

Wells Turbine for Wave Energy Conversion for Malaysian Ocean

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ABSTRACT

Malaysia is surrounded by ocean, therefore Malaysia is a perfect candidate for harvesting ocean energy as electrical generator to distribute to main grid. Malaysian electrical generation still greatly influences by non-renewable energy and the electrical cost increase as the natural resource depleting. The only solution for this problem is to use renewable energy, due to geography of Malaysian land which surround by ocean; ocean energy is the best renewable energy for Malaysia. One method of converting this energy is to use Oscillating Water Column using wells turbine as converter from pneumatic energy to mechanical energy thus convert by generator to electrical energy. However, wave characteristic of Malaysian ocean make conversion of wave energy really difficult. Some parameter that affect the performance of wells turbine need to be changed, so the new geometry turbine can work effectively in Malaysian ocean of the poor ocean characteristics such as low wave high and low frequency. According to Malaysian wave data, the average wave height is from 0.5m to 1.5m with average wave frequency of 0.1 to 0.3Hz and wave period 3.34s to 10s.

KEY WORDS: *Oscillating Water Column; Wells Turbine; Wave Characteristics*

NOMENCLATURE

A	Area of annulus
c	Chord length
D_T	Tip diameter
h	Hub to tip ratio
N	Number of blade velocity gradient

Q	Flow rate
R_H	Hub radius
R_T	Tip radius
T	Torque
U^*	Flow Coefficient
U_{tip}	Blade tip speed
V_a	Air steam velocity
Δp	Pressure drop
η	Efficiency
ω	Rotational speed
σ	Blade solidity

1.0 INTRODUCTION

Malaysian ocean wave characteristic make wave energy conversion very hard to take place. Some parameter that affect the performance of wells turbine need to be changed, so the new geometry turbine can function effectively in Malaysian ocean despite the poor ocean characteristics such as low wave high and low frequency [1]-[2]. For the sake of this paper, parameters of blade profile and turbine solidity are only two parameter that we focused on as those parameters are the most effective on the turbine efficiency according to various literature review. In addition, the aim of this study is to design a turbine that is able to generate energy from Malaysian ocean waves effectively.

The basic principle of wells turbine efficiency are due to profile blade and turbine solidity. According to Raghunathan [3] NACA0020 show the best performance characteristic compared to thinner airfoil from the same series of NACA blades, he suggested that the blade profile geometry is the key parameter in design especially the thickness ratio. Moreover, the profile also improves the starting characteristics [3].

Thakker and Abduladi [4] conclude that the best aerodynamic blade profiles is NACA0020 with rotor solidity 0.64, this is due to the higher frequency in wide range of flow coefficient between those four blade profiles. Researcher mainly focuses on variation of blade profile and its solidity. But that only highlight the performance of blade, this paper will show the relation efficiency and the wave characteristics in Malaysian ocean by comparing the chamber pressure with research done by O.B. Yaakob et al. [5].

2.0 MATHEMATICAL FORMULATION

Turbine solidity is the ratio of the total blade area in plan view to annular duct area, this show the blockage of airflow through the turbine as the mutual interferences with the blades.

$$\sigma = \frac{Nc}{\pi(R_T+R_H)} \quad (1)$$

As stated by Raghunathan, wells turbine will be not sensitive to variations in solidity up to value of 0.5 and decrease efficiency if greater than 0.5 due to the increasing loss of kinetic energy and the associate swirl. However, the problem with low solidity turbine is having poor self-starting characteristics compares to high solidity turbine with solidity ratio above 0.5 [6].

Tip to hub ratios play important role in determining turbine efficiency as stated by Raghunathan, the experiment varies tip to hub ratios but keeping the solidity at constant value of 0.4. The importance of hub to tip ratio in designing of wells turbine clearly proven by the following equation [7]

$$V_a = \frac{4Q}{\pi D_t^2(1-h^2)} \quad (2)$$

Turbine aerodynamic efficiency can be contributed by tip to hub ratio by angle of incidences, leakage loss at the tip and the interferences effect at the hub. Variation of this ratio will affect the tip leakage loss and efficiency constant speed, decreasing hub to tip ratio will cause the efficiency of the turbine to decrease as it introduce stall in early stage for designing purpose, Raghunathan suggest the ratio to be 0.6 [2].

