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Research Article

PERFORMANCE ANALYSIS OF OCEAN CURRENT TURBINE BLADE

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ABSTRACT

Marine current is a flow or movement of seawater which is influenced by surface wind, tides, coriolis effect, solar heating of the waters near the equator, variations in water density and salinity. Hydro kinetic energy is obtained from these marine currents. Even though harnessing of marine energy not widely used at present, it has huge potential for future electricity generation. Globally technologies are being developed to extract energy from marine currents and converting into useful work. A mechanical device which can extract such energy is called hydro kinetic turbine. This project work focuses on optimization of the hydro kinetic turbine blade for any remote location using computational fluid dynamics (CFD) analysis for the different turbine blade profiles such as NACA 0015 and NACA 0018 for solidity ratio of 0.2 and diameter of 1.8 m and for current speed 1.8 m/s.

INTRODUCTION

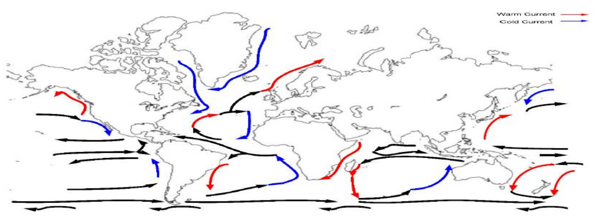

Fig 1 Map of distribution of ocean currents.

Ocean currents are driven by solar heating and wind in the waters near the equator, also by tides, salinity and density of the water. Current can be divided in two types: marine currents and tidal currents. Marine currents are relatively constant and flow in one direction. Tidal currents occurred close to the shore due to gravitational forces.

Through the world there can be found ocean currents of more than five knots or 2.5m/s (1knot=0.50 m/s) and current energy has been estimated greater than 5,000 GW The amount of power that can be extracted from a flowing mass depends on their interaction between the device used to extract the energy and the flowing mass [1]:

Power= (½) ρ A V^3
Where,
ρ = Density of sea water
A = Area of interaction between current(sea water) and turbine.
V = Velocity of attacking water current.
Unit = Watt

Types of Hydro Kinetic Turbine

Straight bladed turbine. [2, 3]

Also called as fixed straight bladed or H-rotar it is self regulating in all speed reaching optimal rotational speed early before its cut in flow speed. Due to lower and predictable stress loading on the blades of vertical axis of the turbines they are the ideal machine for large scale electricity production. Self starting characteristics of turbine are aided by increasing numbers of blades but efficiency is higher if it is low. Turbines with 5 or more blades never have negative starting torque, but high mean starting torque. With the use of ailerons (a hinged surface along the trailing edge of the blade) on straight bladed turbine we can get:

- Increase in starting torque of turbine.
- Improves starting characteristics such as starting torque and start up fluid flow speed
- Control on roll along longitudinal axis

Cross Flow Turbine [2, 4]

2 types Vertical and In-plane axis

- Axis of rotation is perpendicular to free stream velocity
- Lower efficiency than axial flow turbine
- Can operate with any free stream flow from any horizontal direction without yaw control.
- Have symmetric design which makes them balanced

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In Plane Axis

In-plane axis is better known as floating water wheels. These are mainly drag based devices and inherently less efficient than their lift based counter parts. The large amount of material usage is another problem for such turbines.

Squirrel cage Darrieus

Squirrel cage turbine consists of two disks at top and bottom with the airfoil running straight up and down between their rims. This allows the centrifugal force to be handled by the relatively sturdy construction of the disks. The advantage of turbine is that it is able to progressively get into rotation. The low Reynolds number is its disadvantage.

H-Darrieus

1. They are capable of producing much power than most typical marine turbine.
2. H-Darrieus rotor is a lift type device having two or three blades designed as airfoils. The blades are attached vertically to centre shaft through support arms.
3. One major disadvantage of H-type Darrieus turbine is that since lift forces drives them that must be brought to a minimum speed before the forces generated as sufficient to propel the turbine.
4. With increase of height to diameter ratio, velocity magnitude difference from inlet up to rotor increases up to height to diameter ratio 1.0.
5. It can be concluded that velocity difference from inlet up to rotor is responsible for power stroke of blades during its clockwise direction. The Tip Speed Ratio of H-Darrieus turbine is high, hence, it rotate faster.

