Guide Vanes Effect of Wells Turbine on OWC Wave Power Plant Operation

Ahmad Darabi and Payam Poriavali

Abstract—**This paper describes an introduction into ocean wave energy converter and it's impacts on power system. There are a lot of methods and systems for converting wave power into electrical power. The most common structure of wave power plant is Oscillating Water Column (OWC) plant. The turbine employed in OWC plant is normally Wells turbine. The Wells turbine has inherent disadvantages such as low efficiency, and poor starting characteristics. The objective of this paper is introduction of Wells turbine with fixed guide vanes in order to improve turbine performance. Modeling and computer simulation of OWC power plant components are presented and effect of out power fluctuation on power system is investigated.**

Index Terms— **Wave power plant, Wells turbine with guide vanes, Power fluctuations.**

I. INTRODUCTION

Ocean wave energy is a renewable energy source with a large potential that may contribute to worldwide increasing demand for power. First patent for wave energy exploitation dates back to 1799 in France and the first wave energy device was designed in 1960s in Japan. Science and engineering of wave energy conversion, started mainly after 1973, as the oil crises pushed forward the exploitation of all possible alternative forms of energy.

In general wave power plants could be classified into three categories consist of Shore Line Devices, Near Shore Line Devices and Off Shore Devices [1]. Shore line devices can be placed on sea bottom in shallow water. A popular shore line wave power plants is the OWC plant. Illustrative construction of the oscillating water column (OWC) shown in Fig. 1. Under wave action, water surface inside the chamber start to move up and down causing to inhale and exhale air through an opening at the top. The bidirectional motion of air is applied to the turbine and turbine drives an induction generator which is connected to the main via a distribution system [2].

Near shore devices are located in water of depths from 30 to 100 m where they can exploit the greater power density of the deeper waves. One kind of near shore devices is the Direct Drive Converter. This plant consists of a linear generator and floating body, following the water surface in the vertical plane. Fig. 2 shows the Direct Drive proposal, whereby the rotor is coupled directly to the buoy, and the stator is fixed on sea bottom. Under wave action, the rotor moves inside the stator so voltage is induced in the stator windings [3].

Offshore devices will be deployed in deep water so may exploit huge wave potential of open seas. One of off shore wave power plants is the Ocean Power Delivery (OPD). This plant is look like snake converting wave to electrical energy by hydraulic linkage system as shown in Fig. 3. It consists of four similar cylindrical bodies in series connected by three joints. There are a few hydraulic rams inside of each joint that the head and bottom of each ram are connected to end and head of two different cylinders. Under wave action, the cylinders pitch and yaw so hydraulic rams pump oil with high pressure to hydraulic motors via smoothing accumulators. Then the motors drive an electrical generator. The hydraulic ram works as a hand pump to inflate a tire. When hand pump moves up so air moves to cylinder and when it moves down, air is transferred to tire. In OPD plant, ram handle is linked to one cylinder and its body is connected to next cylinder so ram works with angle deviation between cylinders [4].

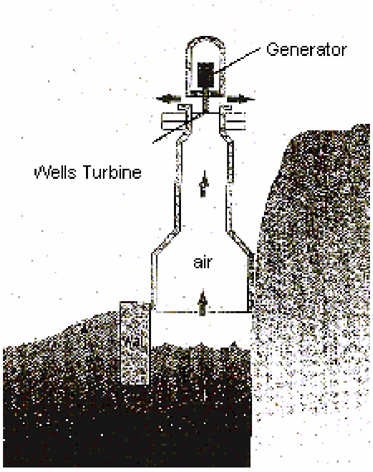

Fig. 1. Construction of Oscillating Water Column

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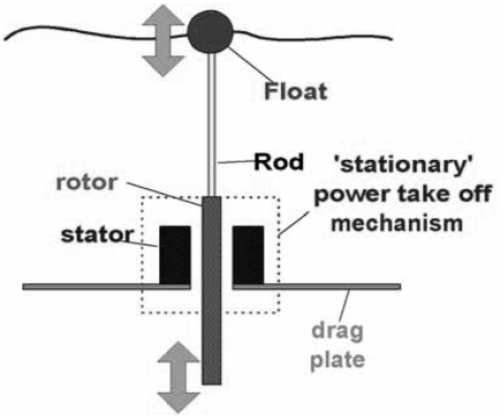


Fig. 2. Overall view of Direct Drive wave power plant

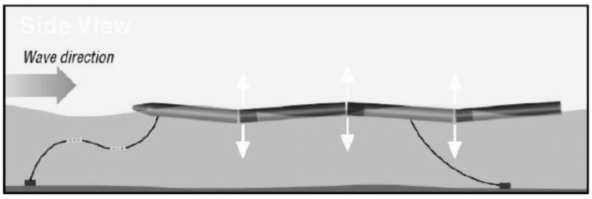


Fig. 3. Schematic of a Ocean Power Delivery plant

In this paper, modeling and computer simulation of OWC power plant components are presented and effect of output power fluctuation on power system is investigated. A common turbine for OWC power plants is Wells turbine. The Wells turbine has inherent disadvantages such as low efficiency, and poor starting characteristics [3]. The objective of this paper is introduction of Wells turbine with fixed guide vanes in order to improve turbine performance.

II. MODELING OF OWC WAVE POWER PLANT

A. Turbine Model

There are various type of turbines for wave power generation, but the Wells turbine invited by Dr. A. Wells in 1976 has become a centre of attraction because of its simple structure and easy maintenance. The most favorable characteristic of the turbine is that it is self-rectifying [3]. In order to improve starting characteristic and efficiency a Wells turbine with fixed guide vanes is applied. Guide vanes cause to improve turbine operation through air path determination. The profile of turbine with guide vanes is given in Fig.4. Turbine model is based on flow coefficient (φ) via torque coefficient (C_T) curve derived from experiment. The flow coefficient depends on air axial velocity through the turbine and mechanical angular velocity according to Eq.(1) while the torque coefficient determines turbine torque.

$$\varphi = \frac{V_A}{r \times \omega} \qquad (1)$$

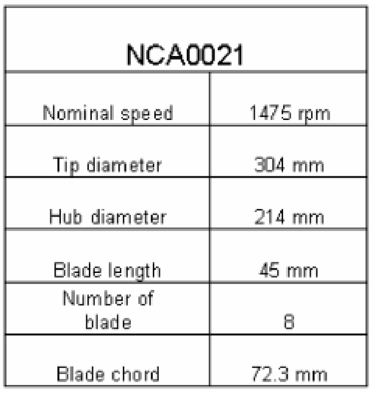
where V_A, r and ω are air velocity, turbine radius and shaft angular speed respectively. Output mechanical torque is calculated by:

$$T_T = K\ C_T (V_A^2 + (r \times \omega)^2) \qquad (2)$$

K is a turbine constant.

Figs. 5 , 6 show the effect of guide vanes from the view of torque and efficiency being of NACA0021. Turbine parameters are given in Table I and The guide vanes consist of 21 blades with a chord length of 59 mm, a chamber angle (θ) 70° and a stagger angle (ζ) 24° [5].

Table I
Turbine parameters



NCA0021	
Nominal speed	1475 rpm
Tip diameter	304 mm
Hub diameter	214 mm
Blade length	45 mm
Number of blade	8
Blade chord	72.3 mm

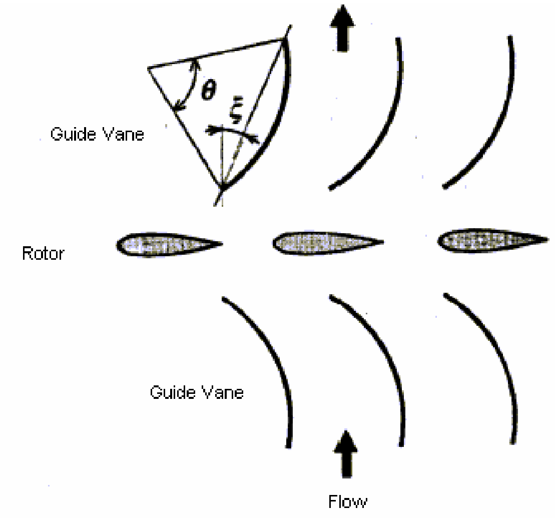


Fig. 4. The profile of turbine with guide vanes

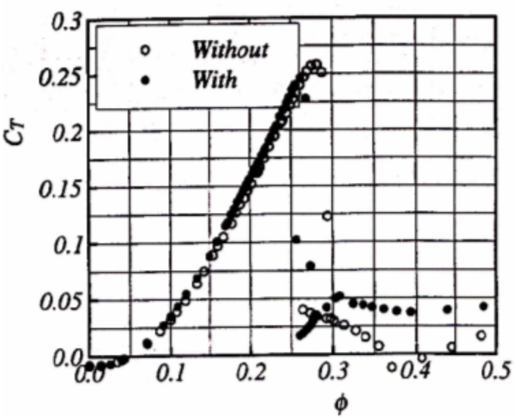


Fig. 5. comparison of torque coefficient between a turbine with and without guide vanes

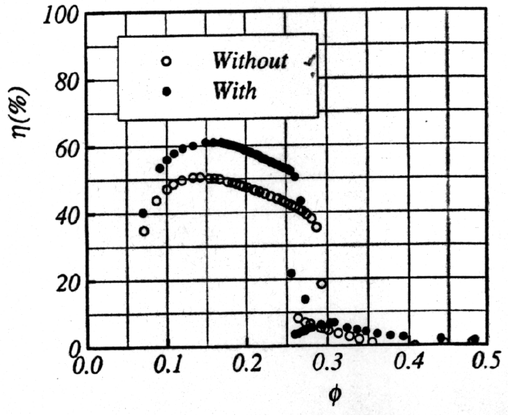


Fig. 6. comparison of efficiency between a turbine with and without guide vanes

B. *Water Column Model*

OWC chamber and wave modeling is required in order to calculation of air blowing velocity through the turbine. In a limited period of time it can be assumed that instantaneous height of water just outside the chamber changes periodically. Therefore water level variations outside the chamber $h_s(t)$ can be simulated easier by the first harmonic or a sinusoidal function as:

$$h_s(t) = H_S \cos(2\pi f t) \tag{3}$$

Where f is the wave frequency and H_S is the maximum water height outside the chamber with respect to mean level of sea water. A typical value for f is about 0.1 Hz. Chamber inlet pressure P in N/m^2 is described by:

$$P = \rho_s g(h_s(t) - h_c(t)) \tag{4}$$

In which ρ_s and g are water density e.g. $1000\ kg/m^3$ and gravity say $9.8\ m/Sec^2$ respectively. $h_c(t)$ is water height inside the chamber with respect to water mean level and can be described as below:

$$\frac{\partial h_c}{\partial t} = (\frac{A_T}{A_W})V_A \tag{5}$$

Where A_T and A_W are cross section of the turbine inlet and cross section of the water surface in the column respectively. Replacing equation 5 in 4, gives air pressure versus output air velocity as:

$$P = \rho_s g\left(h_s(t) - (\frac{A_T}{A_W})\int V_A(t)dt \right) \tag{6}$$

Equation 6 consists of two unknown parameters then another equation is required for unique response. Furthermore for each OWC power plant, equation of air pressure versus applied air velocity can be achieved by some experiments. A typical experimental equation is given as below [6].

$$P = 1.74\ V_A{}^3 + 39.71\ V_A \tag{7}$$

Thus air blowing velocity in m/Sec can be calculated using equations (6) and (7).

III. SIMULATION RESULTS

As mentioned earlier, guide vanes can be used with wells turbine in order to turbine efficiency improvement. In this section, effect of guide vanes on wave power plant operation is given and simulated using Simulink toolbox of MATLAB.

For this study, a wave power plant with mentioned parameters in previous sections which is connected to a distribution network via a transmission line is simulated. Wave power plant is also supplying 100 KW local load. The transmission line is modeled simply by 2 mH inductance. Basic machine parameters are given by Table II. Two simulations have been done for wave power plant without and with guide vanes respectively in the same input. In this simulation damping torque is neglected. Water height outside the chamber as a system input varies with the frequency of 0.1 Hz as shown in Fig.7. Simulation results are shown in Figs.8 through 16. Air blowing velocity through the turbine versus time graph is dependent on plant's structure and they are similar for both simulation modes as shown in Fig.8. The flow coefficient fluctuation is proportional to air blowing velocity through the turbine so flow confident curves are the same for both simulations as illustrated in Fig.9.

Table II
Induction generator parameters

reted power	voltage line-line	frequency	stator resistance	rotor & stator leakage inductance	magnetizing inductance	pole number	rotor inertia
30 hp	380 V	50 HZ	0.11 Ω	0.8e-3 Ω	20e-3 Ω	4	1.7 $(kg.m^2)$

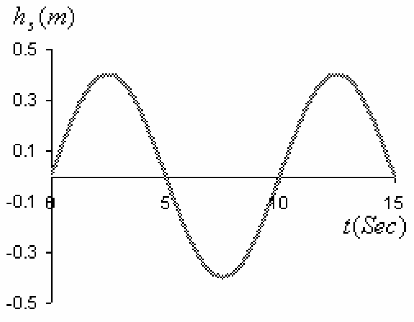


Fig. 7. wave height out side the chamber without (▬) and with guide vanes (⁓)

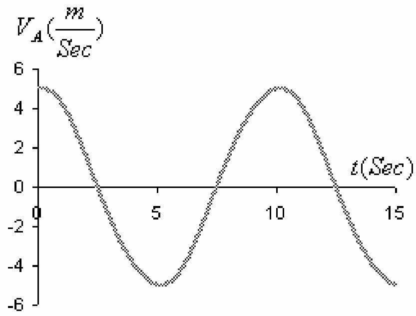


Fig. 8. air blowing velocity through the turbine without (▬) and with guide vanes (⁓)

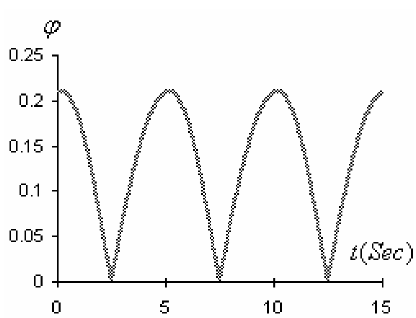


Fig. 9. Flow coefficient without (▬) and with guide vanes(⁓)

As shown in Fig.10 mechanical torque is applied to the rotor in the same direction by Wells turbine. In the second mode the guide vanes increase the mechanical and the electromagnetic torque which are depicted in Figs.10, 11 respectively. Permanent speed of both simulated modes is shown in Fig.12. Rotor and stator currents have the same ripple similar to torque fluctuation and this ripple effect is illustrated in absorbed reactive power by machine in Fig.13. Delivered active power by generator to local load, transferred power of main through local load, overall consumed power by load and load voltage graphs are shown in Figs.14, 15, 16, 17 respectively. Referring to Fig.14 generator output power increase while wells turbine with guide vanes is used although as shown in Figs.16 and 17 load power and voltage fluctuation will increase in the second mode.

