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Performance Analysis of Darrieus Hydro Kinetic Turbine with Aerofoil Blade Profile

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Abstract—*River current generation uses a generator to produce energy, changing the kinetic energy of current into a turning force by setting a water turbine in the river current. Hydro kinetic water turbines arc used to produce small scale power in remote areas that do not have access to electricity. Lot of hydro potential exists in canal & river in India & almost throughout the year with full of water current. However development towards use of kinetic energy form river current is not explored & readily available.*
This paper present the performance analysis of Darrieus hydro kinetic turbine (DHKT) computationally & compared the result with experimental result available in open literature. Our computational analysis has been done in ANSYS FLUENT software for aerofoil blades profile for inlet velocity of water is 0.5 m/s . Then we found Power and Torque produced by turbine & evaluate the Coefficient Power (C_P) & Tip Speed Ratio (TSR).

Keyword: *DHKT, Power, Torque, TSR, C_P.*

Nomenclature

D_T = *Tip diameter of rotor*
D_H = *Hub diameter of rotor*
V_0= *Free stream velocity*
A = Projected Area of rotor
λ = Tip speed ratio (TSR)
r = Radius of shaft
C_P = *Coefficient of power or performance*
ρ = Density of fluid
P_{rot} = *Power develop by runner*
N = Revolution per minute
P_{hyd} = *Hydrokinetic power*
ω = Angular velocity

1. INTRODUCTION

Growth in energy consumption and environmental concerns over conventional power generation technologies has given rise to a need for alternative energy sources. Energy and environmental problems are related each other and needed to discuss comprehensibly. For the solution of these issues, emerging hydro technologies consist of kinetic currents, tidal wave applications and the utilization of renewable energy becomes the target of global attention[18]. Hydropower has been used since ancient times as one of the major renewable energy. However, the "dam type" hydropower generation is difficult to apply strongly because high head hydropower area has been already developed and makes large impact for ecological system[12][2]. On the other hand, River kinetic hydropower is a promising technology that involves the use of underwater turbines in fast moving rivers to produce electricity, low head hydropower area, where the head takes less than 2m or zero, has remained as undeveloped. The technology differs from more conventional hydropower technologies in that it does not require a dam, or powerhouse. River kinetic hydropower is well-suited for distributed power generation [16]. The technology has been available for decades, however despite its minimal environmental impact, commercialization has been limited. Recently, there has been a large resurgence in the interest in all forms of emerging hydro technologies (Sergergren 2005); however, the application of river kinetic hydropower is largely undocumented (Gaden 2006). The utilization of low head hydropower has an advantage that the transmission loss of electricity becomes lower because it is located near the consuming area, however low energy density makes the cost of generation higher[17]. Thereby it is demanded to improve the turbine performances and to decrease the equipment cost for achievement of "the cost-advantage" and "environmental friendly".[1]

Water turbines can be classified by the type of generator used[14][15], or the water resources in the installed place. A water-head turbine is the most generally used system, and this makes the turbine rotate by converting the potential energy of the water in to kinetic energy. This turbine has the advantage of high efficiency, but the construction cost for a dam or waterway is high and can cause significant environmental problems. Water stream turbines are rotated by the force of the river or the ocean current. These turbines are essentially like wind turbines underwater, except that the density of water is 800 times greater than air.[2] There are two types of water stream turbines; Horizontal axis turbines and Vertical axis turbines shown in Fig.1

I-HAWT II-VAWT

Fig. 1: HAWT and VAWT

It consists of three or four blades and a single rotor system. The rotor is rotated by the lift force generated by the fluid flow. The turbine can generate in one way flow or two way flow, according to the geometric shape of the rotor blade and pitch control mechanism.. This turbine is based on the Darrieus wind turbine which is rotated by the lift and drag forces. The vertical axis type has the advantage that the rotor can be rotated regardless of the flow direction.[3]

This paper presents a performance analysis of Darrieus hydro kinetic turbine (DHKT) computationally and validates the result with experimental result available in literature.

2. OBJECTIVE

The thrust of this work is to evaluate the Performance of Darrieus hydrokinetic turbine. This turbine is commonly used in low head water flow. Aerofoil types blade profile Vertical axis hydrokinetic turbine are considered for our analysis. This turbine is taken into study because this is useful in low head flow, small amount of power generation, its construction and installations is simple and operate easily with very small velocity of flowing water and there is no need to gear box for connect the generator with shaft. The main objective of the present work is

* Designing the model of vertical axis Darrieus hydro kinetic turbine using CATIA V5 software.

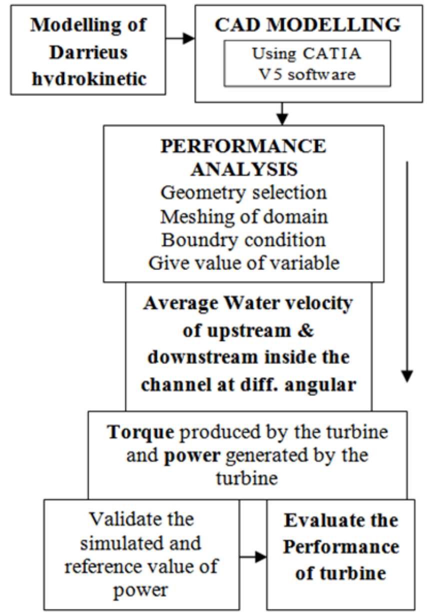
*Analysis the model of turbine for evaluation of performance using ANSYS (FLUENT) software.

3. PROBLEM DESCRIPTION

The configuration consists of turbine of 360 mm dia and length of turbine is 500 mm and cross-section of blade profile is Aerofoil. Kept inside the cylindrical open channel and water flows over the turbine with velocity 0.5 m/s. All work has been perform in ANSYS FLUENT workbench.

4. METHODOLOGY

Table 1



5. HYDRO KINETIC POWER

Hydro power is defined as the power derived from the energy of moving water. There are two areas from which hydro kinetic power can be derived: marine and river power.[4] Marine hydro kinetic power deals with extracting energy in the ocean from tides and currents. Tidal energy comes from the predictable rise and fall of tides generated by the gravitational pull of the sun and the moon where as ocean currents are large convection systems generated by temperature differences. Hydro kinetic power extracted from the river comes from the kinetic energy of the flow[1]. Unlike hydro dams that use potential energy from a stored reservoir and utilize the difference in elevation from inlet to outlet to create a hydraulic head, river kinetic hydro uses the energy from fast flowing water, thus extracting power from the kinetic energy within the flow using the same principles as wind energy. Extracting power in this way is still possible when the river is below critical flow.

6. TURBINE PERFORMANCE

The basic design of the VAHT consists of a rotor with 2 to 5 symmetric hydrofoil blades. In operation, the blades rotate around the shaft at 2 to 3 times the speed of the free stream[10]. The relative velocity between the blade and the free stream induces hydrodynamic forces of lift and drag along the hydrofoil[11]. The ratio between the blade velocity with respect to the free stream velocity is the Tip Speed Ratio (TSR). As the TSR changes, so does the angle of attack of the flow over the blades. The angle of attack varies with the blades' location along its circular path and thus an important operational characteristic of the VAHT emerges[19]. The torque produced by the turbine is not constant throughout each revolution. Although the net torque through one revolution is positive, the instantaneous torque varies depending on its relative blade velocity to the incoming flow[13]. Adjusting the angle of attack as the blade rotates has been investigated to increase efficiency, but this method is not practical. The shaft is connected to a gearbox that increases the RPM to match the generator's specifications. The TSR impacts the gearbox design. In general, gearboxes are available for a speed increase of less than 25:1 ratio so the rotor RPM, gearbox and generator have to be designed accordingly. Adding a second gearbox may not be practical for smaller turbine systems in river applications.[5]

7. TIP SPEED RATIO (TSR)

The TSR is an important non-dimensional number that turbine performance data can be evaluated against. There exists a non-linear relation that links the coefficient of power, Cp , with TSR. Equation 1 defines the TSR as the angular velocity of the shaft times the radius at which the blades are held, divided by the free stream velocity. The formula is further reduced to a function of RPM as expressed in Equation 2. The TSR is also used to compare turbines of different scales and design.

$$TSR=\lambda=\omega R/V_0 \quad (1)$$

$$\lambda = \left(RPM * \left(\frac{2\pi}{60}\right) * R\right)/V_o \quad (2)$$

The TSR shows how the turbine has consistent performance for different flow velocities. Performance curves such as the ones shown are unique to a specific design and configuration of the turbine. The performance of the turbine based on the TSR follows a curve with a point of maximum output and thus maximum efficiency. At low tip speeds, the fluid is allowed to pass freely with little power being extracted. Tip speeds in excess of the optimal point decreases efficiency as the rapidly rotating blades present a solid face to the fluid flow[8][9].

8. EXTRACTABLE POWER

Kinetic turbines generate power by using mainly reaction type turbines with water flowing over hydrodynamic shapes to produce a pressure gradient that turns the rotor [6], which in turn rotates a generator. The amount of kinetic power available for extraction depends on the fluid velocity, rotor area and density of the fluid as expressed in Equation 3.

$$P = \frac{\rho A V_0^3}{2} \quad (3)$$

The total power available cannot befully extracted. According to Betz limit, the maximum extractable power is 59% of the available[7].

$$P_a = \frac{0.59\ \rho A V_0^3}{2} \quad (4)$$

$$P_{rot} = \frac{1}{2} C_p\, \rho A V_0^3 \quad (5)$$

9. COMPUTATIONAL ANALYSIS OF TURBINE

First and foremost step in any simulation problem is to construct a model or geometry. There are number of ways in which we can create a geometry through various design software's available in market. In ANSYS FLUENT (the software which we are using for CFD simulation), there are two ways in which we can create a geometry:-

1) By constructing the model in FLUENT itself through the use ANSYS Design modeler available with it.
2) Or, by importing the geometry made in various design softwares into FLUENT.

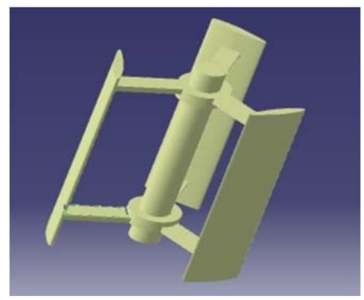


Fig. 2 Turbine of Aerofoil blade profile

Meshing and grid generation has been perform on ANSYS FLUENT software. For meshing of DHKT is place in side the uniform open cylindrical channel and meshing has been done.

Table 2: Mesh detail of turbine

Domain	Nodes	Elements
Pipe	260144	1482325
Runner	50101	220544
All Domain	310245	1702869

10. RESULTS AND DISCUSSION

The analysis were conducted to evaluation of maximum power and torque produced by vertical axis hydrokinetic turbine and also evaluate the C_P and TSR. The input parameter given below are used for calculation of coefficient of performance and torque. The measured free stream water velocity is 0.5 m/s. The analysis is conducted in the ANSYS FLUENT software package and the outlet velocity of water is measured at different angular velocity. Averaging the upstream and downstream value of velocity.

D_T = 0.360 (m) Length = 0.5(m)

r = 0.01(m) D_H = 0.104 (m)

ρ = 1000(Kg/m^3)

Table 3: Calculated data of aerofoil blade DHKT

ω (rad/s)	RPM (N)	P_{rot} in(Watt)	T_{rot} (N-m)	C_p	TSR
6.5	62.1	0.3417	0.0526	0.0303	2.34
6.4	61.12	0.3756	0.0587	0.0334	2.30
6.3	60.16	0.4006	0.0635	0.0356	2.26
6.2	59.21	0.43057	0.0694	0.0383	2.23
6.1	58.25	0.4539	0.0744	0.4035	2.19
6.0	57.29	0.4717	0.0786	0.0419	2.16
5.9	**56.34**	**0.4948**	**0.0839**	**0.0439**	**2.12**
5.8	55.38	0.4898	0.0844	0.0435	2.08
5.7	54.43	0.4823	0.08461	0.04287	2.05
5.6	53.471	0.4344	0.0776	0.0386	2.01

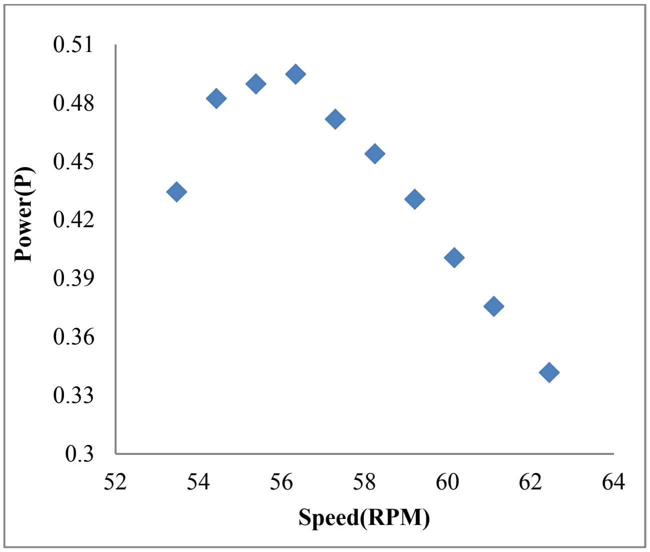


Fig. 3 Power Vs Speed

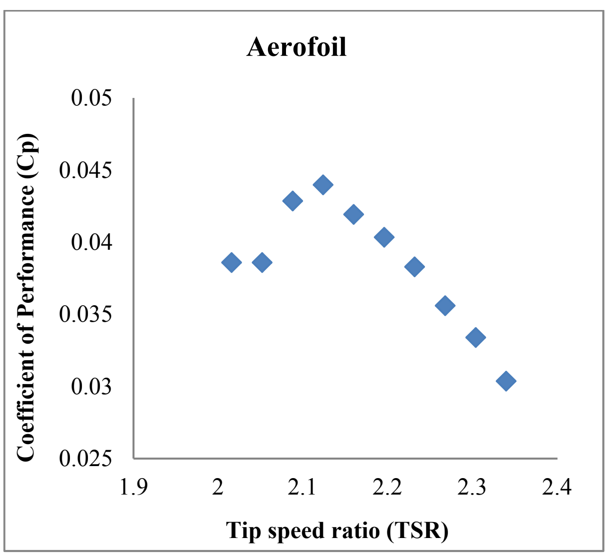


Fig. 4 C_p Vs TSR

11. VALIDATION OF COMPUTATIONAL MODEL

Our Work Has been Validated By the Parameters at Inlet Water velocity V_0 = 0.5 m/s Available in the literature Experimental Investigation of Water Turbine with Fix Vane Angle by Dharmesh D. Jariwala et al. (2014)[3]. Table below shows validation of our work, CFD simulation implies our analysis.

Table 4 Comparison of our work

Authors	V_0 in (m/s)	ω in (rad/s)	P_{rot} in (Watt)	T_{rot} in (N-m)
Jariwala et al.	0.5	5.818	0.588	0.101
CFD Simulation	0.5	5.9	0.4948	0.0839

12. CONCLUSIONS

A CFD-based performance analysis is presented in detail in this paper Power and Torque produced by the turbine is calculated also find the value of C_P and *TSR*. By observing the result it can be concluded that the rotor speed increases the power of the rotor increases up to certain value. But then after though the speed of the rotor increases the power decreases. It can clearly seen the maximum value from the graph and highlighted value in the table 3. Also the *TSR* increases ,the C_P increases up to certain value. But then after though the *TSR* increases co-efficient of performance or power (C_P) is decreases. it can be clearly seen the maximum value from the graph and highlighted in the table 3.

So we can use aerofoil blade type turbine for small scale power generation and further modification in the design will increase the power.

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