Power Generation from Sea Waves Using Experimental Prototype of Wells Turbine or Suggested Special Rotating Mechanism

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***Abstract*—** Fossil fuels is the main pillar of effective industrial progress. Unfortunately, rapid depletion of fossil fuels and emission of harmful gases are a major concern. Thereby, renewable clean energy has attracted most countries attention over the last fifty years in order to fill the gap between their rapidly increasing demand and available energies in addition to providing good environmental usage. Cheap electricity can be generated using a suitable device for wave energy conversion. This paper gives a comprehensive overview of wave energy converter as the oscillating water column device. This device consists of a suitable chamber at the coast which is totally closed except its base is open area for collecting the sea waves. Motion of sea waves pushes an air pocket up and down inside the device chamber. Hence, air flow passes through a suitable air turbine as wells turbine. Also, air can be compressed inside a piston to thrust its shaft for driving the chain of suggested special mechanism which has continuous rotating motion driving a suitable generator. As well as, this paper seeks to enhance investigation of theoretical and experimental results through building a suitable experimental prototype.

***Keywords*—** Renewable Energy, Oscillating Water Column, Mechanisms, Welles Turbine.

I. Introduction

Fossil fuels can be considered the major source to meet the world energy requests but rapid depletion of fossil fuels are of major concern. Clearly, this problem can be treated through the clean renewable energy but improving its usage needs sufficient time to meet the future challenges [1]. Some countries in Africa and middle east region are somewhat modest in their resources of conventional energies (coal, oil and natural gas) as Egypt comparing with most of the middle east countries. Furthermore, past few years showed the increasing of an average yearly fossil fuels expenditure. For assuring the sustainability of energy supply in long term, exploiting secondary sources other than oil must be the challenge of these countries. Another resources as solar, wind and sea waves energies can fill the gap between the increasing demand and available energies in countries have poor in conventional energies. At least 15% of the energy consumed across the world is produced from the renewable energy as solar, wind and sea waves [2].

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It is well known that, the effective solar energy is available for around eight hours daily hence, the solar energy conversion devices can work effectively with a high performance while on third of sunny seasons yearly. Also, the effective strong wind energy is not available with the same manner through the whole day, hence, wind turbines have unstable performance through daytime and different seasons. On the other hand, the effective energy of sea's waves is available through most of daytime and different seasons, hence, devices which converts the motion of seas waves into electricity can work effectively better than solar or wind energy conversion devices.

Renewable clean energy can be produced using seas wave's motion as electricity generation from wave energy conversion, tidal motion and temperature differences between the warm surface waters and cold deep waters. Furthermore, different ideas dealing with seas waves as the wave power conversion systems for electrical energy production purpose which are presented in [3]. Another idea dealing with the wave shoaling phenomenon as the new method for extracting ocean wave energy utilizing the wave shoaling phenomenon which is presented in [1].

Clearly, the installed devices in the seas coasts must have high endurance which leads to long life time. Moreover, there are many trials through the last fifty years to design an effective devices for energy generation from oceans and seas waves but several of these devices failed due to the aggressive environment of oceans and seas. For this reason, researchers till now has not yet settled down to design suitable economical basic devices regardless of long technological researches [4].

Some developing countries tried to fill the gap between their demand and available energies through the use of sea waves energy as the project obtained dealing with station design simulation to produce electricity from sea waves [5]. Moreover, suitable mechanisms can be used for converting the sea wave's motion into mechanical energy. Also, many kinds of devices for sea wave power extraction to electrical energy are presented in [3], [6]. These devices are depending on the ideas of the oscillating bodies system, underwater pneumatic system, wave dragon system and the oscillating water column system. Moreover, the device dealing with the idea of the oscillating bodies system has a submerged oscillating cylinder consists of two parts, the lower part is moored to the seabed and the upper is the float part can move according to sea wave's motion inside the other part through a guide causing relative motion between two parts which can be converted into electrical energy [7-10].

