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Structural and Air Flow Analysis of Vertical Axis Wind Turbine (VAWT) for Optimum Design

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Abstract - The objective is to maximize the torque while enforcing typical wind turbine design constraints such as tip speed ratio and blade profile. In this present work the model of vertical axis wind turbine (VAWT) was created using catia V5 and then analyzed the same using Ansys 15.0 to study the equivalent von-mises and maximum shear stress distribution and deformation development.

A set of models were created by varying the blade width (keeping fixed thickness), height of the turbine and there after analysis were carried to find the optimum parameters of the turbine. Also the analysis test was carried by taking three and four blades of the turbine to find the optimum number of blades for effective performance of the vertical axis wind turbine.

Also the fluid flow (CFX) analysis is carried to study the velocity and pressure profiles along the turbine blades and confirmed the desired positive flow rate.

Key words: Vertical axis turbine, turbine height, blade width.

I. INTRODUCTION

Vertical turbine designs have much lower efficiency than standard horizontal designs. The key disadvantages include the relatively low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the 360-degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modeling the wind flow accurately and hence the challenges of analyzing and designing the rotor prior to fabricating a prototype.

When a turbine is mounted on a rooftop the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of a rooftop mounted turbine tower is approximately 50% of the building height it is near the optimum for maximum wind energy and minimum wind turbulence. While wind speeds within the built environment are generally much lower than at exposed rural sites, noise may be a concern and an existing structure may not adequately resist the additional stress.

II. OBJECTIVE

The objective of this current study is to analyse the effect of the blade cross section size, turbine height and number of blades on the structural capacity of the vertical axis wind turbine. The model is created using Catia V5 software, followed by structural analysis test using Ansys 15.0 software. Also air flow analysis over turbine is carried using Ansys 15.0-CFX to confirm the positive flow through

III. MODELING OF VERTICAL AXIS WIND TURBINE(VAWT)

The step by step procedure followed in creating the model of vertical axis wind turbine (VAWT) model is shown in the following figures.

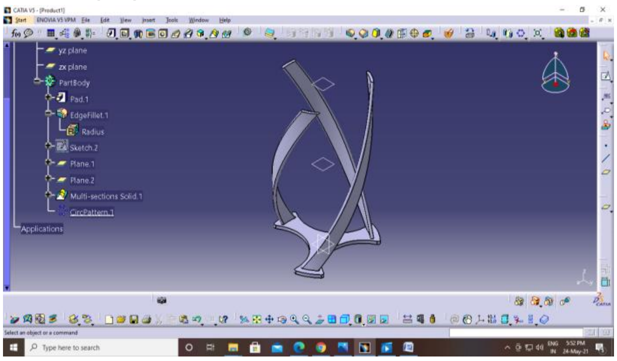

Fig 3.1 Creation of turbine blades in Catia V5

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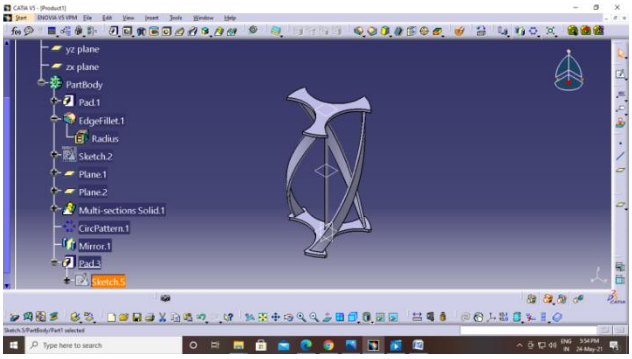

Fig 3.2 Final model of VAWT with 3 blades created in catia V5

The same procedure is applied to create the series of models as follows.

Model-1: 25mm blade width, 300mm height and 3 blades
Model-2: 26mm blade width, 300mm height and 3 blades
Model-3: 27mm blade width, 300mm height and 3 blades
Model-4: 28mm blade width, 300mm height and 3 blades
Model-5: 29mm blade width, 300mm height and 3 blades
Model-6: 29mm blade width, 240mm height and 3 blades
Model-7: 29mm blade width, 260mm height and 3 blades
Model-8: 29mm blade width, 280mm height and 3 blades
Model-9: 29mm blade width, 300mm height and 4 blades

IV. ANALYSIS OF VAWT

Step by Step Analysis Procedure (**Model-1: 25mm blade width, 300mm height and 3 blades**)

Step 1: The Catia model is to be imported in igs format and divided in finite parts and meshed model is as shown in fig 4.1

Step 2: The fixed constraints are applied as shown in fig 4.2.

Step 3: The rotational speed is applied to the model as shown in fig 4.3.

Step 4: The torsional moment is applied to the model as shown in fig 4.4.

Step 5: Then to solve the problem using solver option.

Similar procedure is applied to all the models and results are discussed in the next section.