The efficiency of the turbine is the most important formula to be known, because we want to reduce the losses of converting the wave energy from pneumatic to mechanical energy. In order to study the performance of the well turbine versus flow coefficient, we need several dimensionless parameters:

Flow coefficient;

$$U^* = \frac{V}{U_{tip}} \quad (3)$$

$$V = \frac{Q}{A_{annulus}} \quad (4)$$

Efficiency;

$$\eta = \frac{T\omega}{Q\Delta p} \quad (5)$$

After a few analysis, research and site visit, there are few suggested places from installation for OWC devise base on wave energy distribution that show the wave energy density distribution higher on that particular place. The places are 1) Pantai Cahaya, 2) Pantai Senak, 3) Pantai Irama, 4) Tok Bali and 5) Kuala Besut. These places suitable for installation of OWC devise especially shore mount type as shown in Figure.1.



Figure 1: Recommend places for OWC and well turbines in Malaysia

3.0 NUMERICAL SIMULATIONS

This stimulation represents description of three dimensional flow field of wells turbine, to be used in oscillation water column for wave energy conversion (Table 1). The analysis has been performed by solving numerically the incompressible Navier Stokes equations in a non-inertial reference frame rotating with the turbine. Using medium mesh, the result outcome from this analysis is torque and pressure drop across turbine.

Table1: Well turbine specifics for the current study

Parameter		Actual	Model
Water depth		5	1
Design wave	Period (s)	5	2.24
	Wave height (m)	1.5	0.3
Principal dimensions	Length (m)	4	0.8
	Breadth(m)	4	0.8
	Draught(m)	5	1
	Opening mouth height(m)	3.5	0.7
Air chamber	Curtain wall height (m)	1.5	0.3
	Length(m)	4	0.8
Turbine shell	Breath(m)	4	0.8
	Shell radius(m)	2	0.4
Turbine	Tip radius(m)	1.5	0.3
	Chord length(m)	0.625	0.125

The geometry and mesh elements for this study has been generated using the RANSE solver grid generator (ICEM CFD). Particular care has been given for mesh generation in this research work, where the computational domain has been discretized using volume mesh type of tetra/mixed with robust (Octree) mesh method (Figure 2). The global mesh parameters, scale factor for was taken to be 1 and global element seed size maximum element was 0.05.

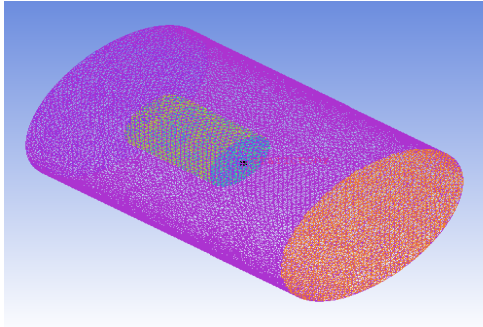


Figure 2: Combination of static, rotational and wells turbine meshing

The total number of unstructured tetrahedron mesh elements that was used in this study is 1101202 (Figures 3 and 4). The turbine model blade characteristics are shown in Table 2.

Table 2: Model blade characteristics

Profile	Blade solidity	h	Rt	c	No of blades	Hub to tip ratio
NACA0015	0.64	0.2	0.3	0.125	8	0.67
NACA0020	0.64	0.2	0.3	0.125	8	0.67
NACA0020	0.60	0.23	0.3	0.125	8	0.77
NACA0020	0.4	0.19	0.3	0.125	5	0.63

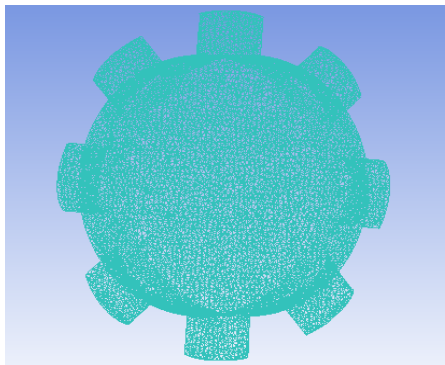


Figure 3: Surface mesh for the well turbine.

Turbine was selected to rotate with constant angular velocity of $104.72 \text{ rad.s}^{-1}$ around the global X axis. The computational domain has been limited for axial direction to two chord length and for upstream direction of seven chord lengths downstream of the turbine blade. The numerical stimulations on this study were conducted based on assuming steady state flow type with two domains one rotational and the other one is static. The rotational and static domains have fluid type of air at 25°C , 1atm reference pressure.

