Wave Energy Conversion-Overview and Perspectives

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***Abstract* — the article is about one of alternative energy type-Sea and Ocean waves. Energy consumption has increased fast during the last decades. That is why humanity needs new energy sources. Waves are predictable and vast energy source. There is an option to harvest this energy near coastline which is close to consumers. It might help level the speed of global warming. To date an effective way to transform wave energy into more useable form has not been discovered, because of the complex nature of waves. The authors gives their vision about field work done, what still have to be done, how it should be done and what will give to society the discovery of profitable commercial converter of wave power. The article shows how the wave energy sector could develop in the near future with many positive side effects. Society should act to facilitate the development of wave power.**

Keywords— ***Wave energy; wave height; energy transformer; renewable energy; Ocean potential; power generation***

I. Introduction

The world's consumption of energy is growing fast *"Fig. 1"*, [1]. That is why society needs more and more energy. For some time the world has been in a warming phase *"Fig. 2"*, [2] Humans can do very little to change this process in general.

However the main harm comes from the unevenness of global warming. The replacement of common energy use by CO_2 free energy might play a significant role in making the Earth more appreciate for human life. That is why in the very near future we should see a significant rise in the demand of renewable energy.

One source of renewable energy is Sea and Ocean waves.

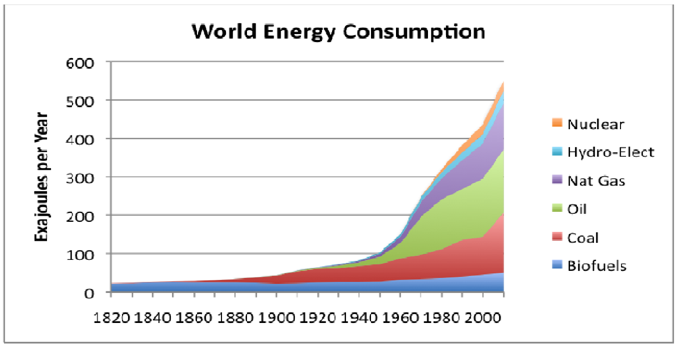

Fig.1. World energy consumption [1].

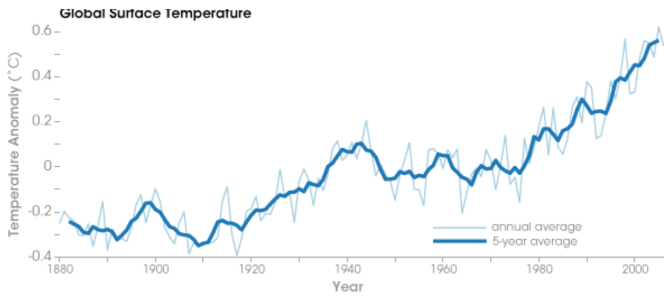

Fig.2. Global Surface Temperature [2].

Here are very rough figures of wind, sun and wave annual average power for Western Latvia *"Fig 3"*:

- Wind – 0.096 kW/m^2;
- Sun – 0.110 kW/m^2;
- Waves – 3.03 kW/m^2

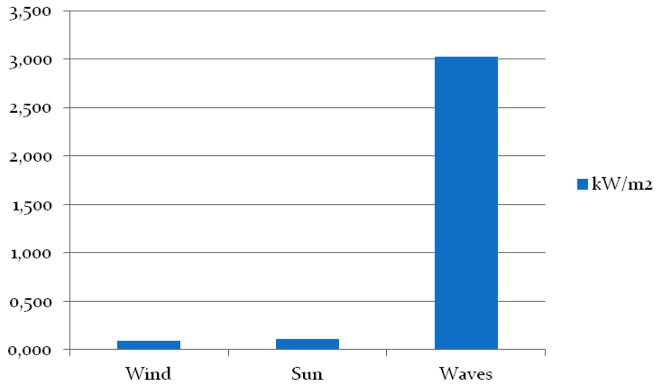

Fig.3. Average Power Intensity Comparison of Three Renewable at the Latvia's West (kW/m^2).

From comparison (Fig. 3) waves looks the most perspective source of energy between considered ones.

Scientists and engineers have been trying to transform wave energy to useable energy forms for at least 150 years. Just during the last several decades wave research has created over 1000 different solutions [3] for wave energy transformation. However the problem how to use waves as source of competitive renewable energy remains unsolved, and the question, what should be done first to open the way for the commercial use of wave energy remains pressing.

