Technical analysis of the economic viability of sea wave power stations.

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Abstract - ***This article is about one of the alternative forms of energy – the algorithm for the development of a sea wave energy converter, which is based on reflection, refraction, diffraction and interference analysis between waves and their energy transformers. This article provides information to the placement of a wave energy converter receiver, specially calculated parallel to the surface, thereby allowing obtaining wave energy step by step. It provides an insight into wave power plant optimization principles.***

Key words - *renewable energy, wave energy, wave energy converter, algorithm development, wave energy receiver, draft control system, anchorage.*

INTRODUCTION

Sea and ocean waves are one of the renewable energy resources. Some authors studies show potential energy from waves to be estimated at between 80 000 TWh and 8,000 TWh per year [1]. To achieve this it is necessary to create a new installation for wave energy conversion (WEC) to create effective power stations. Thus, resolving optimization problems, cheaper electro energy production would be possible. Influencing factors to be taken into account in addressing these challenges, are electro energy wholesale prices, all costs involved in WEC formation, maintenance, connections, etc., wave potential in the target area, distance from the distribution network and efficiency ratios. However, before resolving the aforementioned problems, the development of WEC is paramount.

Every wave energy conversion solution can be used to create a certain algorithm. This article describes one of these algorithms.

At least 140 science institutes in the world are working on wave energy conversion, involved in around 200 various projects since the year 2000, [2]. Authors Hosni Titah-Benbouzid and Mohamed Benbouzid publication "Ocean Wave Energy Extraction: Up-to-Date Technologies Review and Evaluation". Gives insight into current developments in the field, including the classification of power plants and their characteristics [3]. The June 2014 edition of IRENA Ocean Wave Energy Technology Brief 4, [4] gives detailed classification of power plants and calculations of the costs of electro energy production forecast up to the year 2050. These and other links can be found in bibliography [5].

The aim of this article is to describe the development of a WEC algorithm, which could provide the techniques to develop the necessary equipment, taking into account that it must be integrated into specific existing power plants.

WAVE MATHEMATICAL MODEL

A wave is a three-dimensional phenomenon, fluid fluctuations based on various physical processes, waves are characterized by the following parameters; Period T (s), Height H (m), a Length L (m) and speed c (m/s). Wave energy also depends on the density of the liquid (kg/m3) and gravity. Water particles in the wave have a specific rotational movement (See Fig. 1). Their affect decreases as depth increases, practically vanishes at a depth of L/2 from Sea Level *(sl)*. The wave's environment is also determined by density and depth of the specific area of water.

Imagining a vertical plane, X being the perpendicular and Z parallel to the direction of the movement of the wave, we can construct the wave splitting in these planes, and how it "carries" its energy. As the wave, ideally, is in motion, the X plane will be rectangular over its whole width with the height L/2 + A, where the wave amplitude A = H/2.

On the Z plane the distribution of wave energy will be rectangular with the upper edge of L/2 + A and length L. The wave energy from the horizon *sl* - L/2 to the horizon *s*l + A, the energy concentration described in the field is not even. It can be calculated by horizons with kinetic energy E_k and potential energy E_p can be expressed by placing the required thresholds to show a wave vertically as well as horizontally [6]:

$$Ek = \int_{x}^{x+L} \int_{-d}^{\eta} f \frac{u^2\ (z) + w^2(x)}{2} dzdx, \text{(1)},$$

$$Ep = \int_{x}^{x+L} fg[\frac{(\eta(x)+d(x))}{2} - \frac{d^2(x)}{2}]dx, \text{(2)},$$

where:
L - wavelength;
d - water depth;
f - The specific weight of water;
η - water elevation above sea level;
u - particle velocity horizontal component;
w - particle velocity vertical component;
See. Figure 2.

In any sea area we find waves with a variety of characteristic parameter values of T, L, H, direction and c (speed). The waves total energy (E = sum of potential energy (E_p) and the kinetic energy (E k). E p is dependent on H, but E_k - on particle velocity in the wave (See. 1stFig.).

Waves possess reflection, diffraction, refraction and interference [7]. These characteristics must be taken into account during the energy transformation process. The algorithm takes this into account during the observation process to show the changes during the interaction between the wave and the wave energy receiver (WER).

