Optimization of the Wells Turbine by using Slotted blade and Guide Vanes

[1]Karthick.N, [2]Sanjai.M
[1]M.E Scholar, [2]Associate Professor
[1]Department of Mechanical Engineering, [2]Department of Mechanical Engineering
[1,2]RVS Technical Campus, Coimbatore, Tamil Nadu, India.

Abstract : This project is described and analyzed the wells turbine with slots in both side of the symmetrical airfoil and fixed guide vanes to improve the performance of turbine and torque. The torque of the wells turbine blade is improved by the slots on the turbine blade. Additionally, the Guide vanes are installed in the wells turbine to achieve the optimal efficiency, self-rotating characteristics and design performance with stall. This research is analyzed the role of these guide vanes through momentum theory which shows the upstream vanes improves efficiency than the downstream ones. The combination of the guide vanes and the slots on the turbine blades are achieved the higher efficiency and higher rpm of the turbine. This paper is efficiently handled the combined effects of fixed guide vanes and slots on the turbine blades to increase the efficiency with minimum loss of pressure.

***Index Terms* – Guide vanes, torque, wells turbine, slots and airfoil.**

I. INTRODUCTION

The research on wave-energy extraction methods started in several countries during 1970's. Dr. Wells, a former professor of civil engineering at Queen's university of Belfast, introduced in 1976 a form of self-rectifying axial flow air turbine as a device suitable for wave energy conversion using the Oscillating Water Column (OWC) [1]. The simplest form the air turbine rotor consists of several symmetrical airfoil blades positioned around a hub. Due to its simple and efficient operation, the Wells turbine has been widely applied for ocean wave’s energy absorption. Therefore, it has been subjected to a considerable amount of research and development in many counties.

Most research programs are attempted to gain energy from waves based on the OWC as converter mechanism [2]. The water wave energy is converted to pneumatic energy in the air, which passes periodically across a self-rectifying, axial air flow turbine. The first prototype was developed in UK at 1988. This device is located on the Isle of Islay, one of the southern islands in the Inner Hebrides is based on a Wells turbine as final converter. The turbine itself consists in a number of symmetric airfoils set around the hub radially at 90± stagger angle, with the chord plane normal to the axis of rotation (Figure 1). According to the standard airfoil concept, if the airfoil is set at an angle of attack $\boldsymbol{a}$ in a fluid flow, it will generate a lift force FL normal to the free stream and a drag force FD in the direction of the free stream. These lift and drag forces can be combined to get the tangential force FT and the axial force as shown in Fig. 1 for a symmetrical airfoil as considered in the direction of tangential force, FT is the same for both positive and negative values of angle of attack ($\pm\boldsymbol{a}$) as shown in Figure 1.

In a classical well turbine, the performance of Wells turbine was reduced due to lower efficiency, poorer starting, higher noise level and higher axial thrust. In order to increase the performance of well turbine this paper is described and analyzed the wells turbine with slots in both side of the symmetrical airfoil and fixed guide vanes to improve the turbine performance and produce higher torque.

