TITLE OF PROJECT (Design of Micro Hydrokinetic Turbine)

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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June 2020

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ABSTRACT

This thesis describes the theoretical solution of our final year project. The project was started with the aim of designing and fabricating a small portable hydropower generation system. We designed and fabricated a hydrokinetic turbine which is very small in size and portable and gives electric output of 80-90 watts, which is enough to light 2-3 bulbs and charge mobiles, laptops and wirelesses etc.

The stress analysis was performed on our system in ANSYS and flow simulation was performed on SOLIDWORKS to analyze our design. Due to portability concerns material selection has been considered and HDPE is used.

The focus was on portability because it is designed to be used by military in case of military operations in remote areas and during war. Secondly, it is for tourists and adventurous people who go to remote areas where there is no electricity and other basic facilities. Thirdly, many remote areas in Pakistan have access to streams and rivers but these areas don’t have electricity. Best option is to provide them electricity through installing these hydrokinetic turbines.

We have designed a horizontal axis turbine which is channeled at the inlet with the help of duct and diffuser is augmented. This turbine is designed for flow velocities of northern areas i.e. 2.3 m/s.

We concluded that Cp of micro hydrokinetic turbine increases with increase in depth of the turbine in a stream and it also increases with the total depth of the stream. Cp of turbine becomes less dependent on stream depth if we move away from optimum TSR of that turbine. This turbine was designed for 180 watts but due to losses its output will be 70-80 watts (Cp=0.41).

ACKNOWLEDGMENTS

First of all, we thank ALLAH for His blessings and help in the smooth completion of the project.

We also acknowledge the financial support by the department during this project. Special thanks to our project advisor Dr. Imad-ud-Din and project co-advisor Dr. Zaib Ali who helped us in our design phase of this project. We would also like to thank Dr. Sanaa Waheed for guiding us during the simulation of our model in ANSYS. We would also like to thank Lecturer Hamza Asif for his help regarding the techniques which can be used to couple a generator with turbine. Thanks to Dr. Sami Ur Rahman also for his valuable guidance.

Special thanks to our parents for their moral and financial support and prayers due to which we were able to complete this project smoothly.

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ABBREVIATIONS

TSR	Tip Speed Ratio
AR	Area Ratio
HAWT	Horizontal Axis Water Turbines

NOMENCLATURE

P	Power (W)
Cp	Co-efficient of power (efficiency of turbine)
A	Swept area of turbine (m^2)
N	No. of blades of turbine
c	Chord length of blade (m)
l	Length of blade (m)
σ	Solidity of turbine
U	Flow velocity of water at inlet of turbine (m/s)
ρ	Density of water (kg/m^3)
r_t	Tip radius of turbine (m)
H	Height of cross flow turbine (m)
D	Width of cross flow turbine (m)
β	Blade angle (degrees)
β'	Relative blade angle (degrees)
$\Delta\theta$	Wrap angle (degrees)
Δm	Meridional length (m)
D_h	Hub diameter of turbine (m)
D_m	Mean diameter of turbine (m)
Dt	Tip diameter of turbine (m)
ξ	Tip speed ratio of turbine
s	Circumferential spacing of turbine (m)
z_B	No. of blades of turbine
ψ	Flow angle (degrees)
C_L	Lift coefficient
C_D	Drag coefficient
F_L	Lift force (N)
F_D	Drag force (N)
ν	Tangential velocity at tip of turbine (m/s)
ν'	Relative flow velocity (m/s)
c	Chord length (m)
θ	Angle of diffuser (degrees)

L	Length of diffuser (m)
μ	Dynamic friction of water
Fr	Froude Number

CHAPTER 1: INTRODUCTION

Turbine is a device that converts the kinetic energy of moving fluid into rotational mechanical energy. Hydro turbine as the name suggests converts the kinetic energy of moving water to rotational mechanical energy.

Hydroelectricity is an environment friendly and cheap source of energy.

First hydro generator was manufactured by Michael Faraday in 1832 and it opened the doors for more research towards hydel energy. In 1882, first hydro power plant was installed and it had the output power of about 12.5 kW. Then number of these hydropower plants continued to increase in 20th century. In 1936 a large scale dam was built called “Hoover Dam” on Colorado river. It was first mega hydropower plant. Its capacity was 1345 MW. Now the biggest dam in the world is “Three Gorges Dam” in China. It has a capacity of 22,500 MW.

Hydrokinetic turbines are now in use also. These are small run-off river plants. These do not require large space, easy to install, and very cheap sources of energy. Basically, turbine is placed in a flowing stream and that turbine rotates due to the velocity of stream flow. These plants have very low power output because these are small scale plants but can be very useful in remote areas.

Motivation of Work:

Environmental Pollution:

Fossil fuels are also a source of CO_2 emissions and are causing the ozone layer to deplete [1]. Thus fossil fuels are a source of environmental pollution and climate change is a very serious threat these days. Global temperatures are rising and intensity of weather has increased due to climate change. Glaciers on the north and south poles are also melting due to the average increase in global temperature. So many heat waves are also hitting many parts of the world. Environmental pollution in many countries has reached very dangerous levels and it has given birth to many problems like smog etc. This case is mostly in developing countries and energy demand is on the rise in these countries exponentially.

Increase in energy Demand:

Demand for energy is constantly increasing at a rapid rate all around the world. To meet these energy demands, we cannot rely on fossil fuels only because resources of fossil fuels are also depleting all around the world. Secondly, not all countries are blessed to have rich fossil fuel reserves and these countries have to pay a hefty amount to buy these fossil fuels. Switching to renewable energy will help these countries to balance their budget easily.

Following graph shows the increase in energy demand worldwide in the upcoming years: [2]

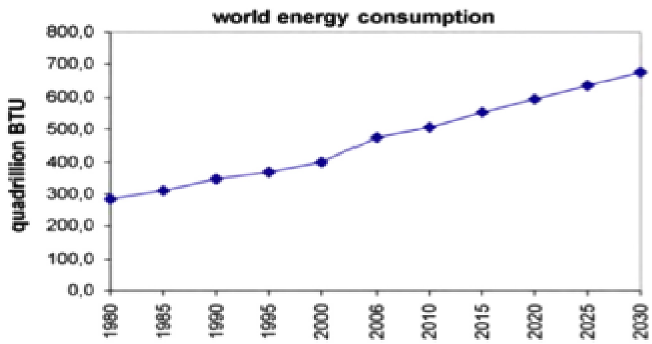


Figure 1: Annual global energy demand record and future forecasts

Crude oil reserves are expected to last for the next 41.8 years and natural gas reserves are expected to last for next 61.3 years [3]. This is a very short period of time given that a major portion of our energy generation is dependent on fossil fuels. Once we run out of fossil fuels and there is no alternative, we go back into the Stone Age. We must find a sustainable and cheaper source of energy to replace fossil fuels.

Energy Supply in Remote Areas:

The easiest source of providing electrical energy to remote areas near streams is hydrokinetic energy. One source of providing electricity can be grid extension but that can be costly and there will be geographical restrictions. Another option is installing diesel generators but with generators, the problem of fossil fuels rises again, and supplying fuel to remote areas will also be a hindrance. These hydrokinetic plants are basically run off river plants. A turbine is placed in the running stream and electricity is produced by letting stream water flow through that turbine. [4]

Problem Statement:

As energy demands are increasing and fossil fuels are depleting. Renewable energy has gained very much importance. Among renewable energies, hydro energy is the most reliable and cheap source of renewable energy.

Large dams can be built to provide hydro energy but these large dams are not that much environment friendly because these dams consume a large of space which can include your forests and other habitats of wildlife. These large dams also change the migration pattern of fish. In short, dams change the climate of their surrounding area. Dams also take a long time to be constructed and a large amount of money and effort is needed.

1/3rd of all population of the world is living alongside rivers and streams but do not have electricity. In military operations in remote areas, soldiers don't have access to electricity, sometimes tourists also don't have access to electricity, a portable hydrokinetic turbine can be useful in such cases

So, we are designing a portable hydrokinetic design with diffuser augmented with it. This system will be run off the river plant and will be portable so that it can be used in remote areas when needed during military operations and sometimes by tourists. This is also an environment friendly and very cheap source of energy.

Objectives:

The main objective of the project is to develop an axial flow hydrokinetic turbine which can be used in run off river plant. The turbine will be able to work in remote areas like northern areas of Pakistan and whole system including turbine transmission gear and generator will give a net power output of 70-80 watts. People will be able to use this turbine to light 2-3 bulbs and charge their mobiles and laptops.

Following are the objectives:

1- Design and Fabrication of axial flow hydrokinetic turbine with diffuser augmentation.

2- Coupling of DC motor to get current due to back emf of a motor which will be generated due to rotation of the motor.

3- To select a proper flow velocity for the working of the turbine.

4- To design and fabricate a stand that will be used to place the turbine in a stream bed.

5- To perform structural and stress analysis on the model of the turbine.

6- To study the effect of stream depth on performance of the turbine.

CHAPTER 2: LITERATURE REVIEW

Turbine:

Turbine is basically a device that converts the kinetic energy of moving fluid into rotational mechanical energy.

Hydrokinetic Turbine:

Hydro turbine as the name suggests converts the kinetic energy of moving water to rotational mechanical energy. This turbine does not require any dam or reservoir. It just rotates due to just flow of water in a river or stream. These turbines use the same phenomenon as wind turbines but these produce more power because of denser working fluid. Water is 800 times denser than air.

