Design and Analysis of Wind Amplifying Rotor Platform for Wind Turbine

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Abstract. Generally, annual wind speed available in India is close 6.5 m/s. Design of optimum, cost effective wind turbine for maximum annual energy extraction is a challenging task. The present work carried out the Design, Analysis and evaluation of Wind amplifying rotor platform module for cost effectiveness and suitability for Indian conditions. The degree of amplification depends on module and system configuration and is typically over 1.5 to 1.8 times of free stream velocity. Two micro wind turbines have been designed and analysed with respect to twist, thickness distribution, blade profile and aerodynamic characteristics using available airfoil data at National Aerospace Laboratories (NAL), Bangalore, India.

1. INTRODUCTION
The World watch Institute has issued a fact stating that the wind turbine industry is growing faster (about 39% annually) than the personal computer industry and almost as fast as the cellular phone market. Wind energy has become the most economic and environmentally benign source of energy from the existing renewable energy technologies. It has the ability to be used as an electrical power supplier from the electrical utility scale (wind farms) to a single-use power supplier. Present day large bladed wind systems (to be referred to as “POP” -- propeller-on-pole) and the 4th generation in wind energy technology -- WARP (Wind Amplified Rotor Platform). Present day wind energy technology (POPs) have continued to evolve through the use of ever larger and larger blades and gearboxes or large, complex customized generators. This continuous increase in size has subsequently increased the costs and complexity of manufacturing, transporting, constructing and maintaining these systems. As with any system, the more complex it is, the greater the chance for system failures (e.g. historically blade and gearbox failures).

The general public has recently voiced concerns regarding the use of POPs. In the forefront of their concerns are the large footprints that wind farms employ (i.e. land sprawl of thousands of acres), the low frequency noise pollution, horizon pollution with its disco effect and the “flicker” interference with TV and telecom transmission, as well as the perception that they are prone to be bird killers. These drawbacks are in addition to the fact that they are only capable of capturing the winds near the surface (that is why they have, in part, gone to taller towers and larger blades -- attempting to reach the greater wind speeds at higher elevations). Finally, the turbine industry has built only about 20,000 turbines, yet no standardization has been achieved. Each larger blade design requires the industry to basically engineer and design it from scratch. Each wind site with its unique characteristics requires another round...
of re-engineering and design or compromise performance. These changes also required extensive retooling at great cost to the industry. The larger the blades, the larger the gearbox typically required. Each increase in size subsequently increased the risks of blade and gearbox failures – increasing the risk of reliability, durability and sustainability of the life of system.

2. OBJECTIVES:
The main objective is to design a system for extracting wind energy from low wind speed regions where commercial large wind turbines are not viable. The work is also focussed on the following aspects.
   a) Three dimensional CFD analysis of isolated single module of WARP tower
   b) Design of micro wind turbine using data like twist, thickness distribution, blade profile and aerodynamics characteristics of aerofoil which are available at NAL
   c) Performance evaluation of micro-wind turbine using commercially available computer code

3. COMPUTATIONAL METHODOLOGY
The methodology adopted for the study is described under the following sections
Geometrical details and Grid generation details of WARP module: CFD- GEOM was used as pre-processor for modelling the WARP tower single module and for generating structured grid. The 2D & 3D drawings of the WARP module shown in the figure 1 and figure 2 respectively

![Fig. 1 2D Geometric details of WARP-single module](image1)

![Fig. 2 3DView of computational domain](image2)
B Grid Generation Details: The details of grid generation and meshing of central wall in the CFD software is shown in the figure 3, figure 4 and table 1

![Fig. 3 Details of module grid generation](image)

![Fig. 4 Details of meshing of central wall and total module](image)

**TABLE 1 Grid generation details**

| Sl. No. | Curves                  | No. of Points | Distribution Type | Power Type |
|---------|-------------------------|---------------|------------------|------------|
| 1       | AB,AD,BC,DC             | 50            | Power law        | 1          |
| 2       | AF,BG,CH,DE             | 50            | Power law        | 1          |
| 3       | ai,ib,lj,gh,he,fe,ed,mr,rq,no,op | 15 | Power law        | 1          |
| 4       | bc,cd,gf,ag,he,ih       | 10            | Power law        | 1          |
| 5       | Al,bk,ij,gm,hr,cq,fn,e_o,dp |               | Power law        | 1          |

Grid Summary:
Total number of nodes = 386512 Number of quad faces = 1121708 Total number of faces = 1121708 Total number of cells = 367696 Total number of domains = 16

4. RESULTS AND DISCUSSION
The results of CFD analysis of WARP modules are discussed and graphical representation of performance evaluation of micro wind turbine.