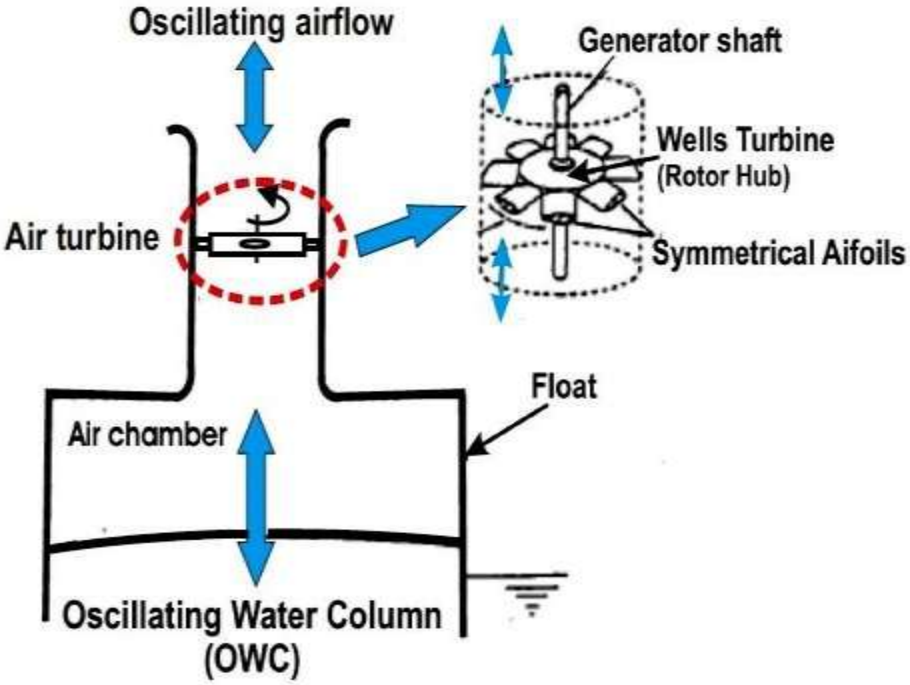


Figure 1 Wells turbine in state of upward and downward air flow

II. LITERATURE SURVEY

S. Anand and V. Jayashankar [3] presented to analyze the Oscillating water column (OWC) based on wave energy plants and constructed with several types of bidirectional turbines for converting pneumatic power to shaft power. Impulse turbines with linked guide vanes and fixed guide vanes were tested by Indian Wave Energy plant. On the other hand the Well's turbine had a linear damping characteristic, impulse turbines have non-linear damping. This is an important effect in the overall energy conversion from wave to wire. Optimizing the wave energy plant required a turbine with linear damping and good efficiency over a broad range of flow coefficient.

David P. Cashman1 and Dara L. O Sullivan [4] investigated the modeling of a quarter scale offshore oscillating water column (OWC) wave energy converter (WEC) with results from a prototype device for validating the model. The OWC WEC was utilized a specialized bi-directional air turbine termed as Wells turbine. The proposed method was investigated to model the turbine and analyzed the electrical output from a generator to be coupled to the turbine. Simulations of the proposed system were carried out based on multiple sea state conditions and were compared to results from the prototype device located at an experimental test site in Ireland.

A. Gareev, P. Cooper and P. B. Kosasih [5] carried out a CFD simulations of reversing flow air turbines used as the power takeoff system in Oscillating Water Column (OWC) Wave Energy Conversion (WEC) plant. The conventional tools which included the blade element/actuator disc methodology were used to analyze this turbine. This requires the input of interference factors to model how the lift and drag characteristics of the cascade of blades on the turbine rotor were related to those of a single isolated aerofoil. In the first phase, CFD was modeled to obtain the lift and drag characteristics of various aerofoils arranged in linear cascades at different stagger angles was described. The CFD cascade lift and drag data were compared with reported experimental cascade aerodynamic data. The agreement within the range of usable stagger angles was excellent in the pre-stall range with some deviations shown in the post-stall. A comparison was evaluated between CFD interference factors and those previously reported by Weinig and others who used analytical, in viscid flow theory. It was found the Weinig in viscid flow theory which was provided a reasonable prediction of the lift interference factor and both the angle of attack, the thickness of the blades was relatively low compared to the distance between blades.

M. Suzuki and C. Arakawa [6] investigate the Guide vanes effect were installed in the Wells turbine to improve its efficiency, self-rotating characteristics and off design performance with stall. This analysis was explained the role of these guide vanes on the basis of momentum theory. It was shown the upstream vanes were more effective in enhancing efficiency than the downstream ones. A design method for guide vanes was suggested based on experimental data and potential theory.

Tae-Hun Kim, Yeon- Won Lee and Toshiaki Setoguchi [7] investigated the aerodynamic characteristics of Wells turbines, which operates in unsteady state like a sinusoidal flow condition, were investigated to reproduce the hysteretic characteristics. The pressure distributions on the suction surface of the blade were investigated to find the cause of the hysteretic characteristics. The results were shown the hysteretic characteristics become more obvious as the blade thickness and the angle of attack become larger. The CFD results support these Phenomena occur due to different behaviors of wakes to increase the process and decreasing process of axial velocity.

M. Takao, T. Setoguchi and T.H. Kim [8] investigated the inherent limitation of Wells Turbine to increase the performance than conventional turbines. This analysis addressed the relative low efficiency and poor starting characteristics. In this case, the guide vanes in front of and behind the rotor may be one of the most effective items of equipment for improving the turbine's performance. In order to further improve the performance of the Wells turbine, the effect of 3-dimensional (3D) guide vanes had investigated experimentally by a model testing under steady flow conditions. The running and starting characteristics under sinusoidally oscillating flow conditions had obtained by a computer simulation using quasi-steady analysis.

