LAB # 14

To Study and Understand the Working Principles of Ocean current and Wave Energy Potential

Objectives:

- To study and understand the working of ocean current and wave energy generation
- To understand how to calculate potential energy, and power density of ocean current and wave energy systems
- To understand how to calculate the global energy yield per person

Related Theory:

Let us discuss two ocean technologies. First there is a ***thermal energy conversion technology***, that uses ***temperature differences*** in different layers of the sea. A second technology converts ***energy*** that is present at locations where ***saltwater mixes with fresh water***. The salinity gradient between fresh and salt water creates an osmotic pressure difference, which can be converted into electrical energy.

Let's really start this lecture with the ***ocean current*** technology. The ocean current is ***caused*** by different ***factors***, like the wind, the temperature difference in the ocean, depth variations and seismic events. The ***flow of water*** carries a large amount of ***kinetic energy***, that can be converted by turbines. In essence, the working principle of the water turbines is ***similar*** to that of ***wind*** turbines.

The ***primary energy potential*** calculation is therefore the same as that of the wind energy potential.

$$E_{kin} = \frac{1}{2} * m * v^2$$

Consequently, the power potential $\boldsymbol{P_{Current}}$ is equal to half the density, multiplied by the surface area of the rotor and the velocity to the power three.

$$P_{Current} = \frac{1}{2} * \rho * A * v^3$$

The ***power potential*** in a water flow, with respect to a similar wind flow, is ***much larger***, since water has a much ***higher density*** than air.

Since the ocean current technology is still in its experimental phase, the ***conversion efficiency*** of an ocean current system is still subject of discussion. However, its energy conversion steps are quite similar to that of wind turbines, only under water.

$$C_p = \frac{Electricity\ Produced\ by\ the\ Turbine}{Total\ Energy\ Available\ in\ the\ Wind}$$

What ***practical issues*** will influence the energy yield of such a system? The ocean water is always moving and therefore the current is ***continuous***. There are, however, ***fluctuations*** in the ***velocity*** of the ocean current. These fluctuations mainly ***depend*** on the wind and the ***temperature differences***, that are a result of ***weather and seasonal variations***.

Let's do a small design ***calculation***. We will imagine a turbine with a diameter of 20 meters and an ocean current velocity of 1.5 meters per second, which is below average for the gulf stream. We will use a power coefficient of 0.3, which is quite a conservative estimation compared to wind turbines. The ocean water density is 1025 kg/m^3. So,

$$D = 20m\ , v = 1.5ms^{-1}\ , C_p = 0.3\ , \rho = 1025\ kgm^{-3}$$

The turbine diameter gives us a rotor surface area of:

$$A = \pi r^2 = \pi * (\frac{1}{2} * 20)^2 = 314m^2$$

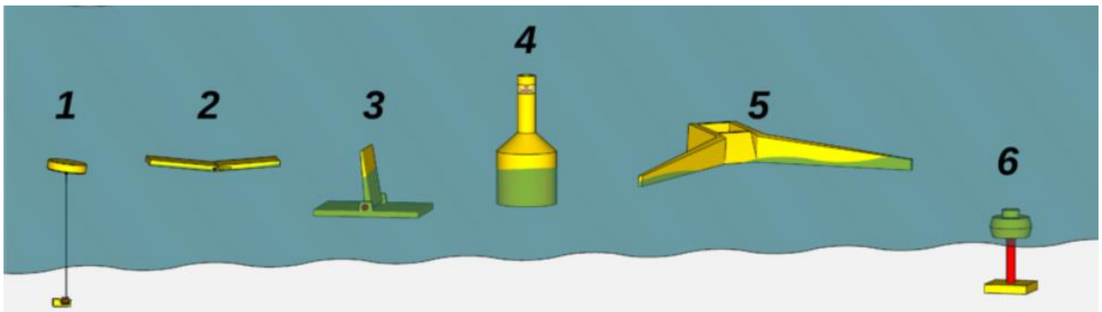
This results in an output power of:

$$P_{Current} = \frac{1}{2} * 1025 * 314 * 1.5^3 * 0.3 = 163KW$$

A big ***advantage*** of ocean current energy is that it provides a ***continuous source*** of energy. Additionally, ***water*** is more than ***800 times*** as ***heavy*** as ***air*** and a similar flow therefore contains a ***lot more kinetic energy***. However, ***challenges*** include ***corrosion***, ***reliability issues*** and ***algae growth***, which can result in high maintenance costs. Furthermore, underwater turbines will impact the ***marine life***.