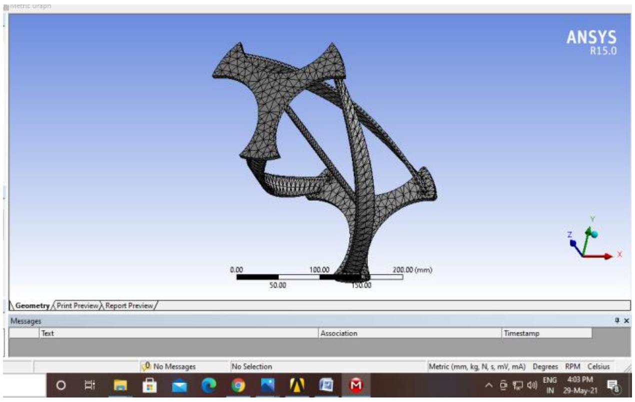

Fig 4.1 Meshed model of VAWT in Ansys 15.0

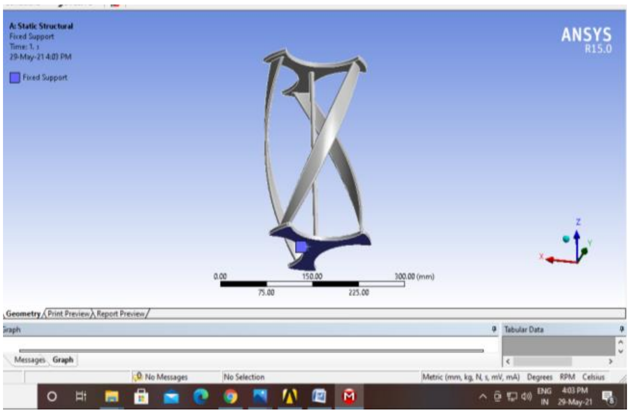

Fig 4.2 Applying fixed constraints in Ansys 15.0

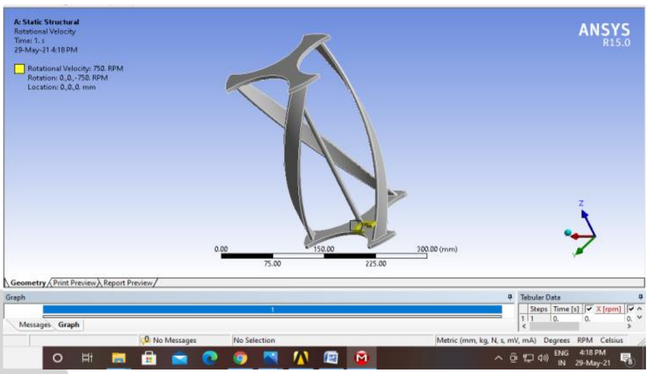

Fig 4.3 Applying rotational speed to the model in Ansys 15.0

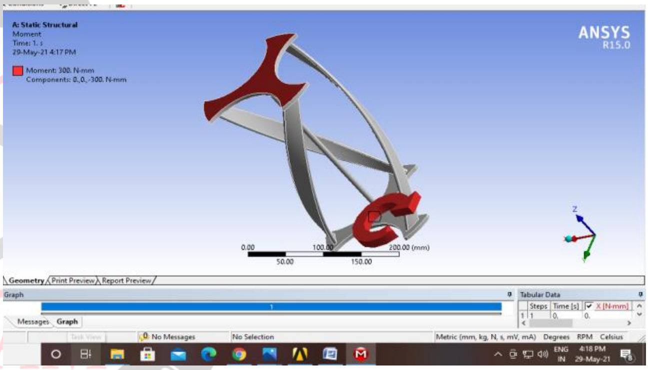

Fig 4.6 Applying torsional moment to the model.

V. RESULTS AND DISCUSSIONS

5.1 3 Blades Vertical Axis Wind Turbine (VAWT) for different blade width

5.1.1 Vertical Axis Wind Turbine with 25mm blade width: Model-1

The fig 5.1 shows the equivalent von-mises stress distribution in vertical axis wind turbine(VAWT) with 25mm blade width mosel-1. The resulting color image reveals that the most of the portion of the blades are under the action of the moderate level of intensity of stress, but especially along the sides of the blade (through thickness), the stress seems to be minimum. The reason is simple the blade leads to bending in addition to the torsion, and the bending possibility is less in that transverse direction (axis along the thickness of the blades). Also it can be observed that blue color was extended on to the blade surface in the middle along its length, which represents that the blade results in twisting about that particular plane surface. This result data helps in understanding the pattern of twisting of blade, which can be

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useful in making suitable length of the blade for effective performance. Also it can be observed that the ends of the blades are represented with light green color followed by yellow and red color at the connection junctions to the rigid upper and lower frames. This indicates that the stress intensity is incrasing from the middle of the blade to its ends along its length. The maximum von-mises stress developed in this model-1 found to be 84.685MPa.

The fig 5.2 shows the deformation developed in the VAWT model-1. The resulting color image reveals that the deformation decreases along the length of the blade from top to bottom, which was represented with red at the top and blue being at the bottom. Even it can be observed that the bottom half of the length of the blade is being uniform deformation along its width, whereas the upper half length of the blade is under peculiar behaviour with higher deformation towards one end. This pattern is due the reason explained earlier, that is due to bending action on the blades which takes place about the bottom fixed end due to action of the torsion, the beam results in opposite nature of bending action on both the ends. The maximum deformation developed in this model-1 is found to be 0.58965mm, which develops close to the top end of the blade. Also it can vbe observed that the rigid frame at the top where it is connected to the blades results in higher deformation with red color representation.