The following figure depicts the basic structure of hydrokinetic turbine:

[5]

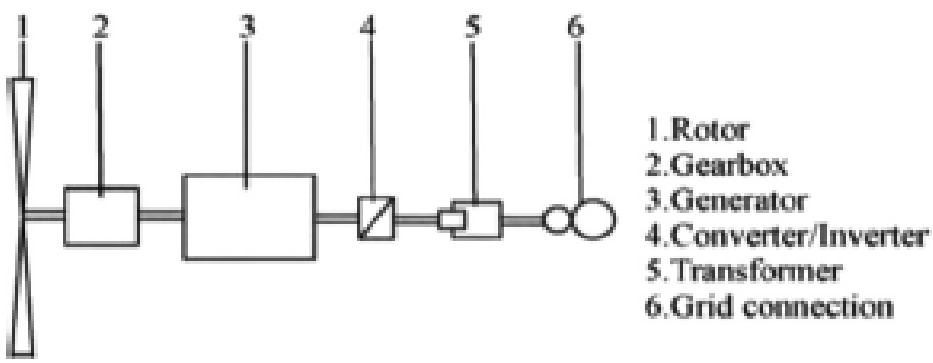


Figure 2: Schematic of axial flow hydrokinetic turbine

Classification of Hydrokinetic Turbines:

1- Hydrokinetic can be classified mainly due to their two types of configurations;
2- Horizontal Axis Turbines or Axial Flow Turbines
3- Vertical Axis Turbines or Cross Flow Turbines

Vertical Axis Turbines:

These turbines have their axis perpendicular to the direction of flow. These turbines have relatively lower co-efficient of performance and cut-in speeds. So these can be used in low water current speeds but the power output would be less as compared to horizontal axis turbines.

These turbines can accept incoming flow from any direction so these turbines do not require yaw mechanism. So these turbines are simpler than horizontal axis turbines to manufacture and operate.

These turbines also do not require sealing of generator as the generator is placed above the turbine and bevel gear is also not needed in their case making their manufacturing easier and cheap.

Following are some vertical axis turbines: [6]

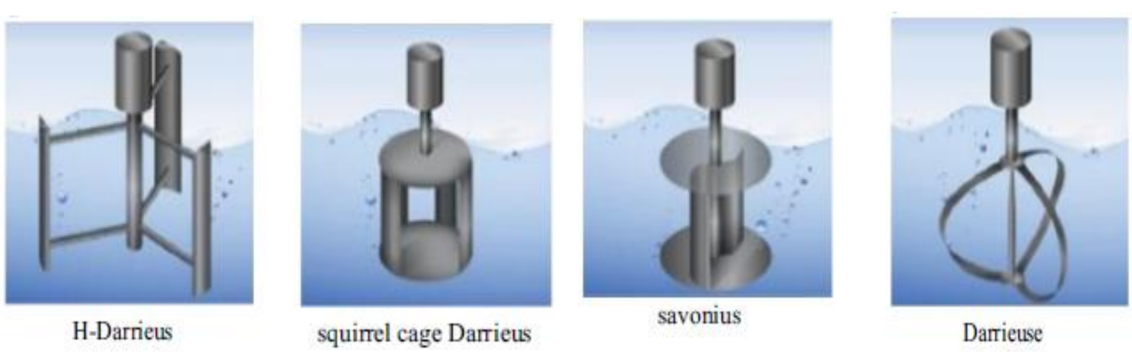


Figure 3: Vertical Axis Turbines

Horizontal Axis Turbines:

As the name suggests, these turbines have horizontal axis of rotation. These turbines generally rotate due to lift force which is applied by the fluid. These turbines are more efficient and produce more power but cut-in speeds of these turbines is also higher which means these can't be installed at the site which has low water current speed. There are also other problems associated with these turbines regarding the coupling of generator because if the generator has to be immersed in water to get coupled to turbine then proper sealing must be applied. You can prevent generator from submerging but that will require a complex design that may include the use of bevel gears etc.

Direction of incoming flow affects the performance of these turbines. So yaw mechanism is used in these turbines to adjust the direction of turbine such that it gives maximum power output.

Basically, there are four installation configurations of these horizontal axis turbines:

- Inclined Axis
- Rigid mooring
- Non-submerged generator
- Submerged generator

Following figures depict these four installation configurations:

[7]

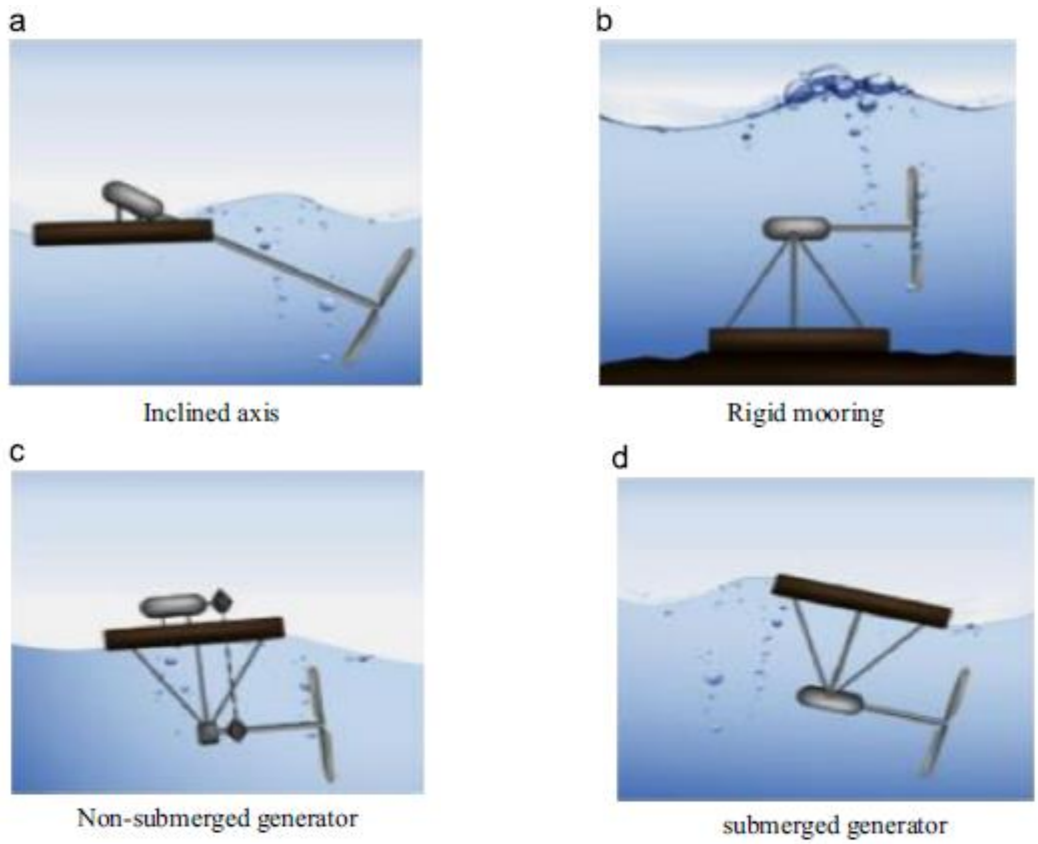


Figure 4: Horizontal Axis Turbines

Inclined axis configuration:

In inclined axis configuration, a turbine is inclined at some angle and is completely submerged in water but its stand is floating on the water on which generator is installed at the same inclination angle as the turbine. This configuration does not require perfect sealing of the generator because it is not submerged in water. It is placed on the stand which is floating on water.

Rigid Mooring Configuration:

In rigid mooring configuration, turbine is completely submerged in water and its axis is perfectly horizontal, there is no inclination of the turbine and shaft. Stand in this configuration is also completely immersed in water and rests on the river bed. Generator is also immersed in water and is placed above the stand through supports in this configuration so this configuration does require a perfect sealing of generator to avoid any damage.

Non-Submerged Generator Configuration:

In this configuration, generator is placed on stand and stand is floating on the water, so generator is not submerged but turbine is submerged and turbine's shaft and generator's shaft are connected through bevel gear. This configuration also does not require sealing of generator because it is not submerged in water.

Submerged Generator Configuration:

In this configuration, generator and turbine are both submerged in water while stand is still floating on the water. Generator is supported by the stand with the help of rigid supports. Overall weight of the whole system should be less than buoyancy force of water. Sealing of the generator is required in this configuration as it is immersed in water.

Design Parameters of Hydrokinetic Turbines:

Following are some design parameters of hydrokinetic turbines, which greatly affect the performance of turbine:

Co-efficient of Power:

Co-efficient of power basically tells us that how much energy or power the turbine can extract from water. We always want to increase the coefficient of power but it can't go beyond a certain limit called betz limit and its value is 0.593.

Total amount of power in water entering the turbine is calculated as:

$$\mathbf{P_{water}} = \frac{1}{2}\,\rho A U^3$$

P_{water} is power in the incoming flow, ρ is density of the water, A is swept area of turbine and U is the velocity of flow entering the turbine.

Amount of power extracted from water by the turbine can be calculated by the following formula:

$$\mathbf{P_{turbine}} = \frac{1}{2}\,c_p\,\rho A U^3$$

$P_{turbine}$ is power in the incoming flow, ρ is density of the water, A is swept area of turbine, U is the velocity of flow entering the turbine and c_p is the coefficient of power of turbine.

