Optimization of an OBREC device Program

1 Introduction

The effects of climate change are becoming more and more evident in the last years. As a result, organized efforts to combat the phenomenon are increasing. The EU has set itself some major targets for this ambition that should have been achieved by 2020, such as reducing greenhouse gas emissions by at least 20 %, increasing the share of renewable energies to 20 %, increasing energy efficiency by 20 % and investing 3% of gross domestic product in research and development.
In the recent decades, the global scientific community has shown a great interest in the generation of electricity from waves.According to the International Energy Agency, wave energy is estimated to be sufficient to cover 10% of the planet's electricity needs. Obrec device is used to produce electricity at the shoreline. This device type is easily accessible and not expensive in the construction of it. On the other hand,the produced energy is less, since the directional spreading of the wave climate is restricted nearshore and also phenomena as wave breaking, refraction, diffraction and shoaling alter the energetic wave content. The main objective is to find a device with high energy efficiency and environmentally sustainable operation.
The methology that is followed to achieve this, aims to identify the optimal combination of crest height and hydraulic height of water above water turbine of Obrec reservoir,in order to maximize its performance.To achieve this is used combined application of wave propagation equations that simulate the compound wave field near coastal structures with an optimization algorithm, that takes under consideration every possible scenario and identify the optimal dimensions of Obrec Reservoir.If some parametres of this algorithm change, it can be used in every port.In order to demonstrate the effectiveness of the methodology, the port of Foiniki in the island of Karpathos in Greece, is used as a case study.

2 Geometric features of an Obrec device

An OBREC device consists of a concrete top element, which can be installed in new or existing breakwater. It is provided with a sloping plate that conveys the overtopping waves inside a reservoir, which later flow in the rear chamber, where the turbine should be installed. The front reservoir captures the overtopping waves to produce electricity.An illustration of the device is presented in Figure 1.

In a wave energy converter the aim is to calculate the crest freeboard Rc, that describes the height between the upper point of the sloping plate of the front

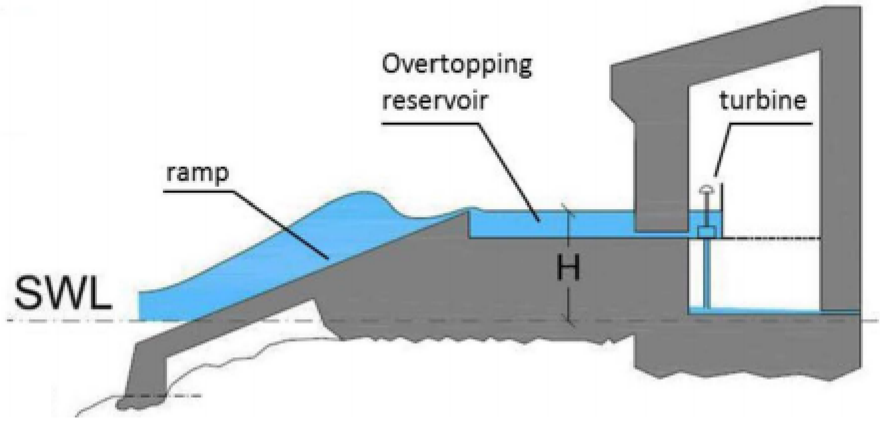

Figure 1: Obrec illustration (source: luppa et al.2016)

reservoir and MSL, the average wave overtopping rate q and the output energy. A variety of mathematical models have been developed which are applied in coastal protection works and in the installation of wave energy converters. Based on Victor and Troch the crest freeboard and the average overtopping rate are calculated by the following equation:

$$q = 0.20e^{(-2.6)\frac{Rc}{Hm}}(gHm^3)^{0.5} \tag{1}$$

In Equation (1), q is the average overtopping rate, Hm is the incident significant wave height at the toe of the structure and Rc is the crest freeboard. As for the calculation of incident wave height firstly it is used JOWNSAP method in order to find effective fetch prices and then these prices are used to find Hm at the toe of the structure for every wind direction and wind speed.

The coefficient 2.6 in equation (1) is a normally distributed stochastic parameter with an associated standard deviation of $\sigma = 0.35$. In order to use the above relationship in a wave energy converter, its range should first be limited. So, limitation were applied for the slope angle of the construction and for relative crest freeboard. Specifically, the range of application of the equation is for slope angles α between $4 \geq \cot x \geq 1$ and for relative crest freeboards $\frac{Rc}{Hm}$ between $3.5 \geq \frac{Rc}{Hm} \geq 0.5$.