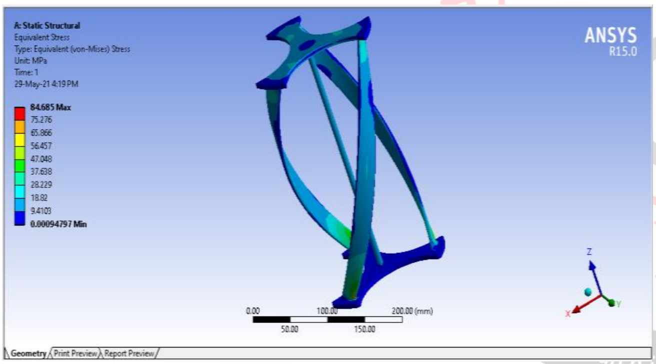

Fig 5.1 Equivalent Von-mises Stress Distribution in VAWT with 25mm Blade width-Model-1

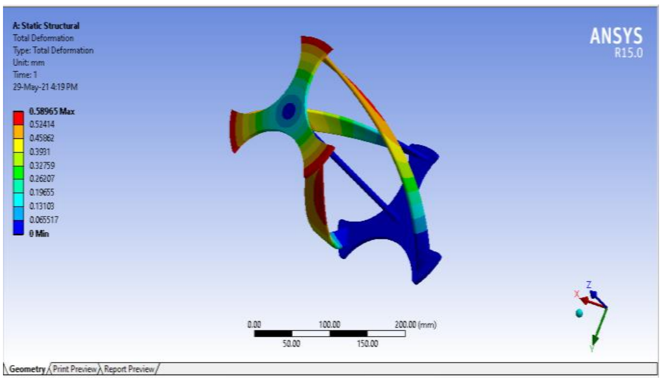

Fig 5.2 Total Deformation development in VAWT with 25mm Blade width-Model-1

5.1.2 Vertical Axis Wind Turbine with 26mm blade width: Model-2

The fig 5.3 shows the von-mises stress developed in the VAWT model-2. The resulting color picture shows that the pattern of the distribution of the stress is similar to the previous model. But the intensity of the stress is decreased in this case up to some extent with a maximum magnitude of 82.34MPa. The maximum stress intensity in this model-2 is 2.7% lower than that of the previous model-1.

The fig 5.4 shows the deformation development in the VAWT model-2. The resulting color picture reveals that the pattern of deformation in this model is following the same trend as that of previous model. The maximum deformation developed in this model is found to be 0.57449, which is 2.57% lower than that of the model-1.

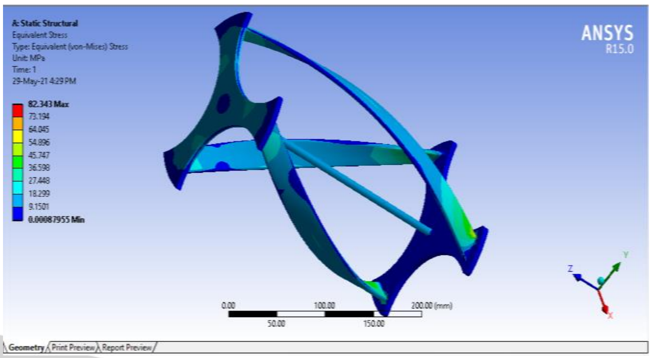

Fig 5.3 Equivalent Von-mises Stress Distribution in VAWT with 26mm Blade width-Model-2

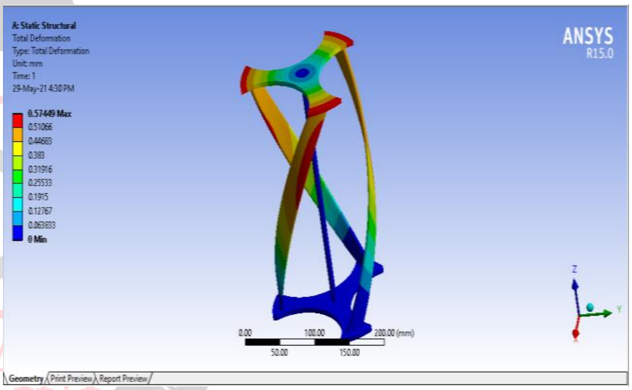

Fig 5.4 Total Deformation development in VAWT with 26mm Blade width-Model-2

5.1.3 Vertical Axis Wind Turbine with 27mm blade width: Model-3

The fig 5.5 shows the von-mises stress distribution in the VAWT model-3. The resulting color image reveals that the pattern of distribution of stress is same as in previous models. But the intensity of the stress has been decreased in this case. The maximum stress intensity is found to be 81.29MPa, which is 1.2% lower than that of model-2 and 4% lower than that of model-1.

The fig 5.6 shows the deformation developed in the VAWT model-3. The resulting picture shows that the pattern of development of deformation is same as in previous models. The maximum deformation developed in this model is found to be 0.581mm, which is 1.2% higher than that of the model-2 and is 1.3% lower than that of the model-1.

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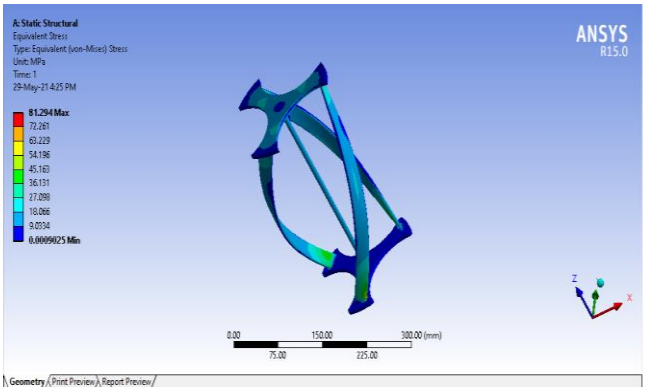

Fig 5.5 Equivalent Von-mises Stress Distribution in VAWT with 27mm Blade width-Model-3