Darrieus Turbine

1. Darrieus turbine is a vertical axis turbine. It has streamlined blades turning around an axis perpendicular to the flow.
2. The curvature of the blade allows the blade to be stressed only in tension at high rotating speeds. It is powered by the phenomenon of lift.
3. In Darrieus blades the airfoils are arranged so that they are symmetrical and have zero rigging angle, that is, the angle that the airfoil are set relative to the structure on which they are mounted.
4. Problem with the design is that the angle of attack changes as the turbine spins, so each blade generates its maximum torque at two points on its cycle, that is, at front and back of the turbine.
5. Its self-starting capabilities are low.

Gorlov Turbine

1. Blade profile is swept in a helical profile along its span.
2. One of the advantage of helical blade is that it improves self-starting of Gorlov turbine compared to Darrieus turbine.
3. Some portion of blade profile is located at optimum angle of attack even in static or slowly rotating conditions, which allows for more uniform starting torque that depend upon turbine azimuthal position.
4. Helical blade shape is reduction of torque oscillation during rotation.
5. Uniform blade coverage, neglecting end effects and wake dynamics, ideally give the turbine torque.
6. The maximum efficiency for Gorlov turbine is around 35% and solidity ratio of 27%.

Model Making [9]

Geometry Preparation

Coordinates of airofoil section for lift based blades without were taken from airofoiltool.com [5, 6] and then modified

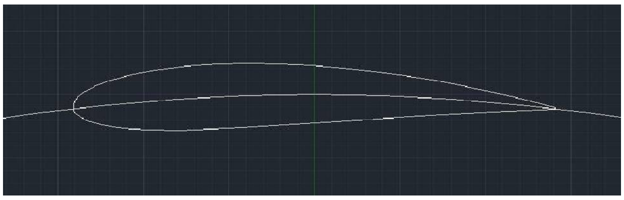

Fig 2 Blade on rotar circumference

Interface used for the initial preparation of the model is “AUTO CAD”.

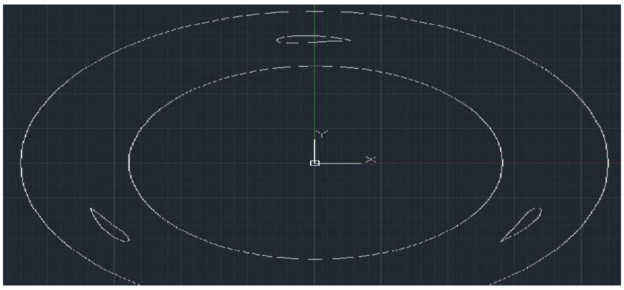

Fig. 3 Rotor geometry

Information about geometry

The geometry to be analyzed is made up of NACA profile and is without camber and it is lift based blade structure. The main parameters used for getting the geometry are as follows:

Rotor diameter- 1.8m
Stator diameter (Inner Circle)-1.4m
Outer stator diameter (Outer Circle)-2.2m
Angle of the blade 1 from centre of the circle- 90deg
Angle of the blade 2 & 3 from blade 1- 120 and 240 respectively

Domain Making

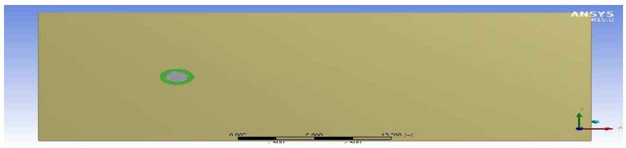

Fig 4 Domain

Domain Information

The dimension of the prepared rectangular domain for analysis is likewise:

Length- 20D
Breadth- 10D
Distance of centre of circle from breadth of rectangle- 5D
Distance of centre of circle from length of rectangle- 5D

Meshing

The meshing for the domain is Orthogonal all over without allowing any transformation.