In the following table are presented all the equations that is used in order to export the geometrical features of the device as well as to export the output power. In Table Hk defines the hydraulic height of water above water turbine(m).

Calculation of geometric features	
Average overtopping rate	$q = 0.20 \cdot e^{(-2.6)\frac{Rc}{Hm}}(g \cdot Hm^3)^{0.5}$
Power obtained	$Phydro = \rho \cdot g \cdot Rc$
Power that is passing through a vertical cross section of the water column	$Pwave = \frac{g^2}{64\pi} H^2 \cdot TP$
Hydraulic efficiency	$nhydraulic = \frac{Phydro}{Pwave}$
Output energy	$Pk, el = nhydralic \cdot \rho \cdot g \cdot qk, s \cdot Hk$

Table 1: Calculation of geometric features

3 Case-study Area: The port of Foiniki,Karpathos

Karpathos is the second largest island of the Dodecanese after Rhodes. It is located in the middle of the Carpathian Sea between Rhodes and Crete. Its area, along with the surrounding islets, is 324.7 square kilometers. According to the 2011 census, the island's total population is 6226 people with 2788 of them located in the island's capital, Pigadia while the rest of the inhabitants are scattered around the island.
According to the Regulatory Authority for Energy, Karpathos is one of the islands with the highest wind potential in Greece and this was the main reason that the specific island has been selected as a study area.In the table below are presented the frequency of each wind operating in the selected port as well as the effective fetch prices for the port(**Table 2** and **Table 3**)

Wind power(BF)	N	NE	E	SE	S	SW	W	NW	Calm	Summary
0									4.704	4.704
1	0.143	3.697	0.121	0.869	0.814	1.793	0.385	1.551		9.373
2	0.825	7.008	0.286	2.410	1.804	4.753	1.826	7.614		26.526
3	1.551	4.698	0.187	2.057	1.144	3.488	1.848	11.761		26.734
4	2.101	2.993	0.110	1.331	0.462	1.870	0.990	9.154		19.011
5	1.793	1.584	0.020	0.627	0.154	0.847	0.363	3.829		9.296
6	1.353	0.660	0.011	0.165	0.055	0.330	0.066	0.847		3.487
7	0.418	0.132	0.001	0.033	0.011	0.033	0.011	0.077		0.726
8	0.099	0.011	0.000	0.011	0.011	0.000	0.000	0.000		0.132
9	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000		0.011
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
Summary	8.283	20.783	0.825	7.514	4.455	13.144	5.489	34.833	4.704	100.000

Table 2: Wind Power(BF)

Feff W	246.40
Feff SW	84.22
Feff NW	187.52

Table 3: Effective Fetch(km)

4 Optimization Model

The purpose of this study is to find the dimensions of Obrec device that maximize the produced energy as well as to find the energy that is produced for all the different dimensions of an Obrec device.To achieve this are used data for the wave conditions and data for the water column inside the pipe above the water turbine, denoted as hs.So, the values that had to be changed in the program to find the dimensions of an obrec device for every port are presented below:

- Effective fetch(m)
- Wind Power(BF)
- Hs(m)

The program has been executed for all the prevailing wave conditions, emerging different size scenarios of the OBREC device. Each scenario presents the geometric shape of the reservoir that maximizes the power of the turbine and the power that is produced for every different value of crest freeboard. To find all the different scenarios for the hydraulic height of water above water turbine two constraints have been used. The first one is that the height of crest freeboard must be bigger than the hydraulic height of the water above the water turbine($Rc > hk$) and the second one is that hk must be bigger than zero($hs > 0$).Using this two parameters and changing the value of the water column in the reservoir in range from 0m to 3.5m with a step of 0.05m all the different size scenarios are tested.
The program is executed for all the prevailing wave conditions in the area of study, emerging different size scenarios of the OBREC device. Each scenario presents the geometric shape of the reservoir that maximizes the power of the turbine, for the steady wave condition that has been introduced as input to the program and finally the scenario that maximize the produce energy is chosen.