W.K.Tease [9] carried out a theoretical and numerical investigation concerning the aerodynamic performance of a variable pitch Wells turbine. Initially, comparisons were made with steady state tests which were carried out on Wavegen's variable pitch turbine test-rig. The turbine blade pitch angle and rotational speed was held fixed while the flow through the system was increased through the full range. The blade pitch angle was increased incrementally through a range of 0 to $30^{0.}$

Toshiaki Setoguchi, Manabu Takao, Kunisuke Itakura and Mamun Mohammad [10] carried out an investigation the effect of rotor geometry on the performance of a small-scale Wells turbine. Four kinds of blade profile were selected based on the blade profile of the Wells turbine. The types of blade profile are as follows: NACA0020; NACA0015; CA9; and HSIM 15-262123- 1576. The experimental investigations have been performed for two solidities by model testing and numerical simulation. As a result, it has been concluded that a suitable choice, namely the preferable rotor geometry, is the blade profile of NACA four digit series with the thickness ratio of approximately 20% and the sweep ratio of 0.35 for the both rotor solidities. In addition, the effect of blade profile on the hysteresis characteristics of the turbine has been clarified experimentally.

M. Webster and L. M. C. Gato [11] carried out an experimental investigation into the effect of blade section on the performance of the Wells turbine. The blades tested included 2 sets of symmetrical constant chord blades: one set had standard NACA 0015 blades, whilst the other had optimized blades. The aim of the experiments was to investigate and compare the aerodynamic performance of the NACA 0015 and the optimized blades for 2 different rotor solidities.

III. PROPOSED METHODOLOGY

In this analysis, the performance of conventional wells turbine increased by two ways. Initially, adapt the slots both on the top and bottom of the airfoil blade profile to increase the torque and to reduce the axial force. Second, install the guide vanes to achieve the high efficiency and overcome the starting capability than the conventional wells turbine.

Working Principle of Wells turbine

In Wells turbine, the symmetric airfoil blades are positioned around an axis of rotation and it will rotate in the tangential force direction regardless of the direction of airflow, as shown in Figure. 2. The force *FT* is responsible for the torque and consequently the blade power, while the axial force *FA* results in an axial thrust along the axis of the rotor, which has to be absorbed by the bearings. This leads to a unidirectional device rotation for an alternating airflow without the need for non-return valve.

The tangential force *FT* and the axial force *FA* shown in Figure 2 can be obtained from:

$$\mathrm{FT} = \mathrm{FL}\sin(\alpha) - \mathrm{FD}\cos(\alpha) \tag{1}$$

$$\mathrm{FA} = \mathrm{FL}\cos(\alpha) + \mathrm{FD}\sin(\alpha) \tag{2}$$

The running characteristics under steady flow conditions are usually characterized by the tangential force coefficient C_T, axial force coefficient C_A and efficiency η with flow coefficient $\boldsymbol{\varphi}$. The tangential force coefficient C_T and the axial force coefficient C_A are calculated as:

$$C_T = F_T[(1/2)\rho(v_A^2 + u_t^2)zbc] \tag{3}$$

$$\mathrm{C_A} = \mathrm{p_0}\ \ \mathrm{t}/[\left(\tfrac{1}{2}\right)\rho(\mathrm{v}^2 + \mathrm{u}^2)\mathrm{zbc} \tag{4}$$

Where $ut = \omega r_t$ is the peripheral velocity, ω is the rotor angular velocity and r_t is the tip radius (Figure 3). Furthermore, v_A is the axial velocity normal to the plane of rotation, z is the number of blades, b is the blade span, c is the blade chord (see Figure 3) and p_0 is the total pressure difference across the rotor.

