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Diffuser Augmented Horizontal Axis Tidal Current Turbines

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Abstract: The renewal energy technologies are increasingly popular to ensure future energy sustenance and address environmental issues. The tides are enormous and consistent untapped resource of renewable energy. The growing interest in exploring tidal energy has compelling reasons such as security and diversity of supply, intermittent but predictable and limited social and environmental impacts. The tidal energy industry is undergoing an increasing shift towards diffuser augmented turbines. The reason is the higher power output of diffuser augmented turbines compared to conventional open turbines. The purpose of this study is to present a comprehensive review of diffuser augmented horizontal axis tidal current turbines. The components, relative advantages, limitations and design parameters of diffuser augmented horizontal axis tidal current turbines are presented in detail. CFD simulation of NACA 0016 airfoil is carried out to explore its potential for designing a diffuser. The core issues associated with diffuser augmented horizontal axis tidal current turbines are also discussed.

Keywords: Diffuser Augmented Tidal current Turbine (DATT), open/naked turbine, shrouded/ducted turbine, tidal current device, tidal current turbine, tidal energy

INTRODUCTION

The world's energy requirement has been fulfilled customarily by conventional methods of burning fossil fuels. The energy demand is increasing with growing population, thus, mounting burden on fossil fuel reserves (Bilgen*et al*., 2008). It is therefore a matter of deep concern that these reserves will run out in coming years. The prices of liquid fuels have been rising and expected to continue rising in future due to increasing demand. Fossil fuels are also the main source of CO_2 emissions (Doman and Conti, 2010), hence, responsible for rise in global temperature due to Green House Effect and devastation of environment. The world has been concerned with fossil fuel reserves depletion since 1970s, however, four decades later alarming climate change is on top of the agenda in addition to fossil fuel reserves depletion.

To address the issues of future energy sustenance and environment, the renewable energy resources have acquired enormous attention in recent years. Ideally, the renewable energy resource should have minimum environmental effect. The tides are an enormous and consistent untapped resource of renewable energy. The growing interest in exploring tidal energy has compelling reasons such as security and diversity of supply, intermittent but predictable and limited social and environmental impacts.

Tides possess both potential and kinetic energy. Tidal energy can be utilized by capturing potential energy i.e., by means of tidal barrage and tidal fence or by capturing kinetic energy i.e., by means of tidal current turbines. This study is focused on diffuser augmented tidal current turbines that capture kinetic energy. The power generated by a tidal current turbine is directly proportional to the cube of velocity of incoming flow, thus, even a minor increase in velocity substantially increases the generated power. The role of the diffuser in diffuser augmented tidal turbines is to help accelerate the incoming current velocity. Consequently, the efficiency of the turbine is significantly increased by diffuser.

The research on tidal energy is underway around the globe (Setoguchi *et al*., 1993; Setoguchi *et al*., 2001; Vijayakrishna *et al*., 2004) and the technology has been tested in many countries (Korde, 1991; Osawa *et al*., 2002; Clement *et al*., 2002). Numerous tidal current turbine designs which incorporate a diffuser have emerged. The tidal current technologies continue to develop and their capabilities to capture more tidal energy are growing. Tidal current technologies are still in development phase and need time to mature to prove their full potential.

The purpose of this study is to present an in-depth review of diffuser augmented tidal current turbines. Its components, relative advantages and limitations and design parameters are presented in detail. NACA 0016 airfoil is investigated to explore its potential for diffuser design. The author also discusses core issues associated with diffuser augmented tidal current turbines.

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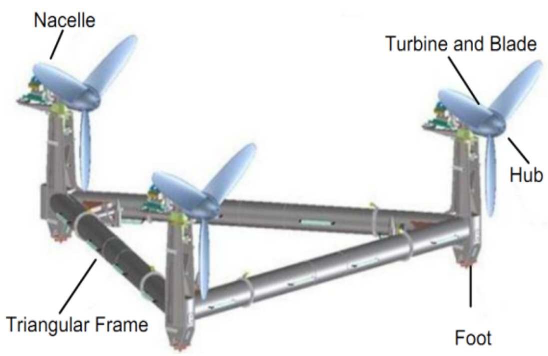

Fig. 1: Delta stream turbine (Tidal Energy Ltd)

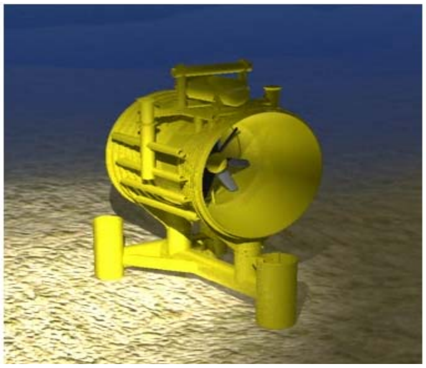

Fig. 2: Rotech tidal turbine (Lunar Energy Ltd)

TIDAL CURRENT TURBINES

Conventional horizontal axis tidal current turbines: The terms conventional, open, naked and un-ducted turbine refer to the same conventional turbine alone. The terms horizontal axis turbine and cross flow turbine refer to the principle that the turbine axis of rotation is parallel to incoming water stream. The horizontal axis tidal current turbine is a popular tidal energy technology which captures the kinetic energy. Horizontal axis tidal current turbines typically have two or three blades riding on a rotor which is oriented in the direction of flow. The lift type blades are used to rotate the generator for producing power. Delta stream turbine, exhibited in Fig. 1, is a conventional horizontal axis tidal current turbine.