5 Different scenarios and optimal solution

The behavior of OBREC reservoir must be tested for all the different scenarios. It is observed that the choice of different bottom height affects the final choice of crest freeboard. In particular, the closer the bottom height is selected to the mean sea level, the pressure head increase and the final crest freeboard decrease. Also, for lower bottom height of the reservoir, the energy produced by the device is increased.In the tables below are presented the produced energy of every scenario compare to crest freeboard height.

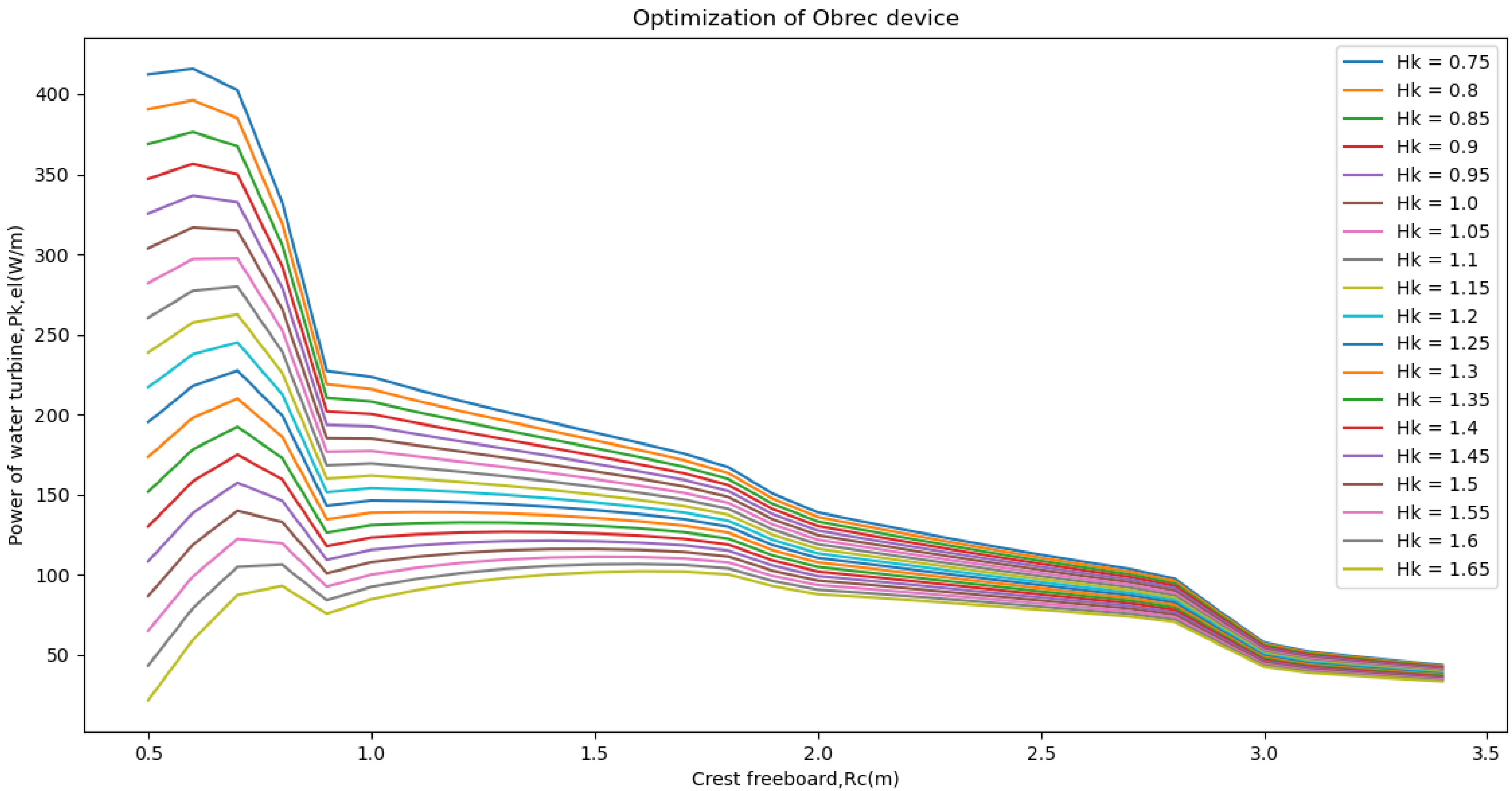

Figure 2: Obrec illustration (source: luppa et al.2016)