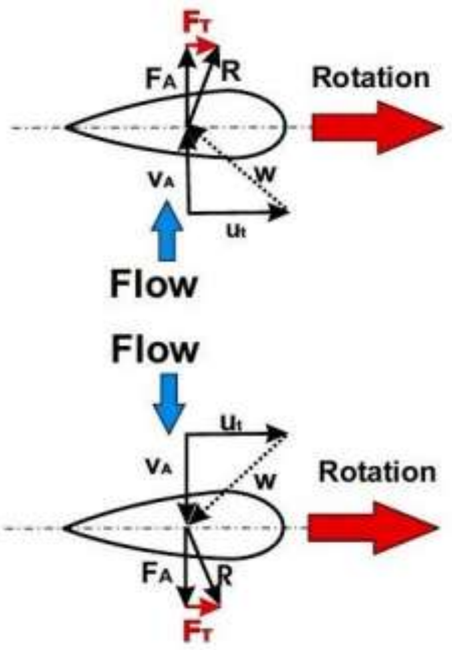


Figure 2 Axial and tangential forces acting on a Wells turbine

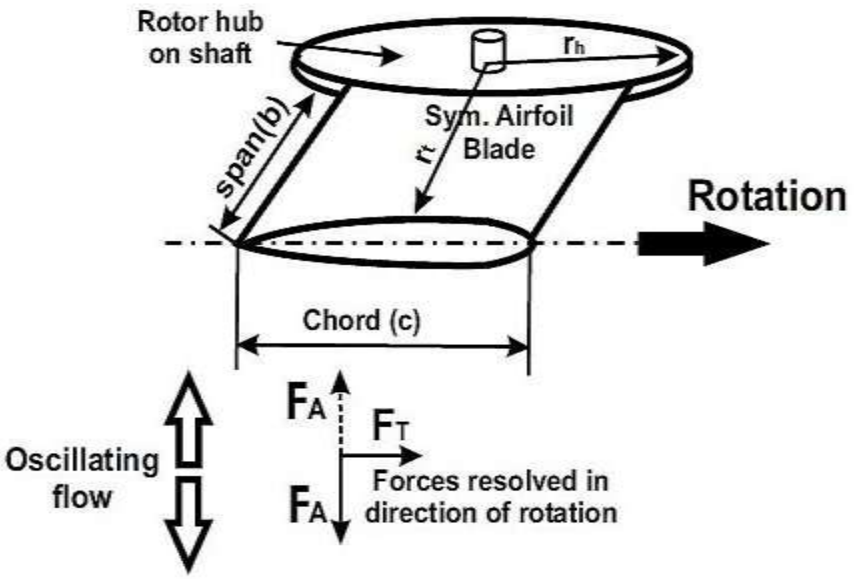


Figure 3 Main geometrical parameters of a Wells turbine.

The non-dimensional variables are increased the performance of a Wells turbine. The function of the aerodynamic force coefficients are defined by

$(CT, CA) = f(\varphi, s, h, AR, \tau, \tau_0, T_w, f^*, Re, blade\ profile\ shape)$

where, ϕ= $v_A/u_t$is the flow coefficient, *s* is the rotor solidity, *h* is the hub to tip ratio (r_h/r_t), *AR* is the aspect ratio (*b/c*), *c* is blade chord, *b* is blade span, τ is the blade thickness, $\tau_c$is the tip clearance ratio, $T_u$is the turbulence level, *f* * the frequency of wave motion and the Reynolds number Re.

Slots on the Turbine Blades

The slots on the top and bottom of the airfoil blade profile are introduced to increase the torque and reduce the axial component force. The air flow in the Wells turbine does not travel from leading edge to the trail edge, the flow is just impacted on the top and bottom surface of the blade section. So, when the slots are introduced on the top and bottom surface of the blade will increase the tangential component force when high pressure is impacted on the slots, thus reducing the axial component force. It also increases the self-starting characteristics of the turbine

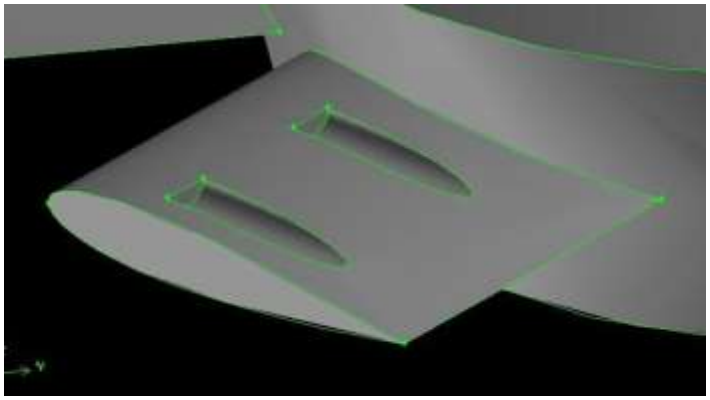


Figure 4 Modifications implemented

Guide Vanes Installation

Several researches had demonstrated the usefulness of 2D and 3D (twisted) guide vanes. The effect of guide vanes had investigated numerically and theoretically by testing a model under steady flow conditions. It is found that the running and starting characteristics of the Wells turbine with guide vanes are superior to those without guide vanes .The results indicated in particular the three dimensional guide vanes (variable angles along the vane span) providing a constant rotor blade angle of attack with radius lead to the best characteristics and are therefore recommended.

