

New approach for renewable energy production from dams

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Abstract: The energy production is among the most critical challenges, is added risks to the environment by the proliferation of greenhouse gas emission. The search for new methods for the production of renewable energy turns out a more imposing need. This article aims to explore a new way to achieve this end based on dams.

Keywords: Renewable Energy, Wind Generated Waves, Dams, Power

1. Introduction

In the general context of current price of energy especially the fossil one, all efforts have to focus on the exploration and development of new renewable energy technology.

Indeed, the global growth is closely correlated to the electricity consumption. In the particular context of economic crisis, the negative impacts on the environment due to energy production don't present a major priority.

The main objective of this article is to investigate a new approach, based on balanced methodology between the pragmatic engineering and the scientific understanding of natural phenomenon, in order to convert it into useful energy.

First, the practical observations occurring at dams will be exposed and the motivation to explore them will be explained. In the following, the theoretical modeling of the wind generated waves is presented, including a preliminary power calculation with exposition of the interest of this new renewable energy method in comparison with the classical one.

2. Practical Observations

Through many observations on diverse sites in Morocco, it was noted that the ponded water at dams present a potential exploitation of natural phenomenon illustrated on Picture 1.

Each phase number is defined on the figure below:

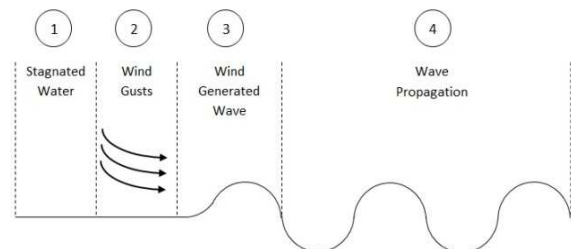
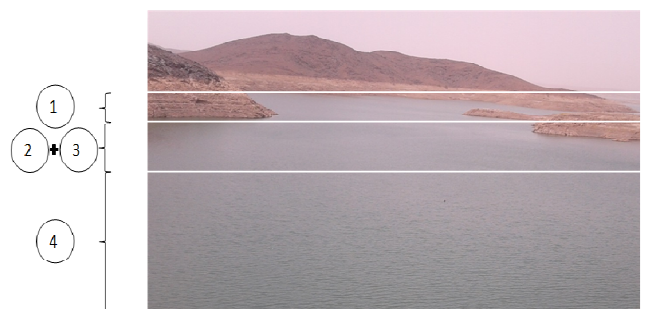


Figure 1. Phases definition.



Picture 1. Illustration of the phenomena at El Mansour Eddahbi dam.

We face coupled phenomena which are: first the wind generated waves creation and secondly their propagation away from their creation location.

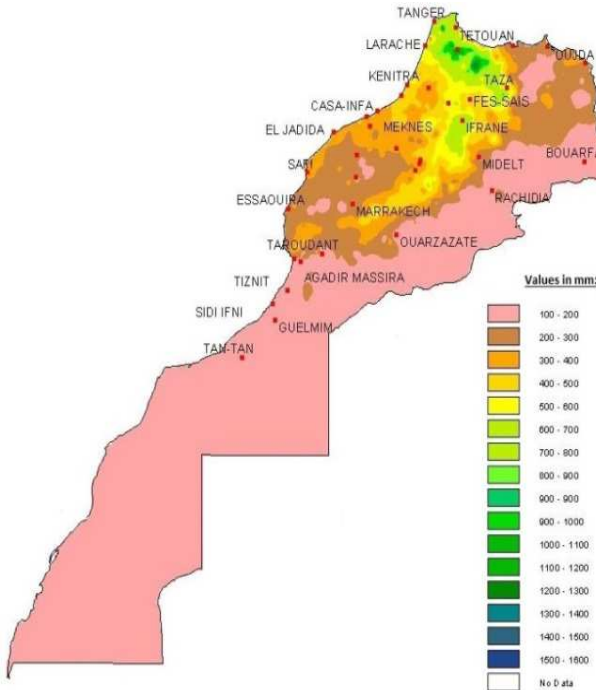
Given these remarks, we will focus on the study of this field which presents interesting features. For the rest of the article and in order to elucidate all the aspects in relation with our issue, the data and technical information used will be based on the Moroccan ones.