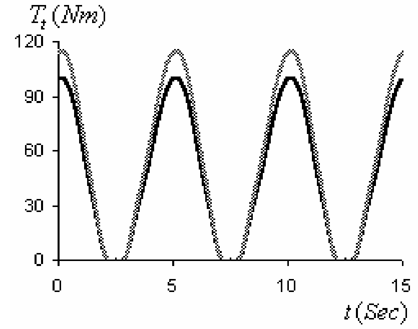


Fig. 10. Mechanical torque without (▬) and with guide vanes (⁓)

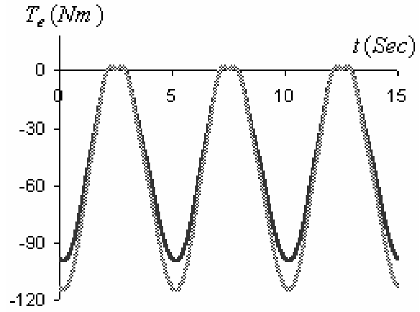


Fig. 11. electromagnetic torque without(▬) and with guide vanes(⁓)

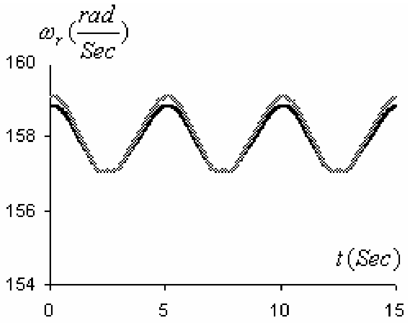


Fig.12. Rotor speed without (▬) and with guide vanes (⁓)

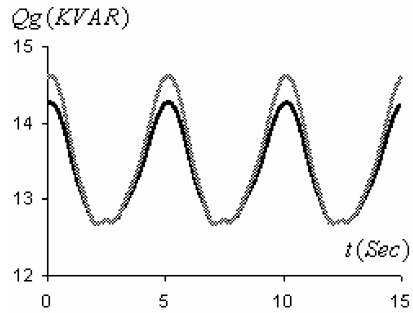


Fig. 13. Absorbed reactive power without (▬) and with guide vanes (⁓)

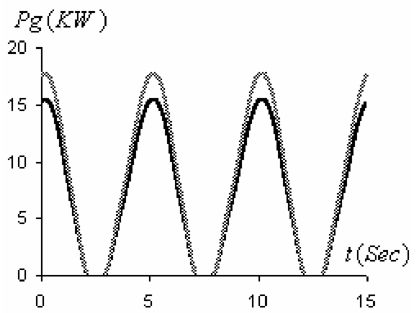


Fig. 14. Delivered power by generator without(━) and with guide vanes (〰)

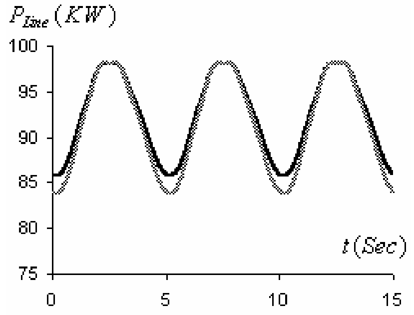


Fig. 15. Delivered power by main without (━) and with guide vanes (〰)

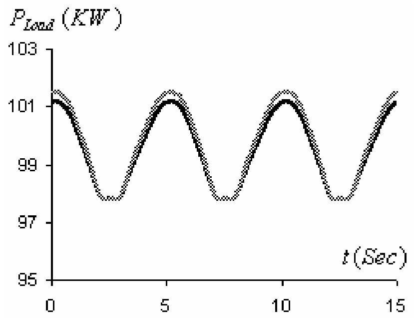


Fig. 16. Load power without(━) and with guide vanes (〰)

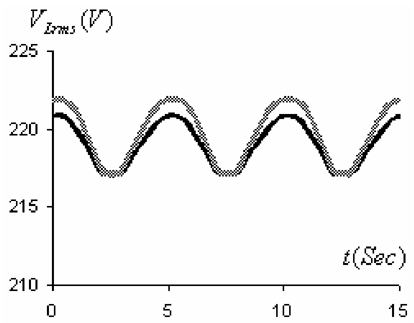


Fig. 17. Net Voltage without (━) and with guide vanes (〰)

IV. CONCLUSION

In this paper, SIMULINK model of OWC power plant's components are simulated and Output power and voltage fluctuations of OWC power plant connected to main supply is investigated. The superiority of using guide vanes as a mean of improving the mechanical power is established by comparative analysis

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