Diffuser augmented horizontal axis tidal current turbines: The terms shrouded, ducted, turbine enclosed in a diffuser and Diffuser Augmented Tidal current Turbine (DATT) refer to the same arrangement i.e., diffuser around conventional turbine.

The energy confined in a tidal current is directly proportional to density, cross-sectional area and cube of velocity of the fluid:

$$\text{Energy Flux} \propto \rho A V^3$$

This energy is converted to power by tidal current turbines, thus, the power generated by a horizontal axis tidal current turbine depends on marine current velocity. The ideal marine current velocity for a horizontal axis tidal turbine is around 2 m/sec. However, average available marine current velocity around the globe is 1 m/sec. In order to harness tidal energy at such low velocity, a much bigger turbine system isrequired. The bigger turbine system creates issues such as water depth limitation, huge support structure and increased drag on the system. Thus, increase in incoming current velocity is severely needed.

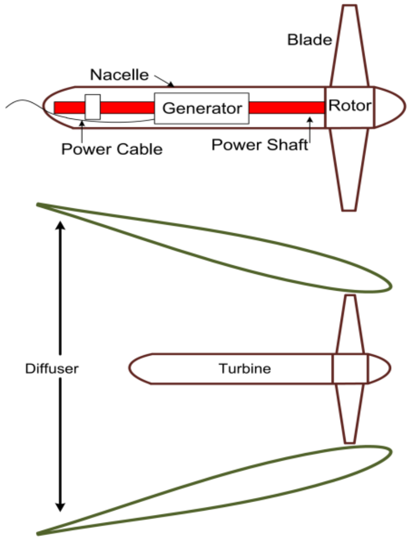

Fig. 3: Diffuser augmented tidal current turbine

The requirement for increasing incoming current velocity is resolved by diffuser augmented tidal turbine. Diffuser acts as a flow amplifying device to accelerate incoming current velocity. The diffuser augmented tidal turbine is based on the principle that even a minor increase in velocity substantially increases the generated power. The diffuser augmented tidal turbine generates same power with a smaller turbine diameter compared to naked turbine. Consequently, diffuser augmented tidal turbine is more viable economically compared to conventional turbine.
Rotech tidal turbine, exhibited in Fig. 2, is a diffuser augmented horizontal axis tidal current turbine.

Diffuser augmented horizontal axis tidal current turbine components: The typical diffuser augmented horizontal axis tidal current turbine, illustrated in Fig. 3, has following components.

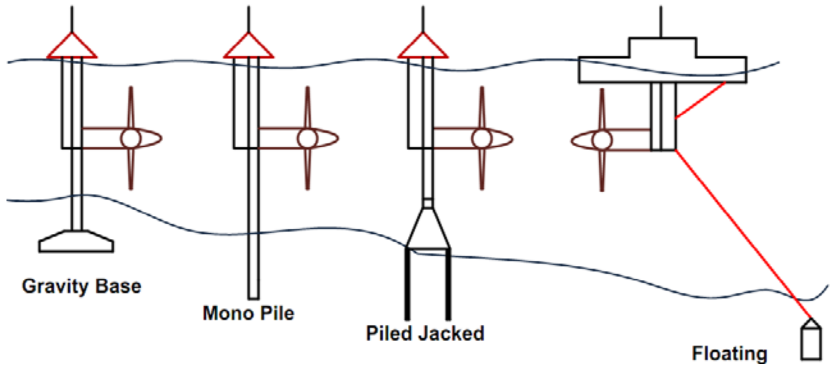

Fig. 4: Different kinds of support structures (Snodin, 2001)

Diffuser: The diffuser is installed around the turbine area to accelerate the velocity of incoming flow.

Blades: The diffuser augmented horizontal axis tidal current turbine typically has two or more blades mounted on a hub, together known as rotor. The fluid flow over blades creates forces to rotate the rotor.

Rotor: Rotor is connected to a power shaft which transmits torque.

Power shaft: Power shaft is connected to a gearbox to get the required RPM from power shaft.

Generator: Torque at required RPM is then transmitted to a generator to produce power.

Transmission cables: The power is then transmitted to land with the help of underwater cables.

Nacelle: All the parts are enclosed in a watertight capsule called nacelle, similar to wind turbines. Nacelle is then mounted on a support structure which bears the loads in harsh marine environment.

Support structure: The choice of support structure depends on size of turbine, water depth and seabed soil conditions. Gravity, piled or floating support structures exhibited in Fig. 4 are most commonly used for tidal current turbines (Snodin, 2001).