The worldwide potential of wave power is more than 2 TW, [4]. Statistical data of parameters let us create a map of wave potential *"Fig. 4",* [5] and the location of electrical energy consumption is also clear *"Fig. 5",* [6]. Therefore it becomes possible to design general perspective areas for the development of wave energy plants *"Fig. 6"*. States which do not have access to coastline would be able to set up power-plants in the neutral waters. Map of annual significant wave height gives a general idea of North Europe wave potential *"Fig. 7"*, [7]. Even the Baltic Sea has enough wave energy potential to establish a commercial wave power plant, according to research by Ansis Avotiņš and Jānis Greivulis, [8]. Meanwhile with simplified digital data projection method we can estimate the wave energy potential for the 170 km of the Latvia West coast to be 9.51 TWh/year.

II. Sector Overview

Some achievements have been made in the wave energy transformation sector during the last 150 years. They can approximately be divided into five subsectors:

- Wave theory (Subsector No1);
- Wave monitoring and data analysis (Subsector No 2);

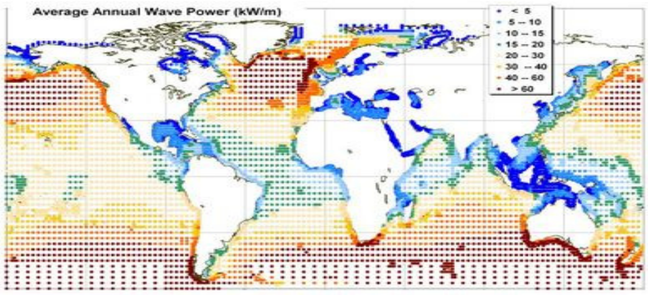

Fig.4. Average Annual Wave Power (kW/m) [5].

Fig. 5 Disposition of world's electricity consumption [6].

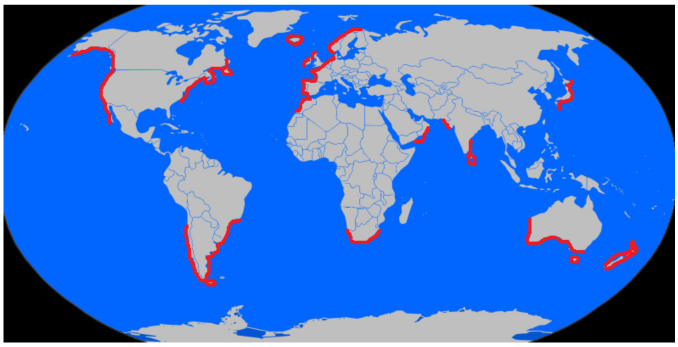

Fig. 6. Perspective areas of wave energy plants.

- Solutions of wave power transforming (Subsector No 3);
- Water area planning (Subsector No 4);
- Development of new industry (Subsector No 5).

Wave Theory

Wave theory is a result of careful research and it needs to be taken into account for any action in any of the other subsectors. That is why we will look at it under the title *"Wave Science basics"*.

Wave Monitoring Data

There are two reasons to collect data about wave parameters (height (H), length (λ) and period (T)):

- To ascertain the potential of wave energy;
- To get input data for the design of a power plant.

Wave monitoring data collection should be made long term. The very minimum time of data collection is one year. Most developed countries permanently monitor the waves of their Seas and adjoining Oceans. There is still a lack of data of many places, which are interesting for potential wave energy use. It is

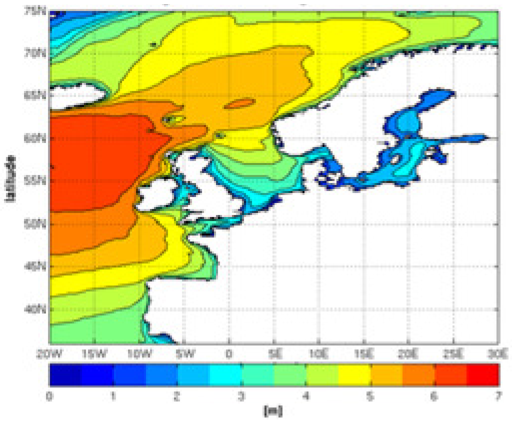

Fig. 7. Annual significant wave height [7].

possible to use a digital projection method, [9] to reduce collection time. However this method is less accurate. Therefore monitoring should be continued and purposefully extended to perspective areas of wave energy plants.

Solutions of Wave Energy Transforming

There is still no commercially viable solution for transforming wave energy, despite the efforts of scientists and engineers for over decades. However, commercial wave farms should appear in the near future for two reasons:

- Scientists and engineers continue work on wave energy transforming;
- The demand for energy grows in general and demand of renewable energy might even grow faster.