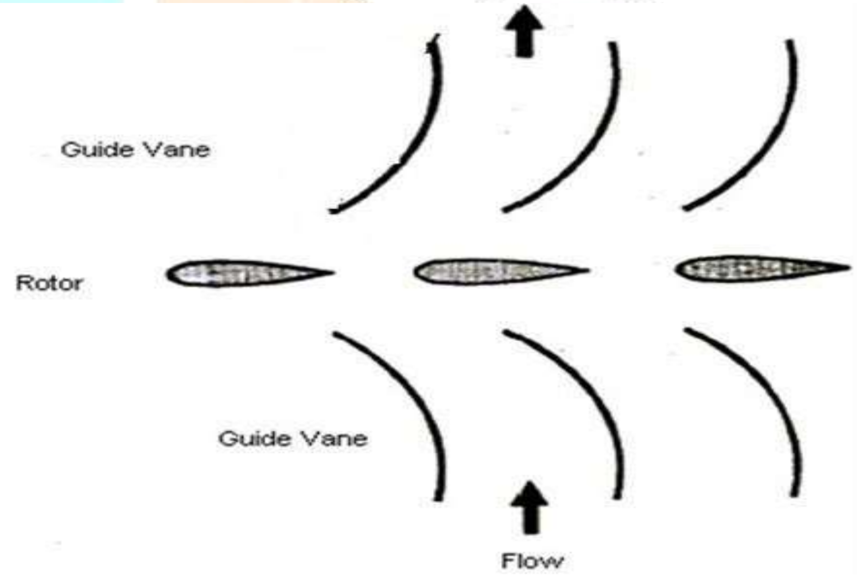


Figure 5 The profile of turbine with guide vanes

IV. RESULT AND DISCUSSION

This section is analyzed the proposed modified design of Wells turbine by using ANSYS 12.0.1 software, and fabricate the new modified Wells turbine and do the experimental analysis for various flow conditions with and without slots on the blade profile. The pressure and velocity distributions are represented in this analysis.

The NACA 0021 Symmetrical Airfoil coordinates is selected and generated a model of wells turbine by using CATIA V5 Software with following parameters.

Table 1 Wells Turbine Parameters

WELLS TURBINE PARAMETERS	
Blade Chord	76mm
Number of blade	8
Hub Diameter	214mm
Tip Diameter	304mm
Air Foil	NACA 0021
Number of Guide Vanes	15

Chord of Guide Vanes	59mm

The design parameters are taken from the [2] to design the wells turbine. The CFD software is learned to carry out this project. We convert that CATIA V5 model to IGS file type and imported that model to Gambit. Unfortunately that converted model shows lot of errors in Gambit, so we generated the total Wells turbine model (with guide vanes) with above mentioned parameter by using coordinate system in Gambit and generated the Wells turbine model (with guide vanes & Slots) in Gambit as shown in Figure 6.

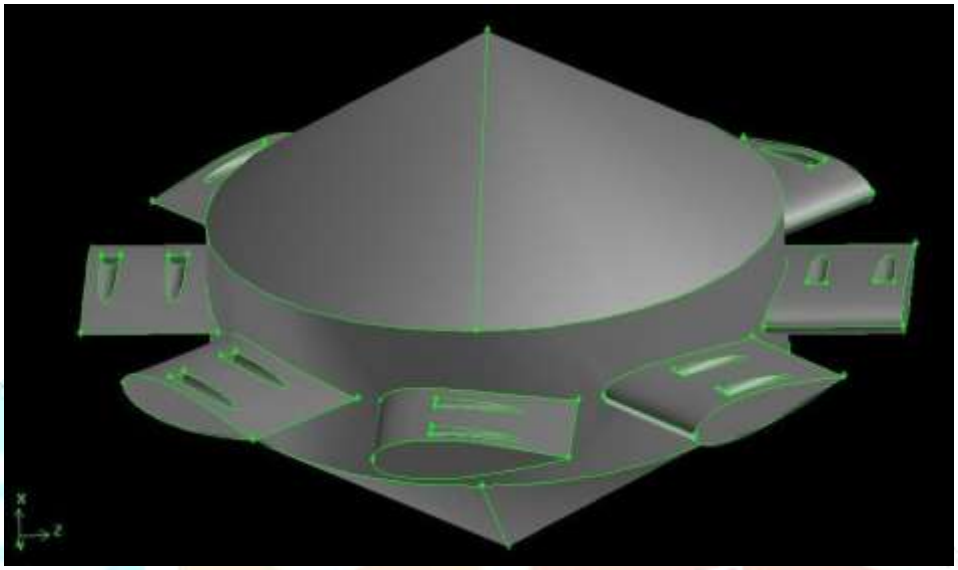
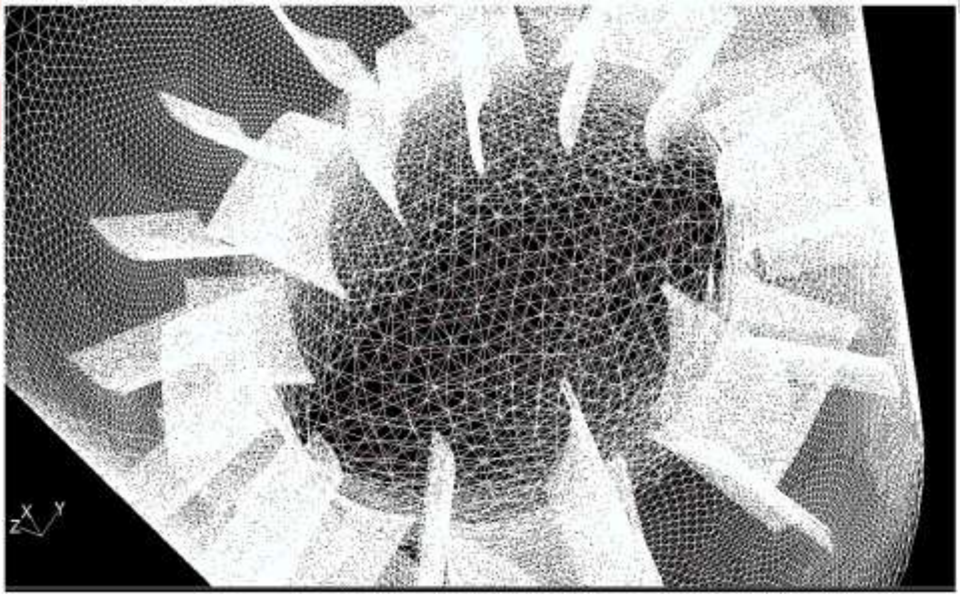