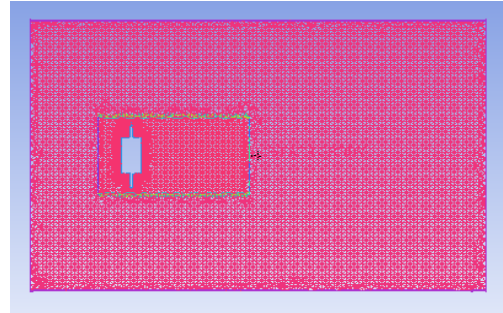


Figure 4: Mesh cutting plane at center of the rotating and stationary computational domains

As the boundary treatment is concern, there is no slip boundary conditions are applied to blade surface, hub, rotor, and static boundary casting. An interface boundary conditions were used at the attached faces between static boundary and rotational boundary. A uniform velocity profile has been use as the inflow surface of turbine with variation of axial velocity U at cart. Vel. Component (Figure 5). Turbulence intensity of inlet is set at 5% of medium turbulence. Moreover, for outlet boundary condition mass and moment values were set to static pressure at 0atm. The combination of velocity inlet and static pressure outlet made the result more stable compared to other combination as referred to literature review [8].

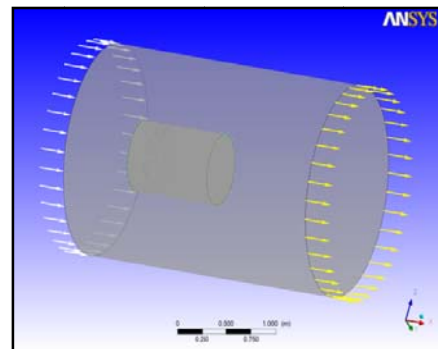


Figure 5: Computational domain for Ansys CFX solver with in and out boundaries

Both domains have fluid models characteristics of k-Epsilon turbulence function with scalable wall function and non-radiation and non-heat transfer function. First order turbulence numeric with 0.2s physical time scale have been used with Ansys CFX solver. The convergence criteria was chosen the RMS residual type of target 0.0001.

4.0 RESULTS AND COMPARISONS

From the numerical analysis, the factor of blade profile can be verify by the thickness of the blade profile, only two sample of blade profile are taken, those are NACA0015 (thin blade) and NACA0020 (thick blade) with the solidity of the turbine of 0.64.

Moreover, for variation of turbine solidity, variation of 0.4 and 0.6 are chosen with constant profile blade of NACA0020. The

numerical results of the current study for the turbine efficiency versus flow coefficient are shown in Figure 6.

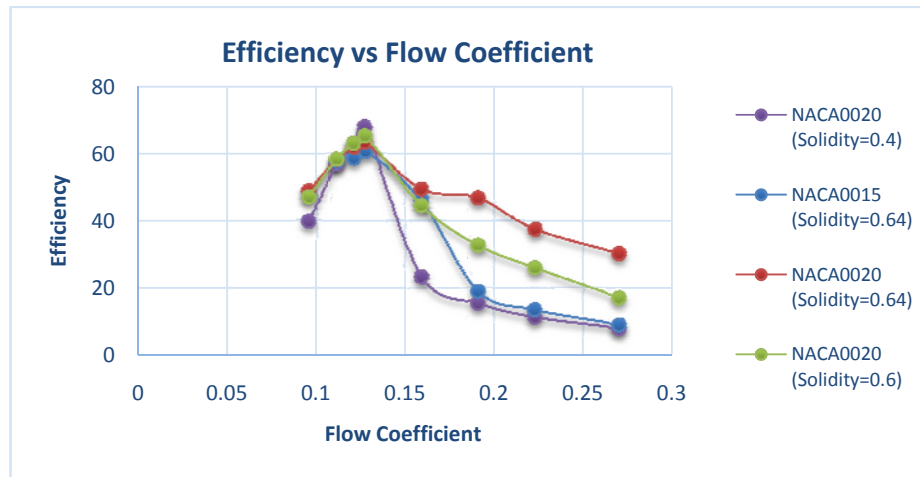


Figure6: Well turbine efficiency vs. flow coefficient

Table 3a: NACA0015 with $\beta = 0.64$

Flow coefficient	Torque (Nm)	Change in pressure (Pa)	Efficiency (%)
0.09549	0.12836	2.31434	48.40300
0.11140	0.22023	2.85190	57.76300
0.12095	0.28947	3.40471	58.57600
0.127323	0.34955	3.77668	60.57900
0.159154	0.34047	3.87276	46.03200
0.190985	0.35398	8.20377	18.82700
0.222816	0.36717	10.3832	13.22600
0.270563	0.38849	13.5739	8.81500