As well as, the device dealing with the idea of the pneumatic system consists of four long cylindrical bodies which are linked by hinged joints in addition to a pump of high pressure fluid to activate hydraulic motors through smoothing accumulators for driving the connected generator [11].

The device which is dealing with the idea of wave dragon system consists of two large arms that emphasis waves up a ramp into a reservoir. Therefore, the force of gravity makes the water returns to the sea through a suitable turbine which drives a generator [11].

The of oscillating water column device (OWC) which can be built at the coast consists of a suitable chamber which totally closed except its base is open area for collecting the sea waves through inclined inlet. The sea wave's motion can push an air pocket up and down compressing the air inside the chamber behind a breakwater. Thus the pushed air could passes through an suitable air turbine can be fixed beside the top of the chamber. As well as, air will pass through the turbine in the opposite direction as a suction effect when the water of wave returns back to the sea. Therefore, this turbine must be designed to turn continually in the same direction regardless of the direction of the air flow [3], [11]. The wells turbine is the best option for this task where it rotates continuously in the same direction. [12].

Clearly, the device (OWC) is economical device especially for developing countries where this device can be fixed beside the coast far from the deep water of seas. Hence, establishing this kind of devices is not complicated and it has a moderate establishment cost. As well as, it has low running maintenance cost in addition to its attractive environmental impact [13].

Moreover, analysis of (OWC) device is presented in this paper in order to generate electricity from sea wave's motion using wells turbine or through using a suggested mechanism which has continuous rotation. Design for a suggested prototype and building small system to convert the wave energy from sea waves are introduced.

II. System Analysis And Modeling

A. Formation of Sea Waves:

Gravity forces, wind intensity and sea surface tension can be considered as the main factors affecting the wave's forming. Propagation of sea waves is shown in Fig. 1 as follows;

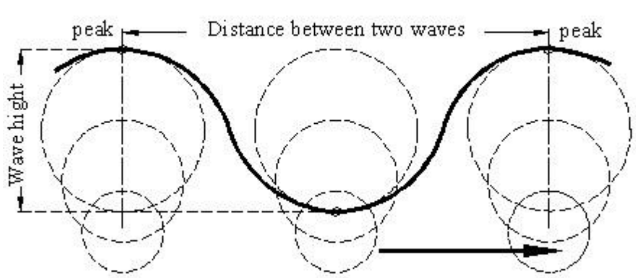

Fig. 1 Propagation of sea waves

When the water particles moved by the effect of wind, it have a circular trajectories with gradually decrease diameters where its highest occurs at the sea surface and diminish with depth of water [3]. The displacement of the water surface at a certain point is presented in [14], [15] as follows;

$$x(t) = \frac{h}{2} \sin (\Omega t - \sigma) \tag{1}$$

Where, (Ω) is the frequency of the wave, (t) is time, (σ) is a phase shift and (h) is the maximum height of wave which is the double of its amplitude as shown in Fig. 2 which indicates wave length (λ) and wave front (L) as follows;.

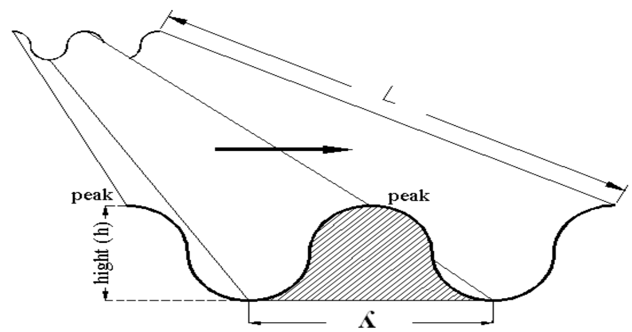

Fig. 2 Geometry of sea wave

The frequency of the wave (Ω) equals to ($2\pi/T$) where (T) is the wave period. The cross section area (A_w) of the effective sea wave is approximately half area of rectangle has sides (h) and (λ) as follows;

$$A_w = \frac{1}{2} h \lambda \tag{2}$$

Hence, the volume (V_w) of moving wave can be formulated as follows;

$$V_w = \frac{1}{2} h \lambda L \tag{3}$$

Also, the sea wave's speed (v_w) can be written as;

$$v_w = \frac{\lambda}{T} \tag{4}$$

The kinetic energy (E_w) of sea waves can be written as follows;

$$E_w = \frac{1}{2} M_w v_w^2 \tag{5}$$

Where, the mass (M_w) of moving wave' water equals ($\rho_w V_w$) and (ρ_w) is the density of sea salt water (ρ_w=1025 Kg/m^3).

