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Investigate air turbines performance for power generation by tidal waves in the river: A review

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ABSTRACT: The phenomenon of climate change resulting from the increase of global warming has become one of the main problems facing the world. Where researchers and specialists have worked for many years to find a solution that reduces this phenomenon and limits its risks. Clean energy is likely an alternative to fossil fuel sources, which are the main source of global warming. One of the clean energy sources is ocean wave energy, which is a huge and untapped energy source, despite the possibility of extracting large amounts of energy from waves. This paper focuses on the study of deep-sea turbines and their results. A study was conducted on the capture chamber. The turbines are driven and generate electricity by using a wave energy harvesting system (oscillating water column). Reaction turbines (impulse and Wells turbines) are tested and evaluated for performance in an oscillating water column system. Reaction turbines have a narrow operating range, and higher peak efficiencies. In contrast, turbines that have a greater operating range and lower peak efficiency are impulse turbines. Wells stator turbine has the highest efficiency while a variable pitch axial impulse turbine has the widest operating range. Better efficiency possessed by turbines with optimized geometry than other turbines.

Keywords: Wave energy, Air turbine, performance, power generation

1. INTRODUCTION

Climate pollution and electricity demand, in addition to high diesel prices, are among the main reasons that encourage the use of renewable energies [1]. It has been proven that -one-third of the world's population does not have access to electricity but has the means to get it [2].

Renewable energy of all kinds provides clean and effective energy by reducing greenhouse gas emissions and providing job opportunities in addition to economic development [1]. Among the forms of renewable energy are the seas and oceans, which store energy in the form of thermal energy, tidal energy, and others. The possibility of using the energy of pecan waves can cover a large part of the electricity consumption.

The concept of collecting and using ocean energy was not new as the (WEC) wave transducer was used in 1799 and was patented [3], and the first practical form of using wave energy was by Y Masuda when he used ocean waves to power navigation buoys. Ocean wave energy has the second largest potential among all ocean renewable energy sources [7], and despite differing opinions, some studies have determined the amount that can be exploited as 10 – 20% of the total potential. [8]

OWC is a type of (WEC) [9] transducer which is one of the ways that are used to extract energy from ocean waves. These systems are one of the solutions to the current problems of energy and an alternative to the use of fossil fuels [11]. Mutriku station is the only commercially powered OWC station in the world now. This system consists of two main components: a concrete chamber and a turbine generator set that converts wave energy into electricity [12]. A partially submerged structure is constructed, where the trapping of air above the surface of the free air depends on the submerged part under the surface of the water, the air moves within the inner surface according to the oscillating movement of water

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that drives the turbines placed across it. The original design of the flow chamber could be detrimental to the operation of the turbine due to water mist from the jet air on the water-free surface. It has been suggested that the air passage be designed to be as smooth and short as possible to prevent poor flow distribution that seriously reduces turbine efficiency [13]. A horizontal baffle plate was used to drain air from the turbine, and its effectiveness has been proven. These systems are affected by wave direction as well as water depth.

Nomenclature

η_{owc} is the total efficiency of OWC.
η Profile of wave.
ρ is density.
P_{OWC} dynamic pressure in OWC.
V_o air volume at the free surface at rest in the chamber.
γ constant specific heat volume and pressure.
E is the power of OWC.
P_2 is the orifice air pressure.
P_0 is air pressure outside the system.
A_2 is the orifice column area.
V_2 is air flow speed around the orifice.
Q_2 air discharge in Orifice.
H the wave height.
t time.
T Wave period.
k the wave numbers.
λ the wavelength.
ω the angular frequency.
a: the amplitude of wave.
d Water depth.
$\vec{F}$ the force vector.