Water area planning.

The situation with water area planning is worse than the situation with wave monitoring. Again- a number of countries (For example Finland, Sweden, Denmark, Germany) do plan and continuously update their plans. Other countries- do not have any water area planning (for example Latvia, Lithuania, Estonia). A national water area planning policy document is the primary legal basis for establishing wave plants. Usually this document should be updated every 10 years. Therefore in the worst case scenario it might happen that a safe setup of wave farms is possible only after 9 years. Legal security for wave power plants is important because of the investment scale. Real security also depends on the level of corruption and responsibility of government officials.

Development of New Industry

New industry will also start to develop after the creation of a successful wave power converter:

- Renewable energy production from Sea and Ocean waves;
- Equipment production and sales

It's pretty clear that wave power plants will appear in areas with more suitable places first. Areas with better conditions means:

- Closeness and significance of the water potential;
- Scale of electricity consumption;
- Support from business environment;
- Existence of wave data;
- Existence of government water area planning policy and appropriate legislation.

Let's quickly introduce wave science to see how it affects the above mentioned subsectors 2, 3, 4 and 5.

Wave Science Basics

Waves as phenomena have been an object of scientific research for a long time and there are many achievements in the field. Today there is little left to research in the area of liquid waves. Just some nuances could be discovered to slightly better the correlation between formulas and physical measurements. Scientists of numerous countries have created a well sustained theory of the liquid wave, its energy and transformation. There are public domain publications by scientists from the USA, Canada, Australia, Japan, Norway, Sweden, Denmark, Germany and other countries.

From the formula of power [10], as in equitation (1), we can evaluate wave properties.

$$P = \frac{fgH^2 c_g b}{8}, \quad (1)$$

where

P – Power (W);

f – Density of water (kg/m^3);

g – Gravitational constant (m/s^2);

H – Height of the wave (m);

c_g – Speed of the wave (m/s);

b – Width of the crest (m).

$$c_g = \frac{gT}{2\pi}, \quad (2)$$

where

c_g – Speed of the wave (m/s);

g – Gravitational constant (m/s^2);

T – Period of wave.

Therefore

$$P = \frac{fg^2TbH^2}{16\pi} \quad (3)$$

"Fig. 8", [12] shows the relationship of wave power to period and height.

The power of deep water waves expands from the surface to depth of λ/2, where λ- is the wavelength, *"Fig. 9"*.

Thus we can conclude:

- Wave power increases with the square of the height;
- Effective wave power depends on the depth;
- Every wave crosses a wave plane [11].

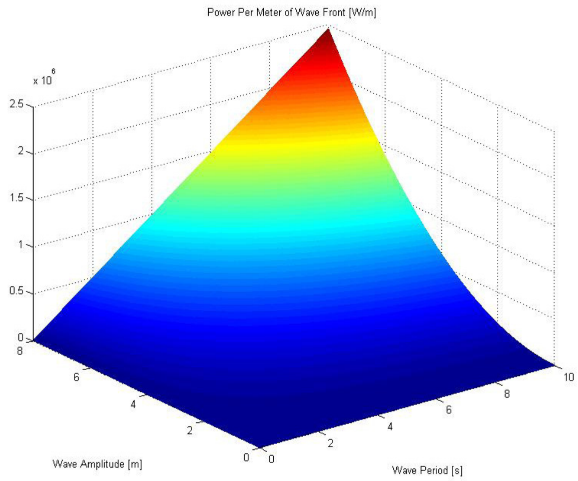

Fig.8. Wave power dependence from the wave period T and amplitude A [12].

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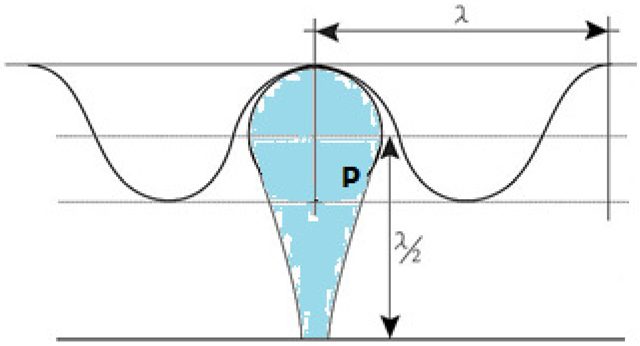

Fig.9. Wave power scheme

Classification of Methods

Let's classify methods of wave energy transforming in order to better identify their respective advantages.