Advantages and limitations of diffuser augmented horizontal axis tidal current turbines: In past, the tidal energy industry used conventional turbines alone but now there is an increasing shift towards diffuser augmented tidal current turbines due to higher power output. However, the higher power output comes at some cost. The relative advantages and limitations of diffuser augmented horizontal axis tidal current turbines are presented below.
The advantages are:

- The diffuser augmented tidal current turbines extract more energy than conventional turbines alone. These turbines are more efficient due to flow manipulation and elimination of tip losses. The diffuser augmented tidal current turbines are smaller in size for the same power.
- The diffuser augmented tidal current turbines are quieter than conventional open turbines.
- The diffuser augmented tidal current turbines are useful against weed growth as they protect the turbine against sunlight.
- The diffuser provides safety against floating debris and divers.
- The diffuser augmented tidal current turbines provide more design flexibility since torque on main power shaft can be eliminated. It is materialized by installing magnet on blades and incorporating stator windings in ducts. Thus the blade also acts as rotor of a permanent magnet generator. This eliminates the need of gearbox as well as torque on main shaft, thus, reducing mechanical parts and increasing efficiency.
- The diffuser can be made with low cost materials. The present efficiency to cost ratio of diffuser augmented tidal current turbines will further increase with increasing use of low cost materials in diffuser fabrication.

The limitations are:

- To achieve high efficiency, small clearance is required between shroud and blade tip. This requires fabrication and assembly of very complex shapes with very low tolerances which is both expensive and complicated.

- The inner and outer profiles of shrouds themselves can be quite complex to fabricate.
- The diffuser augmented tidal current turbines operate at higher RPM which gives rise to vibration issues.
- The diffuser augmented tidal current turbines have more drag than open turbines and require additional support structure.

TIDAL CURRENT TURBINE DESIGN PARAMETERS

Before designing a tidal current turbine, some important design parameters are to be considered and firm understanding of their application is vital. This section is devoted to clearly defining and explaining their role at design stage.

Power of tidal current turbine: Tidal current turbines extract the kinetic energy from tides. The energy flux confined in an ocean fluid stream is directly proportional to density, cross-sectional area and cube of velocity of the fluid. Mathematically:

$$\text{Energy Flux } \alpha\ \rho A V^3 \tag{2}$$

This energy is converted to power by the turbine. The power of tidal current turbine can be calculated from following expression, similar to wind turbine (Andrews and Jelley, 2007):

$$P = 0.5\rho A V^3 \tag{3}$$

where, ρ is the fluid density, A is the swept area of turbine ($A = \pi r^2 = \pi D^2/4$) and V is the fluid stream velocity.

Betz limit: The maximum efficiency of a tidal turbine, like other turbines, is limited by Betz limit. Albert Betz, a German Physicist, in 1919 determined that no turbine can convert more than 59.3% of kinetic energy of the fluid into mechanical energy. This law is known as Betz limit. The theoretical maximum efficiency of anydesign of a turbine is limited to 0.59, referred asmaximum power coefficient (Guney and Kaygusuz, 2010):

$$C_{P\,max} = 0.59 \tag{4}$$

Power coefficient: The actual turbines cannot practically achieve Betz limit due to mechanical losses. The C_P value is unique for a specific turbine type. The turbine performance is characterized by performance curves i.e., C_P as a function of λ (Batten et al., 2007). The efficiency of an actual tidal current turbine ranges between 0.35-0.45. The power of an actual tidal current turbine is expressed as:

$$P_T = 0.5 C_p \rho A V^3 \tag{5}$$

where, C_P is the power coefficient, ρ is the fluid density, A is the swept area of turbine ($A = \pi r^2 = \pi D^2/4$) and V is the fluid stream velocity.

Hence, power coefficient is the ratio of power produced by tidal turbine to power available in tidal stream:

$$C_P = \frac{\text{Power produced by tidal turbine}}{\text{Power available in tidal stream}} \qquad C_P = \frac{P_T}{P} \tag{6}$$

Thrust coefficient: Thrust coefficient is another important design parameter for tidal current turbine (Werle and Presz, 2008). Mathematically it can be expressed as:

$$C_T = \frac{2T}{\rho A V^2} \tag{7}$$

where, T is the maximum axial thrust, ρ is the fluid density, A is the swept area of turbine ($A = \pi r^2 = \pi D^2/4$) and V is the fluid stream velocity.

Tip speed ratio: Tip Speed Ratio (TSR) is ratio of the speed of blade at its tip to the speed of incoming flow (Bahaj *et al*., 2007). Mathematically it is expressed as:

$$\text{TSR} = \lambda = \frac{\text{Blade tip speed } (R\Omega)}{\text{Speed of incoming flow } (V)} \tag{8}$$

where, R is the rotational speed of blade, Ω is the angular velocity and V is the incoming flow speed.

TSR is applicable only to lift type turbines. It is not applicable to drag type turbines.