Tip-speed ratio:

Tip-speed ratio (TSR) is the ratio of tangential velocity at the tip of turbine to the flow velocity. This ratio has a direct impact on coefficient of performance of turbine. Higher TSR doesn't necessarily mean a higher coefficient of power; an optimum TSR speed must be chosen to get a maximum value coefficient of power.

$$\textbf{TSR} = \frac{wr}{U}$$

TSR is tip-speed ratio, w is angular velocity of turbine, r is the tip radius of turbine and U is the velocity of flow which is entering the turbine.

Following graph shows the effect of TSR on coefficient of power of various turbines: [8]

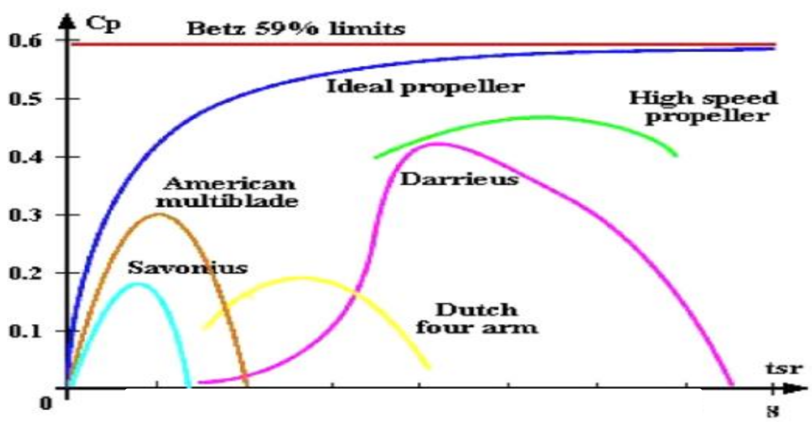


Figure 5: Comparison of C_p – TSR curves

Swept Area:

Swept area is the area swept by turbine blades while rotating when observer is standing directly in front of the face of turbine. This swept area is basically the area in which water or any flow makes contact with rotor blades. Co-efficient of power is directly proportional to swept area but it should not be too large, because too large swept area will require more material and consequently more cost. That why an optimum swept area should be chosen to maintain balance between output power and cost of the turbine. Larger swept area will also negatively affect the portability of turbine.

Swept area of horizontal axis or axial flow turbine is calculated as:

$$\mathbf{A_{swept} = \Pi r^2}$$

A_{swept} is swept area of turbine and r is tip radius of the turbine.

Swept area of vertical axis or cross flow turbine is calculated as:

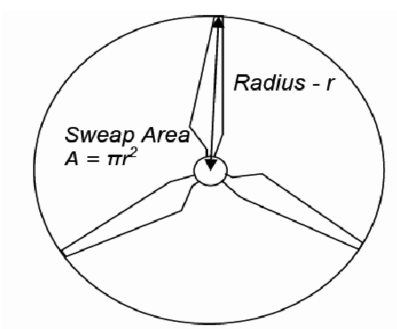
$$\mathbf{A_{swept} = D * H}$$

A_{swept} is swept area of turbine, D is width of the turbine and H is height of the turbine.

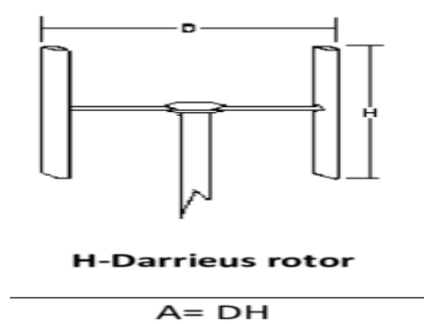
Following figures depict the swept area of axial flow turbine and cross flow turbine: [9] [10]

(a) is for axial flow turbine

(b) is for cross flow turbine



(a)



(b)

Figure 6: (a) Swept area for axial flow turbine. (b) Swept area for cross flow turbine.

Solidity:

Solidity is the ratio of blades' surface area when observing form face of the turbine to the swept area. More solidity gives more power but again cost is the issue here. So a compromise is made between cost and solidity. Another issue is that a very high value of solidity will make the turbine behave as solid disk and it will obstruct the flow of water.

Solidity can be calculated by the following formula:

$$\sigma = \frac{Ncl}{A}$$

σ is solidity of the turbine, N is number of the rotor blades, c is chord length of the blade and A is the swept area of the turbine.

Diffuser Augmentation and Channeling:

Diffuser is augmented at the end of turbine to increase the coefficient of power. Inlet of turbine is channeled with the help of duct and then duct is attached to the diffuser and brims are installed at the end of diffuser.

Diffuser augmentation reduces the back pressure on the turbine and reduces vortices. Brims at the end of diffuser create low pressure regions and flow is forced out of the diffuser smoothly.

Diffuser augmentation causes an increase in the power co-efficient of turbine and that increase depends upon the area ratio of the diffuser. Area ratio of diffuser increases the coefficient of power but up to a limit. So an optimum area ratio of diffuser must be chosen to get maximum power output from turbine.

Following figures show different types of channeling and diffuser augmentation for axial flow and cross flow turbines: [11]

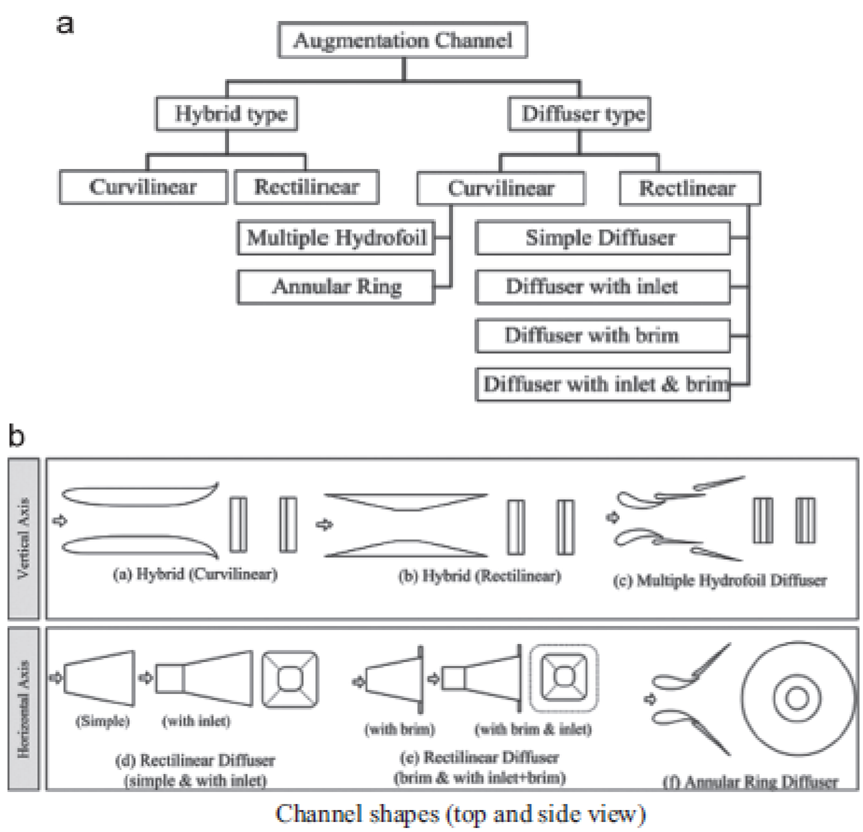


Figure 7: (a) Augmentation channel classification. **(b)** Channel shapes (top and side view)

Components of a Diffuser Augmented Turbine:

We will focus on axial flow turbine that is in domain of our project.

A diffuser augmented axial flow turbine mainly consists of these three components:

A. Rotor
B. Duct
C. Diffuser
D. Stand

Rotor:

Rotor is basically the turbine. It rotates due to kinetic energy of flow. Blades are attached to hub which is fixed with shaft. This shaft transfers power from turbine to the generator. This the main part which draws energy form the flow.

Duct:

Duct is basically a casing around the rotor and shaft to channel the flow into the turbine. Its inner dia is bigger than turbine's tip dia to keep clearance but this clearance is kept minimum. Clearance is kept to avoid collision of turbine blades with casing and turbine is perfectly installed at center of duct to avoid any irregularity in turbine blades' periphery.

Diffuser:

Diffuser is installed at the end of inlet duct. It increases the coefficient of power of turbine and reduces the back pressure on turbine. It also reduces vortices. Its area ratio is not increased beyond a certain limit.

Stand:

Turbine with its casing is placed in a stand to install the turbine in stream or river. Depending on the design, stand can be submerged in water or it can be out of water or it can be partially in water and partially out of the water.