Classification according to the construction [13]:

- Heaving and pitching bodies- motion happens only in vertical direction;
- Cavity resonators- wave power lift up and down the water column which propelled generator;
- Pressure devices- wave power compresses gas of liquid filled elements;
- Surging- wave energy converters- wave impulses turns to impulses of hydro or pneumatic cylinders [14];
- Particle motion converters- circular movement of water particles in the wave turns to movement of receiver;
- Salter's nodding duck - advanced technology;
- Cockerel's rectifier- waves moves hinged pontoons which propel pneumatic or hydro cylinders;
- Russell's rectifier- vertical turbine is propelled by waves [12].
- Wave focusing method [12].

III. Goals for Future Development of Wave Power Industry

A. *Priorities*

Wave theory is well developed and there is very little that needs additional clarification. That is why we need to rank the other sectors of the wave industry in order of priority:

- Solutions of wave power transforming;
- Water area planning;
- Wave monitoring data analysis;
- Optimization of wave energy production and sales and optimization of equipment production and sales.

Solutions of Wave Power Transforming

Scientists should focus on wave energy transformation to acquire usable energy. Scientists can do very little to change world demand for energy. That is why we need to make new discoveries. When an effective solution is found, commercialization will only be able to start in those areas where everything is clear with water area planning and data statistics.

Water Area Planning

Water area planning is the question of next importance because of the lack of suitable places with confirmed area planning.

Wave Monitoring Data Analysis

Areas without wave monitoring information could be monitored later. That is why this sector is in third place. However we should take into account that without this information the opportunity to set up a power – station will be lost for several years.

Optimization of Wave Energy Production and Sales and Optimization of Equipment Production and Sales

Optimization of wave energy production and sales as well as optimization of equipment production and sales will become issues only after the discovery of a commercially viable method of wave power transforming.

Wave power transforming is the sector to focus now. Prerequisites for achieving the sector's objectives are:

- A team armed with necessary knowledge;
- Technique, tools and materials;
- Technology.

With the right project management and continuous funding the goal becomes possible.

"The global technical potential of wave energy is estimated at 11,400 TWh per year. Its sustainable generating potential of 1,700 TWh per year equates to about 10 per cent of global energy needs." [15]. We valuate that only 0,14 % or 100,000,000 EUR of annual (2020) profit would be enough to solve elaboration of device for commercial wave energy plants.

B. Direction of Research and Engineering

A detailed list of technical goals is must. This document should include several topics such as:

- Effectiveness;
- Functionality;
- Security;
- Environmental concerns;
- Scaling.

Effectiveness

Effectiveness is a prerequisite for even raising questions about functionality, security, environment and scaling. Final effectiveness depends on two values:

- Annual sales of produced energy;
- Annual costs of production.

Keeping costs in mind, we conclude that the energy transforming device should be:

- Simple and easy to maintain, preferably without underwater work as far as possible;
- Energy transforming steps should be as few as possible and they should be designed as much as possible in the electrical sector, because electrical transformation is efficient.
- Total cost effectiveness as displayed by a cost effectiveness curve should be as good as possible.

Research of wave power transformer patents suggests that the main challenge for scientists and engineers is to achieve good effectiveness curve. This is understandable immediately after:

- Inserting values into the formula of wave power;
- Realizing that wave power is dependent on depth;
- Considering the movements of water particles in the wave.

The technical challenge is to adequately utilize the uneven nonlinear distribution of wave power in relation to depth. That is why any solid receiver will be an imperfect power receiver. Let's look at one example of a device with a solid receiver, *"Fig. 9"*.

As we see from *"Fig. 10",* [16] the receiver consists from several steal cylinders:

- The weight and size of receiver's moving parts does not change with the size of the waves. They remain constant.
- The bottom part of wave power does not come into play. It remains unused.

Other solid receivers *"Fig. 11",* [17] can receive a larger share of wave power, including power from the wave's lower part, but they still do not change their size to better utilize wave height.

Let's insert concrete values of wave heights and length into the wave power formula. These values vary widely at different sites around the world. Common wave heights in the Baltic Sea would be about 2.5 m. Data from the Pacific Ocean shows that quite common wave would be 15.1 m height. Because wave power varies with square of wave height, scientists and engineers should pay attention to intervals from zero to wave power as per *"TABLE 1"*.