B. Power Estimation of Sea waves:

Ocean waves are important sources for generating energy. The power (P_u) over a unit width of wave front (L) which accompanied with a wave of maximum height (h) and wavelength (λ) is presented in [7], [16] as follows;

$$P_u = \frac{\rho_w g^2 h^2 T}{32\pi} \tag{6}$$

Where, g is the gravity acceleration, g=9.81 m/s^2.

Suppose that, the inlet of device chamber is one meter width means that (L) equals one meter, in addition to one meter maximum height of wave and the period of this wave is one second. The pervious data leads to generate power equals to 980.8 (W) largely associated power with only one meter of moving sea wave through only one second. Thereby, using clean power of sea waves can fill the gap between the demand and available energies in countries which has a long coasts.

C. *Air Flow Speed Inside OWC Chamber:*

The of oscillating water column device (OWC) includes a chamber which is totally closed except its base is open area for collecting sea waves through inclined inlet is shown in Fig. 3 as follows;

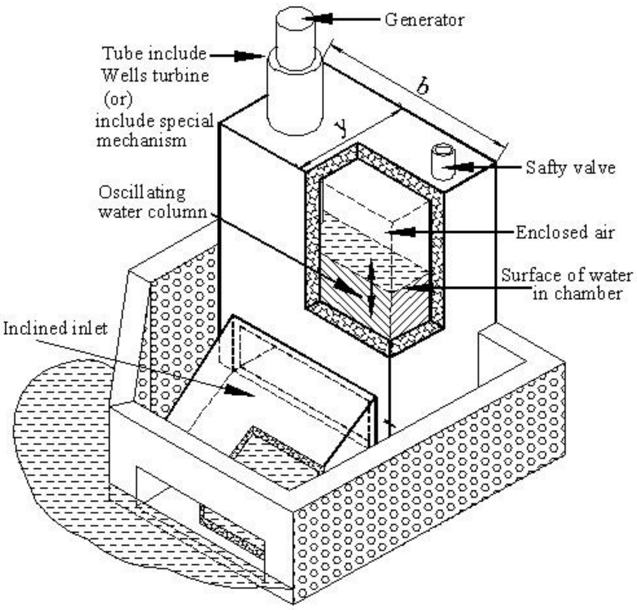

Fig. 3 OWC device

The water column rises in the OWC chamber with a speed (v_i) as a result of collecting water of volume (V_w) inside it. The increasing volume (V_i) of water column equals ($A_i\, v_i$) where (A_i) is the cross section area of OWC chamber. The increasing water volume (V_i) of oscillating water column equals the collected water of volume (V_w) as follows;

$$\mathrm{V}_i = \mathrm{V}_w \tag{7}$$

The pervious relation can be rewritten as follows;

$$y\,b\,v_i = \frac{h\,\lambda\,L}{2} \tag{8}$$

Therefore, the speed (v_i) is given by;

$$v_i = \frac{h\,\lambda\,L}{2\,y\,b} \tag{9}$$

D. *Air Flow Speed Inside Wells Turbine:*

Clearly, the air pocket moves up and down above the oscillating water column according to thrusting and suction actions of waves inside OWC chamber. Hence, the wells turbine which is shown in Fig. 4 can be considered the best option for giving continuous rotating motion in the same direction regardless of the direction of the airflow. Wells turbine has some disadvantages as high noise level and low efficiency. Hence, many of previous studies are presented dealing with improving wells turbine efficiency through selecting its effective dimensions and geometrical parameters as in [17].