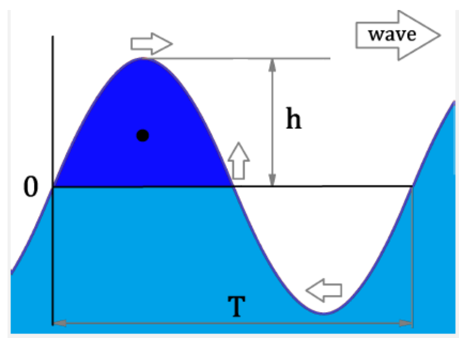
Let us move on to a more developed technology: ***wave energy***. ***The kinetic energy in the wind causes waves to form at the surface of the ocean water***. Such a surface wave contains both potential and kinetic energy.

Many different concepts have been designed to convert the energy from surface waves to electrical energy. This picture shows ***six*** of these concepts, that all use the same basic energy conversion principle. We will focus on the ***second concept***, which is known as a ***surface attenuator***.



An example of a surface attenuator is the ***Pelamis Wave Energy Converter***. By floating on the waves, this machine converts *the energy in the wave into mechanical energy*, and subsequently into electrical energy.

We will use the ***potential energy of the wave*** to ***derive*** the ***primary energy potential***. If we consider this image, where the ***wave*** has been simplified as a ***sinusoidal waveform***. Here '***0***' is the ***average surface level***, "***h***" is the ***height difference***, and "***T***" is the ***wavelength***. The ***effective mass*** of the wave is equal to the ***product*** of the ***volume of the upper part of the wave***, indicated by the dark blue area, and the ***density of the ocean water***. This water mass will ***fall down*** over a height of h, and therefore ***produce energy***. This is represented by the familiar equation of the potential energy:



$$E_{pot} = m * g * h$$

$$P_{pot} = \dot{m} * g * h$$

$$\dot{m} = \frac{1}{4} * \rho * v * h * l$$

Where the mass flow is a function of the water density, the horizontal speed of the wave 'v', the height 'h', and the length of the wave in perpendicular direction, "L". However since "***L***" depends on the length of the device that converts the energy, *it is common to depict the primary potential of the wave as power per unit of length.*

We can now obtain the following expression for the ***primary power potential per unit length***.

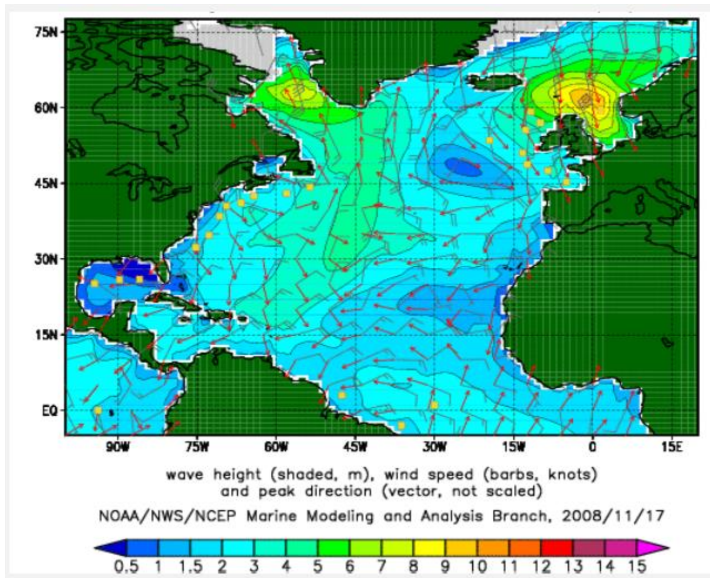
$$P_{pot} = \frac{1}{4} * \rho * g * h^2 * v$$

This power, which is equal to the kinetic power, is a quarter of the density, multiplied by the gravitational constant, the height difference squared, and the horizontal velocity.