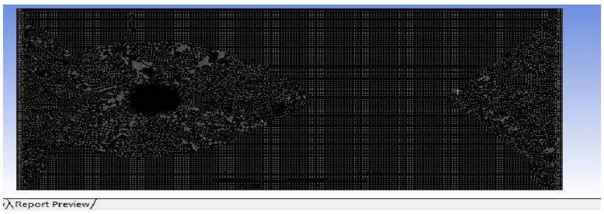

Fig 5 Domain mesh

Rotating Domain Mesh

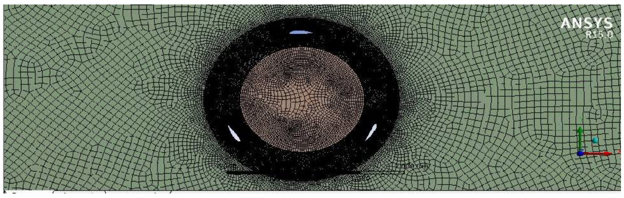

Fig 6 Rotor mesh

Mesh around the blade

The meshing around all the three blades needs to be very fine for analysis purpose.

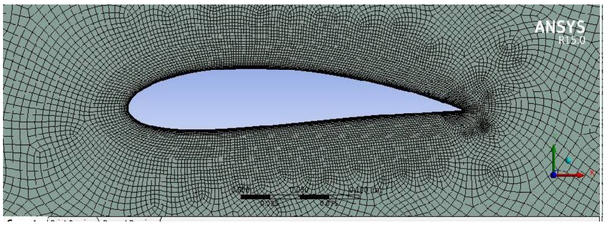

Fig 7 Blade mesh

Named selection

Left width of the rectangle- Velocity Inlet means it is the portion from where the fluent will take the flow.

Right width of the rectangle- Pressure outlet here the outgoing flow will be at the atmospheric condition.

And both the longitudinal portion are taken as Wall (with no slip condition) The whole region of the domain is named as steady outer domain since main consideration is only in the rotor region where the blades are arranged.

The region where the blade are arranged is named as Rotor Inner region of the geometry is named as Stator around which the blades are bound to rotate.

To satisfy the sliding mesh technique Fluent has to be told about the interfaces for rotation of the mesh so the interface between steady outer domain and the rotor is named as Steady outer interface. And the interface between the rotor and the stator is named as the Stator interface

Objective

To carry out CFD analysis on ANSYS Fluent of solidity ratio 0.2 with blade profiles NACA 0015 & NACA 0018. Optimum one is to be selected and further find out the energy generation by the same turbine annually.

Analysis Conditions [7, 8]

Unit for angular velocity- RPM(Rotation Per Minute)

Model- SST(Shear Stress Transport) (k-w)

Material used- Sea water whose specifications are likewise:
$\rho = 1025\ kg/mm3$
$\mu = .00188(N{-}s/m2\ )$
Temp=303 k

Cell Zone conditions- For Every defined domain material type was chosen as fluid (Sea-water) and only for rotating domain the “mesh interface” was and only for rotating domain the mesh motion needs to be defined.
which is different for different TSR value.

Boundary Condition- Here main essential parameters which are required to be define is “Velocity-inlet” and “pressure outlet” and other remaining boundaries parameter are to be checked whether fluent has defined them as per the requirement or not

Like:
Blades as wall, interior surfaces as interior and Interfaces as interface.
Velocity-inlet= Velocity specification method as “Magnitude, Normal to boundary”
Reference frame as “Absolute”
Velocity magnitude as “1.8 m/s”
Gauge pressure as “0 Pa”
Specification method as “Turbulence intensity and Hydraulic diameter” in which Intensity taken as 6% and hydraulic diameter as 0.282m(Chord length)

Pressure Outlet= Gauge pressure is taken as 0 pa and specification method were same as above.

Reason for the above condition taken as so:**-** Since velocity magnitude is given and it is normal to blade without any deviation in y-direction and inlet pressure condition is “0” Turbulence intensity for the rotating machines like “turbine and compressor” which have high Reynolds no’s in fluent it is taken between 5 to 20 percent and for medium Rn nos intensity is taken between 1 to 5 percent.