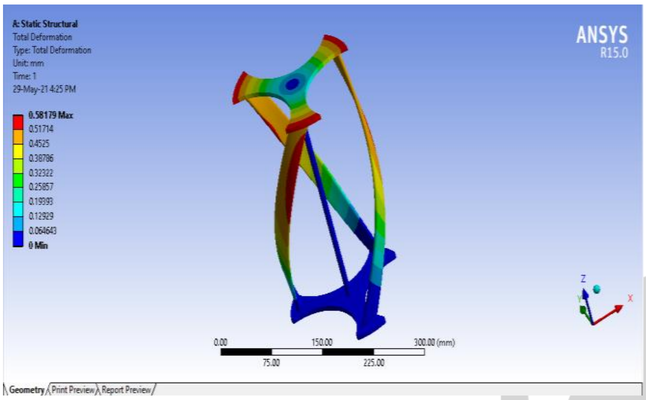

Fig 5.6 Total Deformation development in VAWT with 27mm Blade width-Model-3

5.1.4 Vertical Axis Wind Turbine with 28mm blade width: Model-4

The fig 5.7 shows the von-mises stress distribution in the VAWT model-4. Th eresulting color image shows that the distribution of stress follows the same trend as in the previous models. The maximum stress developed is found to be 78.81MPa, which is 3.05% lower than that of model-3.

The fig 5.8 shows the deformation developed in the VAWT model-4. The resulting color image shows the same pattern as in previous models, but with lower magnitudes. The maximum deformation developed in this case is 0.5671mm, which is 2.5% lower than that of model-3.

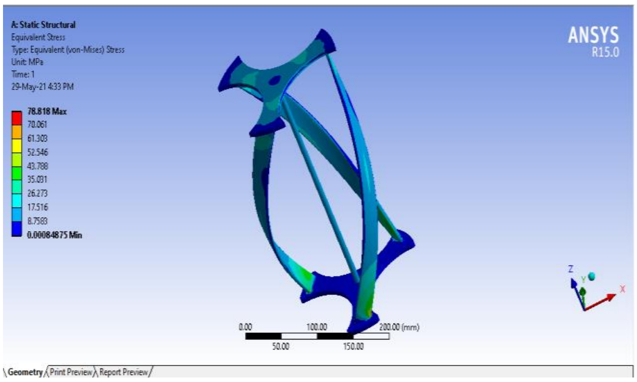

Fig 5.7 Equivalent Von-mises Stress Distribution in VAWT with 28mm Blade width-Model-4

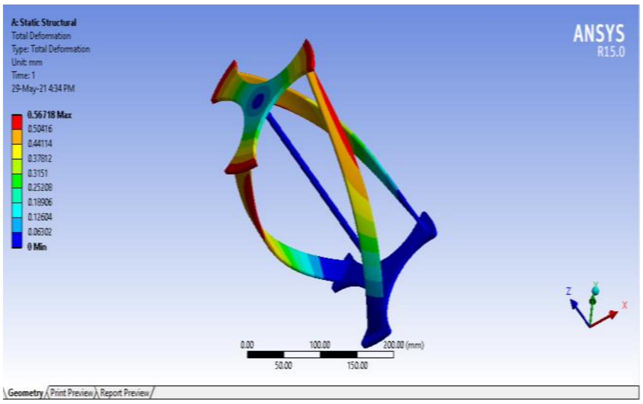

Fig 5.8 Total Deformation development in VAWT with 28mm Blade width-Model-4

5.1.5 Vertical Axis Wind Turbine with 29mm blade width: Model-5

The fig 5.9 shows the von-mises stress distribution in the VAWT model-5. The resulting color image shows that the distribution of stress follows the same trend as in previous models but still with lower magnitudes. The maximum stress developed is found to be 77.5Mpa, which is 1.7% lower than that of model-4.

The fig 5.10 shows the deformation developed in the VAWT model-5. The resulting color image shows the same pattern as in previous models, but with lower magnitudes. The maximum deformation developed in this case is 0.5598mm, which is 1.3% lower than that of model-4.

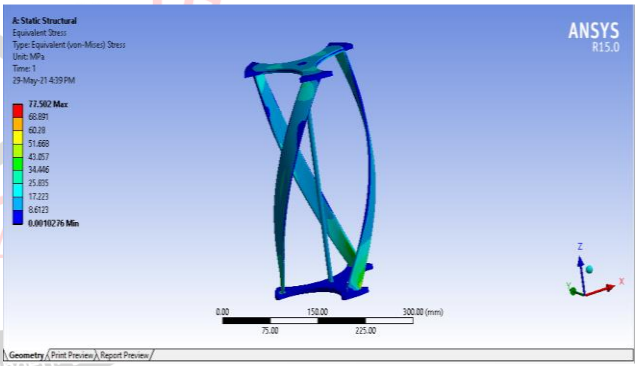

Fig 5.9 Equivalent Von-mises Stress Distribution in VAWT with 29mm Blade width-Model-5

