Effect of Blade Pitch on Vertical Axis Wind Turbine

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Abstract - *This paper represents CFD simulation for evaluation of energy performance and aerodynamic forces acting on a straight-bladed vertical-axis Darrieus wind turbine and the effect of angle of pitch of aero profile.*

Key Words: **Analysis, Blade Pitch, Verticle axis wind turbine**

1. INTRODUCTION

Recently, wind energy is a considerable and significant source of power in the world. Wind power must be classified as one of the significant growths in the 20th century. A few years ago, steam power stations played a wide role in the technology of power generation, and the fossil fuels would seem to have forever relegated to insignificance the role of the wind in energy generation. Nowadays, wind energy is a considerable source of electricity in a lot of countries. Power fields that use wind energy are installed with high capacities in most countries of the world. Converting the kinetic energy has been introduced by many devices, which contained movable parts in the direction of the wind stream to convert it into mechanical work and then to electricity by the generators. Aerodynamic characteristics are the main base in the wind turbines classification. An aerodynamic force acting on an airfoil is conventionally resolved into its components parallel (drag) and normal (lift) to the freestream velocity vector. Therefore, the aerodynamic analysis of the turbine is characterized by the following: (a) the wind turbine that holds and seizes its mechanical energy from the aerodynamic drag force of the wind flow is called a drag wind turbine; (b) the wind turbine that deals with the aerodynamic lift force over the blades airfoils is called lift wind turbine. By this classification and analysis, both of these turbines are designed as vertical a4xis wind turbines. Besides, the aerodynamic parameter called "tip-speed ratio" is used to describe the wind turbine's performance. It is divided into "low-speed turbines" and "high-speed turbines." Wind turbines classification is divided depending on the positions and locations of the turbine axis of rotations. Therefore, it would be assorted into vertical axis wind turbine (VAWT) rotating around this normal axis. In https://doi.org/10.1155/2020/1368369addition, other patterns rotate about a horizontal axis. Therefore, they are called horizontal axis wind turbines and these types are known to the public due to commercial pervasion. Recently, effective and efficient VAWTs were improved and upgraded to be considerable wind converter. Darrieus rotors were invented in the 3rd decade of the twentieth century in France. Regularly, Darrieus rotors consist of 2 or 3 blades but these blades are positioned parallel to the rotor axis. Vertical axis wind turbines (VAWTs) have characteristics of simplicity, easy design, mechanical housing, no yaw systems, gearboxes, and generators, and mechanical and electrical elements are easily reached on the ground level. Therefore, they are characterized by convenient installations and suitable maintenance. Meanwhile, various disadvantages are facing this wind rotor like low efficiency, disability, and insufficiency to self-starting, and no ability to control the motor power output. -therefore, the turbines control speed by using variable pitch angles like other forms of blades. Darrieus rotors (with H-shaped blade) are structured instead of conventional curved blades called egg-shaped blades. As represented in Figure 1, the designer linked the H-rotor blade to the rotating axis by struts [1]. After this display and definition, it is obvious that Darrieus turbines have numerous potential for amplification that were not gained so far. Extra money, additional efforts, and further time are needed to fulfill optimum design for this turbine.

2. METHODOLOGY

A complete validation work based on wind tunnel measurements has been conducted. As shown in Fig. 9, the experimental setup consisted in a classical vertical-bladed Darrieus rotor made of aluminum and carbon fibers, using a NACA 0021 blade profile with a chord length of 85.8 mm, which was tested in Bovisa's low turbulence facility (Milan) As can be seen from Fig. 10, a computational domain of rectangular shape has been chosen, having the same wind tunnel external sizes: the wall boundary conditions of the model consisted in two lateral walls spaced 2000 mm apart from the wind tunnel centerline (the wind tunnel measured 4000 mm in width and 3880 mm in height). The rotor axis was placed on the symmetry position of the wind tunnel section. 2D and 3D simulations were performed, to take into account the drag effect induced by the spokes, too. Only half of the experimental setup was modeled, due to its vertical symmetry: in this case, a symmetry boundary condition was used at the computational domain midsection. Anyway, the geometrical features of the model did not allow other simplifications to be performed. The effect of gravity on the rotor working curves has not been contemplated, being considered not influential for the scope of the validation work. The main features of the validation model are summarized. The correction due to wind tunnel blockage was not applied (both for experimental measurements and numerical computations), to minimize any sources of error due to a wrong After some corrections to take into account spoke drag, the average torque values, measured in the wind tunnel for a 9 m/s unperturbed wind speed at test section entrance (and different tip speed ratios), were compared with those obtained from CFD analysis. For more details about the validation procedure and tests, see Ref. [24]. A comparison of the computed results with experimental data showed that prediction obtained using Enhanced Wall Treatment k-3 Realizable turbulence model successfully reproduced most of the flow features associated with the revolution of the tested rotor. In particular, as can be seen in Fig. 11, the numerical code proved able to replicate the shape of the experimental curve and was able to accurately capture the maximum power coefficient tip speed ratio, thus offering a reliable alternative to the development of experimental tests, at least at a first attempt. The discrepancies between the two curves, roughly constant over rotor operational angular range and corresponding to about one half of the two-dimensional power coefficient for optimum tip speed ratio, are due to the combined effects of finite blade length and spokes drag, as described by Raciti Castelli et al. [24].

Blade profile NACA 0021

Chord length 85.8 [mm]

Drotor [mm] 1030

Hrotor [mm] 1456.4

As [m2] 1.236

s [-] 0.5

N [-] 3

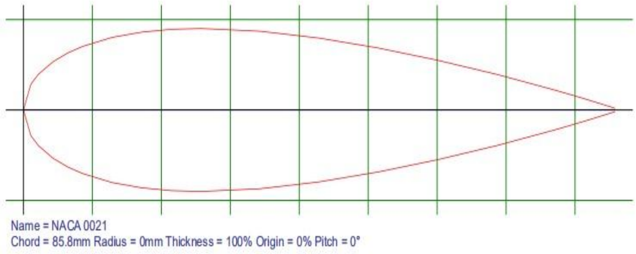
Spoke-blade 0.5 c

connection

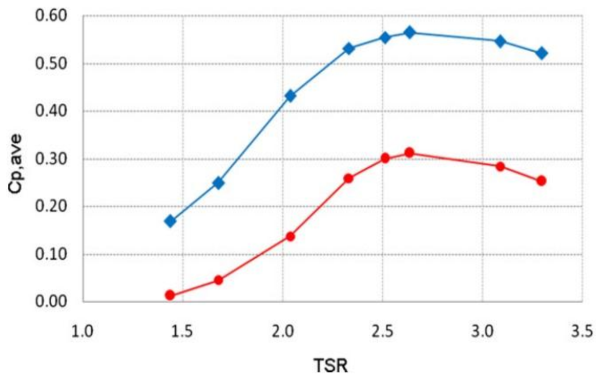
Hwind tunnel [mm] 4000

Wwind tunnel [mm] 3800

NACA 0021



Experimental Data



Comparison between wind tunnel measured (red) and numerically determined 2D power curve (blue) for wind speed at the test section entrance of 9 m/s (correction due to wind tunnel blockage was not considered). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The approach is taken for optimizing the vertical axis wind turbine by varying the pitch of the aerofoil shape. The selected aerofoil profile NACA 0021 was taken into consideration and was studied for power and torque generation of zero degree pitch at a different azimuthal angle so after that the pitch of aerofoil varies between -15 to 15. And this data was simulated to find torque and power characteristics at different pitch angles. This turbine has been designed to operate in low wind speed and it can capture the wind in any direction due to the shape and design of the rotor blade. The wind turbine model has a rotor diameter of 1030 mm and a rotor height of 1456.4 mm. This innovative rotor can rotate at low wind speed (2m /s to 12m /s)and able to produce a good mechanical power that could be used to generate electricity.

2.1 Design Calculations Formula

T.S.R. (λ) = $\frac{\omega D}{2U}$

Power output (P) = 0.5 × A × ρ × V3 × Cp

Power = Torque × Angular velocity (ω)

Aspect Ratio (α):

It is the ratio of the height of the rotor to its diameter. It is a measure of the extent to which the maximum dimension of the rotor differs from the minimum dimension.

$$A = \frac{H}{D}$$

Tip Speed Ratio (λ):

Tip speed ratio or TSR is the ratio of the rotational speed of the blade to the actual velocity of the air stream. A higher tip speed ratio is indicative of higher efficiency but is also related to higher noise levels and the need for stronger blades. TSR is quite important in the design of any wind turbine. If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Alternatively, if the rotor turns too quickly, the blades appear stationary to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power out of the wind as possible.

$$\lambda = \frac{\omega D}{2U}$$

Reynolds Number (Re):

Reynolds number is the non-quantity that gives a measure of the inertial forces to the viscous forces in a given flow. They are used to perform a dimensional analysis of a given problem. The length scale that is used to obtain the Reynolds number is different in different situations. In each of the cases discussed in the report, the length scale is given by the diameter of the rotor, and the Reynolds number is hence, given by:

$$Re = \frac{\rho U D}{\mu}$$

Torque Coefficient (Ct):

The torque Coefficient is the dimensionless torque of the rotor. The formalizing term is the product of the dynamic pressure due to the wind, an area term, and a length equivalent of the rotor. The starting torque coefficient (Cts) is another non-dimensional quantity associated with the performance of a rotor. It is obtained by replacing the torque in the torque coefficient equation by the starting torque. It is given by:

$$Ct = \frac{4\,T}{\rho\, U^2 D^2 H}$$

Coefficient of Power (Cp):

The coefficient of power is the non-dimensional power that is generated in the rotor. It is the ratio of the power produced in the rotor to the total kinetic energy of the air interfaced by the rotor. It is given by; [2]

$$Cp = \frac{\text{The power produced by the rotor}}{\text{The energy in interfaced air}}$$

$$Cp = \frac{P}{\left(\frac{1}{2}\rho\, U^3\right)(DH)}$$

$$Cp = \frac{2\,T\,\omega}{\rho\, D\, H\, U^3}$$

Cp = Ct .TSR

Power Output

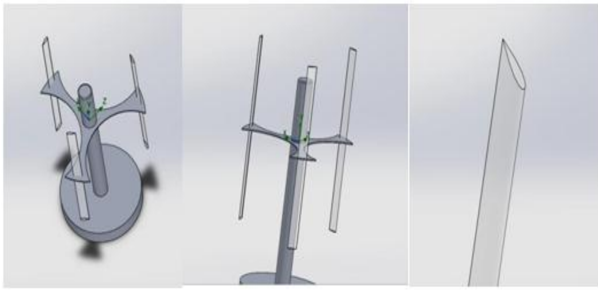
Power output (P) = 0.5 × A × ρ × V3 × Cp

Power = Torque × Angular velocity (ω)

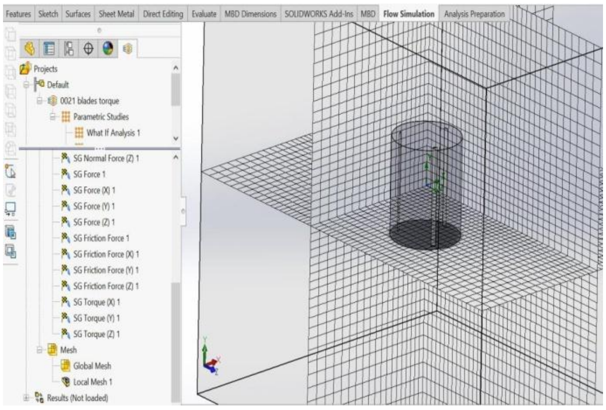
3. MODELING AND ANALYSIS

3.1 Steps involved:

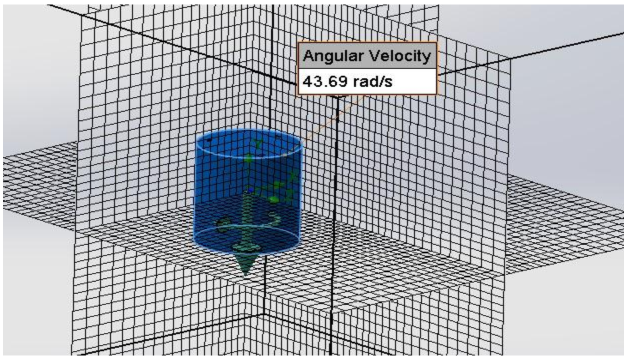
A. CAD Modelling



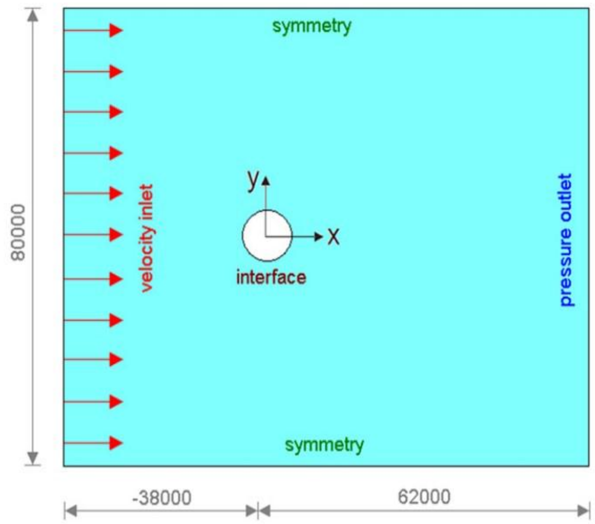
B. Meshing The Geometry



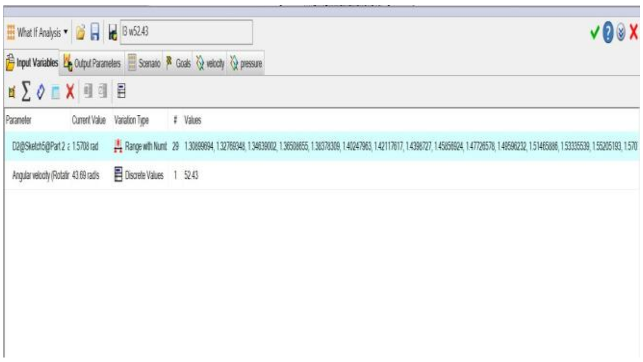
C. Defining The Boundary Conditions



D. Carrying Out Mesh Dependency Test



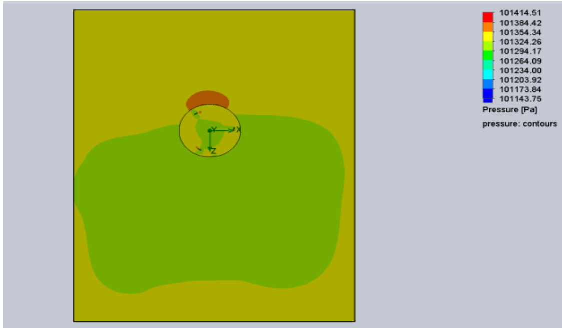
E. Performing A Parametric Study



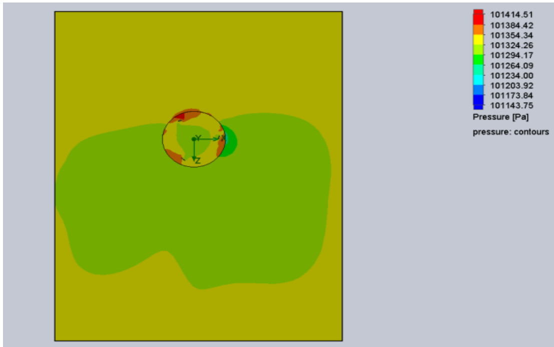
F. Post- Processing And Analyzing The Results

Pressure Plot for TSR 2.5 at different design points

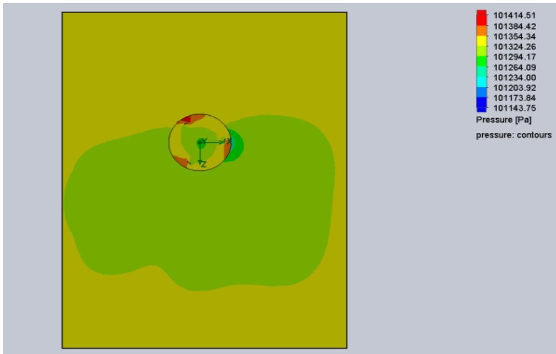
Design Point 15



Design Point 25

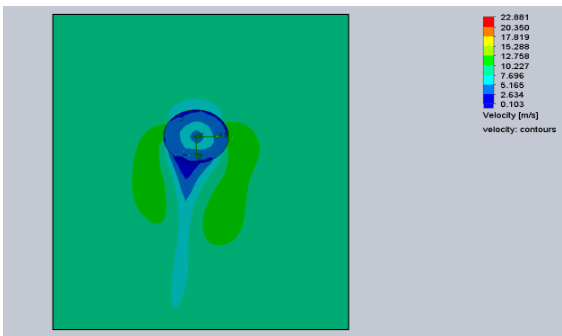


Design Point 26



Velocity Plot TSR 2.5 at different Design Points

Design Point 15



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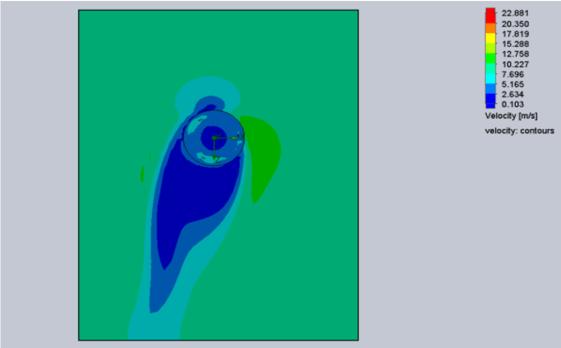
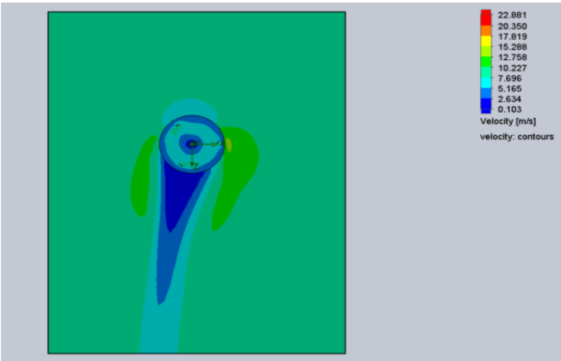
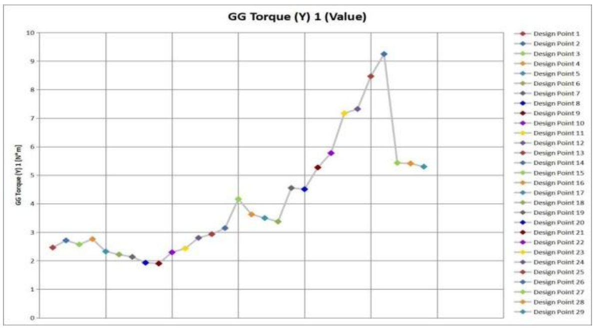
Design Point 25

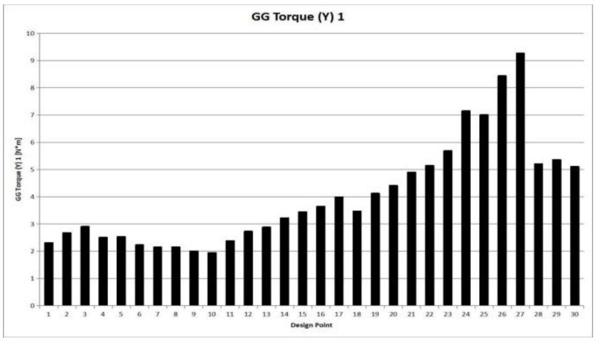


Design Point 26



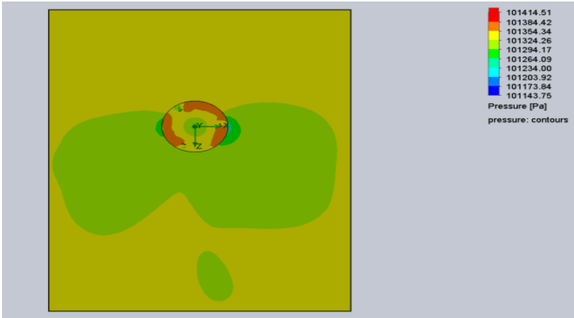
Torque



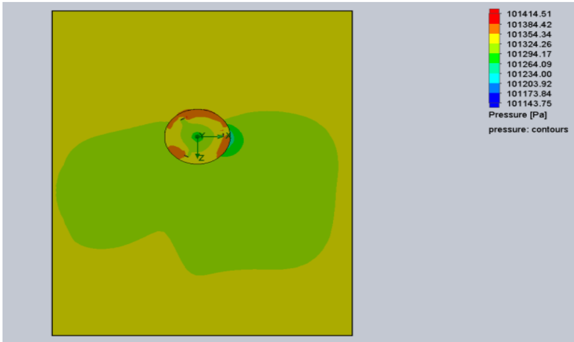


Pressure Plot TSR 3 at different Design points

Design Point 1



Design Point 15



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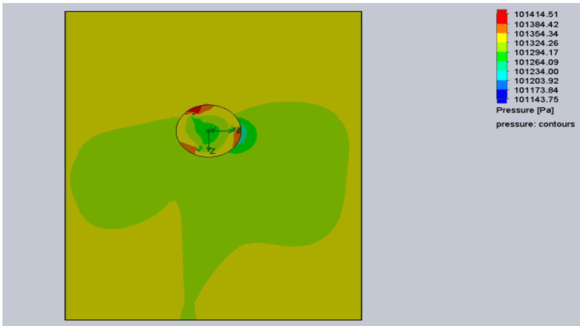
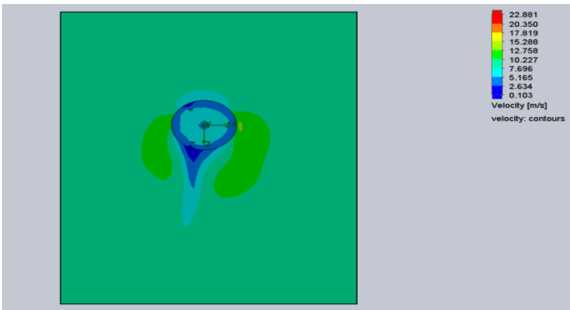
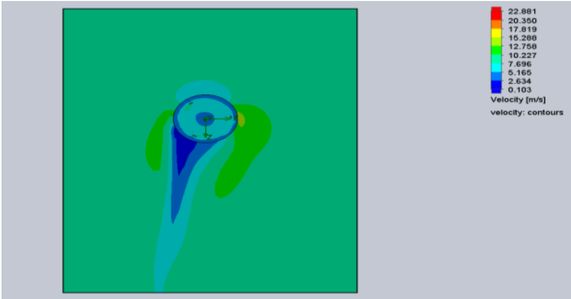


Velocity Plot TSR 3 at different Design points

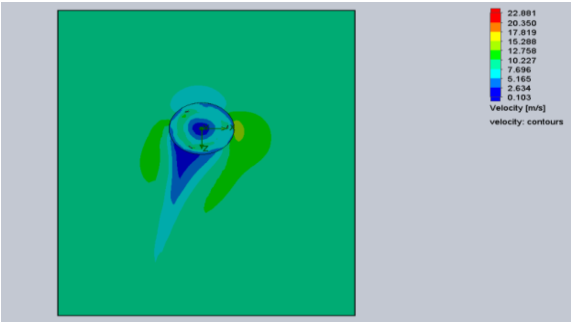
Design Point 1



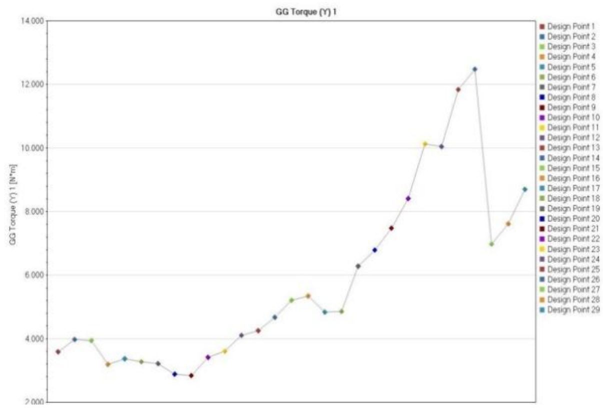
Design Point 15

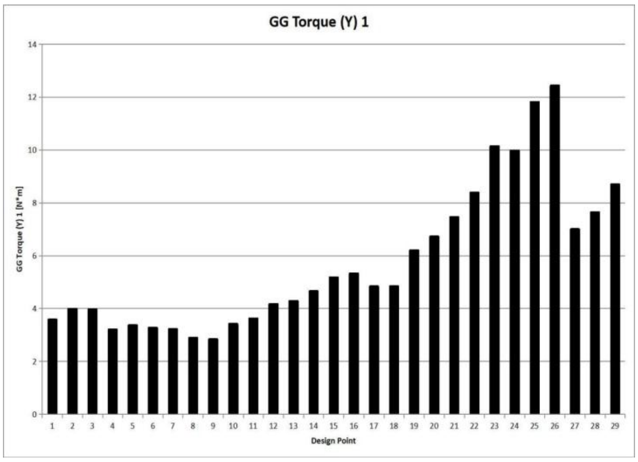


Design Point 26



Torque





At design point 26 Maximum torque is produced.

λ TSR	ω rad/sec	N rpm	Cp	P Experimental	T (simulation)	ω	P (simulation) T× ω	Torque #	P# T# ×ω
2.5	43.69	417.21	0.30	160	3.64	43.69	159.0316	9.26	404.569
3	52.43		0.50	267.393	4.26	52.43	223.3518	12.47	653.8021

Table -1:

AT optimum design point

4. CONCLUSIONS

Thus from the simulation results obtained we conclude than changing the pitch angle has a significant effect on the power characteristics of the verticle axis wind turbine.

As the blade pitch increases power output increases up to a certain pitch (for the case +12 degrees from 90-degree base pitch point and then decreases again.

+12 degree is the most optimum pitch at the 0-degree Azumutal angle to get maximum power output.

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