1.1 hydrodynamic pressure and OWC hydrodynamics

Since the 1970s, the free inner surface was considered a weightless solid piston to determine the hydrodynamic pressure in OWC, which is a simple model. The equation of motion, as did Sykes, has been used to describe the behavior of OWC [15], as the pressure on the free surface is assumed to be zero and pressure constant across S at z=-L:

$$\rho S(L+\eta_{owc})\eta_{owc} + \rho S_g \eta_{owc} = SP_{owc} \qquad (1)$$

Where ρ is density, η_{OWC}(t) and P_{OWC}(t) are the height of the free surface of the water column and dynamic pressure in OWC. These models ignore the spatial differences of the inner free surface and therefore will only be appropriate when the diffraction pressure is zero across the horizontal plane.

Pressure distribution theory which was formulated by Falcao [4] and generalized by Evans [5], is the second method for evaluating hydrodynamic behavior in OWC. This theory allows for an accurate description of the free inner surface. Some equations that govern the behavior of OWC are mentioned which are still in the potential flow framework:

(1) Equation of air mass conservation:

Using the Sarmiento method of Falcao (1985), which postulates the theory of equal evolution. This theory assumes equality and the following expression is used for the evolution of the air volume in a chamber Chatry:

$$q^t(t) = \frac{-dV(t)}{dt} - \frac{V_0}{\gamma p_a}\frac{dp_{(t)}}{dt} \qquad (2)$$

Where: Vo air volume at the free surface at rest in the chamber, $dV(t) \ / \ \mathrm{d}t$ is the hydrodynamic flux of volume, $V_o \ / \ \gamma p_a$ Air Compression Effect (pa: atmospheric pressure, γ: constant specific heat volume and pressure).

(2) Equation of governing for devices OWC:

Hydrodynamic volume flow using the above decomposition into a problem of diffraction radiation, and this equation allows modelling of the behavior of OWC:

$$q^t(t) = q^D(t) + q^R(t) - \frac{V_o}{\gamma p_a}\frac{dp(t)}{dt} \qquad (3)$$

A significant improvement in OWC performance can be achieved by improving turbine rotational speed control as well as improving rotor diameter as demonstrated by Falcao [3].

1.2 Calculating Wave Energy Using an Oscillating Water Column (OWC)

There are many things to know before calculating the energy of a wave in the model, including the ocean energy of wave potential, chamber dimension, the gravity of the earth, and the specific gravity of the wind [4]. To calculate the wave energy, the following equation is used:

$$E = (P_2 - P_0)A_2V_2 \qquad (4)$$

Where E is the power of OWC, P_2 is the orifice air pressure, P_0 is air pressure outside the system, A_2 is the orifice column area, V_2 and is air flow speed around the orifice.

To get parameters in the above equation we use the following equations:

$$V_1 = \frac{\omega}{2}H\,sin(\omega t) \qquad (5)$$

$$V_2 = \frac{A_1}{A_2}V_1 \qquad (6)$$

$$P_2 = P_0 + \rho\left(\frac{A_1}{A_2}\right)\frac{d\phi}{dt}\ \rho\frac{Q_2}{A_2}(V_2 - V_1) \qquad (7)$$

Power of electrical generated from energy wave can be to calculate, use the following equation:

$$\mathrm{P}_{owc} = \frac{\rho g^2}{64\pi}H^2Tw\eta_{owc} \qquad (8)$$

Where P_{owc} is electrical power, H is wave height, T is wave period, w is chamber width.

The total efficiency of an (OWC) is the product of the sum of the efficiencies of the generator, chamber, and turbine used in the (OWC) system. According to several studies, 0-20% is the total efficiency of the (OWC) of the system from the total potential energy generated by the waves, depending on the height of the wave and its period [5].

$$\eta_{owc} = \eta_t\eta_p\eta_g \qquad (9)$$

Where η_{owc} is the overall efficiency of OWC, η_g is the efficiency of generator, η_p is the efficiency of chamber, η_t and is the efficiency of turbine.