Figure 6 GAMBIT Model of Wells Turbine

Figure 7 Mesh of Wells Turbine without slots on blade

Meshed that model in Gambit and created the inlet and outlet boundaries for that meshed volume.



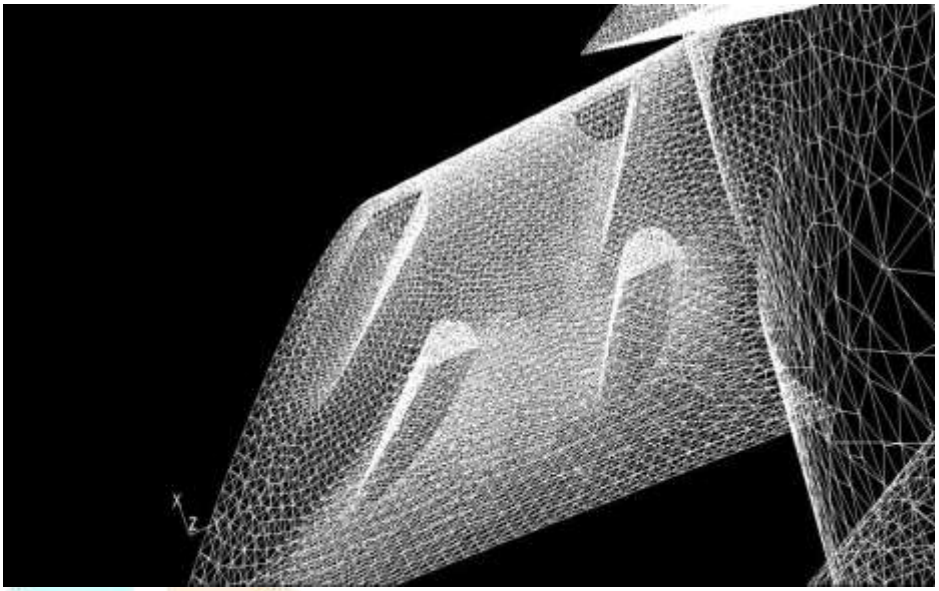


Figure 8 Mesh of Wells Turbine with slots on blade

Imported that mesh in Fluent 5/6 and changed that meshed volume to mm scale. Given boundary condition for that meshed volume and started iteration process in Fluent. The flow analysis is examined by using the fluent software.

COMPARISON OF FLOW PATTERN

The models of Wells turbine with and without slot on the blade profile is generated and meshed by using GAMBIT software and the flow analysis is carried out using ANSYS FLUENT. The flow patterns along the blade profile of the Wells turbine with and without slots are displayed in Figures. The flow analysis is carried out at the same boundary condition for both the models.