The efficiency of a turbine is ratio of the extracted energy to the available energy in a tidal stream. The turbine efficiency and TSR are closely related. The tidal flow rotates turbine blades which ultimately results in electric power generation. The blades should be in contact with as many fluid particles as possible to achieve higher turbine efficiency. The higher contact rate with fluid particles can be achieved by designing blades that rotate faster for a given fluid speed. Hence, larger TSR means a more efficient turbine. In contrast, lower TSR results in flow of fluid particles through blades without contact and their kinetic energy cannot be converted to electrical energy.

The higher TSR also poses some limitations:

- The higher TSR exposes the leading edge of the blade to erosion. This can be avoided by using special erosion resistant coatings like ones for helicopter blades.
- The higher TSR results in higher noise which can disturb marine life.
- The higher TSR also causes structural vibrations which require additional structural support.
- The high TSR implies high rotation speed which can lead to runaway turbines, resulting in disintegration or catastrophic failure. This can be avoided by higher safety factor in structural design and redundancy.

The limitations of higher TSR require that tidal current turbines are designed with optimal tip speed ratio. The optimum TSR for 'n' number of turbine blades is governed by following relationship:

$$\lambda_{OPT} = 4\pi/n \tag{9}$$

Table 1 summarizes optimum TSR for various number of blades calculated by Eq. (9).

Pitch control mechanism: Pitch control mechanism is installed to account for incoming flow speed fluctuations. The speed of incoming flow fluctuates up and down in marine environment. If speed of the incoming flow increases beyond a certain point, it can cause heavy damage to turbine and/or support structure. In contrast, lower incoming flow speed results in lower power output.

The function of the pitch control mechanism is to turn the turbine blades with respect to incoming flow speed to manipulate exposed surface area and ensure maximum possible power output. The pitch control mechanism turns the turbine blades toreduce exposed surface area in high incoming flow speed and vice versa.The pitch control mechanism is also used to shut down the turbine if the incoming flow speed exceeds the maximum allowable speed, in case of emergency and in case of maintenance.

Pitch control mechanisms are of two types. The first one is called 'active pitch control' and second one "passive or stall pitch control".

In active pitch control mechanism, the blades of the turbine rotate around their longitudinal axis and require a computer controlled mechanism. Active pitch control requires expensive equipment but it is very effective.

Table 1: Optimum TSR for different number of blades

Number of blades	Optimum TSR
1	12
2	6-6.5
3	4-4.5
4	3-3.5
5	2.5-3
6	2-2.5

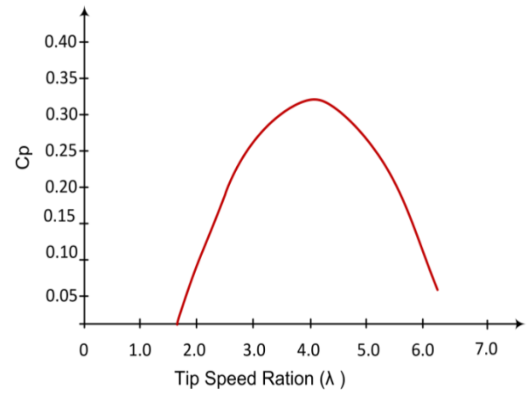

Fig. 5: C_P-λ curve (Bryden *et al*., 1998)

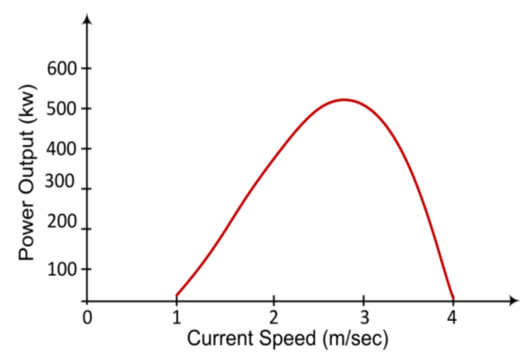

Fig. 6: Power output vs. current speed, rotating once every 10 sec (Bryden *et al*., 1998)

In passive or stall pitch control, the blade is not rotated around its longitudinal axis. The blade is designed such that it naturally creates a stall to lower the rotational speed for high speed incoming flow. Passive pitch control requires very precise blade design and very low tolerances in fabrication.

Relationship between power coefficient and tip speed ratio

The value of C_P is mostly function of tip speed ratio and flow speed. The C_P–λ curve for a four bladed turbine is shown in Fig. 5. The exact shape of the curve depends on blade profile and number of turbine blades (Bryden *et al*., 1998).