2. Wave Modeling

Profile of wave (η) and (H) water height may be given by

$$\eta = \frac{H}{2}\cos(kx - A\omega t + B) \quad (10)$$

Where vector of a wave $k = 2\pi / \lambda$, $\omega = 2\pi / T$. Denotes the depth of the water d and the horizontal wave x:

$$\omega^2 = kg \cdot \tanh(kd) \quad (11)$$

$$\lambda = \frac{T^2 g}{2\pi} \cdot tanh(kd) \quad (12)$$

Wave mirrored image without delay influences the effects in each experimental and numerical wave tank. It is essential that forcing or damping situations on the limitations are correctly implemented in VOF modelling. By this means, wave oscillations and reflections may be decreased across the limitations. While diverse damping/forcing strategies may be implemented on a numerical wave tank the results of those strategies had been now no longer significantly studied in the gift study. Instead, the damping duration, x_d, turned into decided to be identical to the wavelength from the opening boundary to the fine x-direction. It may be mentioned that the handiest small reflections are seen at x_d=λ in which the damping duration is identical to the wavelength.

3. Turbines

OWC plants must be equipped with air turbines such as (Wells turbines, radial turbines, Savonius turbine, and impulse turbines) [6]. Air turbine conventional is used to convert a secondary part of the energy into an OWC wave transducer, but in large energy of a wave, such systems cannot be adopted because the valve becomes large. If self-correcting air turbines are used, no correction valve is required to convert wave energy.

Impulse turbines with steering rotors actively controlled using a hydraulic actuator have been proposed and selected [7]. The authors have also proposed a radial turbine with actively controlled steering vanes to convert the energy of waves [8] but according to the latest research, the efficiency of the turbine is not good [9].

The features of air turbines for converting the energy of waves were studied through numerical simulation and offshore experiments under the condition of irregular flow and it has been found that turbine impulse type could outperform well turbine [6]. The performance of a unidirectional impulse turbine has been experimentally under steady flow conditions using a piston with a wind tunnel [10]. The unidirectional turbine has shown good efficiency over a wide range [11]. The authors have suggested with twin turbines are using a new topology that promises to produce 50% of the wave -to-wire efficiency of the OWC [12].

OWC stations must be equipped with self-correcting turbines which can maintain the same direction of rotation regardless of the direction of the air. Among these turbines, well turbines are the most common and over many years, designs have been developed to eliminate their flaws and make them better than conventional turbines such as by reducing noise, and increasing efficiency [13].

With much research and experiments conducted to improve the efficiency of the turbines used in OWC, it was found that the thrust turbines are more suitable for the sudden rise in wind power and their efficiency is up to 75% [14]. In power plants, two types of turbines are used across Europe, Japan, Korea, and India well turbines and impulse turbines [15][12].

3.1 Wells Turbine

A Wells turbine is an axial flow reaction turbine used specifically to harvest wave energy using an oscillating flow of air. A Wells turbine is always rotating in the same direction and a low-pressure air turbine, regardless of the direction of the oscillating airflow. It is a self- rectifying axial air turbine. Its blades have a symmetrical profile, the plane of symmetry of which is in the plane of rotation and perpendicular to the airflow. Self- rectifying air turbines are used to extract power from the mechanical transmission. The velocity of the blade tip determines the rotational speed, which approaches the speed of sound. An electric generator is coupled to the turbine which works with or without vanes of guide. became synthetic as proven in Figure .1.

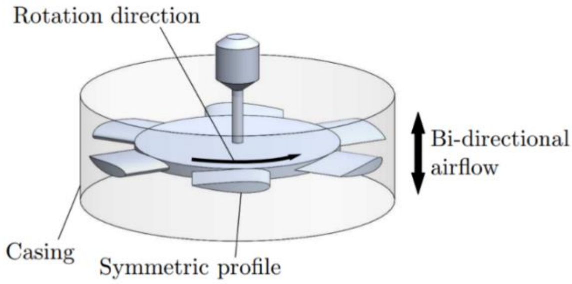

FIGURE 1. **- Photograph of the turbine model**

3.1.1 Operation Cycle

The Well Turbine duty cycle is divided into two phases based on the operation of the OWC. First, the compression stage, in which the water level in the casing rises, see Figure (2) (a). The resulting aerodynamic force $F_R$from the lift (L) and drag forces (D) is given by:

$$F_R = \sqrt{L^2 + D^2} \qquad (13)$$

This force can be broken down into two components in the axial and tangential directions in terms of lift and drag components [16]:

$$F_A = L\,cos\,\alpha + D\,sin\,\alpha \qquad (14)$$

$$F_t = L\,sin\,\alpha - D\,cos\,\alpha \qquad (15)$$

Second, the suction phase, where the water level falls, the air is sucked into the canal, and a similar velocity and force analysis as shown in Figure (2) (b) can be presented. Figures (2) (a) and (2) (b) show that the axial force reverses direction, while the tangential force maintains the same direction during both phases. For a symmetrical aero foil section, the direction of F_t remains the same for both negative and positive value α. The aileron blades are adjusted around the axis of rotation. Regardless of the direction of the air flow, the rotor rotates in the direction of F_t, up and down strokes.

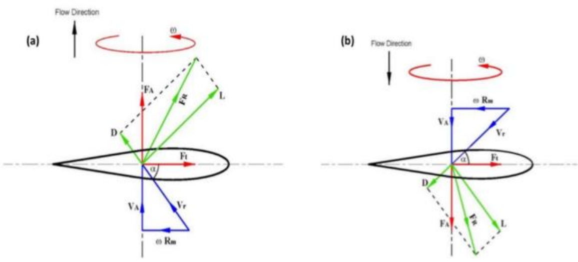

FIGURE 2. **– Forces of Aerodynamic (a) compression stages (b) suction stages**

3.1.2 Performance Parameters of Well Turbine

Several factors influence the design and thus the performance of the well turbine. Optimizing and improving these parameters is mainly aimed at overcoming the existing weak points in the system. Among the disadvantages of the Well turbines are: low tangential force, resulting in low turbine power output; high axial force; low aerodynamic efficiency; and limited range due to stalling. This section of the article aims to review efforts to overcome these shortcomings and improve performance by controlling design parameters.

One of the factors affecting the performance of the Wells turbine is the tip clearance and vane angle. Some research has been conducted to study the effect of vane angle on the efficiency of Wells turbines, one of these studies Halder and Samad (2014). For a given (NACA 0021) 11.8° guide vane angle for maximum efficiency. Effectiveness is maximum at 1% tip clearance [16]. In addition, a circumferential groove [17] with a groove depth of 3% of the chord length ensures maximum power and the largest working range. With this method, an efficiency improvement of 26% is already achieved for a specific operating point [18].

3.2 Impulse turbines

The main difference between impulse turbines and reaction turbines are the way the power is transferred to the rotor. Depending on the direction of air flow, impulse turbines are divided: radial and axial. The impulse turbine can be designed as a turning turbine with blades on both sides of the rotor. The turbine is given a "thrust" by airflow deflected the guide rotor blades. Regardless of the direction of airflow, the turbine always rotates in the same direction due to the symmetry of the rotor blades (figure 3). This type of turbine is also known as a self-healing turbine. In addition, vanes can be rigid, self-steering, and connecting [16].

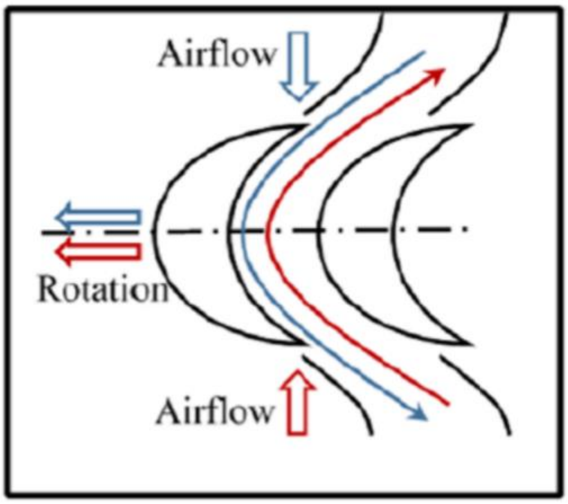

FIGURE 3. - diagram of the flow through impulse turbine

3.3 Comparison of impulse turbine with wells turbine

Aerodynamic losses are one of the major drawbacks of the impulse turbine, due to the high angle of the airflow near the lower row of the blade [16]. One comparison between the two types is that Wells turbines have a smaller radius than impulse turbines. For impulse turbines, performance efficiency is more than 50% (Figure 4). Efficiency goes down dramatically when a shutdown occurs at higher flow rates in the case of Wells turbines. It is suggested to change the vane geometry to reduce losses. (Figure 4) shows a comparison of the two types of turbines in terms of efficiency at different flows. Changing the Reynolds number has a significant effect on the efficiency of the Wells turbines, according to the Falcão and Gato analysis (2012). Compared to the efficiency of the impulse turbine.

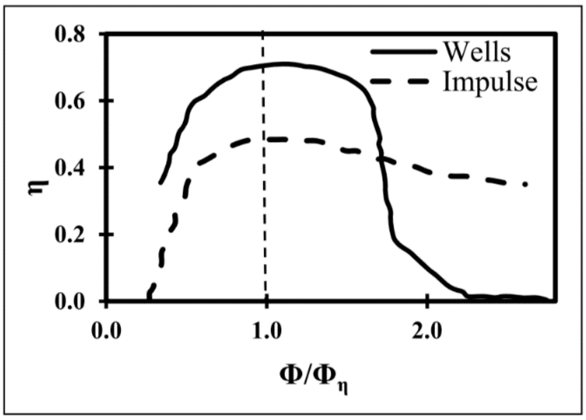

FIGURE 4. – Comparison of impulse and Wells turbines in terms of efficiency

3.4 Air turbines Optimization

To find the best solution using qualitative and effective quantitative methods, a mathematical process known as optimization is used. Where some literature presents the behavior of some turbines in addition to the interpretation of performance. Significant performance improvements can be made by optimizing the entire system with modern computational methods.

To improve efficiency in air turbines optimization is used. The literature on optimizing wave energy systems is limited. Optimization here, using different algorithms to numerical optimization, as opposed to trial and error. In the past, some authors have developed an optimized OWC air turbine geometry that exhibits superior performance over traditional turbines. In this section described the optimization methods used in air turbines.

Badhurshah and Samad (2015) performed many genetic replacement algorithms based on the MOO algorithm on pulsed turbines to improve efficiency. A design variable is the number of blades and vanes, and the goal was to minimize pressure drop and maximize turbine shaft performance. In this study, efficacy increased by approximately 11% (Figure 5). The efficiency can be increased to 13% by optimization of the impulse turbine, according to a study by Badhurshah and Samad (2014). As shown in (Figure 6).

Using a genetic algorithm or numerical analysis (CFD) to evaluate performance, the system can be optimized, as in the study of researcher Mohamed (2011). The production rate is increased to 11.3% due to the improved of the shape the of the blade (figure 7), and the total efficiency increase of 1% over the entire range of operating. A significant improvement in turbine efficiency occurs for the same algorithm applied to asymmetric blades, according to a study by Mohamed and Shaaban (2014) [19].

Gomes uses two-step (2012) development method to optimize the 2D cross-section of axial vanes of impulse turbine. Optimized 2D slices are used across the spanwise to achieve the 3D geometry. Shows a 5% performance increase in the numerical analysis of the original and improved design. The optimum speed of the -Wells-type turbine was determined using the optimization technique according to the study by Halder and Samad (2016). To determine the optimal turbine speed for different flow rates a multiple replacement approach is used. Numerical analysis shows that a rotor with a groove depth of 3% performs better than a rotor with 1% endplay. To optimize the pitch of the blade, the modelling technique was used, according to research by Halder et al (2017). The optimized blade of the turbine has a backward movement in the middle part and a forward movement in the tip part [20]. With the optimized geometry, the working range by 18.18% and the torque ratio increased by 28.28%. In order to improve the performance of the air turbine optimization methods have been applied. Full 3D optimization can give a more accurate result but is more complex and numerically expensive.

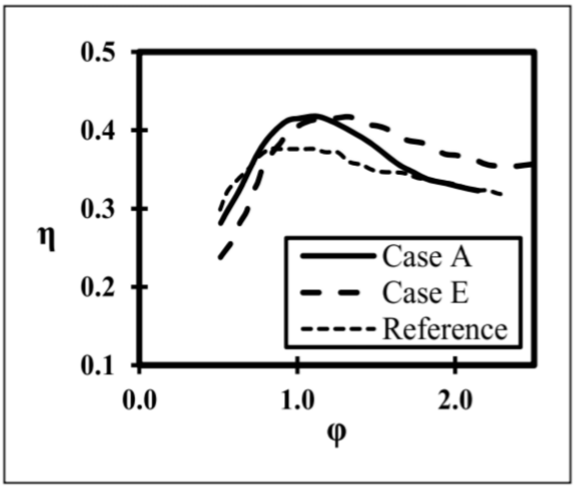

FIGURE 5. - Comparison of efficiency between Badhurshah and Samad (2015) and differently optimized

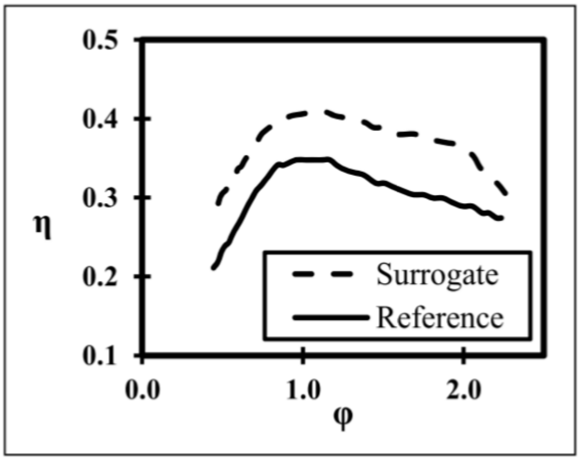

FIGURE 6. - Comparison of efficiency between Badhurshah (2014) and surrogate predicted mode

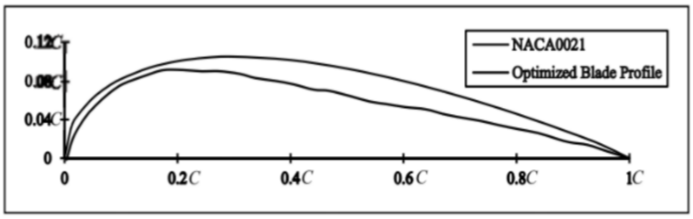

FIGURE 7. - Comparison of the optimized blade and NACA0021 profile

4. Conclusions

In contrast to previous reviews, this paper focuses on optimizing the air turbines used in OWC with an overview of the air turbine parameters. We hope this article helps OWC optimization researchers to get acquainted with additional information. These are the main findings of this paper: Most air turbine work has considered the geometry of turbines. The hydrodynamics of the OWC affects the performance of the air turbines. An analysis of the effectiveness of air turbine OWCs is proposed as future research, the turbine optimization of (OWC) is one of the areas covered in the study.

A Wells turbine is an axial flow reaction turbine used specifically to harvest wave energy using an oscillating flow of air. A Wells turbine is a low-pressure air turbine and always rotates in the same direction, regardless of the direction of the oscillating airflow. While Impulse turbines are divided: radial and axial according to the direction of airflow.

The tip clearance and blade drag are the most important factors affecting the Wells turbines efficiency. The narrow nozzle spacing increases productivity by reducing wastage, while the wide nozzle spacing delays stalling and provides a wider operating envelope. Turbine efficiency is limited by stalling, and a wide operating range is favoured over efficiency of turbine in changing sea conditions, Impulse turbines required guide vanes to work with a bi-directional airflow. Variable pitch vanes outperform fixed vanes in a higher efficiency and wider operating range, Blade shape optimized for impulse and Wells turbines provide better performance than reference turbines.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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