BOUNDARY CONDITIONS

- INLET – Velocity Inlet (10 m/s)
- OUTLET – Pressure outlet (1 atm)

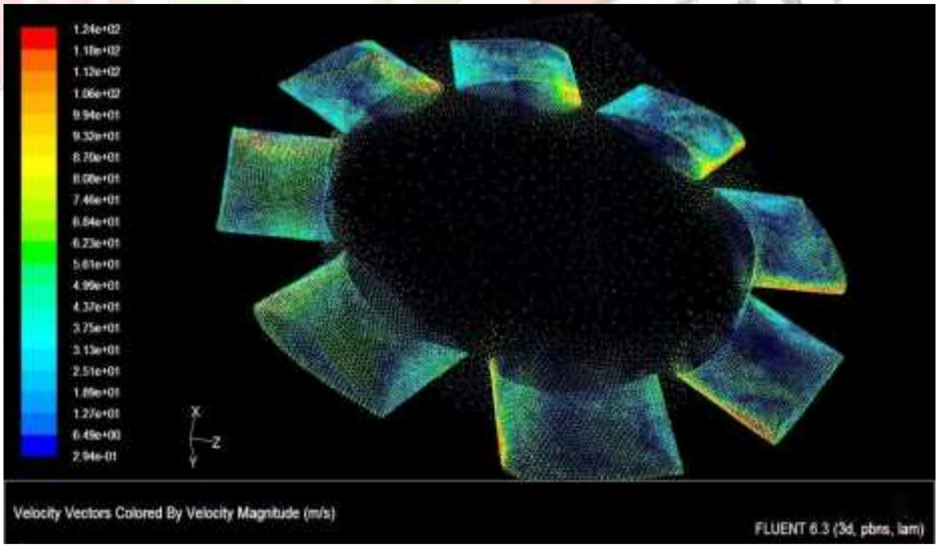


Figure 9 Velocity vectors for Wells Turbine without Slots

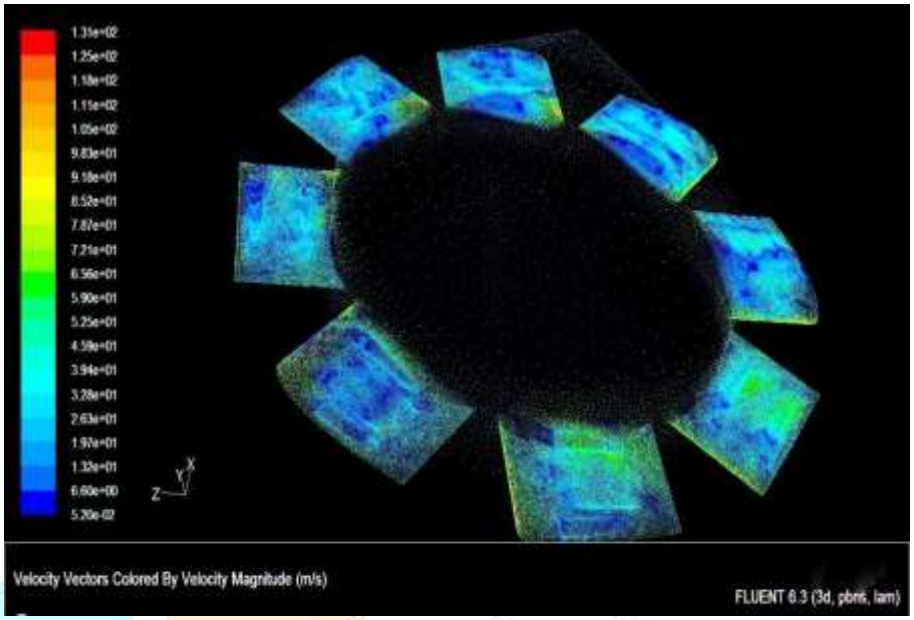


Figure 10 Velocity vectors for Wells Turbine with Slots

By comparing the flow patterns of the model provides the detailed study about the better velocity distributions that is the model with slots on the blade profile gives higher tangential component force when compared with the model without slots.

After completing the model assemble which is tested by wind tunnel with various flow speeds. First, wax is placed in the blade slot to take without blade slot reading. Second, remove the wax from the blade slot to take with blade slot reading. The table2 shows the value for both with and without blade slot reading.

Figure 11 Final Assembled Wells Turbine

Table 2 RPM comparison of wells turbine with and without slots

S.No	Air velocity m/s	Rpm of Wells Turbine Without slot	Rpm of Wells Turbine With slots
1	9	250	610
2	10	360	820
3	11	420	902
4	12	500	990
5	13	555	1010
6	14	590	1210
7	15	600	1305