Table 3c: NACA0020 with $\beta = 0.40$

Flow coefficient	Torque (Nm)	Change in pressure (Pa)	Efficiency (%)
0.095	0.120709	2.24294	46.964
0.111	0.201109	2.5814	58.274
0.121	0.361706	3.95874	62.948
0.127	0.435983	4.37745	65.186
0.159	0.585063	6.88905	44.467
0.191	0.573738	7.68008	32.596
0.223	0.57772	8.364	25.833
0.271	0.600963	10.9535	16.898

Table 3b: NACA0020 with $\beta = 0.64$

Flow coefficient	Torque (Nm)	Change in pressure (Pa)	Efficiency (%)
0.095	0.132362	2.36865	48.765
0.111	0.231245	2.97106	58.219
0.121	0.29931	3.33359	61.858
0.127	0.351137	3.6309	63.295
0.159	0.514559	5.45779	49.365
0.191	0.51834	4.8321	46.805
0.223	0.542098	5.4228	37.387
0.271	0.589938	6.0414	30.076

Table3d: NACA0020 with $\beta = 0.60$

Flow coefficient	Torque (Nm)	Change in pressure (Pa)	Efficiency (%)
0.095	0.231106	5.09072	39.617
0.111	0.4592446	6.05501	56.732
0.121	0.652224	7.13014	63.021
0.127	0.809982	7.80713	67.904
0.159	0.498336	11.19497	23.308
0.191	0.499076	14.2831	15.246
0.223	0.507374	17.2108	11.025
0.271	0.508729	20.1978	7.758

The variation of blade profile shows that, NACA0015 have lower efficiency with small range flow coefficient of high efficiency and NACA0020 show high efficiency compared with NACA0015 with wider range of flow coefficient of high efficiency. On the turbine solidity, solidity of 0.6 has better average efficiency compared to lower solidity of 0.4 throughout flow coefficient. However, turbine solidity 0.4 have higher maximum efficiency compared to 0.6, this show turbine solidity 0.4 only can be operate effectively at small range of flow coefficient.

From the CFD results (Table 3), every turbine has differences in efficiency versus flow coefficient profile, but to choose the best wells turbine blade to be used in Malaysian ocean is another case, whereby we need to match with open water column that available so that a better efficiency of energy conversion can be taken place. Open water column from O.B Yaakob et al. (2013) [5] with reflector slope of 45° is chosen to verify the suitable geometry of well turbine in Malaysian ocean. Wave height of 0.25m and wave period of 2.24s are chosen to compare the flow of air inside the water column and match with the four wells turbines as the value of the wave height and wave period chosen at the middle point of average Malaysian wave characteristics to choose the best turbine for Malaysian wave conversion.

Result shows, NACA0020 with turbine solidity of 0.64 have a wide range of high efficiency but slightly lower maximum efficiency then other turbines, but in average, NACA0020 with turbine solidity of 0.64 have the advantage of the poor wave characteristic of Malaysian ocean to make it as the effective turbine to be used in converting wave to useful electrical energy.

5.0 CONCLUSIONS

As conclusions of this study, a design of wells turbine that able to generate energy from Malaysian ocean wave effectively is establish with profile blade of NACA0020 and turbine solidity of 0.64 with range of turbine efficiency of 30% to 64% throughout flow coefficient using CFD code AnsysCFX.

NACA0020 turbine with 0.64 turbine solidity have a wider range of operating with high efficiency compare to other turbines. More, some conclusions can be made of the profile blade thickness, thicker profile blade of NACA0020 have better efficiency compared with thinner blade profile of NACA0015. Moreover, turbine solidity contributes high impact on maximum efficiency of wells turbine but not affect the overall efficiency of the turbine.

Furthermore, the recommended places for the Open Water Column especially for shore mount are in the state of Kelantan

and Terengganu. Where the places of study are, PantaiCahayaBulan shoreline in Kelantan, PantaiSenak shoreline in Kelantan, PantaiIrama shoreline in Kelantan, Tok Bali shoreline in Kelantan and Kuala Besut shoreline in Terengganu. More, for floating OWC, the recommended places are Kelantan and Terengganu offshore.

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