3. Motivation

To deal with the growing demand for water, the public authorities have to invest in facilities to meet this need of first necessity. Out of this fact, the dams are the technical infrastructure required to mobilize significant water reserves. With technological advances the roles of dams are not restricted only to ensure the storage of this precious resource but several others purposes are covered. The Figure 3 provide an idea of the distribution of single-purpose referenced dams, which present 71,4 % of the whole dams¹.

As we can deduce, the hydropower production presents the second most important purpose of dams. The turbinning operation requires inevitably the use of stored water through the potential energy of gravity to produce electricity.

However, for a country such Morocco, with arid climate over the most of its territory, as shown on the following map²:



Map 1. Average annual rainfall on Morocco.

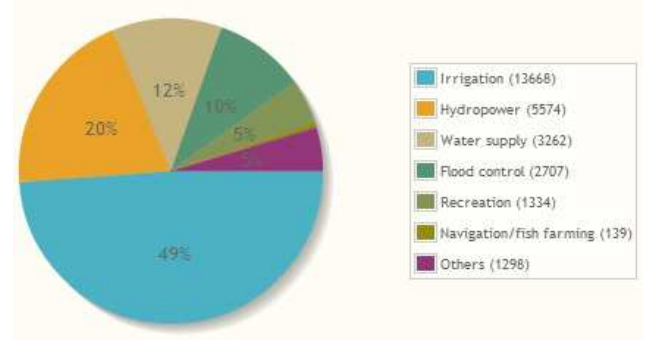


Figure 2. Single-purpose referenced dams distribution.

The priority will be given to the storage and water supply versus the electrical energy production. This fact is confirmed by national electric power production data³ which indicates that hydraulic energy production is about 7% of the global one.

Therefore, to maintain the precious levels of the stored water on dams and at the same time produce electrical energy, it seems interesting to explore the observations aforesaid to achieve both objectives and this is what will be addressed in the following.

4. Theoretical Modeling

The issue of the interaction between wind and waves is a problem that has been widely discussed. Many scientists have studied the question and different theories have emerged. Various mechanisms for describing the problem of the generation and evolution of waves by wind exist of which those of Kelvin-Helmholtz [1], Jeffreys [2] [3], Phillips [4] and Miles [5].

Regarding this part we will try to establish a theoretical modeling for the phenomena presented previously. Taking in consideration the observed waves profile, we suppose in first order, that they can be assumed linear (Cf. [6], [7], [8]). In this case, nonlinearities can present perturbations to the linear solution.

4.1. Governing Equations

Conservation of the mass can be written in terms of the Laplace Equation:

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial z^2} = 0$$

where x and z are the horizontal and vertical coordinates, respectively, of the two dimensional solution domain. The velocity potential ϕ is defined by:

$$\begin{cases} u(x, z, t) = -\frac{\partial \phi}{\partial x} \\ w(x, z, t) = -\frac{\partial \phi}{\partial z} \end{cases};$$

¹ International Commission on Large Dams web site: www.icold-cigb.org.

² Morocco Weather: www.marocmeteo.ma.

³ Based on 2012 data of the National Office of Electricity and Potable Water: www.one.org.ma.

and where u and w are the horizontal and vertical components of velocity \vec{V} , respectively, and t refer to time.

The conservation of the momentum is represented by the unsteady Bernoulli equation:

$$-\frac{\partial \phi}{\partial t} + \frac{p}{\rho_w} + gz = 0$$

where:

- p : the pressure;
- ρ_w : the density of the water;
- g : the gravitational acceleration.

4.2. Boundary Conditions

The above equations will be solved with respect to the following boundary conditions and domain presented hereafter:

4.2.1. Dynamic Boundary Condition at the Free Surface

At the free surface, $z = \eta$, the pressure is atmospheric, $p = 0$ and we have:

$$-\frac{\partial \phi}{\partial t} + g\eta = 0 \text{ at } z = 0.$$

4.2.2. Kinematic Boundary Condition at the Free Surface

Withing condition we haven't any fluid transport through this surface and it implies the equality between the vertical velocities of the free surface and the fluid:

$$w = \frac{D[\eta(x,t)]}{Dt} \Rightarrow w = \frac{\partial \eta}{\partial t} + u \frac{\partial \eta}{\partial x} \text{ at: } z = \eta$$

Under the assumption of small amplitude, the slope of the water surface can be considered as the following:

$$\frac{\partial \eta}{\partial x} \ll 1$$

and the boundary condition can be rewritten as:

$$-\frac{\partial \phi}{\partial z} = \frac{\partial \eta}{\partial t} \text{ at } z = 0.$$

4.2.3. Kinematic Boundary Condition at the Bed

In similar way as we process in the previous case and using the fact that there is no flow through the solid bed, we have:

$$w = -\frac{\partial \phi}{\partial z} = 0 \text{ at } z = -d$$

4.3. The Solution

The solution of the problem based on the Laplace equation and the boundary conditions previously made explicit, as summarized in the figure hereinafter:

Figure 3. Governing equation and boundary conditions presentation.

is defined as follows:

$$\phi(x, z, t) = \frac{ag}{\omega} \frac{\cosh[k(d+z)]}{\cosh[kd]} \cos(kx - \omega t)$$

where:

- a : is the wave amplitude and we have $a = H/2$;
- ω : is the wave angular frequency and we have $\omega = 2\pi/T = 2\pi f$;
- k : is the wave number and we have $k = 2\pi/L$.

Given that, we can deduce the wave profile η expressing the free surface:

$$\eta = \frac{1}{g} \left[\frac{\partial \phi}{\partial t} \right]_{z=0}$$

which lead us to get:

$$\eta = a \sin(kx - \omega t)$$

4.4. Water Practical Motion

From the definition of water components velocity, we can calculate them:

$$u = \frac{agk}{\omega} \frac{\cosh[k(d+z)]}{\cosh(kd)} \sin(kx - \omega t)$$

$$w = \frac{agk}{\omega} \frac{\sinh[k(d+z)]}{\cosh(kd)} \cos(kx - \omega t)$$

The displacements of the fluid, in the horizontal and vertical directions, can be expressed as follows:

$$\xi = \int u dt; \quad \zeta = \int w dt$$

Hence, from the mean position, we can write:

$$\xi = \frac{agk}{\omega^2} \frac{\cosh[k(d+z)]}{\cosh(kd)} \cos(kx - \omega t)$$

$$\zeta = \frac{agk}{\omega^2} \frac{\sinh[k(d+z)]}{\cosh(kd)} \sin(kx - \omega t)$$

Using these expressions and substituting the dispersion relationship for ω^2 in both of them:

$$\frac{\xi}{A^2} + \frac{\zeta}{B^2} = 1$$

where:

$$A = a \frac{\cosh[k(d+z)]}{\sinh(kd)} ; B = a \frac{\sinh[k(d+z)]}{\sinh(kd)}$$

As we can deduce from the expressions above, the representation of the fluid motion has an elliptic form and which depend on the water deep. The particular cases of these representations are presented on the following figures.

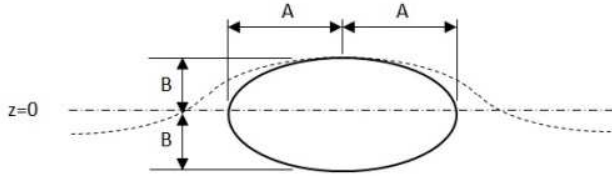


Figure 4. Representation of the motion of a fluid as predicted -Shallow water wave-.

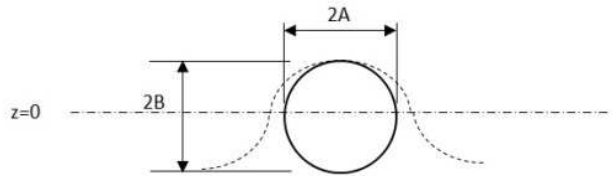
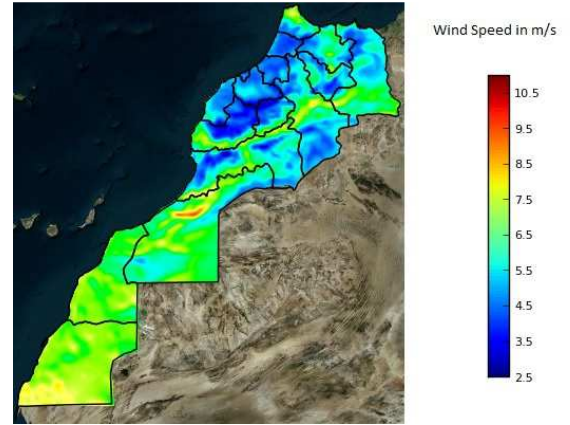