And hydraulic diameter for every TSR was define as chord length because blade was the main consideration which is to be analyzed For pressure outlet pressure is taken as 0 because it at a far distance from the rotator domain so the effect of it on the body is negligible.

Mesh Interface- Since while using sliding mesh technique it is essential to define this for Analysis purpose so. Here interface between rotor and stator; Rotor and outer domain is defined.

Reference value- As the analysis needs to take place from inlet so reference of velocity inlet condition is taken. As it is 2-d geometry so length and height are given one. And make sure that density and temperature are as per sea water.

Solution method- Solution scheme chosen as SIMPLE (Semi implicit method for pressure linked)
The parameters used for calculating the results are as follows:
Solidity Ratio(∇)= **(**B*C)/(pi*D)
Where
Pi= 3.147
B= Number of blades
C= Chord Length
D= Diameter of Rotor

Tip speed ratio (TSR) is defined as the ratio of rotor tip speed to the flow velocity
Tip speed ratio = Rotor tip speed / water speed

Hydrokinetic power is the power of a free water current through a cross-flow area *A* is
Pin(Input Power) = 0.5 ρ A *v3* … (2)
Where,
A = Projected area of turbine
ρ = Density of water
v = Velocity of water
The turbine efficiency also called power coefficient (Cp) is the ratio of the turbine power output to the power carried by the flow through the projection of the turbine section region onto the plane perpendicular.
Cp=Pout (Output Power)/Pin

RESULT COMPILATION

Methodology

The computational fluid dynamics (CFD) analysis results are used to get the effect of solidity ratios on different hydrofoil blade profile for two different flow conditions. Then optimum solidity ratio and the blade profile will be selected from these CFD results for the particular flow condition. Further when best profile will be selected based on ripple factor calculation.

Analysis requirement

The basic analysis requirements are as follows

a. Turbine diameter 1.8 m
b. Water velocity 1.8 m/s
c. Blade profile NACA 0015, NACA 0018
d. Solidity ratio 0.2
e. TSR range for predicting RPM(Rotation Per Minute) for different analysis is 1.0 to 3.0 *(at most 8 values)*

Hence, the total numbers of analyses are 1 x 2 x 1 x 8 = 16 ≈ 20 combinations (minimum)

Performance of NACA 0018 for flow1.8 m/s at different solidity ratios

The configuration of the straight bladed turbine is as per the following
Diameter: 1.8 m
Length: 5 m
Water velocity: 1.8 m/s
Solidity ratio: 0.2
The chord length for the solidity ratio of 0.2 is calculated as
Chord length, C = (SR*πD)/(B)
Therefore,
C = (0.2*π*1.8)/3
C = 0.3767 m or 376.74 mm

Table 2 Summary of Ø 1.8 x 5 m turbine with SR 0.2 of NACA 0018 at 1.8 m/s water Velocity

TSR	RPM	Avg Torque/m (N-m)	Total Torque(N-m)	Power(Watt)	Cp
1.25	23.8	665.156	3325.78	8284.51	0.3
1.5	28.64	707.877	3539.38	10607.54	0.4
1.75	33.42	689.529	3447.64	11722	0.43
2	38.1	571.663	2858.31	11147.43	0.4
2.25	42.9	446.25	2231.27	9817.62	0.36
2.5	47.7	326.246	1631.23	7893.04	0.25

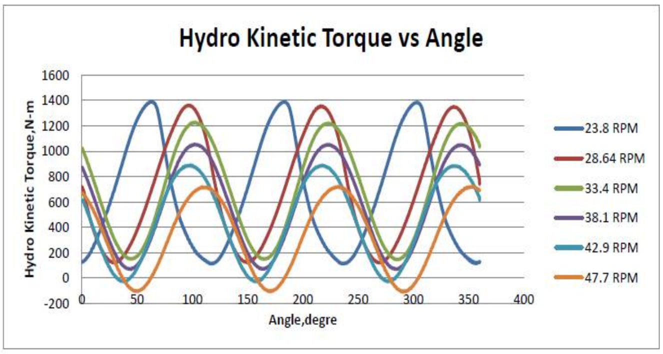

Fig 10 Torque ripple for NACA 0018 with 1.8 m/s flow, chord 0.376m and Ø 1.8 x 5m turbine