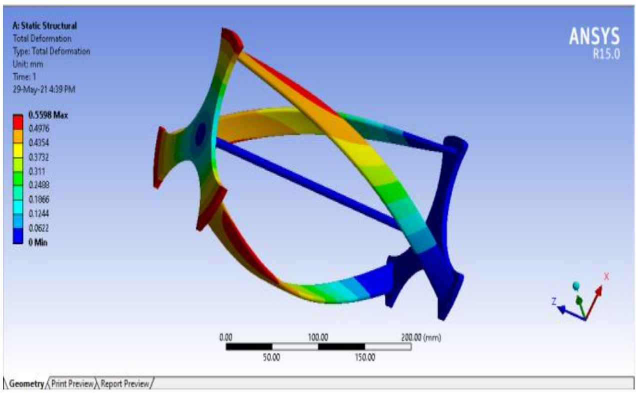

Fig 5.10 Total Deformation development in VAWT with 29mm Blade width-Model-5

5.2 3 Blades Vertical Axis Wind Turbine (VAWT) for different heights

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5.2.1 Vertical Axis Wind Turbine with 240mm height: Model-6

The fig 5.11 shows the von-mises stress distribution in the VAWT model-6. The resulting color image shows that the patternof distribution of stress in this model is same as in previous models, but with some variation. The stress intensity in this model is dratically reduced compared with previous all models, because of variation in its height. It is observed that the stress distribution salong the length of the blade was higly influenced by the height of turbine, which results in eduction of stress intensity. The color representation on the blade shows that the major portion of the blade is under moderate stress with only minor region under higher stress intensitioes towards the blade ends. Though this pattern is same in previous models, the area under higher stress intensity at the ends of the blades is lower than that of th eprevious model with 300mm height. The reduction in height of the turbine system, also results in the reduction in the length of the blade, which there by increases its strength. Also it can be observed that dark blue color spread over the middle portion of the blade is similar to the previous models, again some change can be identified, with one more blue color origin is seen even in the bottom half of the blade. Though it is small, it shows that one more plane is also starte dto resist the bending action over the blade. Thus the length of the blade in between these two origins can be identified as strong portion of the blade which resist the applied torsional moment. The maximum stress developed in this model is found to be 58.64MPa.

The fig 5.12 shows the deformation development in the VAWT model-6. The pattern of development in this model is same as that of previous model with a maximum magnitude of 0.3198mm.

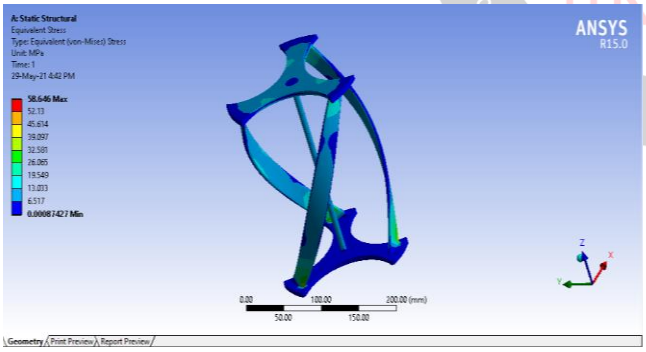

Fig 5.11 Equivalent Von-mises Stress Distribution in VAWT of 240mm height-Model-6

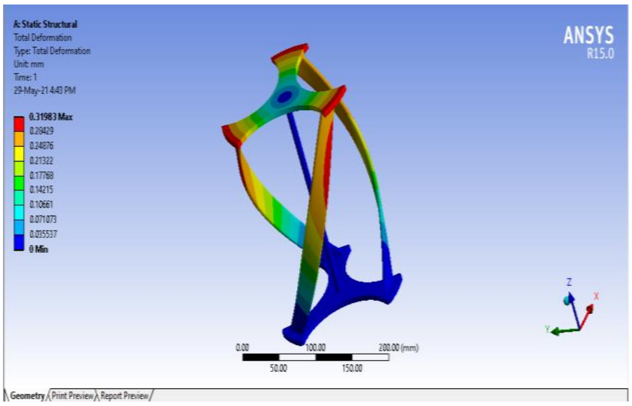

Fig 5.12 Total Deformation development in VAWT of 240mm height -Model-6

5.2.2 Vertical Axis Wind Turbine with 260mm height: Model-7

The fig 5.13 shows the von-mises stress distribution in VAWT model-7. The pattern of distribution is same as in previous model. The maximum stress developed in this model is found to be 64.218MPa, which is 9.5% higher than that of model-6.

The fig 5.14 shows the deformation developed in the VAWT model-7. The resulting color image shows the same pattern as in previous models, but with higher magnitudes. The maximum deformation developed in this case is 0.3891mm, which is 21.6% higher than that of model-6.

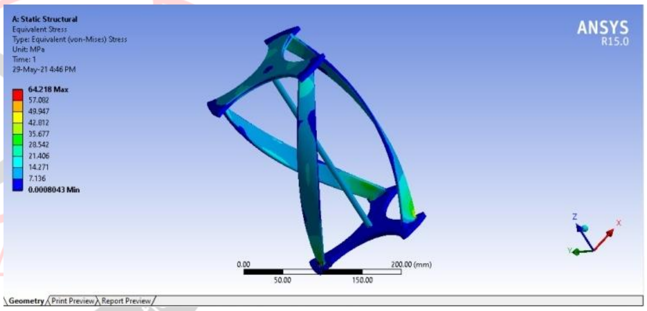

Fig 5.13 Equivalent Von-mises Stress Distribution in VAWT of 260mm height-Model-7

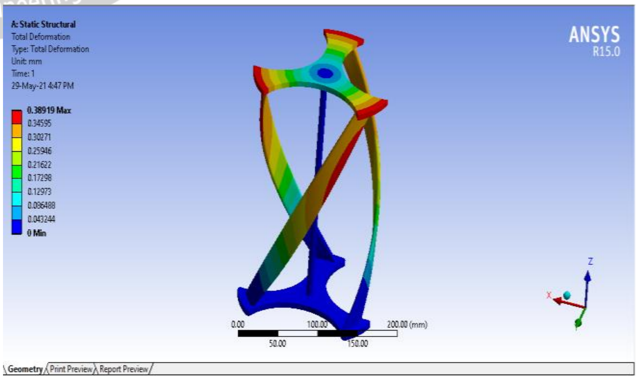

Fig 5.14 Total Deformation development in VAWT of 260mm height -Model-7

5.2.3 Vertical Axis Wind Turbine with 280mm height: Model-8

The fig 5.15 shows the von-mises stress distribution in VAWT model-8. The pattern of distribution is same as in previous model. The maximum stress developed in this

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model is found to be 67.37MPa, which is 4.9% higher than that of model-7.