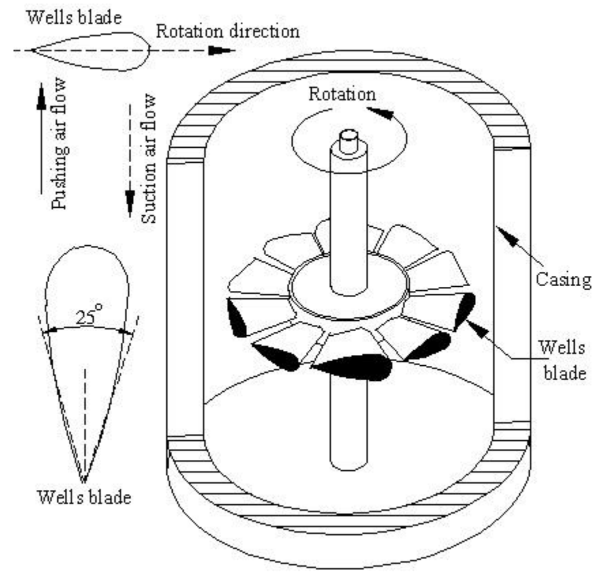

Fig. 4 Wells turbine

The volume (V_o) of air which passes through the turbine tube of diameter (D_t) equals the increasing volume (V_i) of oscillating water column as;

$$\mathrm{V}_o = \mathrm{V}_i \tag{10}$$

The pervious relation can be rewritten as follows;

$$\frac{\pi}{4} D_t^2\, v_o = y\,b\; v_i \tag{11}$$

Therefore, the speed (v_o) is given by;

$$v_o = \frac{4\,y\,b}{\pi\,D_t^2} v_i \tag{12}$$

Power (P_t) of wells turbine is depending on the air flow velocity in addition to the turbine parameters as in [10], [18]. Clearly, the power (P_t) can be given as follows;

$$P_t = \eta_t\,\eta_c\,P^* \tag{13}$$

Where, (η_t) is the turbine efficiency, (η_c) is the efficiency of OWC chamber and power P^* is the power which can be associated with water volume (V_w) of sea wave equivalent to the increasing water volume (V_c) of the oscillating water column inside OWC chamber. Water volume (V_c) equals (ybh_c) where (h_c) is the changing head of the oscillating water column inside OWC chamber. Hence, the following formula can be written as;

$$\frac{1}{2} h\,\lambda\,L = y\,b\,h_c \tag{14}$$

By assuming that (λ=2π h), the maximum height (h_*) of equivalent wave of one meter front (L) can be given as;

$$h_* = \sqrt{\frac{y\,b\,h_c}{\pi}} \tag{15}$$

Hence, power P^* can be given as;

$$P^* = \frac{\rho_w g^2 h_*^2 T}{32\pi} \tag{16}$$

As well as, flow rate coefficient (ϕ) which is the ratio of axial air velocity (v_o) and rotor tip speed ($0.5\omega D_t$), where (ω) is the angular velocity of the wells turbine axis. Hence, ϕ can be written as presented in [19], [20];

$$\phi = \frac{v_o}{0.5\omega D_t} \tag{17}$$

Hence, the angular velocity (ω) can be given by;

$$\omega = \frac{v_o}{0.5\phi D_t} \tag{18}$$

Relation between flow rate coefficient (ϕ) and wells turbine efficiency (η_t) of four blades of NACA0021 aerodynamic profile of wells turbine is presented in [20].
Torque (T_t) at the turbine axis is giving by;

$$T_t = \frac{p^*}{\omega} \tag{19}$$

Special mechanism which can be used instead of wells turbine in OWC device is shown in Fig. 5 as follows;

