Research Article

Investigation and Analysis of The Performance Characteristics of Horizontal Axis Wind Turbine Blade with Dimple By Using CFD

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Abstract: Renewable energy can realize by the amount of energy which is continuously required for the present and future generation. Wind energy is one of the rapidly growing power producing technology in this world. Wind power is extracted from air flow using wind turbines to produce the electricity. Wind power is an alternative to burning fossils which is clean and doesn't produce any greenhouse toxic and poisoned gases during its operation. The main idea of this project is to investigate and analyse the aerodynamic effects of dimples on the surface of the horizontal axis wind turbine blade. This investigation speaks about the increase in efficiency when the dimples are added on the blade surface of the wind turbine.

Introduction:
GOE 239 aerofoil is used for the blade design. The structural design has done in the SOLIDWORKS software and the computational analyses were done in the ANSYS FLUENT. The rotor blade is 36 meter of a length. The energy that is absorbed from the wind is converted into mechanical energy that is used to drive electrical generator and then it is transformed into electrical energy [1]. In the global scenario, wind turbines and their aerodynamics are always subjected to constant research for increasing their efficiency which converts the abundant wind energy into usable electrical energy [2].The investigation of Lanchester and Betz (1920) tells that the maximum extraction of energy possible from a wind turbine rotor is 59.3% of the available kinetic energy [5]. Wind turbines are placed on top on top of vertical structures called wind tower [7]. Two blades were analysed with 20 m/s inlet velocity in ANSYS FLUENT and torque results are calculated. This paper shows the analysis results of two designed blades of dimple and without dimple, aerodynamic effects by addition of dimples on the surface of the blade.

Objective:

To place the dimples on the selected aerofoil blade, by optimising the shape, size and the exact place of the dimple on a blade and to examine the aerodynamic results of a dimple placing in different positions in wind turbine blade and finally compare the results of a plain rotor blade and a dimpled rotor blade.

Methods:

Shear stress transport turbulence model is used for the analysis. The k-ω model is well suited for simulation of flow in the viscous sublayer. This model is used to anticipate the result of turbulence. The shear stress limiter helps the k-ω model avoids a build-up of excessive turbulence kinetic energy near the stagnation points.

Turbulence kinetic energy:

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = P_k - \beta^* k\omega + \frac{\partial}{\partial x_j}\left[\left(\nu + \sigma_k \nu_T\right)\frac{\partial k}{\partial x_j}\right]$$

Specific dissipation rate:

$$\frac{\partial \omega}{\partial t} + U_j \frac{\partial \omega}{\partial x_j} = \alpha S^2 - \beta\omega^2 + \frac{\partial}{\partial x_j}\left[\left(\nu + \sigma_\omega \nu_T\right)\frac{\partial \omega}{\partial x_j}\right] + 2(1-F_1)\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i}$$

Blending function:

$$F_1 = \tanh\left\{\left\{\min\left[\max\left(\frac{\sqrt{k}}{\beta^*\omega y}, \frac{500\nu}{y^2\omega}\right), \frac{4\sigma_{\omega 2} k}{CD_{k\omega} y^2}\right]\right\}^4\right\}$$

CD_{kw}

$$CD_{k\omega} = \max\left(2\rho\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i}, 10^{-10}\right)$$

Kinematic eddy viscosity:

$$\nu_T = \frac{a_1 k}{\max(a_1\omega, SF_2)}$$

Second blending function:

$$F_2 = \tanh\left[\left[\max\left(\frac{2\sqrt{k}}{\beta^*\omega y}, \frac{500\nu}{y^2\omega}\right)\right]^2\right]_b$$

Production limiter:

$$P_k = \min\left(\tau_{ij}\frac{\partial U_i}{\partial x_j}, 10\beta^* k\omega\right)$$

Structural design:

GOE 239 is the aerofoil used for the structural design for the blade with and without dimple of blade length 36 meters using SOLIDWORKS software.

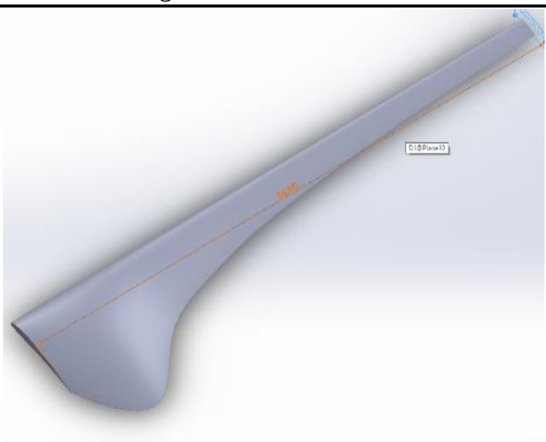

Fig 1: Structural Design of A Blade Span of 36 Meters Without Dimple in SOLIDWORKS Software.