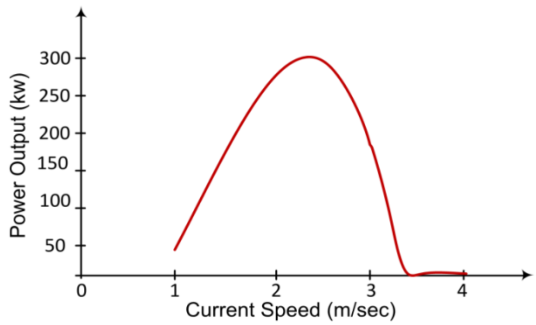

Fig. 7: Power output vs. current speed, rotating once every 12 sec (Bryden *et al*., 1998)

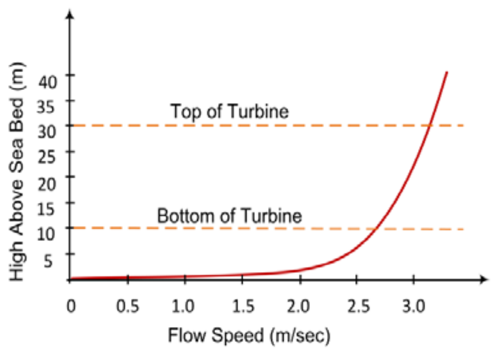

Fig. 8: Vertical velocity profile (Bryden *et al*., 1998)

Relationship between current speed and output power: The power output of a tidal turbine is a function of current speed and rotational speed. The relationship between power output and current speed for a tidal turbine having 20 m diameter rotating once every 10 sec is shown in Fig. 6 based on same data as used in Fig. 5 (Bryden *et al*., 1998).

Figure 7 shows the relationship between power output and current speed of a tidal turbine having 20 m diameter rotating once every 12 sec based on same data as used in Fig. 5 (Bryden *et al*., 1998).

Figure 6 and 7 illustrate the impact of current speed and turbine rotational speed on power output.

Turbine diameter and depth: The turbine size is limited by water depth. The speed of fluid flow increases with height from seabed which is important for positioning of the turbine. The relationship between flow speed and height from seabed is shown in Fig. 8. Bryden *et al*. (1998) suggested that the top tip of the blade should be at the lowest astronomic tide minus 1.5 m for the lowest negative storm surge, minus 2.5 m for the trough of a 5 m wave and minus 5 m to minimize the potential damage from shipping and waves. The bottom tip of the blade should not be below 25% of water depth at lowest astronomic tide. He further suggested that the turbine diameter should be 50% of the water depth with hub at mid water point.

Table 2 summarizes relationship between water depth and turbine diameter.

Table 2: Water depth vs. turbine size

Depth (m)	Rotor dia (no shipping exclusion) (m)	Rotor dia (shipping exclusion) (m)
<20		10
20-25	5	120
25-40	10	20
>40	20	20

DIFFUSER DESIGN FOR DIFFUSER AUGMENTED TIDAL CURRENT TURBINES

Diffuse shapes: The efficiency of a horizontal axis tidal turbine depends on marine current velocity and water depth. Diffuser acts as a flow amplifying device to accelerate incoming flow velocity. Limited research results are available on diffuser design for diffuser augmented tidal turbines due to their emerging nature, large and costly research & development setup, startup cost and proprietary issues. CFD simluation resuts for NACA 0016 airfoil are presented in this section.

There are mainly two main types of diffuser shapes as shown in Fig. 9.

- Rectilinear shape
- With inlet
- Without inlet
- Without inlet having flange or brim
- With inlet and flange or brim
- Annular ring shap

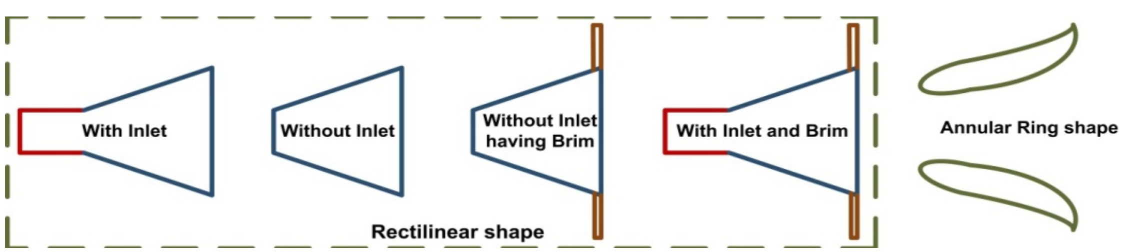

Fig. 9: Types of diffuser shapes.

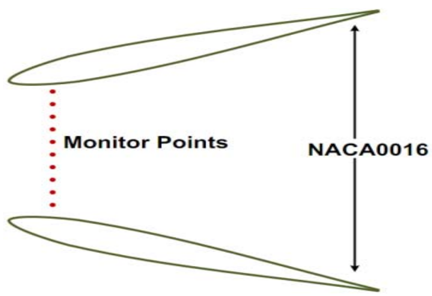

Fig. 10: Schematic view of the diffuser with monitor points

Diffuser model and boundary conditions: NACA 0016 airfoil is used to create the 2D model of diffuser. Diffuser model is prepared using Pro Engineer. The diffuser is explored at fourteen different lengths i.e., 400, 450, 500, 550, 600, 650, 700, 710, 750, 800, 850, 900, 950 and 1000 mm, respectively. The diffuser is also explored at seventeen different angles i.e., 0 to 16º. The diameter of the throat is fixed at 710 mm since the diameter of the turbine is 700 mm.

For in-depth analysis and comparison of velocity profile, ten monitor points are created at the throat of the diffuser. The schematic view of the diffuser with monitor points is displayed in Fig. 10.