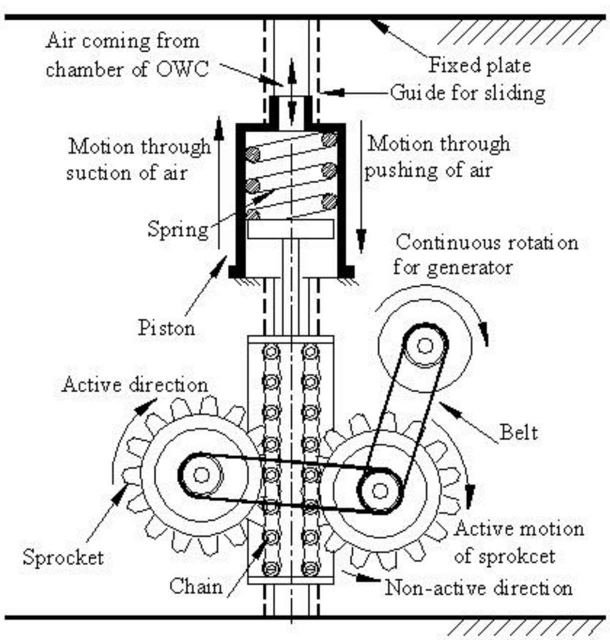

Fig. 5 Special mechanism

The special mechanism consists of a sliding reciprocated block carries chain gives a rotation motion to the two sprockets. These sprockets are similar to sprockets types which are using with air bicycles. This type of sprocket has a positive action rotates its shaft through a certain rotation's direction but it freely rotates without driving its shaft in opposite rotation's direction [21].

The positive action's direction of the first sprocket in inverse direction of the second one. Hence, one sprocket has a positive action through the forward stroke of sliding reciprocated block and the other sprocket has its positive action during reverse stroke of sliding block. Therefore, generator shaft has continues turning through belt transfers turning motion from first sprocket to its shaft in addition to another belt between two sprockets. The piston shaft gives the reciprocated motion to the sliding block where this motion of piston's shaft comes from the up and down motions of air pocket inside OWC chamber.

Using Bernoulli's principle and neglecting the head difference, the changing of air pressure (Δp) inside the piston can be written as follows;

$$\Delta p = \frac{1}{2}\rho_a v_o^2 \tag{20}$$

Where, ρ_a is the air density, ρ_a=1.225 Kg/m^3. Hence, thrust force (F_p) of piston has cross section area (A_p) is giving by;

$$F_p = A_p \Delta p \tag{21}$$

Thus, the torque (T_g) at the generator axis is a function of force (F_p) and generator pulley diameter (D_g) as follows;

$$T_g = \frac{1}{2} F_p D_g \tag{22}$$

III. Experimental Prototype

Model testing beaker is an important stage in the development of wave energy converters. Many of previous theoretical and experimental studies are dealing with improving oscillating water device through testing its prototype as [22-24].

The prototype design of small system to convert the wave energy from waves is shown in Fig. 6 as follows;

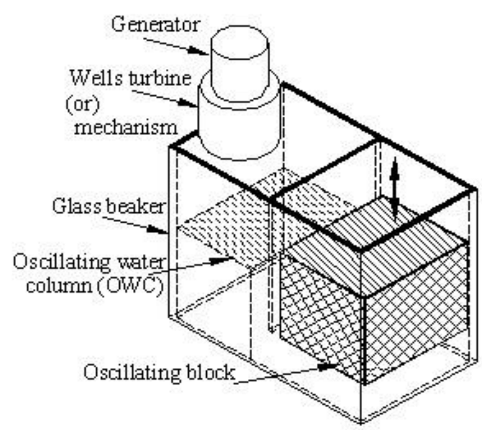

Fig. 6 Design of prototype

Small prototype system which built is shown in Fig. 7. The prototype consist of glass beaker of approximately 40 cm width, 75 cm long and 42 cm depth. This beaker has barrier at its middle with 30 cm depth. This beaker includes oscillating block which moves up and down in the right side of beaker to simulate the wave motion. A tube is supported above the other side includes wells turbine of four blades of NACA0021 aerodynamic profile.