CFD modelling and meshing:

After the designing of the blade, the file is imported to the ANSYS FLUENT, the domain is created around the blade for the study which acts as the virtual boundary of the fluid and finally mesh is generated. The behaviour of a wind turbine rotor in a flow field may efficiently be analysed by using the actuator disc principle [3]. However in the resent and now a days, this job of testing and analysis has been highly computerized and now is figured out by using Computational Fluid Dynamics (CFD)[4].

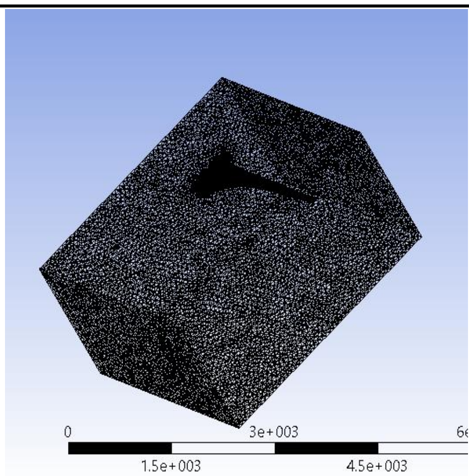

Fig 2: Mesh Profile of a Blade without Dimple

Mesh type	tetrahedral

Min size element	1m
Face sizing	90 mm
Nodes	240598
elements	1317621

Fig 3: Mesh details of blade without dimple.

Mesh type	tetrahedral
Min size element	1 m
Face sizing	60 mm
Nodes	295243
elements	1635750

Fig 4: mesh details of blade with dimple.

Boundary conditions and inputs:
To find the result, we need to give some basic inputs to the meshed file. K- omega model is selected for the analysis and the solution is converged at the 5,325. The below mentioned conditions were given for both the designed blades of with and without dimple. For design considerations the maximum wind speed is taken as 20 m/s for increasing the safety [8].

Boundary name	Boundary conditions	Input variables
Inlet	Subsonic flow and velocity inlet	Static pressure is 101325 pa and inlet velocity 20 m/s
outlet	Subsonic flow and pressure outlet	No information is needed for this boundary.

Fig 5: Boundary conditions used for the analysis, subsonic flow of inlet velocity with 20 m/s and static pressure of 101325 pa.

Results and discussion:
The plain blade was first analysed with above mentioned conditions and the following results were obtained. The pressure contour on the blade as shown in the Figure 5 shows the low pressure created at the top surface of the wind turbine blade. The pressure developed at the bottom is significantly higher when compared to that of the top side of the blade which confirms that lift is generated.

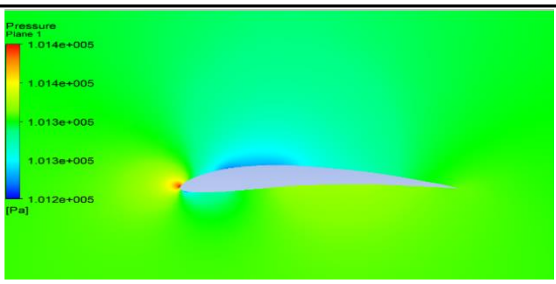

Fig 6: Pressure distribution without dimple which shows the max pressure at the leading edge of 1.014*10^5 pa.

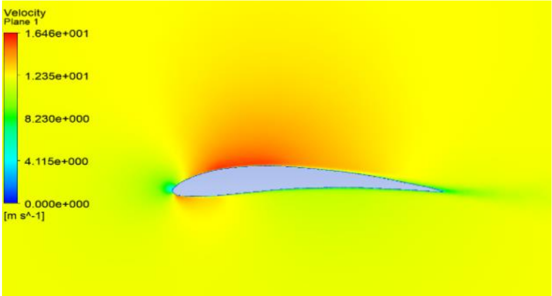

Fig 7: Velocity distribution without dimple which shows the max velocity at the upper surface of the aerofoil of 1.646*10^1 m/s.

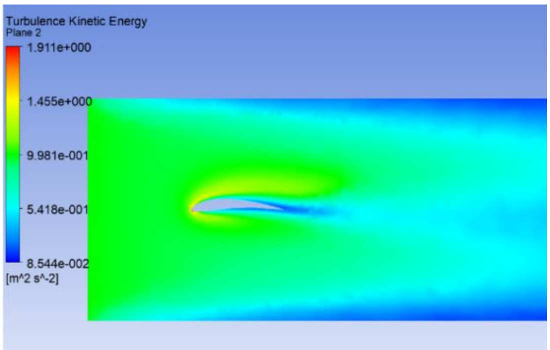

Fig 8: Turbulence kinetic energy without dimple which shows the flow separation for the without dimple blade of the highest value of 1.911 m^2/s^2

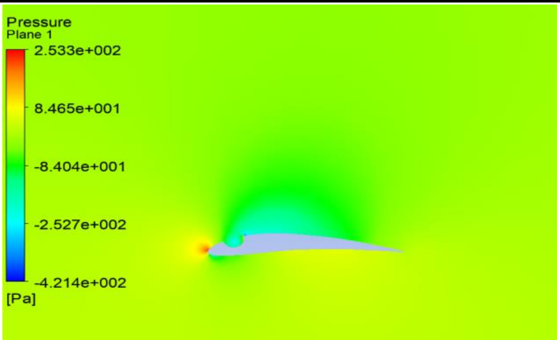

Fig 9: pressure distribution of blade with dimple, which shows the maximum pressure at leading edge of 20 m/s inlet velocity and also the negative pressure increases inside the surface which means flow gets decelerated

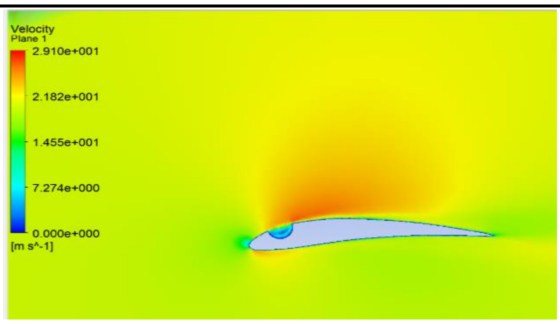

Fig 10: velocity distribution of a blade with dimple, which shows the maximum velocity on the upper surface of the section of 2.91*10^1 m/s and also the velocity gets decreased inside the dimple which means pressure is increased inside the dimple.

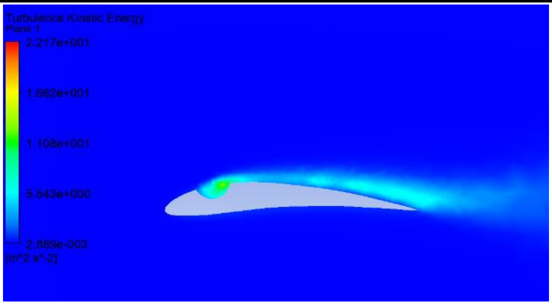

Fig 11: turbulence kinetic energy with dimple which shows the flow separation for the dimple blade and it also shows turbulence kinetic energy is very high inside the dimple of 5.54*10^1 m^2/s^2.

After the inclusion of dimples on the upper surface of blade by the mentioned conditions, betterment in the performance was observed and also the pressure developed at the bottom surface is higher compared to the upper surface which implies, lift is generated on the blade, after placing the dimple the flow turns turbulent and remains attached to the boundary layer for some more time, thus delaying the boundary layer separation, this results in increment in the lift after placing dimples.

Torque and power analysis:
The torque of the rotor blade is calculated by using the function calculator in ANSYS CFD. Torque of the blade is calculated by defining the z-axis as the axis of rotation in this model.P= $2\pi NT/60$, Where, P is the power, N is the seed of rotation in rpm and T is the torque produced.

No of blade	Torque	Power
1	2,51,344 N-m	5,85,631.52 W
3	7,54,032 N-m	17,56,894.56 W 1.756 MW

Fig 12: Torque and power calculations of blade without dimple, which were done by the formula mentioned above

No of blade	Torque	Power
1	2,85,327 N-m	6,64,811.91 W
3	8,55,981 N-m	19,94,435.73 W 1.994 MW

Fig 13: Torque and power calculations of blade with dimple, which were done by the formula mentioned above.

Conclusion:
The computational investigation on wind turbine blade designed with dimples was done to increase the aerodynamic efficiency by reducing the drag. In this work, wind turbine blade is done by using SOLIDWORKS, meshing is done using ANSYS meshing tool and CFD analysis is done using ANSYSFLUENT.
The below mentioned conclusions can be drawn from this work. From the above results we can infer that:

- This investigation was carried out to mainly focus on the increment in torque which also leads to increment in power and it was done.
- GOE 239 aerofoil was chosen for the blade design to obtain good performance to generate 1.8 MW power.

- From fig 12, 7,54,032 Nm torque was produced for 3- blade without dimple and from fig 13, 855981 Nm was produced for 3- blade with dimple.
- From fig 12, 1.756 MW power is generated for 3 blades without dimple and in the fig 13, 1.994 MW power is generated for 3 blades with dimple.
- These results were shows that about 13.5 % increase in the power by the inclusion of dimples on the upper surface of the wind turbine blade.

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