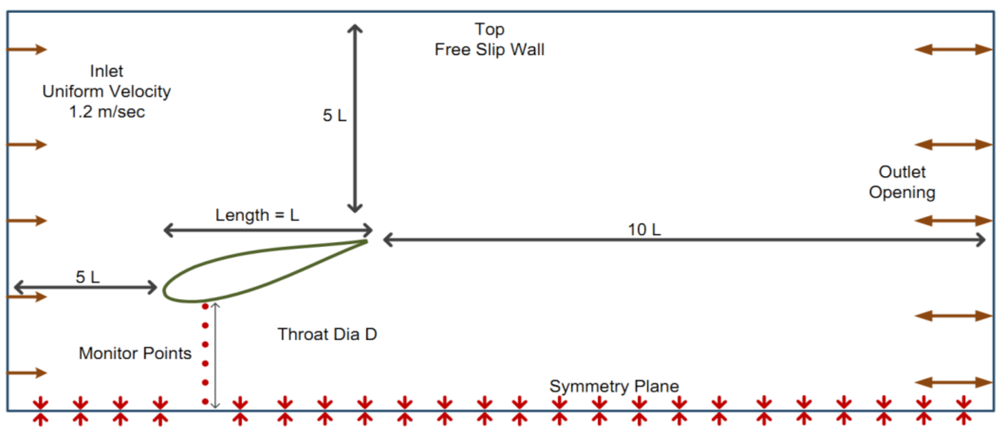

Fig. 11: Schematic view of the domain and boundary conditions

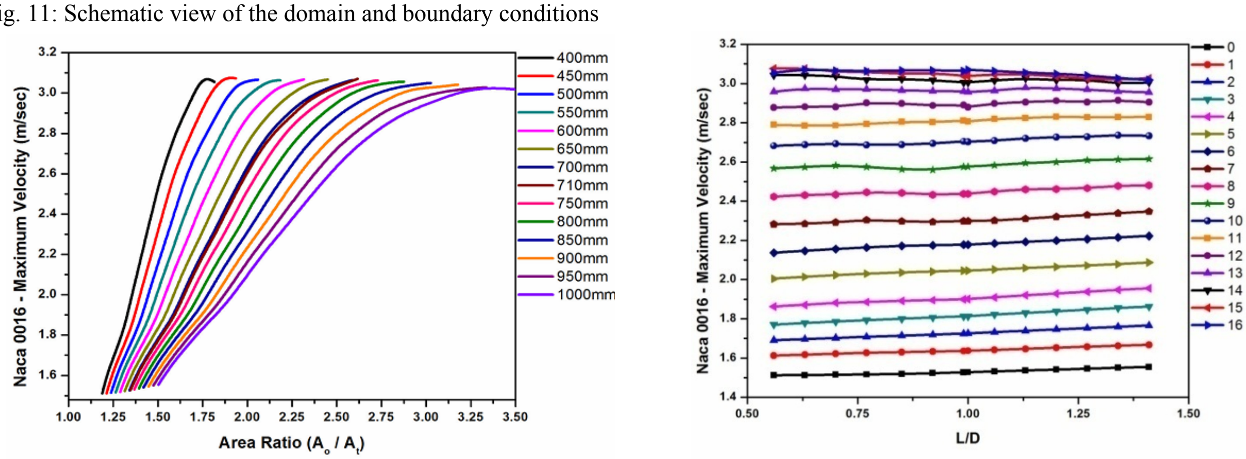

Fig. 12: Maximum velocity vs area ratio and L/D ratio

Ansys ICEM is used for creating mesh. The domain inlet is taken 5 L upstream of the diffuser with a uniform flow velocity of 1.2 m/sec. The outlet is 10 L downstream of the diffuser as shown in Fig. 11. Mesh is generated using AnsysICEM, the y+ value is less than10 for mesh spacing. The simulation is carried out using commercially available software Ansys CFX. K-omega SST turbulence model is used due to its good performance for predicting boundary layer separation with adverse pressure gradient.

RESULTS AND DISCUSSION

In Fig. 12, maximum velocity at throat is plotted against area ratio and length to diameter ratio.There is a gradual increase in maximum velocity with increase in

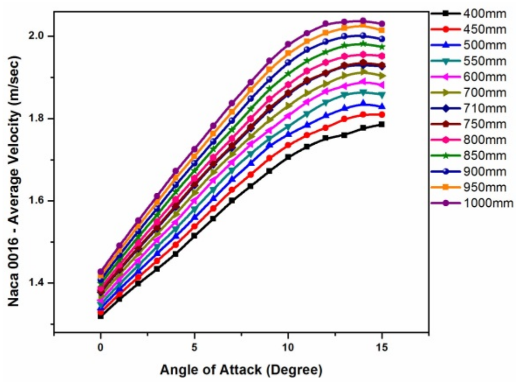

Fig. 13: Average velocity vs angle of rotation

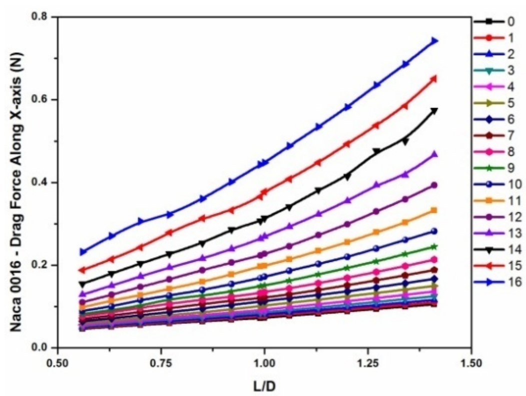

Fig. 14: Drag force vs L/D ratio

area ratio. There is settle increase in maximum velocity with increase in length to diameter ratio.