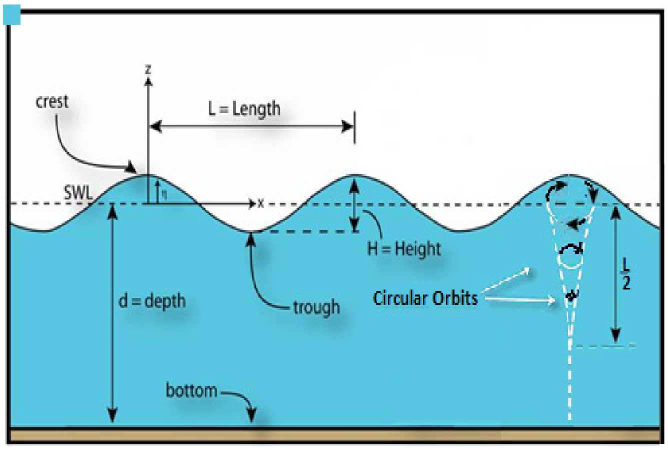

Figure 1.

Illustration of wave and particle motion in wave

WER analyses changes and draws conclusions about possible improvements. The next incoming waves are distorted as a result of reflection. Particle movements within the wave are effected by static and dynamic pressure fluctuations.. Ideally in deep water this particle movement creates a cyclical laminar flow. In addition, a certain quantity of water moves in each wave [7].

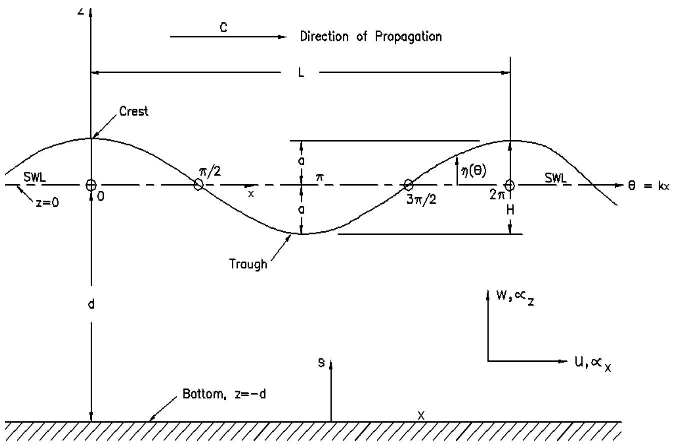

Figure 2.
Wave term definition, [6]

CONVERTER MODEL WITH UNKNOWN PARAMETERS

A - Facility flowchart

Let us use an imaginary estimated wave energy converter (WEC) (Ref. Fig. 3.), which consists of at least, but not only a wave energy receiver (WER), energy converter (WEC), draft regulation systems (DRS) including pontoon and anchorage (ENC), and how the wave energy will affect it.

B – WEC mathematical model

In sea or ocean water areas, waves tend to have various parameters. Let us define 4 types of border waves X_0, X_1, X_2 and X_3 with parameters (See. Figure 4) - the wave height H_n (or 2A n wherein A - amplitude of wave) L_n wavelength and wave period T_n.