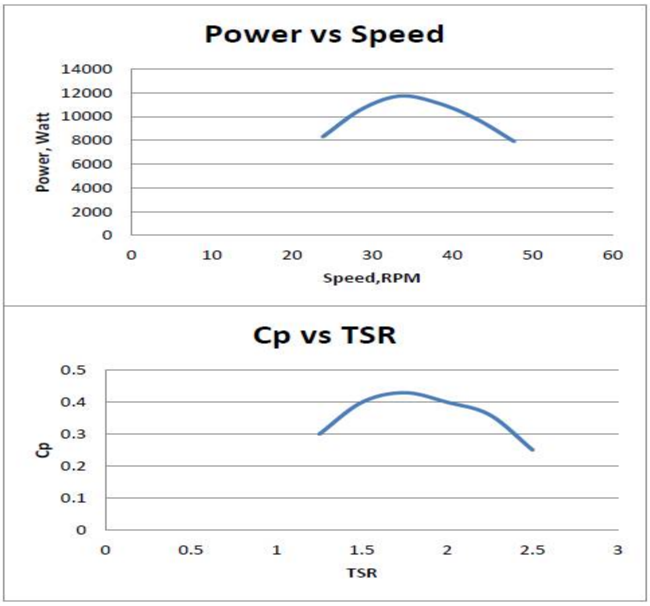

Fig 11 Performance of NACA 0018 with 1.8 m/s flow, chord 0.376m and Ø 1.8 x 5 m turbine

Performance of NACA 0015 for flow1.8 m/s at different solidity ratios

The configuration of the straight bladed turbine is as per the following
Diameter: 1.8 m
Length: 5 m
Water velocity: 1.8 m/s
Solidity ratio: 0.2
The chord length for the solidity ratio of 0.2 is calculated as
Chord length, C = (SR*πD)/(B)
Therefore,
C = (0.2*π*1.8)/3
C = 0.3767 m or 376.74 mm

Table 4 Summary of Ø 1.8 x 5 m turbine with SR 0.2 of NACA 0015 at 1.8 m/s water velocity

TSR	RPM	Avg Torque/m (N-m)	Total Torque(N-m)	Power(Watt)	Cp
1.5	28.64	522.8895	2614.447	7843.342	0.29
1.75	33.42	531.3751	2656.875	9299.064	0.34
2	38.19	529.4892	2647.446	10589.78	0.39
2.25	42.97	433.0784	2165.392	9744.265	0.36
2.5	47.74	331.3635	1656.818	8284.088	0.3

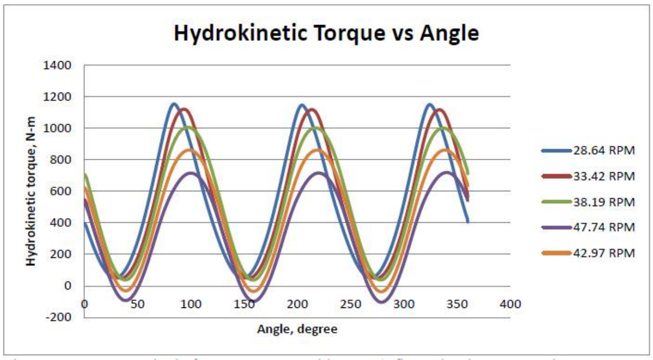

Fig 14 Torque ripple for NACA 0015 with 1.8 m/s flow, chord 0.376m and Ø 1.8 x 5m Turbine