CHAPTER 3: METHODOLOGY

The Design Parameters:

To design a turbine there comes two approaches which can be applied: bottom-up and top-down. The top-down approach considers the global characteristics and thus composes the subsystem that results in the desired characteristics whereas the bottom-up approach considers the subsystems and modeled them to gain global characteristics. In our case the top-down approach has been implemented to figure out the global characteristics and accordingly have considered the subsystems depending upon Power, Cp i.e. the efficiency and flow velocity, and subsequently derived the Diameters (Dt, Dh and Dm) and the blade angles (($\beta 1$, $\beta 2$) and relative blade angles β'. And the meridional length, Δm, the circumferential spacing, s, the number of blades ZB, $\Delta\theta$ the wrap angle. The power predictions were within 7.0% of the prescribed power input. Due to the equality between relative incidence and deviation flow angles, the leading edge and trailing edge relative blade angles have the following relationship: $\beta 1' = \beta 2' = \beta'$. [12]

Mathematical Modelling:

The Design Parameters:

At different values of inlet flow velocity (U), the C_p values and the input power the values are plugged in the mathematical model of turbine design parameters to determine the optimized design parameters, the iteration been done are shown in table 1. below, the results are finalized as an optimum value for the specific value of velocity conditions corresponding to an overall 44% efficiency of the turbine, considering the factor of portability of the turbine. [12]

Table 1: Calculations for Design Parameters of Turbine

1. Tip diameter	2. Hub diameter	3. Mean diameter	4. Angular velocity	5. Blade angle
0.414452981	0.041445298	0.291593519	15.708	45.5155771
0.383708901	0.03837089	0.269963141	15.708	43.3081399
0.358926811	0.035892681	0.252527395	15.708	41.4036313
0.338399442	0.033839944	0.238085112	15.708	39.7366452
0.321033899	0.03210339	0.225867369	15.708	38.2604424
0.306093813	0.030609381	0.215356086	15.708	36.9404827
0.752423201	0.07524232	0.529376646	15.708	73.914776
0.280459164	0.028045916	0.197320512	46	63.1364891
0.271323166	0.027132317	0.190892768	15.708	33.6835821
0.262123081	0.026212308	0.184419934	15.708	32.7775326
0.253799582	0.025379958	0.178563834	15.708	31.9415944

0.246221761	0.024622176	0.173232364	15.708	31.1670837
0.23928454	0.023928454	0.168351597	15.708	30.4467646

6. Relative blade angle	7. spacing, s	8. Chord length	9. Meridional length	10. wrap angle
70.00691315	0.30529841	0.253397684	-0.253156115	93.58964268
69.51018394	0.28265141	0.234600669	0.232041018	93.29076681
69.18384902	0.26439618	0.219448832	0.219448797	93.09059869
68.98762717	0.24927511	0.206898343	0.0509211	92.96878595
68.89292742	0.23648314	0.196281002	-0.112055637	92.90960716
68.87881434	0.22547782	0.187146593	0.037396367	92.90076603
82.28989201	0.55425735	0.460033599	-0.448688054	98.6959468
76.85082412	0.20659458	0.171473498	0.154087322	96.98285912
69.18014562	0.19986473	0.165887724	0.162185356	93.08830975
69.36313432	0.19308767	0.160262767	-0.105769456	93.20094323
69.57614921	0.18695633	0.155173757	-0.136856631	93.3308614
69.81435695	0.18137429	0.150540657	0.000677962	93.47461733
70.0738004	0.17626412	0.146299221	0.108513967	93.62935123

11. Input Power	12. Cp	13. Velocity	14. density
230	0.3	2.25	998
230	0.35	2.25	
230	0.4	2.25	
230	0.45	2.25	
230	0.5	2.25	
230	0.55	2.25	
230	0.6	1.2	
180	0.48	2.3	
230	0.7	2.25	
230	0.75	2.25	
230	0.8	2.25	
230	0.85	2.25	
230	0.9	2.25	

The formulas used as mentioned in table x. systematically as:

1. $$D_h \cong \sqrt{D_t^2 - \frac{8P}{C_p \pi \rho U^3}}$$

2. 0.1*D_m

3. $$\omega = \frac{\xi * U}{r}$$

Where ξ = Tips Speed Ratio taken as 2.8 through C_p TSR curve.

U= inlet flow velocity taken as 2.3 m/s for finalized design

r= mean radius of turbine blade

$$D_m = \sqrt{\frac{1}{2}(D_t^2 - D_h^2)}$$

4. $$\beta = \tan^{-1} \xi$$

5. $$\beta' = \psi' = \beta + 24.874\xi^{-0.876}$$

6. $$s = \frac{\pi D_m}{Z_B}$$

7. $$c = \sigma s$$

Where σ = solidity i.e. 83% for three Hydel blades turbines

8. $$\Delta m = c \cos \psi$$

9. Where $\varphi = \beta' the\ relative\ blade\ angle$

$$\Delta\theta = \frac{2c}{D_m} \sin \psi$$

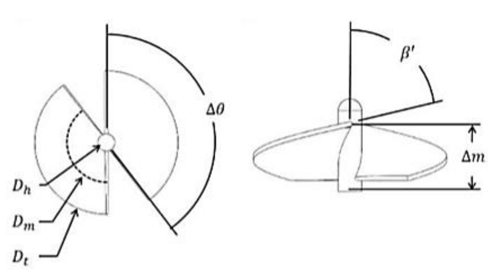


Figure 8: Turbine design parameters

10. Power input is taken as 180 W considering all the losses associated with turbine and assuming the turbine to be 44% overall efficient to generate an output power of 79.2W, as the final output power.
11. C_p is taken as 0.48 for the diffuser augmented turbine having Area Ratio of 1.54.
12. The flow inlet velocity (U) is taken as 2.3 m/s for optimized design and for the bare minimum requirement of flow conditions for the turbine to operate on a wider range.
13. Density = 998 kg/m^3 Standard value at room temperature.

Lift and Drag Calculations:

To calculate the lift and drag values of the turbine the airfoil NACA-63215 values [12] are used as it gives values of C_L and C_D with respect to angle of attack, for the specific Reynold's number range of the turbine. Table 2 shows the results values for the optimum design as finalized above, the angle of attack corresponding to the respective values of chord length.

Table 2: Design Calculations for Lift and Drag forces

14. Radius of turbine	4.Angular velocity	15. Blade speed	16. Flow angle	5. Blade angle	18. Angle of attack
0.012620662	46	0.580550469	75.82604573	9.62563496	66.20041077
0.025241325	46	1.161100937	63.20776948	18.7368724	44.47089712
0.037861987	46	1.741651406	52.86021471	26.9672981	25.89291662
0.050482649	46	2.322201874	44.72028119	34.1539156	10.56636557
0.063103312	46	2.902752343	38.38772336	40.2997114	-1.911988009
0.075723974	46	3.483302812	33.43312534	45.5024615	-12.06933613
0.088344637	46	4.06385328	29.50537934	49.895543	-20.39016362
0.100965299	46	4.644403749	26.34285986	53.6131982	-27.27033831

0.113585961	46	5.224954217	23.75646946	56.7750252	-33.01855573
0.126206624	46	5.805504686	21.61008836	59.4814807	-37.87139232

19. Re	20. C L	21. C D	22. Relative velocity	23. FL	24. F D	13. Velocity
16580.1768	1.25	0.2	2.372138033	1.480515	0.236882	2.3
33160.3537	1.25	0.2	2.576461796	6.432155	1.029145	2.3
49740.5305	1.25	0.2	2.885021598	16.20557	2.592892	2.3
66320.7074	1.25	0.2	3.268427993	32.63861	5.222178	2.3
82900.8842	1.25	0.2	3.703507954	57.78646	9.245833	2.3
99481.061	1.25	0.2	4.174134458	93.7868	15.00589	2.3
116061.238	1.25	0.2	4.669572088	142.8058	22.84893	2.3
132641.415	1.25	0.2	5.182710312	207.0188	33.123	2.3
149221.592	1.25	0.2	5.708778028	288.6031	46.17649	2.3
165801.768	1.25	0.2	6.24450836	389.7365	62.35783	2.3

15. Radius = $D_m / 2$

16. $\nu = r_t * \omega$

17. Flow angle = $tan^{-1}(\frac{U}{v})$

18. Angle of attack = Flow angle – Blade angle

19. $Re = \frac{\rho * U * c}{\mu}$

Where c be the chord length at specific value of radius

20. C_L from the graph of NACA-63215

21. C_D from graph of NACA-63215

22. Relative velocity $v' = \sqrt{U^2 + v^2}$

23. $F_L = C_L * 0.5 * A * v'^2$

24. $F_D = C_D * 0.5 * A * v'^2$

The Lift and Drag forces derived at the tip of the blade are used to find out the Stress analysis on the Turbine through Ansys, the results are discussed in next section.

Diffuser Augmentation:

The diffuser is augmented to further increase the C_p value at the same value of inlet velocity. When we augment diffuser with a wind turbine then its power output becomes up to 4.25 times that of normal wind turbine working at optimum conditions. This has been applied to micro hydrokinetic turbines as well and different diffuser designs have been used. Mehmood et al. [13, 14] numerically predicted diffuser models to be of hydrofoil geometries, this will cause the maximum flow through the center line of the diffuser. Diffuser designs these days are not sufficient. These diffuser designs must be optimized and tradeoffs should be minimized. One thing which should be kept in view is that diffuser design must provide additional downstream thrust. Preliminary characterization of normal hydrokinetic turbines and hydrokinetic turbines with diffuser augmentation can provide minimal expectations for power generation, thrust generation of the unit and flow field characteristics near the unit. [12]

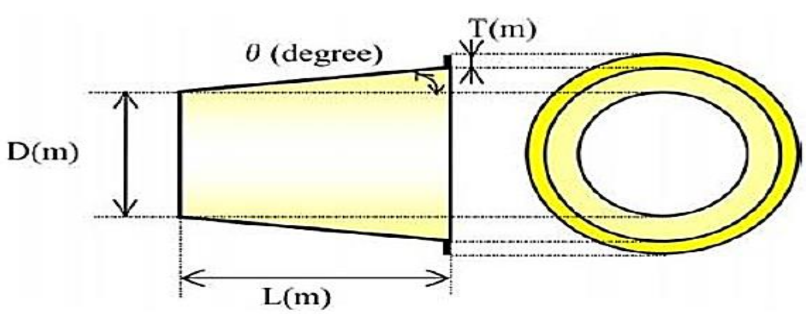


Figure 9: Diffuser front and side view

Relationship of C_p and Thrust Generated by Diffuser:

Normalized Turbine

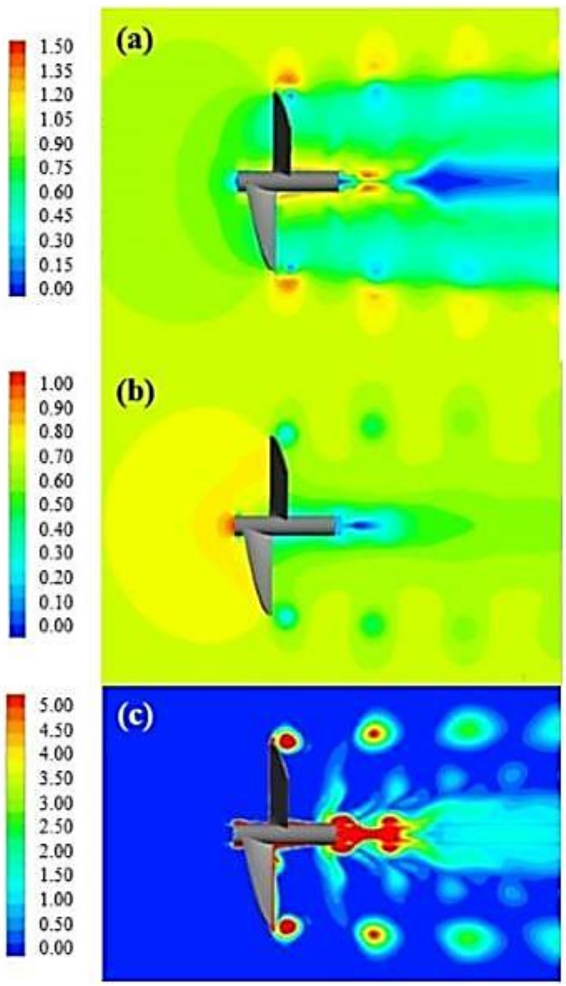


Figure 10: (a) Flow simulation without diffuser

Diffuser Augmented Turbine

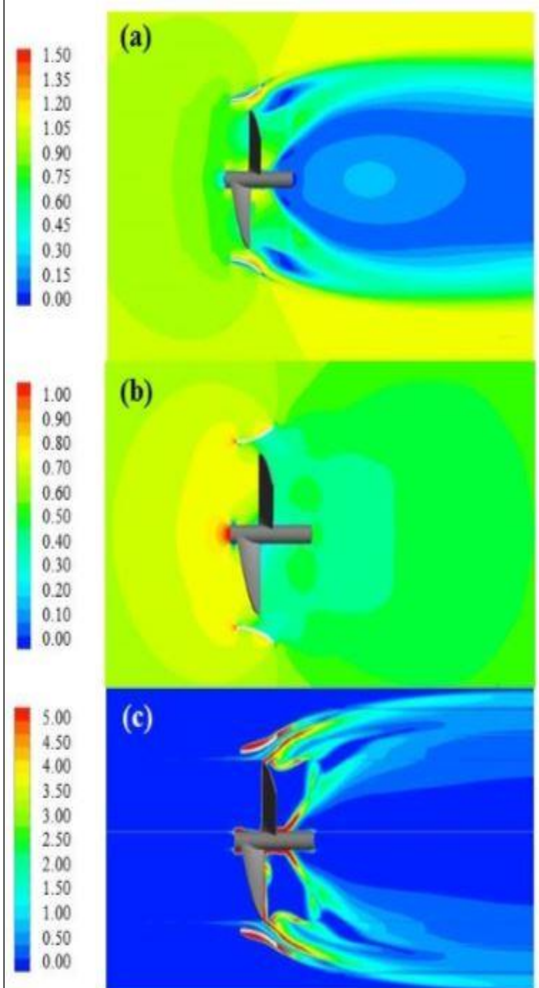
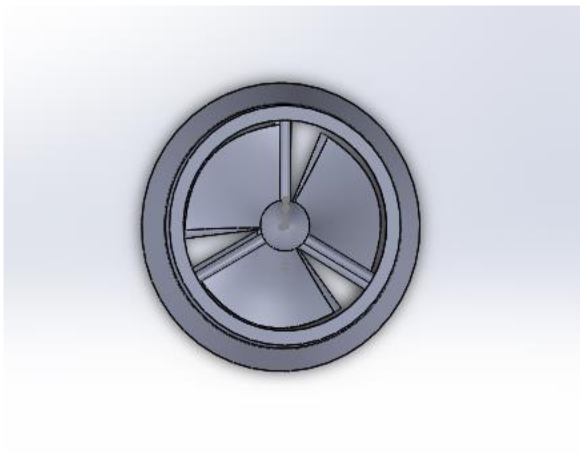
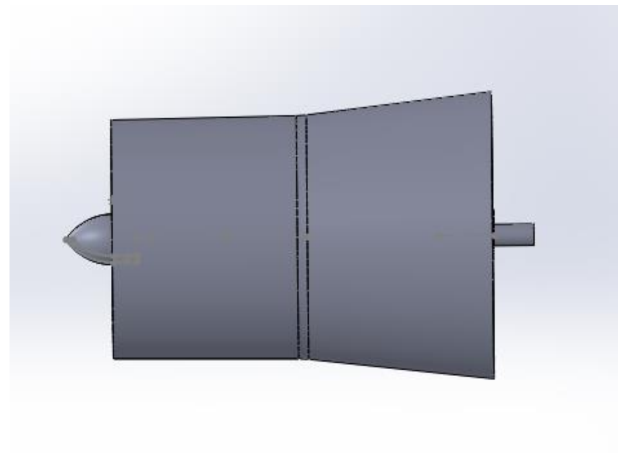


Figure 10: (b) Flow simulation with diffuser

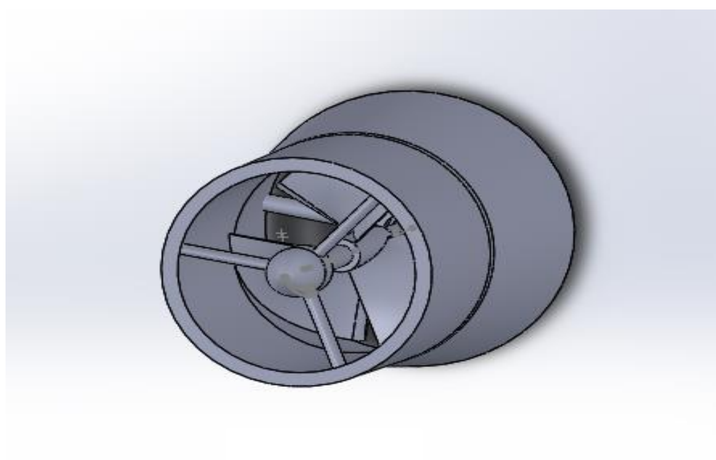
<table>
<tr><td>a) velocity b) pressure c) vorticity</td><td>a) velocity b) pressure c) vorticity</td></tr>
<tr><td>The velocity is disruptive</td><td>The velocity is quite uniform</td></tr>
<tr><td>There was adverse pressure gradient</td><td>The adverse pressure gradients are removed</td></tr>
<tr><td>The vorticity was disruptive</td><td>The vorticity is decreased</td></tr>
<tr><td colspan="2">A pressure drop is experienced when a diffuser is augmented with turbine and that pressure drop causes the vortices to go away from the center of turbine and the distortion of the tip vortices also as the flow was accelerated more rapidly at the blade tip in a normalized turbine which results in the greater concentrated and deficit regions of velocity whereas in the diffuser augmented turbine the velocity's is shifting towards more uniformity. On the whole, there is an increase of 48% in the power as compared to a normalized turbine. With regard to thrust forces as you increase the area ratio the thrust coefficient on the turbine increased which is a strong function of Area Ratio that's it is kept in safe limits of 1.54[12]</td></tr>
</table>

CAD Model:





(a) **(b)**



(c)

Figure 11: CAD model (a) Front view. (b) Side view. (c) Isometric view

Turbine 2D Drawings:

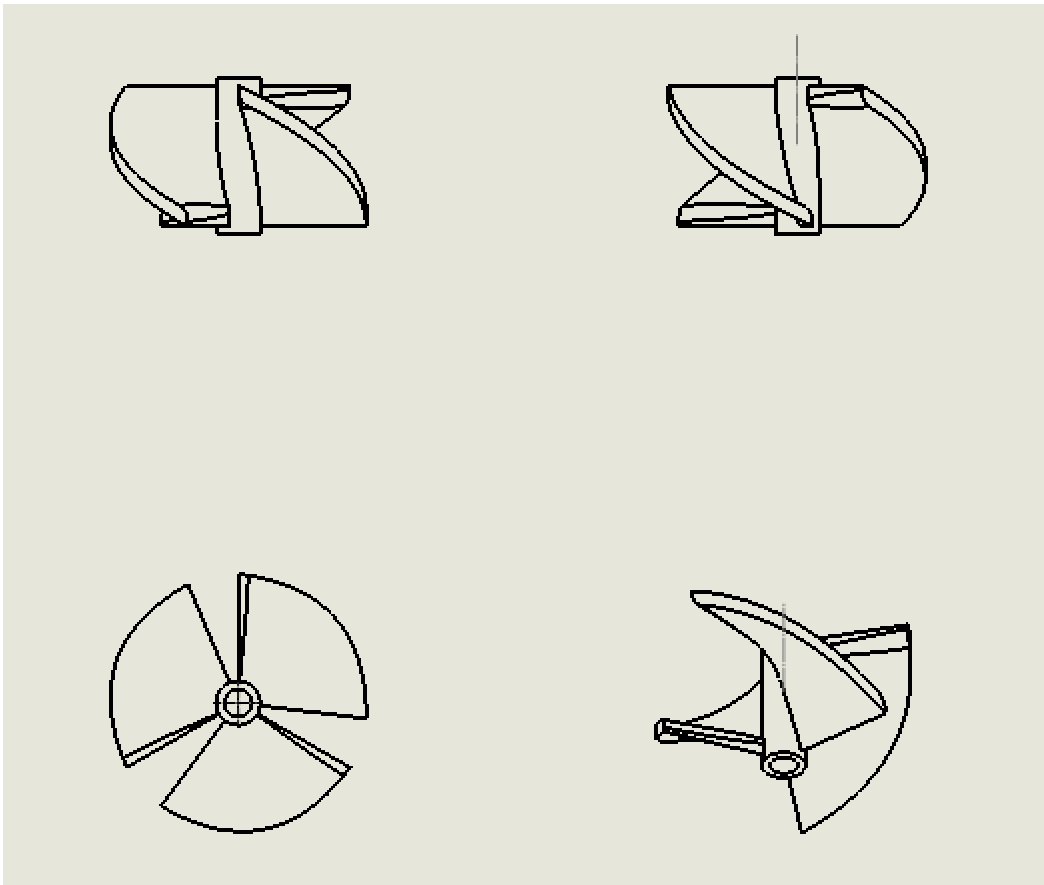


Figure 12: Turbine 2D drawings

CHAPTER4: RESULTS AND DISCUSSIONS

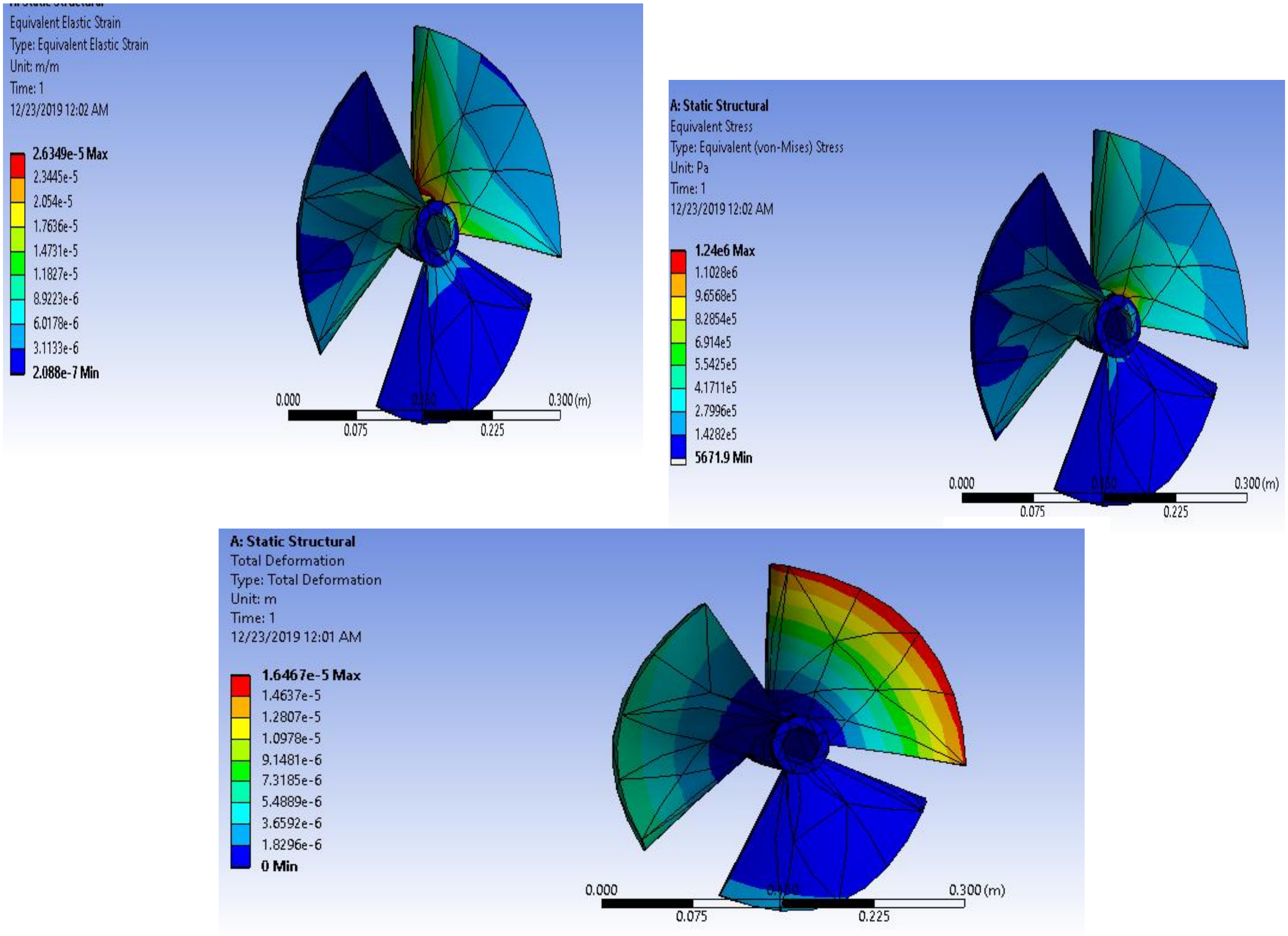
Deformation & Stress Analysis:

Deformation analysis is done using Ansys. Forces (lift and drag) obtained analytically as mentioned above, are used as inputs for the stress & strain analysis.

Stress & Deformation Analysis of Turbine Blades:

Analysis:

Total deformation values are in the range of **1.829e-6 -1.646e-5** (m) which is quite acceptable considering the yield strength of the material of blades which is Aluminum Alloy**. Equivalent Strain** values range from **2.088e-7** to **2.634e-5 (m/m)**. Maximum Stress induced is **1.24e6 (Pa)** which is less than the yield strength of aluminum that is **310Mpa.** Hence the results show that the forces applied on the blades will not cause the failure of material because the deformation, strain and stress values are in safe ranges a shown below in the figures;

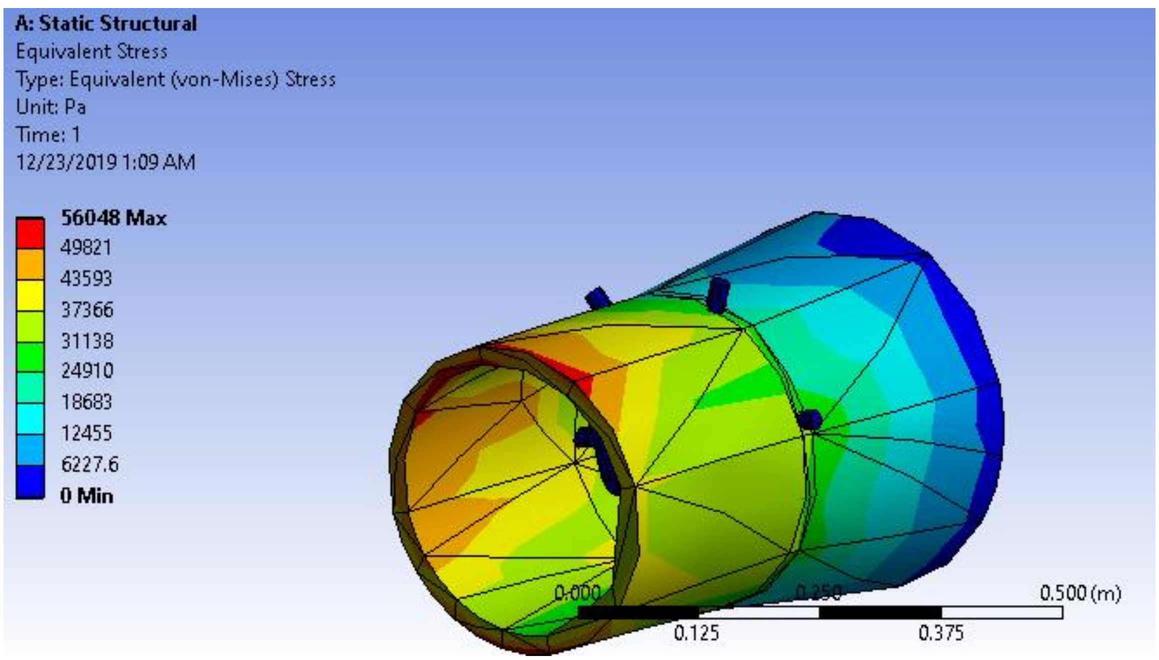


(c)

Figure 13: (a) Strain analysis of turbine. (b) Stress analysis of turbine. (c) Deformation analysis of turbine

Deformation & failure analysis of turbine with Diffuser augmentation:

Total deformation values are in the range of **0 -5.23e-5** (m) which is quite acceptable considering the yield strength of the material of **Diffuser** which is HDPE (**High Density Polyethylene**). **Equivalent Strain** values range from **0** to **5.65e-5 (m/m)**. Maximum Stress induced is **56048 (Pa)** which is less than the yield strength of HDPE that is **23-29.5MPa** and the material breaks at **33 MPa**. Hence the results show that the forces applied on the blades will not cause the failure of material because the deformation, strain and stress values are in safe ranges as shown in the figures below;