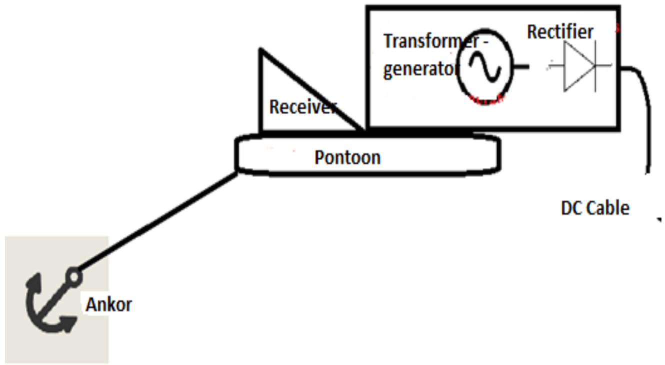

Figure 3.
WEC flowchart

In the case of X_0, all the waves characteristic parameter values are 0 in other words there are no waves. X_1 parameter value is determined by its minimum power that is able to start the expected WEC See Fig. 4. The image shows the minimum depth for placement of equipment. From the picture we see that the minimum depth of water for positioning of the power plant is determined by the maximum wavelength (X_3). This is because such waves are rare, and the plants task will be to continue to work in safer conditions by increasing the immersion depth. In the algorithm we assume that X_2 parameter value is determined by maximum wave power at which the WEC would work at the highest intrinsic efficiency. In turn, X_3 parameter values show the maximum waveform ever recorded at the chosen location. Thus, at these intervals, shown in the algorithm as: [X_0; X_1] – WEC does not work. Due to insufficient wave power; [X_1; X_2] – the WEC functions as specified by the efficiency coefficient curve; [X_2; X_3] - WEC runs following a downward coefficient curve. In the last interval the efficiency of the WEC decreases, as this type of wave power grows in the direction of X_3 relative to the WEC's receiving power. Using an imagined perpendicular cut X through vertical wave direction. We can describe the wave height H projection on the WER. From here we can conclude that the WER height must be $L_2/n + A_2$ (1) where L_2 - X_2 wavelength A_2 - X_2 wave amplitude, 1/n - coefficient, which includes economically viable energy absorption depth. Factor of 1/n calculated by optimizing the WER. From Figure 4 it can be concluded that optimum use of the WEC receiving area, interval [X_1; X_2], it has to be moved vertically in relation to sea level sl. However, interval [X_2; X_3] it must be submerged deeper, but not only to protect the structure from excessively large waves.

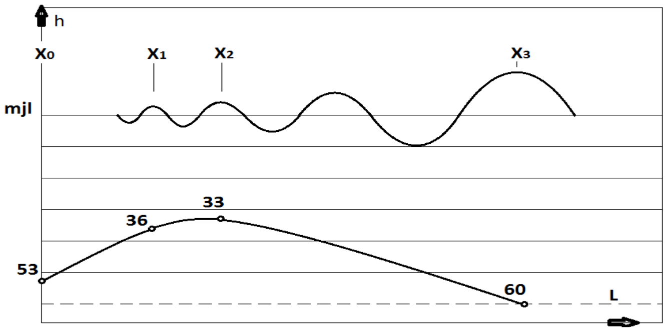

Figure 4.
Border waves and WEC installation depth

The algorithm includes the following research: wave power range factors, static and dynamic pressures, VEP test reflection, refraction, diffraction, and turbulence interference observations, as well as the coefficient of performance calculations. Wave energy distribution depending on the depth of the horizon (Example) shown in Figure 5. The wave energy steady splitting surface profile shown in Figure 6.

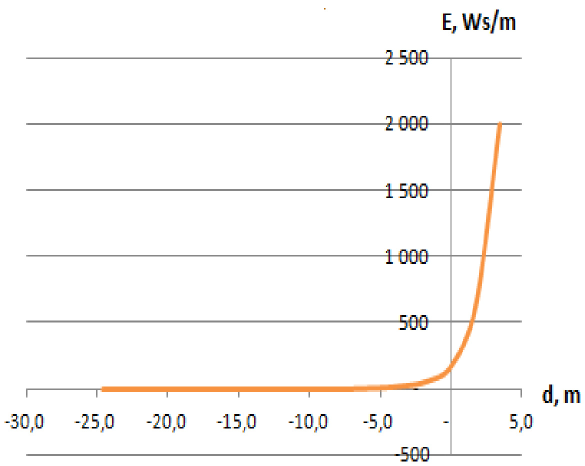

Figure 5.
Wave energy distribution depending on the depth of the horizon (example)

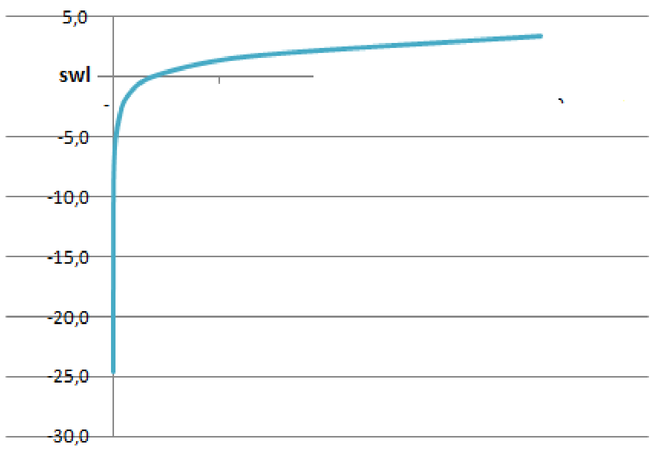

Figure 6.
Wave energy division smooth surface profile

Depending on the parameters the wave energy curve (depending on the depth horizons) will change. Therefore, it should also be modified to capture smooth surface profile. Before this function a simple technical solution, the one constant can be optimized surface target wave basin interval [X_1; X_3]. Optimization task solution will provide information to which draft horizon the projected WEC's waveband will be operating.

Wave Model and WEC Interaction Optimization.