The fig 5.16 shows the deformation developed in the VAWT model-8. The resulting color image shows the same pattern as in previous models, but with higher magnitudes. The maximum deformation developed in this case is 0.46641mm, which is 19.8% higher than that of model-7.

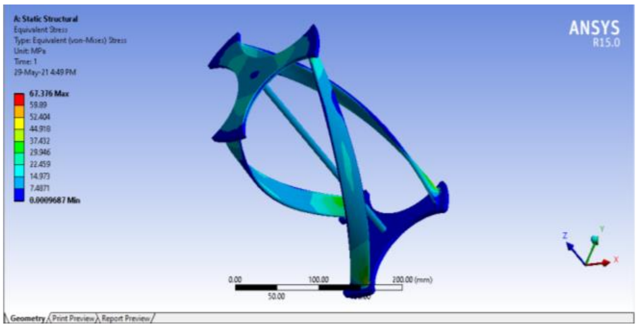

Fig 5.15 Equivalent Von-mises Stress Distribution in VAWT of 280mm height-Model-8

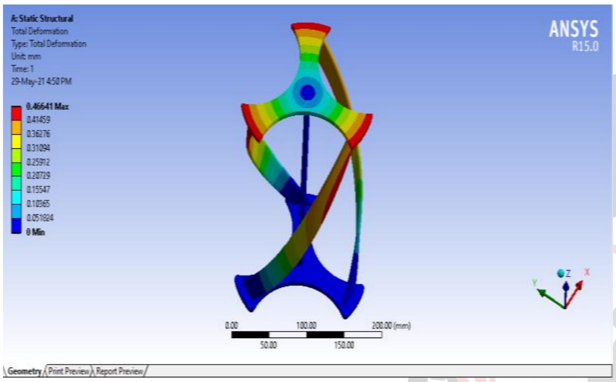

Fig 5.16 Total Deformation development in VAWT of 280mm height -Model-8

5.3 Vertical Axis Wind Turbine with 4 blades: Model-9

The fig 5.17 shows the von-mises stress distribution in the VAWT model-9 with 4 blades. The pattern of distribution of the stress is similar to the previous model with 3 blades, but with lower intensity. The reason is that due to increase in number of blades the angular distance between two extream ends of individual blade decreases, this inturn reduces the bending moment action on the blades and also the torsion moment. Also it can be observed two origins with light blue color along the length of the blade which strengthen the statement of development of one more resisting plane to the bending or twisting action. Even it can be observed that the higher stress zone is reduced with the representation of very little area in yellow and red colors. Thus the intensity of stress in this model is lower than that of the models with 3 blades. The maximum stress intensity developed in this model is found to be 63.618MPa.

The fig 5.18 shows the deformation developed in the VAWT model-9. The rsulting color image shows that the pattern is same as in previous models with 3 blades. The maximum deformation is identified at the bottom junction of the blades where itthey are connected to rigid frame. The maximum deformation developed is foun dto be 0.38497mm.

The fig 5.36 shows the safety factor attained in the VAWT model-9. The image shows that the pattern is similar to the previous models, with a critical value of 3.9297.

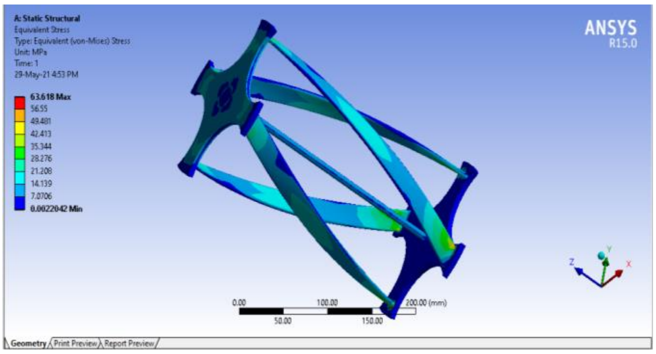

Fig 5.17 Equivalent Von-mises Stress Distribution in VAWT with 4 blades-Model-9

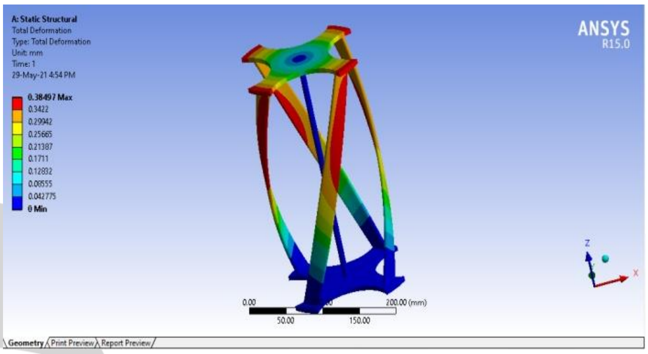

Fig 5.18 Total deformation development in VAWT with 4 blades-Model-9

5.4 Comparision of results of different models

The fig 5.19 shows that the von-mises stress decreases with increase of the width of the blade almost with the same rate for every increment/decrement in the width of the blade. The fig 5.20 shows the variation of deformation with increase in blade width. It shows that though the deformation decreases with increase of blade width, there is a slight deviation at blade width of 26mm and the reason for it was explained earlier.

