentioned incompatible information; "Tidal lagoons are similar to tidal barrage,

except that they are not necessarily connected to the shore” (Kempener & Neumann, 2014, p. 10), published by IRENA (International Renewable Energy Agency), this report proved that National Geographic’s information is the true ones, which resemble a great weakness for the journal.

2.4 Advantages and Disadvantages of Tidal Energy

The advantages of tidal energy are numerous. “Tidal power is an environmentally friendly energy source. In addition to being renewable energy, it does not emit any climate gases and does not take up a lot of space.” (Tidal Energy Pros and Cons, 2019). Also, it’s predictable energy as the tides have certainly known cycles which helps in constructing the power plants. The most important advantage of the tidal energy is that it’s effective at low speeds; because of the water’s high density, tidal power can generate electricity at very low speeds, and so it’s better than the wind energy which is limited to have a high wind current; even the tides differ every day, “tidal generators are used, they produce a steady, reliable stream of electricity.” (NationalGeographicSociety, 2012).



The disadvantages of the tidal energy are studied to be solved in future, the most important one is the environmental impact of the generators, “Tidal fences do have the potential to injure or kill migratory fish, however, but these structures can be designed to minimize such effects.” (Selin, 2019), “the change in water level in the tidal

Barrage	Country	Capacity (MW)	Power generation (GWh)	Construction costs (million USD)	Construction costs per kW (USD/kW)
Operating					
La Rance	France	240	540	817 ¹	340
Sihwa Lake	Korea	254	552	298	117
Proposed/planned					
Gulf of Kutch	India	50	100	162	324
Wyre barrage	UK	61.4	151	328	534
Garolim Bay	Korea	520	950	800	154
Mersey barrage	UK	700	1340	5741	820
Incheon	Korea	1520	2410	3772	286
Dalupiri Blue	Philippines	2200	4000	3034	138
Seyern barrage	UK	8640	15600	36085	418
Penzhina Bay	Russia	87000	200000	328066	377

Note: ¹ Cost equivalent for 2012
Based on Wyre Energy Ltd, 2013.

lagoon might harm plant and animal life, fish are blocked into or out of the tidal lagoon. Turbines move quickly in barrages, and marine animals can be caught in the blades”. (NationalGeographicSociety, 2012). Another disadvantage is that some types of generators are too expensive, barrages are the most expensive generators, although there’s no fuel cost, it costs a lot of money to construct and monitor, hard supervision is needed to adjust the power output.

2.5 Investment in Tidal Power

“Although worldwide more than 150 coastal sites satisfy the physical

(Fig. 8) Investment in Ocean Technologies

requirements for power generation, only a few tidal power plants have been constructed” (Pinet, 2008, p. 287), Fig. 8 explains the international investments in ocean/ tidal technology, “The market for ocean technologies started to grow in 2004: 2007... In 2008 the investments dropped by \$26 million...The future promise of tidal/wave technology is great.” (Alternative Energy/Paper - Commons-Based Research, n.d.)

(Fig. 9) Total Costs and Output of Tidal power plants Examples

Expensive costing is the main reason preventing countries from investing in tidal power. Fig. 9 shows the total costs and the output of some tidal power plants, the least amount of power generation is a 100-gigawatt hour by Gulf of Kutch, which isn’t an easy amount to generate using fossil fuels. Countries all over the world should give more concern to tidal power investments.

3 CONCLUSION

For conclusion, although the Sun’s gravitational attraction affects the tides, tides are mainly resulted from the Earth-Moon system because of the closeness of the Moon to the Earth. Many Types and characteristics are given to the tides as according to their intensities low and high tides while for their frequencies as diurnal, semi-diurnal and mixed tides. Tidal energy is alternative-renewable energy, called a double-current power and is a continuous electric generator. There are many types and methods applied to convert the tidal energy into electric energy as the tidal fences, turbines, barrages, lagoons and many others. The main type of generators is the tidal turbines, they are used alone or as the generating part in the barrages which are big dams. All the tidal generators work mainly on converting the mechanical energy being resulted from the movement of the tides into electric energy. It’s proved that the electric energy produced from the tidal energy will saturate the human need in the future. In addition to its renewability, tidal energy has many other advantages as to be Eco-friendly, predictable and effective at low speed. Unlike wind power, the tidal power, because of the high density of the water, can produce great amounts of energy at lower speeds. And unlike any other energy type, it’s double-current energy which means that the same tidal current is used twice to produce energy. The tidal energy has few disadvantages and studies are done to solve them, as that tidal power plants have to be near the coastline which is used in many different purposes; during its construction and operation, tidal barrages can disturb the marine ecosystem. On the other hand, Tidal turbines are developed to be safe for the oceanic creatures swimming close to the power plant area.

4 RECOMMENDATIONS

1. Further research is recommended to determine the maximum achievable amount of energy that can be produced by tides using their different types especially the spring and the neap tides.

2. More research about how to reduce the disadvantage of being near to the coast, by researching for how to build floating tidal power plants, in the higher tidal currents' places.
3. More research about how to keep the marine creatures safe during constructing and operating the tidal power plants
4. Increase the awareness of environmental issues and how much it's important to use alternative energies instead of fossil fuels.
5. As a role applied by the United Nations, increase international awareness of the importance of using tidal energy.
6. Build co-operated tidal power plants between two or more country, so that the cost will be reduced and the output share will still be enough for both of them.

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