Figure 5. Representation of the motion of a fluid as predicted -Deep water wave-.

4.5. Preliminary Power Calculation

The wind resources are not available all the time and are variable in both speed and direction. These variations are related to spatial and temporal parameters. The following maps⁴ show more clearly this fact.



Map 2. Wind speed map in Morocco.



Map 3. Wind direction map in Morocco.

Hence, in order to evaluate the power resulting via the wind generated waves at ponded water in dams conversion, we calculate standard power produced due to the given fluid flux.

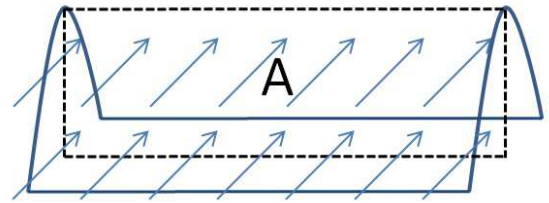


Figure 6. Fluid flux.

The kinetic energy is given by:

$$E_K = \frac{1}{2} m V^2$$

and the power which is kinetic energy per unit time:

$$P = \frac{1}{2} \dot{m} V^2$$

⁴ National Agency for the development of renewable energies and energetic efficiency: www.aderee.ma.

On the other hand:

$$\frac{dm}{dt} = \rho_w AV$$

then, we get:

$$P = \frac{1}{2} \rho_w AV^3$$

where ρ_w is the water density, A express the swept area and V is the wind generated waves velocity.

To take into consideration the efficiency in extracting the power, C_p , a power coefficient is used, expressing the ratio of power effectively extracted:

$$P_E = C_p \cdot P$$

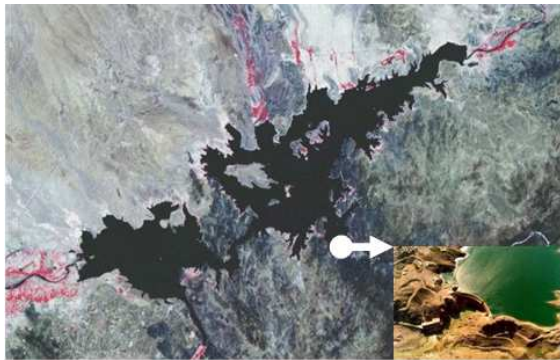
with:

$$C_p < 1.$$

Even if the height of the waves is evaluated to be between 20 cm and 30 cm depending on region and the site conditions (Cf. Map2 and Map3), which is the main parameter for the calculation of the swept area A , we estimate that the capture of this power and its conversion will be useful.

Indeed, in the case of dams, the surface of the stored water is very important. For example, in the case of El Mansour Eddahbi dam this area is about 15.000 km² [9].

As it was mentioned previously, after their generation the waves are transported far away from their creation location. The local phenomenon is expandable to a massive surface motion affecting a large area of the ponded water at dams (Cf. Picture 2). It represents a great potential of renewable energy production. At the same time, the quantity of the stored water will be conserved.



Picture 2. El Mansour Eddahbi dam water reserve.

5. Conclusion

In this article, we were able to present an opportunity to develop the renewable energy production using a new method based on dams without the use of the classical approaches. The theoretical modeling can predict the creation and evolution of the wind generated waves as observed.

The particular interest of this new method is that the energy can be produced while maintaining the stored water. The existing electrical plant facilities at dams can be used to inject the electrical production into the network after deploying the needed adaptations.

The preliminary power calculation shows that this surface motion presents an important field given the extent of the surface of the ponded water at dams.

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