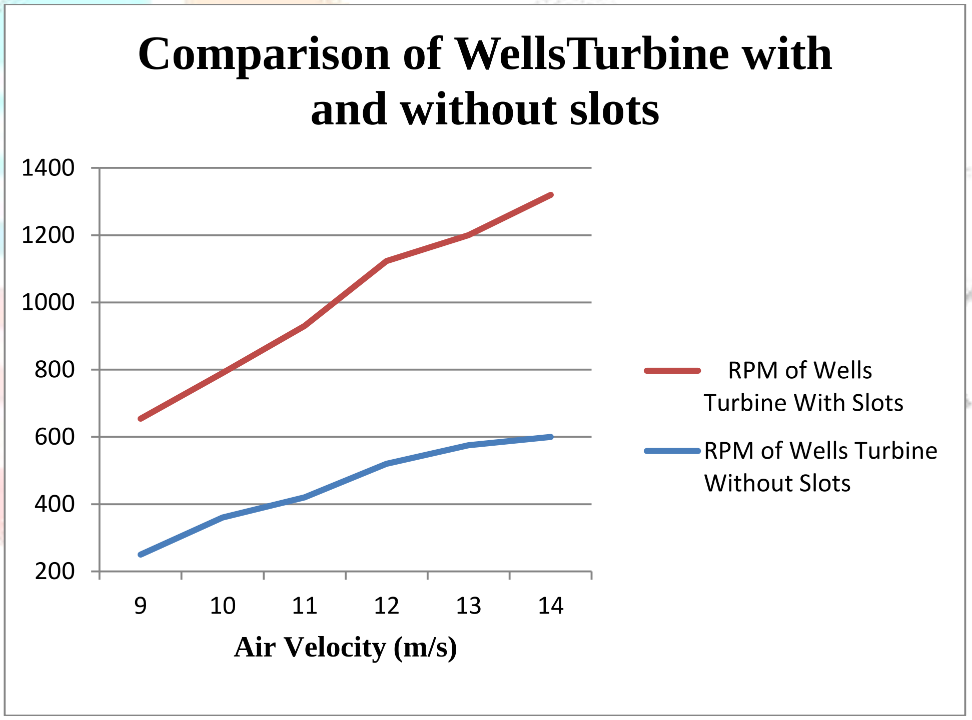


Figure 11 RPM comparison of turbine with and without slots

Figure 11 shows the RPM comparison of turbine with and without slots. From the line chart and corresponding table, the result shows RPM of wells turbine with slot provide better performance than RPM of wells turbine without slot.

V. CONCLUSION

The proposed enhanced well turbine increase the performance than the conventional well turbine by overcome the limitation such as low tangential force, high axial force, low aerodynamic efficiency and limited range of operations. From the proposed well turbine models shows the slot increase the tangential component force. The numerical analysis shows the rpm of turbine with slot is higher compare to the turbine without slots. The combined effects of guide vanes and slots on the blade provide better starting characteristics higher efficiency and higher range of operations.

REFERENCES

[1] Falcão, A. F., and Henriques, J. C. 2016. Oscillating-water-column wave energy converters and air turbines: A review. Renewable Energy, 85, 1391-1424.

[2] DARABI, A. P., and Poriavali, P. 2007. Guide Vanes Effect of Wells Turbine on OWC Wave Power Plant Operation. In World Congress of Engineering (Vol. 1).

[3] Anand, S., Jayashankar, V., Nagata, S., Toyota, K., Takao, M., and Setoguchi, T. 2007. Turbines for wave energy plants. In Proceedings of the 8th International Symposium on Experimental and Computational Aerothermodynamics of Internal Flows (pp. 1-7).

[4] Cashman, D. P., O'Sullivan, D. L., Egan, M. G., and Hayes, J. G. 2009. Modelling and analysis of an offshore oscillating water column wave energy converter. In Proceedings of 8th European Wave and Tidal Energy Conference (pp. 924-933).

[5] Gareev, A., & Cooper, P. 2009. CFD analysis of air turbines as power take-off systems in oscillating water column wave energy conversion plant.

[6] Suzuki, M., and Arakawa, C. 2000. Guide vanes effect of Wells turbine for wave power generator. International Journal of Offshore and Polar Engineering, 10(02).

[7] Kim, T. H., Lee, Y. W., Park, I. K., Setoguchi, T., and Kang, C. S. 2002. Numerical analysis for unsteady flow characteristics of the Wells turbine. In The Twelfth International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers.

[8] Takao, M., Setoguchi, T., Kim, T. H., Kaneko, K., and Inoue, M. 2000. The performance of Wells turbine with 3D guide vanes. In The Tenth International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers.

[9] Tease, W. K. 2003. Dynamic response of a variable pitch Wells turbine. In Fifth European Wave Energy Conference Proceedings. University College Cork, Ireland.

[10] Setoguchi, T., Takao, M., Itakura, K., Mohammad, M., Kaneko, K., and Thakker, A. 2003. Effect of rotor geometry on the performance of Wells turbine. In Proc. of the Thirteenth International Offshore and Polar Engineering Conference.

[11] Webster, M., and Gato, L. M. C. 1999. The effect of rotor blade shape on the performance of the Wells turbine. In The Ninth International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers.