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Numerical Analysis of low head darrieus water turbine with higher solidity

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***Abstract*—This paper describes the strategy to develop 2D cfd model of darrieus turbine for low head application. The model was implemented in cfd solver to predict the turbine performance. The CFD modelling is based on two dimensional numerical solution of the rotor motion using unsteady Reynolds average navier-stokes solver. A transient-rotor-stator model with a moving mesh technique was used to capture the change in flow field at a particular time step. A shear stress-transport k-ω turbulence model was used to model turbulent features of the flow. A rotor diameter with 0.5 m and height 0.3 m with solidity 0.9 is used for 2D CFD analysis.**

***IndexTerms*—Darrieus turbine, low head, computational fluid dynamics**

NOMANCLATURE

A	swept area of the rotor(m^2)
C_p	turbine power coefficient
c	blade chord length (m)
N	number of blades
R	turbine rotor radius (m)
H	Turbine height (m)
T	turbine torque (Nm)
V	free stream flow velocity (m/s)
λ	tip speed ratio of turbine
ρ	density of water (kg/m^3)
σ	solidity of turbine
ω	turbine rotational velocity (rad/s)
C_t	torque coefficient
Δt	Time step size

I. INTRODUCTION

In recent years, renewable energy sources draw attention due to reduction of fossil fuels and increasing energy demand of the world. In addition, renewable energy sources are becoming popular because of global warming and environmental concerns. Many investigations have been made in renewable energy field such as wind, solar, ocean wave and tidal current energy. Tidal energy is converted into useful power by using tidal stream turbines. They are also called as low head turbines, hydrokinetic turbines or water turbines. Although they are less efficient than commercial water turbines used in hydroelectric power stations, these turbines do not need construction of a dam or waterway. Hydrokinetic turbines harness the kinetic energy of tidal or river stream and convert to useful power. These turbines are like commercial wind turbines operating in water stream. Their classification and technology are similar with wind turbines. They are classified by their axis of rotation as horizontal axis water turbines (HAWT) and vertical axis water turbines (VAWT). [1]

Among various types of vertical axis wind and hydrokinetic turbines, the Darrieus rotor configuration has gained significant attention owing to its unique performance, operational and design features. French inventor G. J. M Darrieus patented this concept in 1931 with the U.S. Patent Office, which employs a set of curved blades approximating the shape of a perfectly flexible cable, namely the Troposkien shape. Later vertical axis designs comprising straight blades appeared under names such as, 'H-Darrieus' or 'Squirrel Cage Darrieus' turbines. [2]

Although most vertical axis turbines were studied for wind energy conversion, these concepts can be equally imparted in hydro applications. River Current Turbines (RCT) and tidal energy converters are examples of such hydrokinetic turbines where kinetic energy of moving water is converted into usable forms of electrical or mechanical energy. [2]

The main drawbacks are lower efficiency compared to horizontal axis turbines and the variation in the torque generated. On the other hand, the main advantages of Darrieus turbines are their geometric simplicity and compactness. Furthermore, the power density per square meter could be higher than the configurations used before. In other words, Darrieus turbines can be used closer to each other than horizontal axis turbines. [1][8]

In order to improve the technology for energy extraction, the numerical simulations provide a valuable tool for numerous virtual experiments prior to the real prototypes being manufactured**.** The bases of all CFD algorithms consist in numerical schemes for

the NaviereStokes equations solution, grid generation techniques and turbulence physical modeling. The most known method is the Reynolds Averaged NaviereStokes model (RANS). [3]
In the 2D work of Lain and Osorio [3], the three bladed VAWT test case of Dai and Lam [4] is considered. With the following turbine all geometric data (radius, 450 mm; reference area = 0.63 m^2) of a turbine. Span of straight blades (700 mm) are based on symmetric NACA0025 airfoil. Considered case has been 3S2R17 (profile chord, 132.75 mm), resulting in a solidity s = 0.89.the turbine is prone to a strong dynamic stall regime with significant 3D effects. The experimental power coefficient measured by Dai and Lam is 52%. These authors found 58.6% and 46.3% using respectively the CFX solver and the DMS model. Lain and Osorio found 52.8%, using the Fluent solver, a value very close to the experimental one.
Another cfd work is done by T Maitre[5], two main features of the modeling are studied. The first deals with the influence of the near wall grid density on the numerical results, the second feature concerns the ability of a 2D modeling to represent, the actual 3D flow in the turbine. The power coefficients CP are compared to those obtained in the hydrodynamic LEGI tunnel on a small scale model.

II. NUMERICAL MODEL

The aim of the present work is to numerically analyze the performance of a three bladed Darreius water turbine with solidity 0.9, for a constant water speed of 0.625 m/s. The main features of the turbine are summarized in table 1.

Table 1: Turbine data

D (m)	0.5
H (m)	0.3
Blade profile	NACA 0018
Chord c (m)	0.150

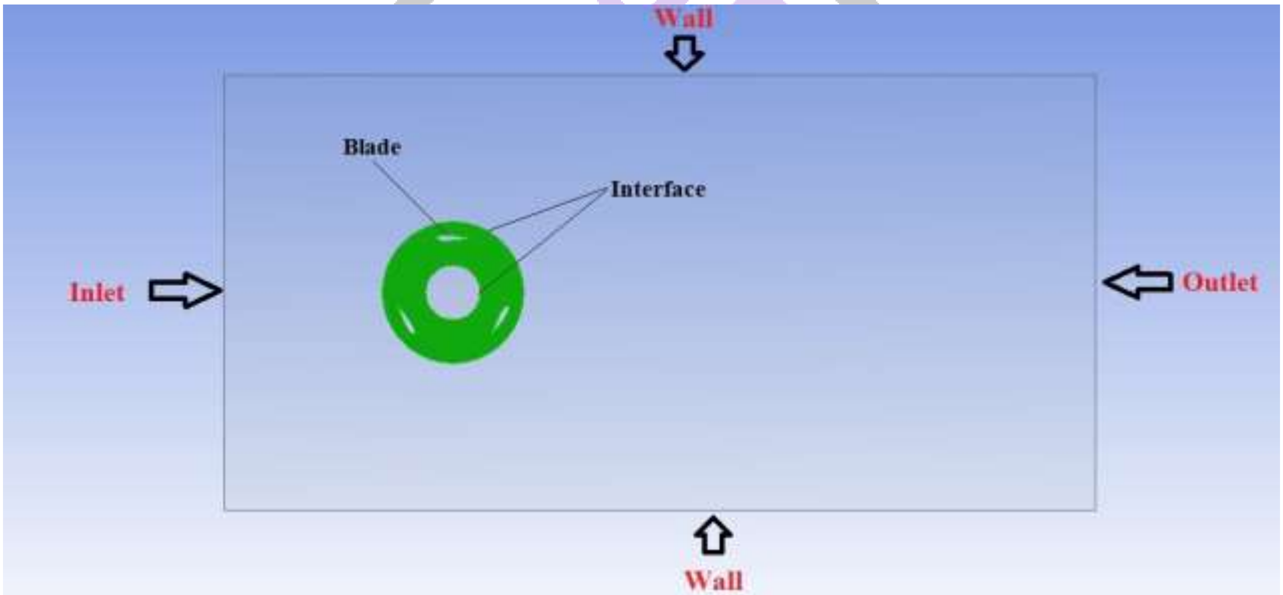


Figure 1: 2D domain

Schematic view of the 2D calculation domain is shown in Figure 1. The sizes of the domain are selected according to the domain size independency study performed by McLaren [6]. The left hand side boundary of the rectangle is set as the velocity inlet, whereas, the right hand side is set as the pressure outlet where the pressure is atmospheric pressure. The upper and lower boundaries are set to be no-slip walls in order to represent the water tunnel walls. The circular ring part of the domain is the rotating domain while the outer and inner domains are stationary. The interface between the stationary and rotating domain is modeled by the sliding mesh model.

Since flow dynamics of Darrieus turbine is complex due to flow separations and reattachments occurring on the blades, meshing of the domain is one of the key points. When such flow characteristics are present, using structured mesh rather than unstructured mesh shows better performance for the accuracy and stability of the solution [7]. However, the usage of structured mesh in the analysis of VAWTs is difficult. Thus, structured mesh is used only on airfoil surfaces and outer stationary domain. In the rotating domain, quadrilateral cells are used, with a fixed growth rate of 1.05.

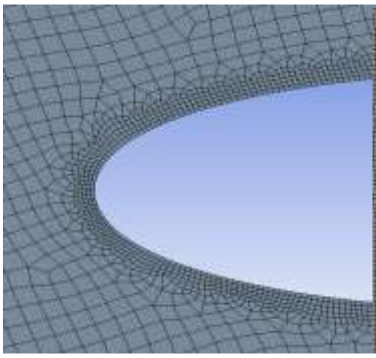
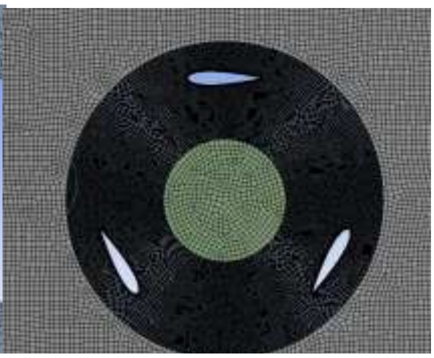



Figure 2: Mesh near Blade **Figure 3: Mesh near rotor**

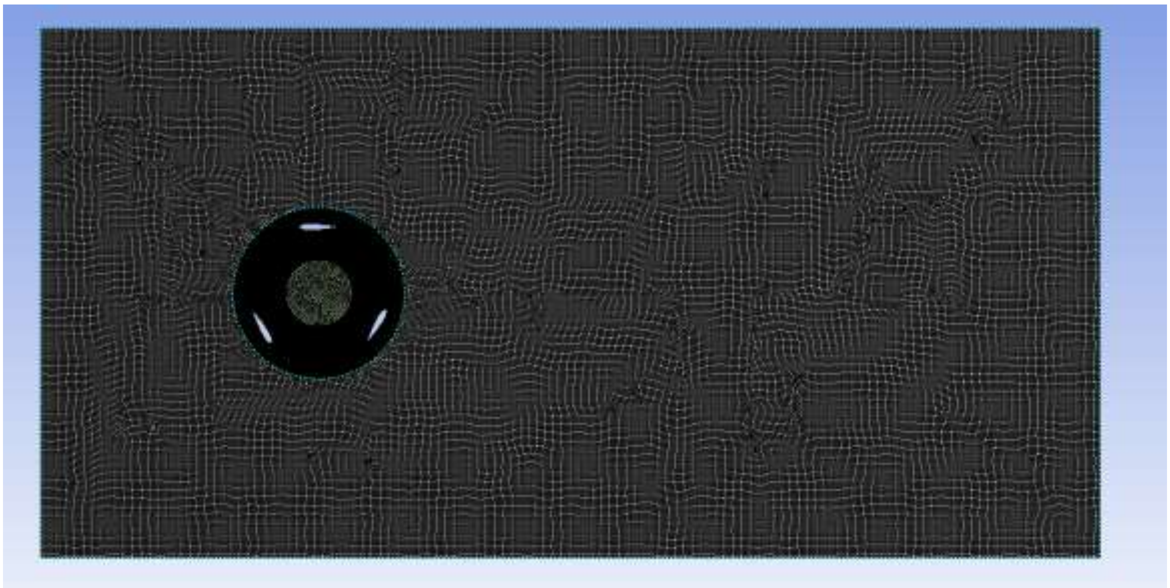


Figure 4: Mesh of the 2D model

The mesh generated has a total of 161060 nodes and 158758 elements. Complete 2d model mesh and mesh near rotor for the numerical analysis are shown in figure.

III. NUMERICAL SIMULATION

2D numerical simulation is performed by Fluent commercial software capableof solving Unsteady Navier Stokes equations. The SIMPLE algorithm is used for pressure velocity coupling. k-ω SST turbulence model is employed for turbulence modelling since it shows better performance for complex flows including adverse pressure gradients and flow separations like in VAWTs as mentioned. The numerical simulation parameters are shown in Table 2.

Table 2 Numerical Modeling Parameters

Pressure Velocity Coupling Scheme	Green-Gause Node Based
Gradient	Second Order
Pressure	Second Order Upwind
Momentum	Second Order Upwind
Turbulent Kinetic Energy	Second Order Upwind
Specific Dissipation Rate	Second Order Upwind
Transient Formulation	Second Order Implicit

For the flow condition in the CFD analysis, a constant inlet velocity 0.625 m/s is used for the tip speed ratio and the corresponding angular velocity is shown in table 3.

Table 3Flow condition

λ	1	1.5	1.8	2	2.5
ω (rad/sec)	2.5	3.87	4.5	5.233	6.38

IV. TIME STEP CALCULATION

The flow over Darrieus turbine is periodic and a proper time step selection is important in order to ensure the solution is independent of the time step. The time step corresponds to one-degree rotation of the turbine is expressed as,

$$\Delta t = \frac{x}{\omega \frac{\pi}{180}}$$

V. VALIDATION

For the validation of present work analysis methodology, we have solved the papers and compare results with the paper results, and it follows the paper result with error in the range of ± 6 to ± 10 %.To check the methodology, analyzed the 2D cfd simulation with tip speed ratio ,1.5,2,2.5 with constant inlet velocity as per T Maître[5]. From this result, verification of my methodology of analysis has verified.

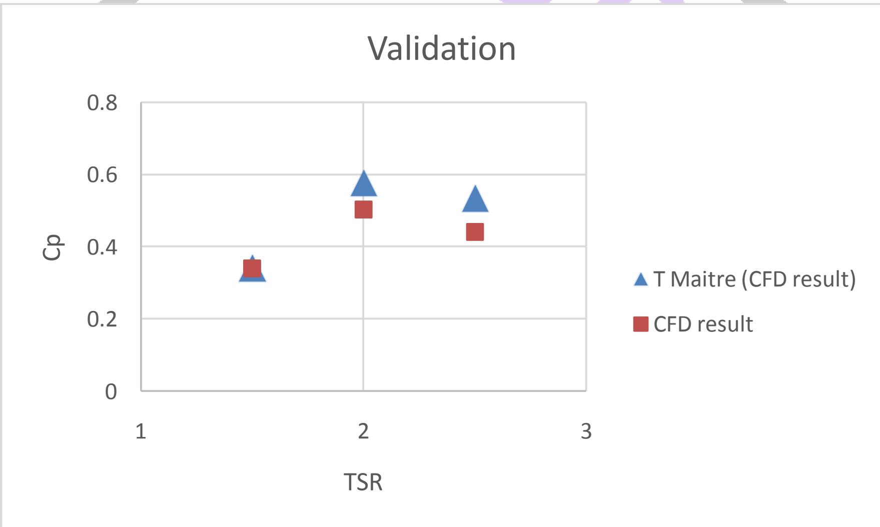
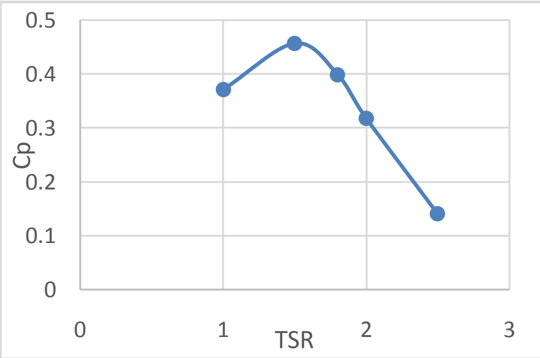


Figure 5: TSR vs Cp for validation

VI. RESULT AND DISCUSSION

several simulations were performed for the rotor to calculate the power coefficient.Now the coefficient of moment $C_t$is calculate for the three blade and then an average of value is plotted with respect to TSR. From average of torque coefficient power coefficient is calculated. Further with the help of these parameters characteristics curve was drawn to show the performance of the turbine, the relationship between power coefficient and tip speed ratio shown in figure 6 and the relationship between torque coefficient and tip speed ratio shown in figure 7.



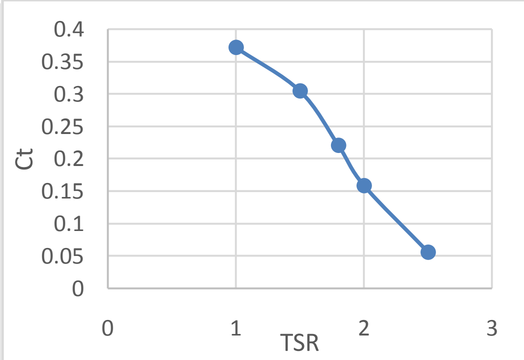


Figure 6: Cp vs TSRFigure 7: Ct vs TSR

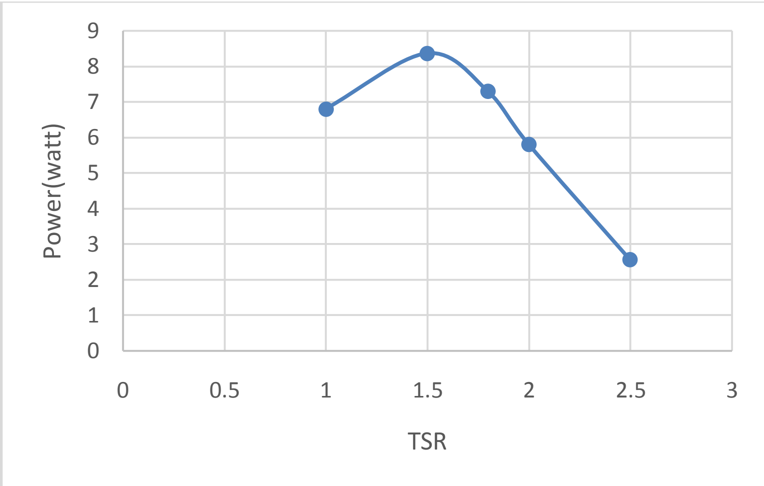


Figure 8: Power vs TSR

From result it is found that a maximum power coefficient of 0.4575 and torque coefficient of 0.305 is obtained at tip speed ratio of 1.5.

VII. CONCLUSION AND FUTURE WORK

In this paper numerical investigation of performance of Darrieus type straight bladed hydro turbine with higher solidity 0.9 and NACA0018 blade profile. In the numerical investigation, 2D unsteady flow of turbine is analyzes using CFD.A study of unsteady flow around a turbine has been carried out using a transient rotor-stator approximation with a moving mesh technique in turbulent flow Also, average torque and power coefficients versus tip speed ratio curves have been constructed for referred turbine. Maximum power is obtained at tip speed ratio 1.5.
However, in future considering the predictive result of the 2D CFD model, this will use for comparison with experimental result with same geometrical data.

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