Chapter 7

Conclusion and Discussion

7.1 Conclusions

This thesis is focused on development of Vertical Axis Wind Turbine with objective of minimizing the self-starting wind speed using multi-storey turbine approach. This development of turbine includes selecting appropriate number of storey, size and orientations of stories with reference to each other. The effects of these design parameters on the performance parameters viz. self-starting speed, power coefficient, lift and drag coefficients are studied using wind tunnel test and Computational Fluid Dynamics (CFD) analysis of turbine model. Further, structural analysis of full scale turbine model is carried out using Finite Element Modeling approach. Furthermore, the field-testing of full-scale prototype is carried out at a particular wind site. Conclusions of these studies are summarised below:
7.1.1 CFD Analysis and Wind Tunnel Testing of Turbine Model

In this section the conclusions of the results obtained using CFD analysis and wind tunnel testing of VAWT models are discussed:

- Wind tunnel test results indicate that with increase in number of storey, self-starting wind performance is improved. Minimum wind speed required to self-start the one-storey turbine is 7 m/s which was reduced to 2-2.6 m/s for three-storey turbine. The minimum wind speed required to self-start the multi-storey turbines are independent of blade orientation with respect to wind direction.

- The numerical and experimental analysis indicates that the three-storey turbine show good power performance and also the operating range of tip speed ratio as compared to other two turbines viz: one storey and two storey. The values of drag and lift coefficients of three-storey turbine have higher values compared to other two turbines which indicates that the multi-storey turbine performance is contributed by drag as well as lift forces. The CFD analysis results are reasonably matching with the experimental results.

- To study the effect of storey height and storey orientation, three models with equal height with $0^\circ$-$90^\circ$-$0^\circ$, three storey with middle storey with larger height and $0^\circ$-$90^\circ$-$0^\circ$ orientation and three storey with middle storey with larger height and $0^\circ$-$120^\circ$-$240^\circ$ orientation was developed. The effect of number of storey, different configurations and orientations on the performance of the turbine is studied in terms of self-starting speed, coefficient of power, lift
coefficient and drag coefficients at different tip speed ratios. The computational predictions and experimental results it is seen that equal storey height VAWT configuration starts at low wind speed as compared to that of other configuration. It is seen that equal storey height turbine is independent of blade and flap orientation with respect to wind direction.

- Computational predictions and experimental results shows that the Coefficient of power of equal storey height VAWT is maximum as compared to other configurations viz: $0^\circ-90^\circ-0^\circ$ and $0^\circ-120^\circ-240^\circ$. The blades and flaps of equal storey height contribute equally for harnessing power from wind from all directions. The blades and flaps of upper and lower storey of increased middle height and reduced upper and lower storey height configuration VAWT do no contribute for harnessing wind power. Numerical predictions of drag and lift force coefficients of equal storey height VAWT is high as compared to its counterpart.

### 7.1.2 Structural Analysis

This work has also dealt with the detailed structural analysis of full scale model using finite element method. ANSYS 12.0 software was used for structural analysis. Structural and Modal module has been used for the analysis. The structural analysis has been done for estimation of stress, deflection, eigenfrequency and mode shapes. Turbine is made of mild steel sheet of thickness 2 mm. The structural analysis is done to check the integrity of the of turbine parts against gust load.

The structural analysis of full scale model has been concluded as follows:

- Stress estimation: From the analysis it is seen that the maximum stress
induced in blade is 1.98 $N/mm^2$. The stress magnitude is high at the supported ends. The maximum stress induced for flap is 55 $N/mm^2$. The stress magnitude in the mid portion of flap is in the range of 30-43$N/mm^2$. The maximum stress induced in plate is at the periphery of magnitude 78 $N/mm^2$. The induced stress values in the turbine parts are very less as compared to the yield strength of material. The turbine is fairly safe for gust load condition.

• Deflection: The maximum deflection found at the central part of blade of magnitude 0.008 mm. The maximum deflection for flap estimated is 0.006 mm. Whereas the maximum deflection of plate is 0.4 mm.

• Eigenfrequency and Modeshapes: Eigenfrequency was recorded for sheet metal thickness range 0.5-3.5 mm. It is found that forcing frequency is considerably less than the natural frequency of turbine components. Modal analysis of turbine for six modes is simulated.

7.1.3 Field Testing of Full-Scale VAWT

The field testing full-scale model is carried out at a particular site. Conclusions of this study are summarised below:

• Self starting speed: Turbine initially self starts at wind speed of 2-3 $m/s$ and the rotor speed accelerates with further increase in wind speed. The turbine has steady rotation above 5$m/s$ wind velocity. The turbine rotor speed ranges from 20 rpm to 70 rpm for wind velocity range 5-7 $m/s$. It
is noted that the turbine self starting is independent of wind direction as estimated by wind tunnel test.

- **Coefficient of Power:** $C_P$ is very low for a vertical axis wind turbine operating at tip speed ratios below 0.28. For tip speed ratios above 0.28, the vertical axis wind turbine is able to extract power from the wind to accelerate itself up to the desired operating angular velocity. The highest value of $C_P$ as the experimental site is noted as 28% for wind speed of 7 m/s.

- **Vibration Analysis:** It is observed that, their are vibrations in X and Y direction dominant as expected. These vibration are at the starting of the wind turbine. It is seen that when the turbine gains speed and steady state condition is achieved, the vibration in X and Y direction has been reduced considerably. The vibrations in Z direction is not significant at the start and also when the turbine gains speed. The turbine fabricated is in balanced condition.

### 7.2 Future Scope

This thesis has made an attempt to study the effect of number of storeys, effect of orientation of storeys on performance of Vertical Axis Wind Turbine. Further structural analysis of wind turbine parts has also been carried out. This work forms foundation for future work described below:

- **Materials:** The bulk weight of the turbine can be reduced by using composite materials. As composite materials are light weight and having strength more
than mild steel. Due to reduction in weight the performance of the turbine may improve.

- **Artificial Intelligence:** Artificial Neural Network, Genetic Algorithm for estimation of power of multistorey vertical axis wind turbine. An algorithm can be developed for fast and accurate estimation.

- **Design and Manufacture:** Innovative turbine can be designed with less number of parts. The manufacturing tools required for cutting and joining the parts must be readily available at remote locations so that it would be readily manufactured.