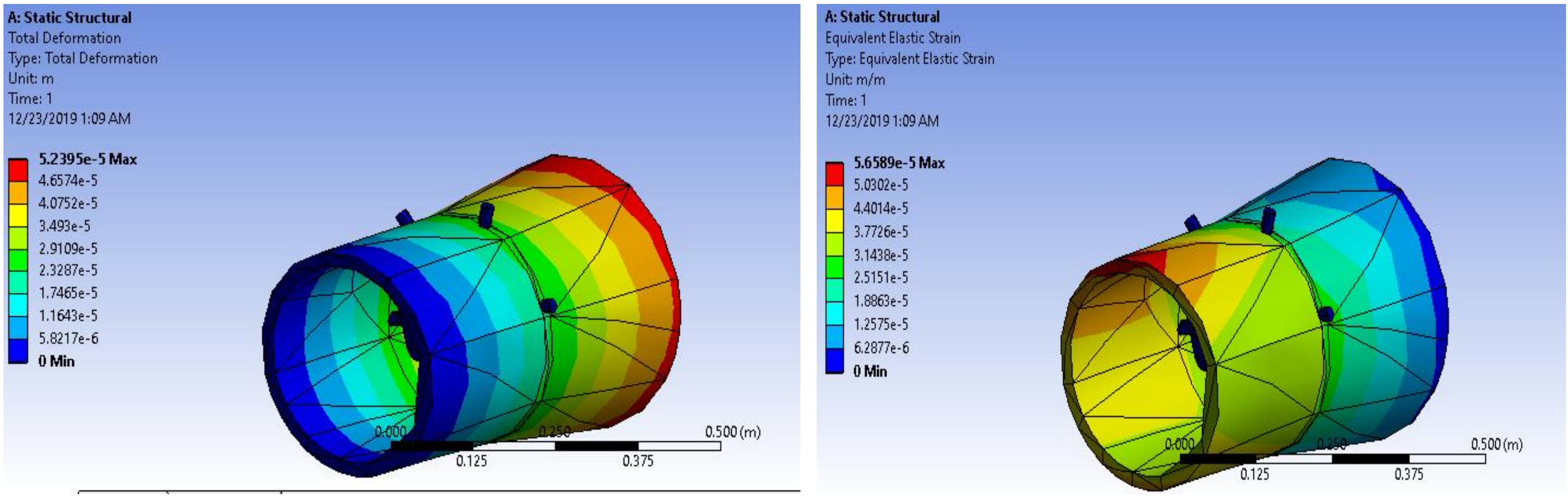


Figure 14: (a) Stress analysis of turbine. (b) Deformation analysis of turbine. (c) Strain analysis of turbine

Generator Augmentation

For exploiting power from the output of the hydel turbine, a generator is needed to convert the mechanical energy into electrical energy. A brushed DC motor is used as a generator in the system for generating power output from the system. DC motor contains a permanent magnet inside around its armature and after coupling the shaft of the motor with the shaft of the turbine, the coil of the motor will be rotated in the presence of turbine torque. As the coil rotates, current will be generated in the coil while in the presence of the magnetic field. The battery is replaced by a load and voltage across that load will be like a rectified sine wave.

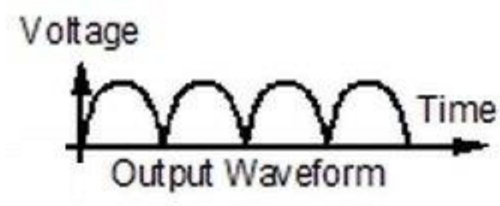


Figure 15: Rectified sine wave

The ripples of the output voltage will be removed using a capacitor in parallel with load which will be getting the power output.

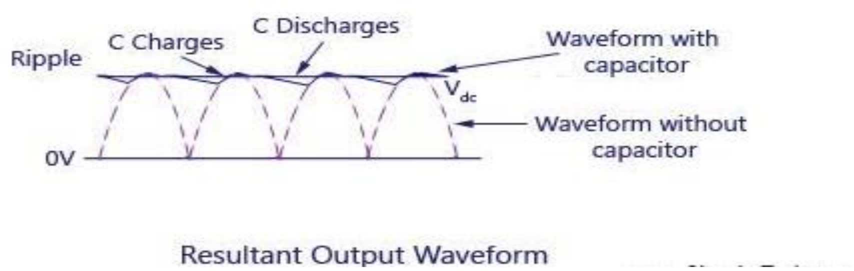


Figure 16: Output waveform of capacitor

The DC motor used in the system is a 12 V motor giving an output of 3000 rpm. So, using a relation for the value of torque constant $\boldsymbol{K_t}$:

$$V = K_t w$$

The value torque constant K_t is 0.004 V/rpm. Using the value of torque constant, the motor will be generating a voltage of 4.8 volts at 1200 rpm which is our output of the turbine shaft.

Effect of Depth of the Turbine in a Stream on Power Output

The scope of this phenomenon is dealt with using the non-dimensional analysis done by Riglin, J., Chris Schleicher, W., Liu, I.-H., & Oztekin, A. (2015) [15]. In which the performance of turbine was characterized using the Cp values obtained for different depths which corresponds to different Froude's Number.

Formula for Froude number is:

$$Fr = \; v / (gd)^{1/2}$$

Where v= the velocity of fluid at the turbine rotor i.e. free stream velocity

d= the depth of the fluid from the tip of the blade to the surface

There are assumptions made which states that the boundary layer of the fluid is not being distorted or disturbed during the analysis [15]. And to analyze the impact of depth the model on an excel sheet was developed to assess the performance of the turbine in terms of Cp. The non-dimensional relationship used is as follows:

$$C_p = \frac{8P}{pv^3 D_t^2 \pi}$$

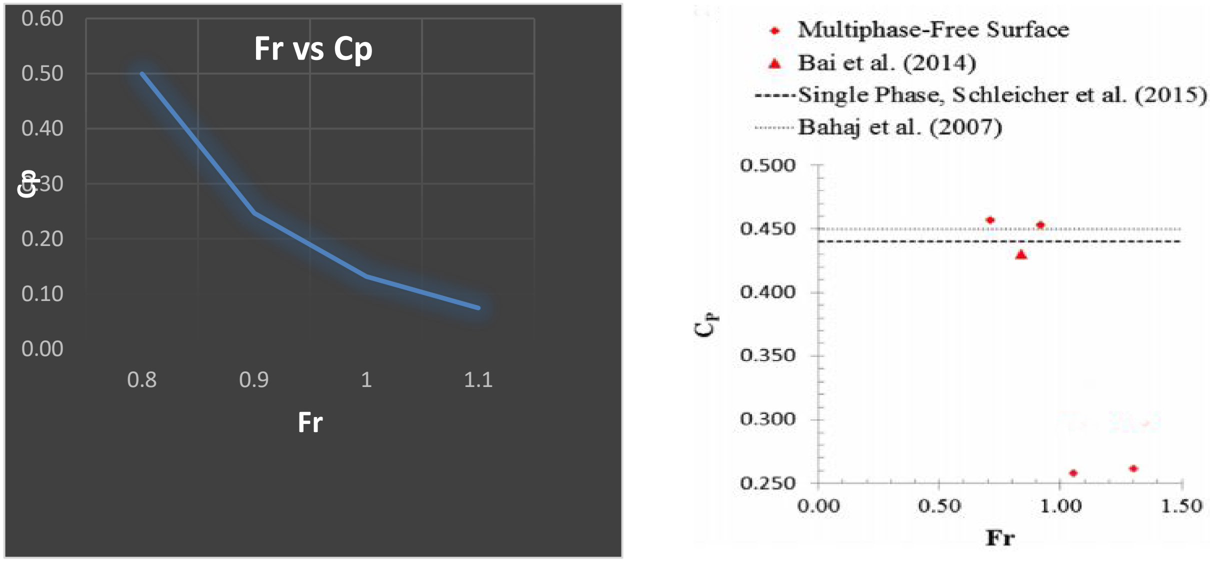
Where P= Designed output power, D_t= The tip diameter of the turbine, v= Free stream velocity at turbine interface, p= Density of water i.e. 998 kg/m^3

In the sheet, the different depths were considered to obtain the values for Fr number for the sub-critical, critical and super-critical flow. And thus, correspondingly the free stream velocity profile for the turbine is obtained. Keeping all the factors in the above formula at constant the varying velocity was input to get the values of Cp for the different flow conditions. The complete analysis is given in the appendix section. The refined results are as follows:

Depth	Fr	Velocity	Power	Tip dia	Density	C_p
0.4	0.8	2.51	180	0.241	998	0.50
0.4	0.9	3.18	180	0.241	998	0.25
0.4	1	3.92	180	0.241	998	0.13
0.4	1.1	4.75	180	0.241	998	0.07

Table 3: Relationship of Fr to C_p values for turbine

Here the depth has been kept at $2D_t$ which is in conjunction to the analysis done by Riglin, J., Chris Schleicher, W., Liu, I.-H., & Oztekin, A. (2015) [15]. The different depths values are also analyzed by changing the depth and for the constant depth at different Fr numbers which are given in the appendix section. However, at the depth of 0.4 m the results obtained conforms to the analysis done by Riglin, J., Chris Schleicher, W., Liu, I.-H., & Oztekin, A. (2015) [15].



(a) **(b)**

Figure 17 : (a) Fr Vs C_p for the non-dimensional model **(b)** Fr vs Cp From Riglin, J., Chris Schleicher, W.,

From the two graphs, it can be seen that the results are conforming to the generic behavior which dictates that at the super-critical values the Cp falls exponentially which is evident from the comparison therefore for the constant depth of 0.4m for the given design conditions the turbine output power will be optimum at Fr=0.8 i.e. at the subcritical value.