In Fig. 13, average velocity at throat is displayed. Average velocity drops after 14 degree. Mass flow rate is the function of velocity and cross sectional area, thus, mass flow rate also drops after 14 degree.

Drag force is calculated on the diffuser along x-axis. Figure 14 illustrates that drag increases with increase in length to diameter ratio. Figure 15 and 16 display velocity profile for 12^o and 14^o angle of rotation respectively at 1000 mm length.

CORE ISSUES

Corrosion: Marine environment is very harsh and unforgiving. Corrosion is a very serious issue for structures operating in marine environment. Support structures made of metal are vulnerable to corrosion. Corrosion is electrochemical oxidation of a metal (Nestor, 2004). Corrosion can be explained as reversion of any metal to its ore form. In case of iron, iron reverts to iron oxide as a result of corrosion. Sea water is a saline solution. It is complex and very aggressive in nature. Seawater affects nearly all structural materials. Marine corrosion depends on numerous factors such as temperature, galvanic interactions, alloy surface films, bio-fouling, water chemistry, alloy composition, microbiological organisms, geometry and surface roughness etc., (Robert, 2005). It is important to understand how these factors affect marine corrosion to design a robust support structure for tidal current turbine.

Generally, corrosion accelerates with increase in temperature. In shallow seawater, marine corrosion occurs almost uniformly. In deep water, corrosion rate decreases with depth as temperature decreases (Boyd and Fink, 1978). Other catalysts such as concentration of oxygen and marine biological activity should also be considered. The solubility of oxygen decreases with increase in temperature. Corrosion of metals in seawater is also affected by turbulent or laminar flow.

Corrosion rate accelerates with increase in fluid flow by taking off the protective film. On the other hand, increased fluid flow may also help decrease corrosion by removing the aggressive ions that begin to accumulate on metal surface. Generally, cavitation and erosion-corrosion are forms of flow influenced corrosion.

Cavitation: Cavitation occurs in liquids flowing at high velocity, causing a pressure drop at body which leads to formation of vapor bubbles. The cavitation phenomenon starts when the static pressure of liquid falls below the vapor pressure.

The liquid pressure has two components, static and dynamic. The dynamic pressure is due to flow velocity and static pressure is the actual fluid pressure. Formation of vapor bubble or boiling is a function of static pressure. Cavitation mostly occurs near the fast moving blades of the turbine. The reason is that local dynamic head increases and thus static pressure falls.

Bubble formation during cavitation is not the real issue, the real issue is the breakdown of these bubbles. The breakdown results in high frequency pressure wave which is very damaging and causes erosion on surface, also termed as cavitation erosion. Small sized bubbles only damage blade surface and do not cause efficiency drop. Large bubbles reduce the efficiency of turbine by disturbing fluid flow and causing flow separation.Cavitation can be avoided by designing the turbine blades such that the static pressure may not fall below vapor pressure at any point. This can be accomplished by controlling cavitation number. Cavitation number is expressed as (Shah *et al*., 1999):