TABLE 1

Eventual maximal power – plant wave parameters of one meter of wave front

	f	g	H	c	b	P
	kg/ m^3	m/s^2	m	m/s	m	kW/m
Baltic Sea	1006	9.81	2.5	2	1	15.42
Pacific Ocean	1035	9.81	15.1	2	1	578.77

Fig. 10. Device with solid receiver [16].

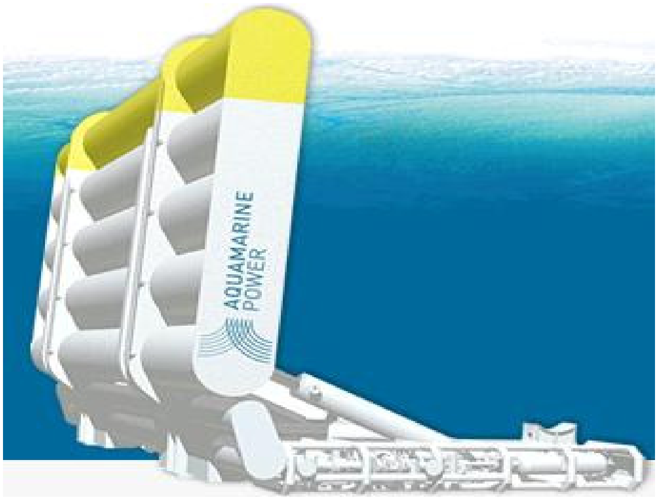

Fig. 11. Oyster wave energy converter [17].

From the power's figures we can see that a technical wave energy transformation solution for the Baltic Sea should be designed for the absorption of power between 0 and 15 kW/m. Pacific Ocean phenomena show that the necessity to accommodate power levels about 38 times larger. This leads to conclusion that receiver capacity should be as proportional as possible to incoming power. The weight of the receiver should be as low as possible to reduce inertia and keep the efficiency curve as straight as possible. But low receiver's mass will raise the problem of transforming capacity and possible overload of the speed of the transformer movement. Speed overload problems could be solved with a multistep system of transformer. More complex is the problem of refraction [18] that has a negative effect on receiver capacity. Refraction will happen in any receiver and any refraction is a loss of useful energy. From J. Berins point of view to keep refraction's negative impact to a minimum, the receiver should be located +/- 0.125 λ from the plane of absorption [19]. In the case of the Baltic Sea a one step receiver could be imaginable that is filled with air. In case of the Pacific Ocean the receiver should be filled with a light liquid and should have several steps, conceptually analogous to gears in an automobile. But this leads to heavier receiver, that causes more reflection [20] and refraction lower total efficiency.

Nature offers us waves with power values in intervals ranging from 0 – 15 kW to 0 – 579 kW per meter of wave. The large differences in the amplitude of incoming wave power leads to the following conclusions:

- Receiver, transformer and generators should be operating proportionally to incoming power;
- This energy transformer should have a multistep system to avoid overloads and skewed efficiency curve.
- There should be balance between the mass of the transformer's moving parts and their speeds;
- The transformer should work with minimal wave reflection and optimal refraction and optimal efficiency curve.

Functionality [21]

Mainly the functionality of wave power transformer is determinate by the ability to automatically assume a correct position, the possession of fully automated security mode including the ability to continue work in case of oversize waves and easy maintenance.

Security

- Ability to take safe position in case of oversize waves;
- Hostilities;
- Ice and icebergs;
- Others [21]

Scaling [21]

There are two reasons why scale is important:

- The large variance in wave parameters in different places;
- The ability to cost effectively utilizes wave energy at different water depth. Of course energy prices are important in this regard, and in other regards as well.

IV. Conclusions

- The speed of energy consumption increase demands for a new sources of energy;
- Intensity of Sea/ Ocean wave energy exceeds sun or wind energy in general.
- A significant share of the world's total wave energy could be harvested near big energy consumers;
- Society needs a wave energy transformer that produces renewable energy at competitive price to meet increasing demand of CO_2 free energy;
- Scientists and engineers should pay more attention to preparing the technical agenda for creating a cost effective wave power transformer. Analysis of wave

theory and existing results of experiments should be taken in account before creating of this document;

- Society should pay more attention to wave power and invest more funds in wave power development, specifically in the development of energy transformer. 100,000,000 EUR should be enough to elaborate the device for commercial power-plants.
- Once wave power transformation becomes feasible, a new important industry will be created. This means new economic activity, a huge industry, a positive export/ import balance, less unemployment, less CO_2 emission;
- Countries, which do not have Sea or/ and Ocean coasts could develop wave power production in neutral waters.

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