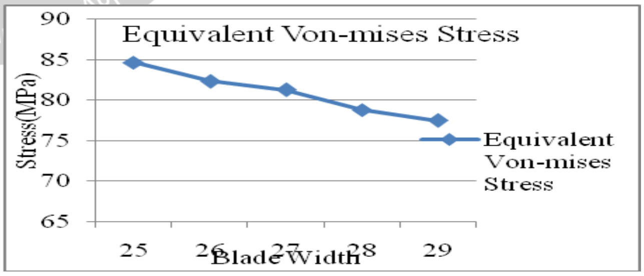

Fig 5.19 Effect of blade width on stress intensity

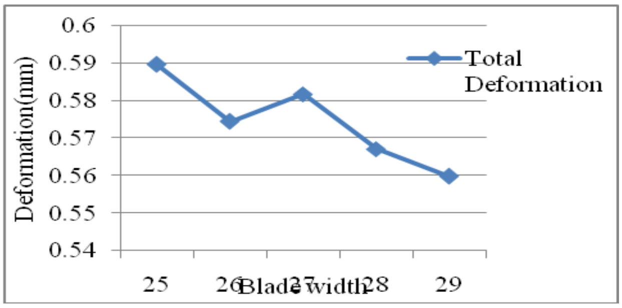

Fig 5.20 Effect of blade width on the deformation development

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The fig 5.21 shows that stress intensity increases with increase of turbine height, with a maximum stress values in turbine with 300mm height. The fig 5.22 shows the effect of turbine height on deformation, which reveals that deformation increases with height of the turbine.

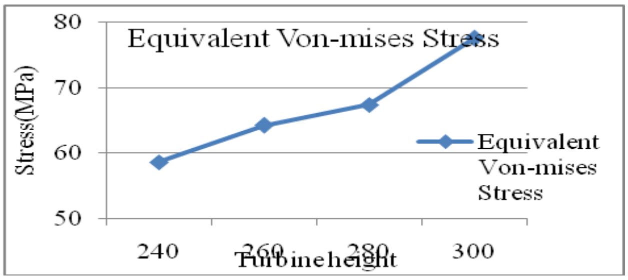

Fig 5.21 Effect of the turbine height on the maximum stress development

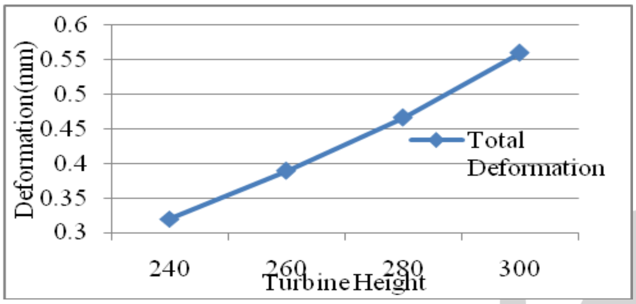

Fig 5.22 Effect of the turbine height on the deformation

The fig 5.23 shows the comparison chart of stress intensities between turbine with 3 and 4 blades, which reveals that turbine with higher number of blades results in lower stress values. The fig 5.24 shows the comparison chart of deformation between turbines with 3 and 4 blades. This reveals that deformation is less in turbine with 4 blades compared to 3 blades.

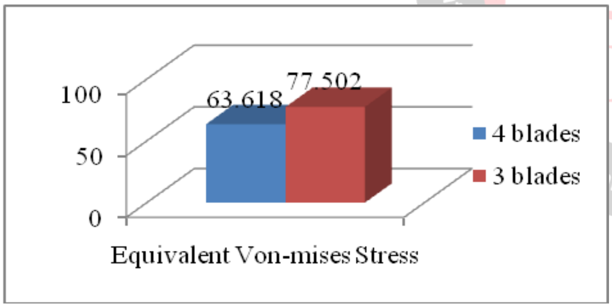

Fig 5.23 Comparison of stresses in 3 and 4 blades turbine

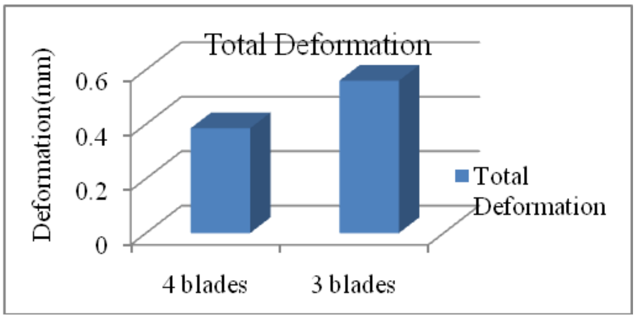

Fig 5.24 Comparison of deformation in 3 and 4 blades turbine

5.5 FLUID FLOW(CFX) ON VERTICAL AXIS WIND TURBINE WITH 4 BLADES

The fig 5.25 to 5.28 shows the velocity and perrssure profiles along the flow of air through the vertical axis wind turbine obtained in Fluid Flow (CFX) analysis using Ansys 15.0. The fig 5.25and 5.26 shows the velocity profile along the mid plane through the turbine in the direction of the air flow, whereas the fig 5.27 shows the velocity profile along the entire considered volume of turbine. The results reveals that a swirl flow pattern can be identified which confirms that the air streams hitting the turbine blades taking a angular diversion, which thereby makes the turbine blades to rotate along its axis. The higher velocity profile stream lines can be seen in the region where the air streams striking the turbine blades, representing the positive flow pattern through the turbine blades.