Since the ***efficiencies*** depend on the type of system used, each conversions method has some unique conversion losses. However, roughly speaking, each system will have ***mechanical conversion losses***, caused by the interaction of the waves with the hydraulic chambers. Additionally, some ***electrical losses*** will be present due the operation of the generator and other power electronics.

The changing magnitude of the ***wind force*** will mainly cause the ***fluctuations*** in ***energy yield***. Ocean wave conversion technology has a capacity factor of around ***35%***.

Let's go through a ***calculation***. Let's assume a part of the Atlantic Ocean between North America and Europe. We can gather that the highest waves occur around the North Sea. Let's take a moderate estimate at this location; a wave speed of 11 meters per second and a height of 5 meters.



$$v = 11ms^{-1}, h = 5m$$

$$\rho = 1025kgm^{-3}$$

$$P_{pot} = \frac{1}{4} * 1025 * 9.81 * \; 5^2 * 11$$

$$P_{pot} = 691\ KWm^{-1}$$

The main ***advantages*** of wave energy are its ***predictable*** character and ***low operational costs***. However, it is a technology with ***high investment costs***. Ocean wave technology has some other inherent ***challenges***, such as ***environmental effects***, the ***obstruction*** of sea travel, and the ***unavailability*** of suitable locations.

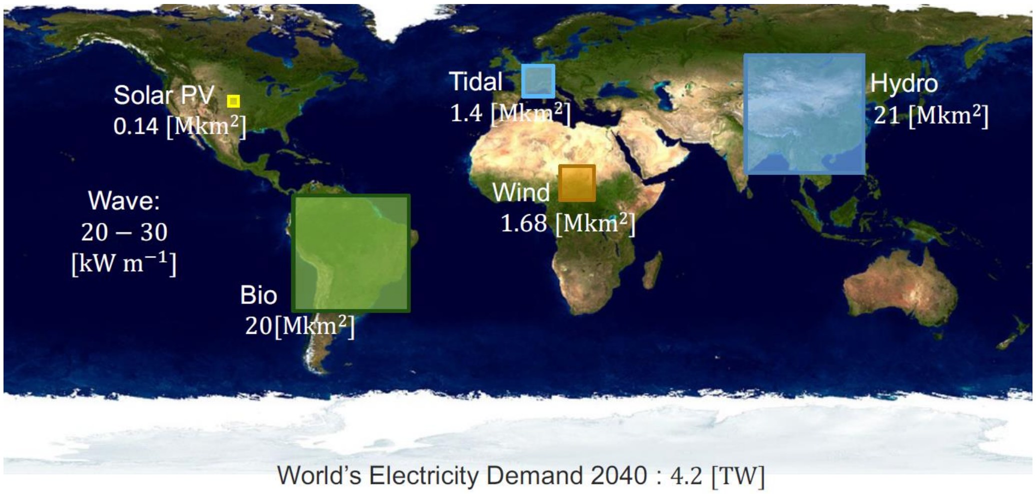
Let's look at ***wave energy*** from the world's perspective. In ***2016*** the global installed capacity was ***1.1 MW***. According to the capacity factor of ***35 %*** the global energy yield is ***3.37 GWh***. If we take a world population of 7.5 billion this results in a global yield as:

Global Energy Yield= $3.37\ [\text{GWh year}^{-1}]$ Global Population= $7.5 * 10^9 [\text{person}]$

$$E_{GlobalYield} = 3.37\ [\text{GWh year}^{-1}] * {}^{1}/_{7.5 \; * \; 10^9}\ [\text{person}^{-1}] * {}^{1}/_{365}\ [\text{year day}^{-1}]$$

$$E_{GlobalYield} = 0.45\ [\text{Wh person}^{-1}\text{day}^{-1}]$$

Let's take a look at the ***map*** that shows the ***area required to cover the world's electricity*** demand with a ***single*** renewable energy technology in ***2040***. The potential power density of wave energy is around 20 to 30 kW per meter of coastline. Therefore, 168000 km of coastline is required to meet global demand. This means that there isn't enough energy potential available to meet the global demand.



World's Electricity Demand 2040 : 4.2 [TW]

Conclusion and Comments:

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