$$\sigma_c = \frac{(P_f - P_v)}{0.5\rho U^2} \tag{10}$$

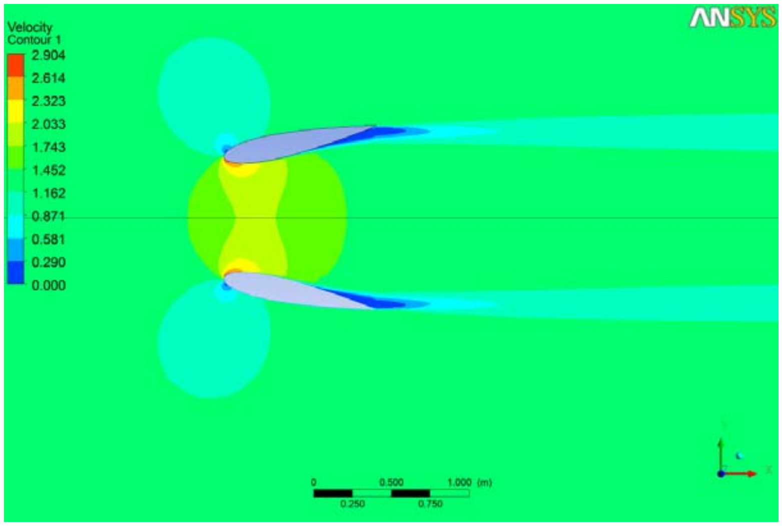

Fig. 15**:** Max velocity at 1000 mm length and 12^{o} angle of attack

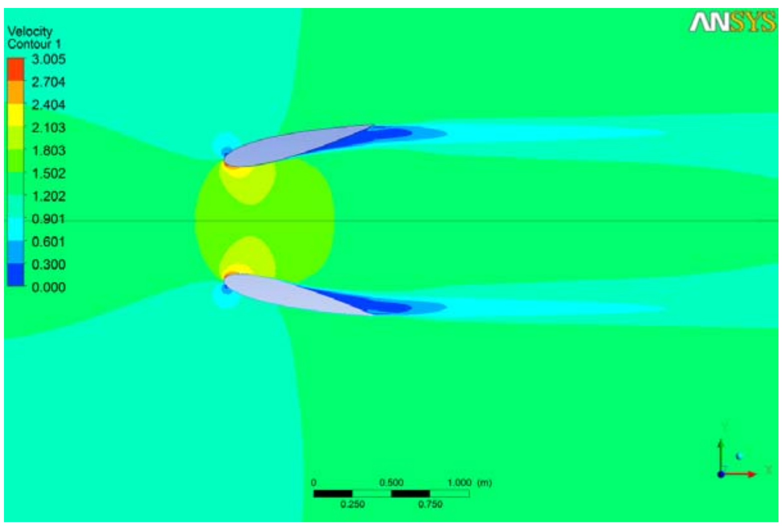

Fig. 16: Max velocity at 1000 mm length and 14^{o} angle of attack

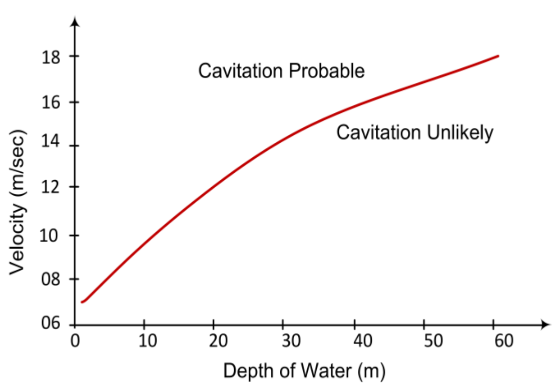

Fig .17: Velocity and depth plot for cavitation

where, P_f is the downstream pressure, P_v is the vapor pressure, ρ is the density of fluid and U is the fluid velocity. The higher valve of σ_c means that cavitation is less likely to occur and vice versa. The same principle is illustrated in Fig. 17 in terms of probability of cavitation as a function of velocity and depth (Fraenke, 2002).

Extreme loading conditions: Tidal current turbines are exposed to extreme structural loading conditions in marine environment. Seawater has a density of approximately 1025 kg/m^3 so the forces acting on turbine and support structure are enormous. Turbines facing the flow direction are exposed to a thrust force while extracting kinetic energy from flow stream. This thrust force has to be absorbed by support structure. The thrust force encountered by a tidal current turbine is expressed as (Bahaj *et al*., 2007):

$$T_{max} = 0.5\ \rho A C_T V^2 \qquad (11)$$

where, ρ is the density of fluid, A is the cross sectional area and C_T is the thrust coefficient.

CONCLUSION

The study has presented an in-depth review of diffuser augmented horizontal axis tidal current turbines. Due to depleting fossil fuel resources, their rising cost and adverse environmental effects; the world must quickly develop alternate energy resources. These alternate energy resources should ideally be renewable with minimal environmental effects.

Tidal energy technologies are answer to mankind's worst fears of energy resource depletion and deteriorating environment. The tides are an enormous and consistent untapped resource of renewable energy. The reasons for growing interest in exploring tidal energy include security and diversity of supply, intermittent but predictable and limited social and environmental impacts.

Diffuser augmented tidal current turbine is a popular tidal energy technology. The diffuser integration is based on the principle that generated power is directly proportional to cube of flow velocity. Hence, the installation of diffuser around the conventional turbine significantly increases its power output capabilities. The function of the diffuser is to help accelerate the flow velocity. The study presented diffuser augmented tidal current turbine components, relative advantages and limitations and design parameters.

CFD simulation of diffuser for diffuser augmented tidal current turbine is also presented. NACA 0016 airfoil has been investigated at different lengths and angles to explore its potential for designing a diffuser.The simulation illustrated that velocity increases as length or angle of attack is increased. Since generated power is directly proportional to cube of velocity, the generated power will be significantly increased by diffuser. Drag is a very important parameter while considering commercial projects since it governs the required support structure. Drag also increases with length and angle. There is always a compromise between maximum velocity and drag for optimal design in diffuser augmented tidal current turbine.

Towards the end, the author presented core issues such as corrosion, cavitation and extreme loading conditions which pose major challenge today as these technologies develop and will continue to be important in future. In addition, issues such as underwater sealing, deployment and retrieval of these systems, optimization of resources involved in installation and retrieval, routine maintenance and long term impact of presently unseen and minor environmental factors are important and require further exploration.

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