The fig 5.28 shows the pressure counter in the considered volume of turbine flow. The resulting color image shows that higher pressure buildup in the turbine zone and especially the red color pattern near the blades represents the positive obstruction of flow by turbine blades. Thus all the following resulting color images confirms the desired flow pattern in the turbine.

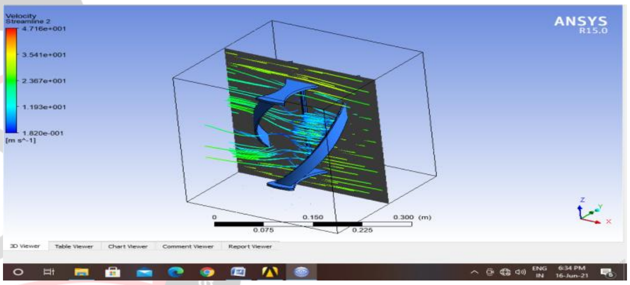

Fig 5.25 Velocity stream lines along mid plane in fluid flow (CFX) analysis in Ansys 15.0

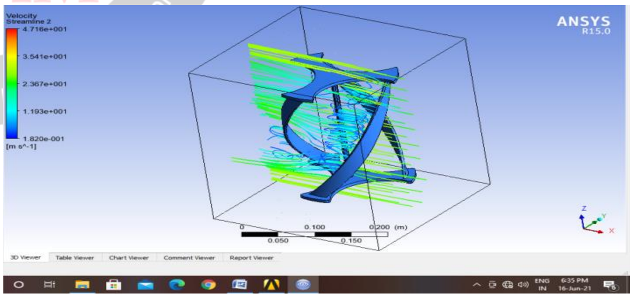

Fig 5.26 Velocity stream lines along mid plane (invisible) in fluid flow (CFX) analysis in Ansys 15.0

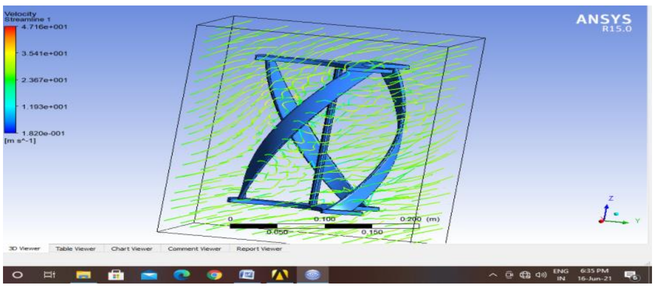

Fig 5.27 Velocity stream lines along the considered volume in fluid flow (CFX) analysis in Ansys 15.0

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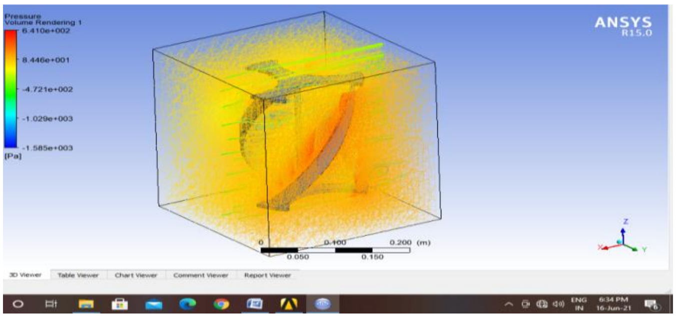

Fig 5.28 Pressure counter along the considered volume in fluid flow (CFX) analysis in Ansys 15.0

VI. CONCLUSIONS

The following conclusions were drawn by conducting series analysis tests in Ansys 15.0 on the vertical axis wind turbine (VAWT) model by varying the width of blades, height of the turbine and number of the blades.

- The von-mises stress in the VAWT model decreases with increase of turbine blade width and the lowest stress intensity is developed in model-5 with 29mm width, which is 8.5% lower than that of model-1 (25mm blade width).
- The deformation in the VAWT model decreases with increase of turbine blade width and the lowest deformation is developed in model-5 with 29mm width, which is 5.06% lower than that of model-1 (25mm blade width).
- The von-mises stress in the VAWT model increases with increase of turbine height and the lowest stress intensity is developed in model-6 with 240mm height, which is 24.3% lower than that of model-5 (300mm height).
- The deformation in the VAWT model increases with increase of turbine height and the lowest deformation is developed in model-6 with 240mm height, which is 42.8% lower than that of model-5 (300mm height).
- The von-mises and shear stress in the VAWT model with 4 blades is 17% lower than that of stress in the turbine with 3 blades.
- The deformation in the VAWT model with 4 blades is 31.2% lower than that of deformation in the turbine with 3 blades.
- The velocity and pressure counters through fluid flow (CFX) analysis confirms the desired positive air flow pattern along the turbine blades.

Thus concluding with the turbine with 4 blades, 29mm blade width with 240mm turbine height is optimum design for effective performance of the turbine.

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