From the wave power equation we can deduce its dependence on the wave height squared. This fact creates a need to "stretch" the WEC transformed power range, which will require technical solutions. Wave energy is characterized by the value during a specified period, which crosses the plane X. By contrast WEC - costs that are allocated to the receiving area in m2; and the energy conversion efficiency rate. The power stations targeted area depending on predicted electricity prices, the wave potential, [8] and WEC cost optimization task solution will give the greatest energy at the least cost. The real work is organized as follows: We choose one such rotating WEC receiver, which complements the described wave model in the covering area, and then with the help of computer programs optimize WEC model receiver shape so as to minimize energy losses due to reflection and turbulence. Then the selected basin wave parametric statistical calculation of the optimum wavelength interval [X_1; X_2] and [X_2; X_3] and following the interval of wave power (3) and WEC performance coefficient curve we calculate theoretically obtainable energy. Using equations (1) and (2) optimize WEC receiver height, depending on energy prices and existing WEC costs.

Economic Model of Sea Power Plant.

Approximate sea wave power plants (SWP) (270 km front) profit/loss example, based on the Latvian exclusive economic zone (EEZ) of wave energy potential data [8] shown in Table 1. In the calculation we assume that the relationship between technically achievable and wave energy potential in the EU / E is 75% and plants average efficiency is 33% of the E_u. Such an average coefficient of performance is assumed on the fact that Solter's "oscillating Duck 'in some cases works with an efficiency of over 90% [9]. In our calculations we have made the following 3 assumptions-

1. Power station operations scheduled to begin in 2023, and electricity wholesale prices are forecast to be 80.00 EUR / MWh;
2. There is no VAT because production is subsidized;
3. There are no insurance expenses as without a working history it is impossible to insure this sort of power station.

1. Table

SWP Profit / Loss Calculation

Income	EUR
Wave potential (E), MWh	3 230 000,0
Eu/E	0,7
Quantity of receivable energy (Eu), MWh	2 422 500,0
Average power plant efficiency coefficient, η	0,3
Average wholesale electricity price, EUR/ MWh	80,0
Quantity of electro-energy produced MWh/year	799 425,0
Income from production EUR/year	**63 954 000,0**
Subsidies EUR/year	**51 000 000,0**
Total income EUR/year	**114 954 000,0**
Expenses	
Depreciation EUR/year, made up of:	**103 850 000,0**
Power station pre-planning and planning costs	*350 000,0*
Equipment value	*70 000 000,0*
Transport and instalattion costs	*3 500 000,0*
Power station connection to distribution networks	*30 000 000,0*
Maintenaince costs EUR/year, incl.	**6 300 000,0**
Technical maintenaince	*3 000 000,0*
Repairs	*3 000 000,0*
Navigational and safety maintenance costs	*300 000,0*
Taxes EUR/year	**906 210,0**
VAT	
Dabas resursu nodoklis	*574 770,0*
Natural resource tax	*91 440,0*
CIT	*160 800,0*
IIT	*79 200,0*
Administration costs EUR/year incl.:	**720 000,0**
Wages	*360 000,0*
Other administrative costs	*360 000,0*
Bookkeeping and audit EUR/year	**12 000,0**
Insurance	-
Other costs EUR/year	**3 000 000,0**
Total expenditure	**114 788 210,0**
Profit	**165 790,0**

CONCLUSIONS

1. In this modified efficiency analysis and any improvements, reflection, refraction, diffraction and flow turbulence observations and coefficient of performance calculations will be used.

2. WEC receiver projection of the plane wave will be one or more rectangles.

3. For the even distribution of wave energy, WEC receivers will be deployed along with special surfaces, where the basis of calculation will be used for points (1) and (2).

4. In order to give a fuller picture, the X and Z planes are displayed in pressure field charts and the changes during the test.

5. In the case of each sea area, wave thresholds X1 and X2 detectable optimization process depends on the wave potential.

6. Economically efficient SWP creation should be in a selected area with a larger and more evenly distributed, in time, (compared to the Latvian EEZ) wave energy potential.

FUTURE WORK

WEC developments need technical work which depending on developments during the trial, and on the WEC reflection, refraction, diffraction, interference and turbulence observation, as well as the efficiency ratio calculation results. Suitable computer programs must be applied to the WEC.

Sea / ocean wave power plant electricity price optimization software must take into account price influencing factors. (price, all costs associated with the establishment of WEC, maintenance, connections, etc., wave potential target water area distance to the connection with the distribution network and the efficiency coefficients)

Wave energy division smooth surface profile developed target basin wavelength interval [X_1; X_3] as the last element of the optimization task.

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