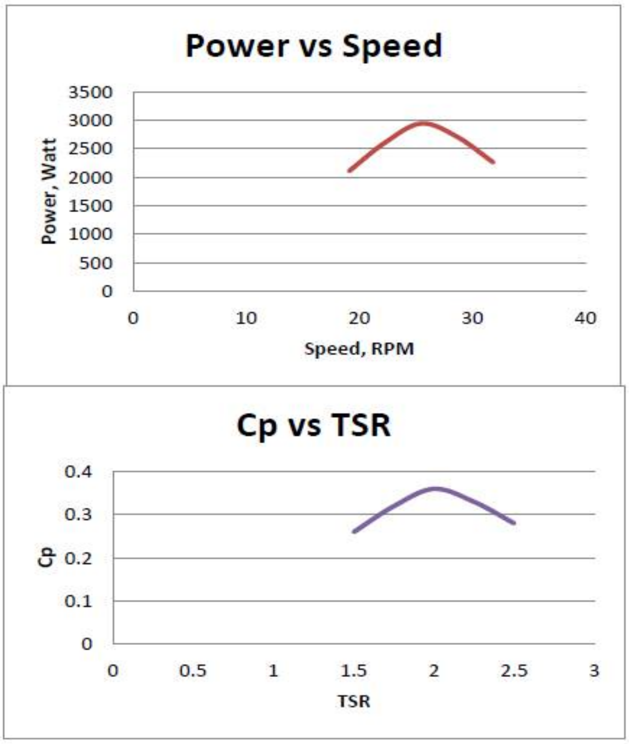

Fig 15 Performance of NACA 0015 with 1.8 m/s flow, chord 0.376m and Ø 1.8 x 5 m turbine

Selection of Best Profile

Ripple Factor Calculation

The study of the flow field with flow speeds of 1.8 m/s is studied around the blade for its three different positions which changes continuously.

Profile is chosen on the basis of the torque ripple calculation since due to change of position of the blade the moment also changes continuously. Hence calculation of ripple factor is done for selecting of the blade profile.

After the analysis results shown above for flow 1.8 m/s for blade profile NACA 0018 and NACA 0015 for the chord length 0.376m(SR 0.2) the ripple factor is calculated which nothing but the ratio of:

(maximum- minimum) torque to the average torque

Table 5 Calculation of ripple factor for turbine Ø 1.8 x 5 m with SR 0.2 of NACA 0015 and NACA 0018 for flow 1.8 m/s

Profile	SR	CL(m)	Flow(m/s)	Max Torque(N-m)	Min Torque(N-m)	Avg Torque(N-m)	R.F
NACA 0018	0.2	0.376	1.8	1226.71	146.39	689.52	1.55
NACA 0015	0.2	0.376	1.8	1004.71	37	529.48	1.83

***Note-** *RF= Ripplle Factor*

After taking ripple factor into consideration it can be seen that the most suited profile is NACA 0018 with SR 0.2 with chord length 0.376m (look onto the table), and in previous pages above of result compilation (analysis results compilation) we can see that for the flow 1.8m/s Cp of 0.43 is given by this profile and that to at lower RPM only. So we can say that NACA 0018 (SR 0.2) in both the flow condition is suitable for generating power at low loading condition.

CONCLUSION

The main objective of the project was to analyze the turbine blades which can generate optimum amount of power from the ocean current. The CFD analysis was carried out for φ 1.8 m diameter turbine at water velocity of 1.8 m/s for NACA 0015 and NACA 0018 profiles with different solidity ratios. This report also contains the method adopted for CFD analysis and the results summary of the analysis for the two profiles in different flow condition. The results in report clearly show that NACA 0018 blade with SR 0.2 gives the better performance in the given flow condition. NACA 0015 as compare to NACA 0018 do not gave high Cp its maximum Cp was 0.4 with SR 0.2 for flow 1.8 m/s and also the hydro kinetic torque ripples factor for the profile is higher than that of NACA 0018. So NACA 0018 with 0.2 solidity ratio has been finalized. Hence an ocean current turbine is designed using this profile for getting the power from the generator directly connected to Ø 1.8 x 5 m turbine in the remote location with such a flow speed of the current like in Andaman and Nicabar Island.

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