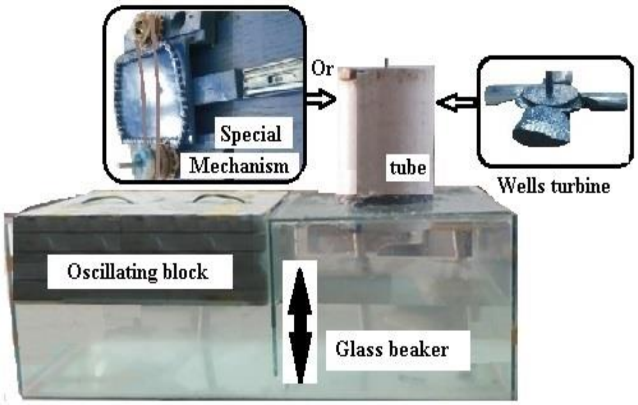

Fig. 7 Small prototype system

IV. RESULTS AND DISCUSSION

Speed (v_i) of oscillating water column in beaker calculated through measuring the changing column head (h_c) and its occurrence time.

The following data was used; η_t=55%, η_c=80%, g=9.81 m/s^2, ρ_w=1025 Kg/m^3, ρ_a=1.225 Kg/m^3, D_t=0.163 m, D_g=0.03 m, the area of oscillating water column in beaker is (0.1414m^2). As well as, four blades of NACA0021 aerodynamic profile is used in wells turbine. Hence, flow rate coefficient (ϕ) equals 0.11 which corresponds (η_t=0.55) in the relation which is presented in [20].

The relation between theoretical and actual torque to (v_i) using wells turbine is shown in Fig. 8 as follows;

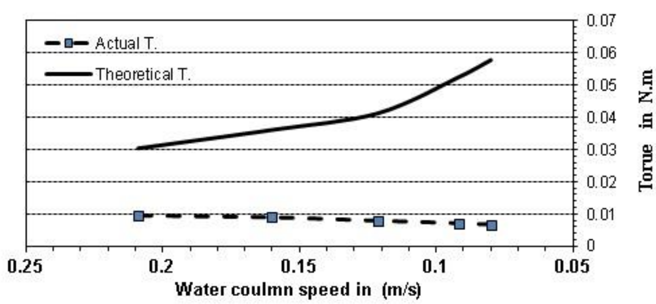

Fig. 8 Theoretical and actual torque using wells turbine

Curves of theoretical and actual torque have a convergence trend with increasing (v_i) as indicated in Fig. 8. As well as, the relation between theoretical and actual torque to (v_i) using special mechanism is shown in Fig. 9 as follows;

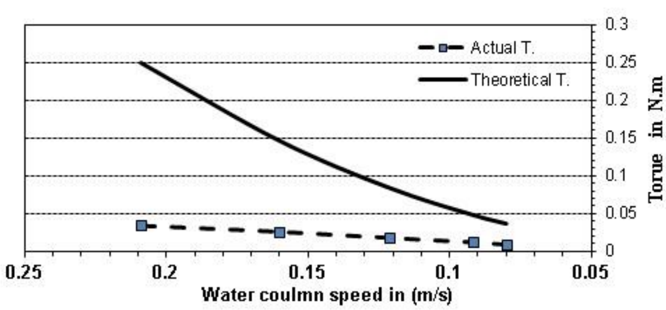

Fig. 9 Theoretical and actual torque using special mechanism

Curves of theoretical and actual torque have a divergence trend with increasing (v_i) as indicated in Fig. 9.

V. CONCLUSION

Operating and maintenance costs of devices converting wave energy into electricity are not expensive where no fuel is required and no waste and harmful gases is emitted. This paper deals with analyzing and designing experimental prototype model depending on the idea of oscillating water column (OWC) which is suitable for work in countries have climate condition of moderate wave height and shallow water areas.

Obviously, the experimental results revealed that wave energy can be harnessed into convenient work to drive a suitable air turbine or providing a reciprocating motion to piston shaft for driving the chain of special mechanism. The efficiency of using wells turbine is lower than using the suggested special mechanism. Also, mechanism manufacture is easier than the turbine.

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