Effect of Stream Depth on Power Output

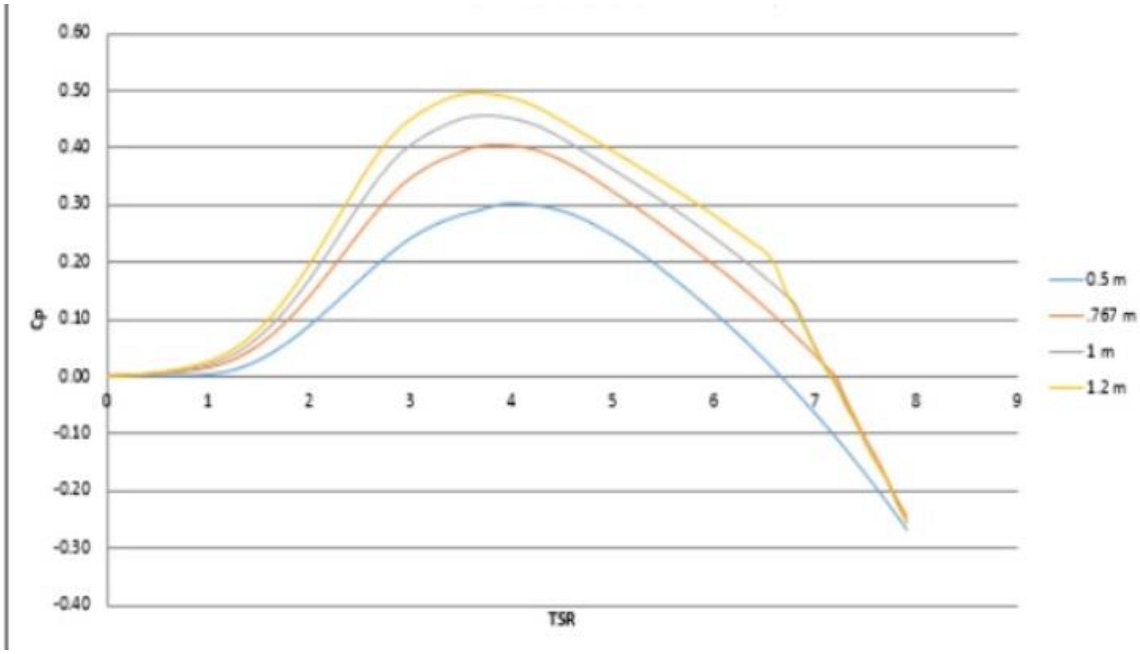


Figure 18: Effect of TSR and Stream depth on Cp of the Turbine [16]

The above figure shows that as we increase the depth of the stream, Cp of the turbine also increases, this has direct relation with the performance of turbine with respect to its death in stream. More the depth of the stream, more can be the installation depth of the turbine and hence more will be Cp of the turbine.

This figure also shows the relation between TSR of turbine and the depth of stream…..Cp of turbines increases with TSR up to some point but after a certain TSR value, Cp values goes down very quickly. Reason for this is that with low TSR, most of the water is not used and goes to waste and with high TSR water faces obstruction in its passage. So an optimum value of TSR must be used to get maximum Cp value for a given turbine.

Another main thing to note here is that when you go away from optimum value of TSR, dependence of Cp value on stream depth decreases and at lower TSR values, it disappears. So, thing to conclude is that if u want the depth of stream to affect your Cp then you should be at optimum TSR and if u want your Cp value to be independent of the depth of stream, then your TSR value should be far away from optimum but there is no advantage in latter as Cp values at very low or very high TSR are very low.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Conclusion

Micro hydrokinetic turbines are very useful in remote areas. These can provide electricity to those areas at very low cost and without changing the flow pattern of the rivers. These turbines are thought to harm the fish but studies have shown that fish movement near turbines is very low which means fish do not go near the turbine.

Micro hydrokinetic turbines' Cp value can significantly increase by installing diffuser after those turbines. Diffuser basically reduces back pressure and creates suction which allows more water to pass through the turbine and at greater speed. Different types of diffusers are being used now days depending on the need.

There are two types of turbines, VAWTs or cross-flow turbines have low cut in speeds, which means that these turbines can be used in low water speeds also but Cp of these turbines is very low as compared to HAWTs or axial flow turbines. On the other hand, HAWTs have high cut in speeds and have high Cp values. These are selected based on the need. VAWTs work due to drag force and HAWTs work due to lift.

Basically velocity of water and size of turbine directly affects the power output. So, a compromise has to be made if you want to make a portable turbine. Either the flow speed should be very high or turbine size should be bigger to get higher power output. If water velocity is low then you have to choose between keeping the turbine portable or getting the higher power output.

Depth of turbine and stream depth also hugely impact the performance of power. Froude number is another factor which plays a huge role in determining the co-efficient of power of the turbine.

Following are some points about the effect of stream depth, turbine depth and Froude number on the performance of the turbine:

- Cp decreases with increase in Froude number at constant depth.
- Cp decreases exponentially at supercritical values of Froude number at constant depth.
- Maximum Cp at a constant depth is obtained at sub critical values.
- Cp decreases and becomes independent from stream depth as we move away from optimum TSR; and it is maximum and hugely dependent on stream depth at optimum TSR.
- Cp increases as stream depth increases.

Turbine’s power output also depends on many factors like solidity, depth of turbine, depth of the stream, TSR and blade profile etc.

Recommendations

Despite all the advantages of these turbines, these still have very low efficiency as compared to other hydro-power plants and this is one of some very important things which give an edge to the dams over micro hydrokinetic turbines despite dams being a huge source of CO_2, CH_4 and N_2O. All these gases have huge global warming potential.

These turbines are not that harmful for fish but still, there is room for more improvement. Still, we can save some marine mammals, fish and birds by improving the installation design of these turbines.

Another important feature that can be added to these turbines is variable pitch. Variable pitch can allow us to make an efficient hybrid turbine, which will be able to produce electricity through water as well as wind.

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APPENDIX I:

DATA FOR EFFECT OF TURBINE'S DEPTH ON POWER OUTPUT

depth	Fr	Velocity	Power output	Tip Dia	density	Cp
0.4	0.9	3.18	180	0.241	998	0.25
0.5	0.8	3.14	180	0.241	998	0.26
0.6	0.7	2.88	180	0.241	998	0.33
0.7	0.6	2.47	180	0.241	998	0.52
0.8	0.5	1.96	180	0.241	998	1.05
0.9	0.4	1.41	180	0.241	998	2.81
1	0.3	0.88	180	0.241	998	11.49
1	0.9	7.95	180	0.241	998	0.02
0.9	0.8	5.65	180	0.241	998	0.04
0.8	0.7	3.85	180	0.241	998	0.14
0.7	0.6	2.47	180	0.241	998	0.52
0.6	0.5	1.47	180	0.241	998	2.48
0.5	0.4	0.78	180	0.241	998	16.36
0.4	0.3	0.35	180	0.241	998	179.56
0.4	1	3.92	180	0.241	998	0.13
0.5	1.1	5.94	180	0.241	998	0.04
0.6	1.2	8.48	180	0.241	998	0.01
0.7	1.3	11.61	180	0.241	998	0.01
0.8	1.4	15.38	180	0.241	998	0.00
0.9	1.5	19.87	180	0.241	998	0.00
1	1.6	25.11	180	0.241	998	0.00
1	1	9.81	180	0.241	998	0.01
0.9	1.1	10.68	180	0.241	998	0.01
0.8	1.2	11.30	180	0.241	998	0.01
0.7	1.3	11.61	180	0.241	998	0.01
0.6	1.4	11.54	180	0.241	998	0.01
0.5	1.5	11.04	180	0.241	998	0.01
0.4	1.6	10.05	180	0.241	998	0.01

0.4	0.6	1.41	180	0.241	998	2.81
0.4	0.7	1.92	180	0.241	998	1.11
0.4	0.8	2.51	180	0.241	998	0.50
0.4	0.9	3.18	180	0.241	998	0.25
0.4	1	3.92	180	0.241	998	0.13
0.4	1.1	4.75	180	0.241	998	0.07
0.5	0.6	1.77	180	0.241	998	1.44
0.5	0.7	2.40	180	0.241	998	0.57
0.5	0.8	3.14	180	0.241	998	0.26
0.5	0.9	3.97	180	0.241	998	0.13
0.5	1	4.91	180	0.241	998	0.07
0.5	1.1	5.94	180	0.241	998	0.04
0.6	0.6	2.12	180	0.241	998	0.83
0.6	0.7	2.88	180	0.241	998	0.33
0.6	0.8	3.77	180	0.241	998	0.15
0.6	0.9	4.77	180	0.241	998	0.07
0.6	1	5.89	180	0.241	998	0.04
0.6	1.1	7.12	180	0.241	998	0.02
0.7	0.6	2.47	180	0.241	998	0.52
0.7	0.7	3.36	180	0.241	998	0.21
0.7	0.8	4.39	180	0.241	998	0.09
0.7	0.9	5.56	180	0.241	998	0.05
0.7	1	6.87	180	0.241	998	0.02
0.7	1.1	8.31	180	0.241	998	0.01
0.8	0.6	2.83	180	0.241	998	0.35
0.8	0.7	3.85	180	0.241	998	0.14
0.8	0.8	5.02	180	0.241	998	0.06
0.8	0.9	6.36	180	0.241	998	0.03
0.8	1	7.85	180	0.241	998	0.02
0.8	1.1	9.50	180	0.241	998	0.01

All units are in SI