A. Result of CFD Analysis of WARP Module:
The velocity magnitude contour results of inlet free stream wind conditions of V=8m/s, P=101325N/m², T =288.15K is show in figure 5 and figure 6
Fig. 5 Velocity magnitude contour (X-cut) for the inlet velocity 8m/s

Fig. 6 Enlarged view of the velocity contour for inlet velocity 8m/s

Fig. 5 to 12 show vector as well as contours of wind flows over a WARP module. Fig 5 shows the velocity magnitude at the expected location of the micro wind turbine. The flow direction is as shown in the figure. Two Micro wind turbines would be mounted perpendicular to the flow on either side of the WARP module. It can be observed from the figure 5 that the flow velocity increases as it approach the module channel and the flow velocity gets decreased as you move out of the module channel or far-field. The amplification of flow at the turbine location is in the range of 1.3 to 1.5 times the inlet flow. Figure shows that the velocity is zero at the wall boundary as expected within the flow module. figure 6 shows enlarged view of the flow near the module.

Fig. 7 Free stream wind velocity amplified zone at module flow channel.

Figure 7 shows Iso-metric view of the amplified flow pattern around the module in the downstream. A large wake has been created at the downstream of the flow module due to WARP model. It could be observed from the figure 8 that the magnitude of ISO velocity is zero close to the WARP module flow channel and the magnitude increases as one move outwards up to certain distances and then approaches the free stream velocity lines. This is as expected from the WARP module. Even though certain patch of velocity magnitude is as high as 1.5 times the free stream, average velocity amplification is close to 1.3. This results in 120% of increased
power in comparison to free stream velocity.

Fig. 8 ISO-’Velocity contours and Local VAF in the WARP module channel free stream wind speed 8m/s

Figure 9 and Figure 10 shows the flow pattern plotted at different planes. It can be observed that flow decelerates as it approaches the WARP module and flow gets split near the module and then again it's starts accelerating and reaches its maximum near the location of turbine. However as earlier as large wake could be seen after the WARP module

Fig. 9 Velocity magnitude contour (Z-cat) for inlet velocity 8m/s

Fig 10 velocity magnitude contour (Y-cut) for inlet velocity 8m/s

Fig. 11 Vector plot of velocity contour for inlet velocity 8m/s
Figure 11 and Figure 12 show the vector plot of the velocity plot for the free stream wind speed of 8 m/s. In this plot, the flow direction at every grid point can be observed. It can be observed from the plot that how the flow stream splits near the WARP module in the upstream and guided through the module channel along the downstream. Figure 3.8 shows the enlarged view of vector plot, which shows high intensity of separation with reverse flow at downstream of the WARP module. With in the wake region, you can observe a number of high intensity local whirl formed due to the WARP module. At the same time, the effect of increased wind speed near to the location of wind turbine could also be seen.

A figure 13 shows the static pressure contour at wind speed of 8 m/s, though there is no applicable change in static pressure, the small change in the static pressure could be observed from the figure.

![Fig.12 Enlarged view of velocity vector plot](image)

![Fig.13 Static pressure plot (Y-cut) for the inlet velocity 8m/s](image)

### TABLE 2

| Air free stream Velocity m/s | Amplified Velocity at Tower Module, m/s | VAF (Velocity Amplification Factor) | Average Available velocity at WARP module m/s | Avg. VAF |
|-----------------------------|----------------------------------------|-----------------------------------|--------------------------------------------|--------|
| 2                           | 3.081                                  | 1.54                              | 2.6                                        | 1.30   |
| 3                           | 4.602                                  | 1.53                              | 3.96                                       | 1.32   |
| 4                           | 6.108                                  | 1.53                              | 5.2                                        | 1.30   |
| 5                           | 7.695                                  | 1.54                              | 6.56                                       | 1.31   |
| 6                           | 9.324                                  | 1.55                              | 7.85                                       | 1.31   |
| 7                           | 10.87                                  | 1.55                              | 9.22                                       | 1.32   |
| 8                           | 12.24                                  | 1.53                              | 10.54                                      | 1.32   |
| 9                           | 13.77                                  | 1.53                              | 11.83                                      | 1.31   |
| 10                          | 15.50                                  | 1.55                              | 13.18                                      | 1.3    |
| 11                          | 17.16                                  | 1.56                              | 14.45                                      | 1.3    |
| 12                          | 18.48                                  | 1.54                              | 15.8                                       | 1.32   |
Figure 14 and Table 2 shows the variation of free stream wind velocity v/s increased wind velocity at the WARP module flow channel. Figure 15 shows the velocity amplification factor for free stream wind speed. Though the amplification factor ranges from to 1.5 around the flow channel, the average amplification factor is close to 1.32. It is observed from the graph that for a given free stream wind velocity, the wind velocity near the WARP module increases and it is ranging from 1.3 to 1.5 times the free stream wind velocity. This results in higher wind power, since the wind power is proportional to the cube of the wind velocity. The design of flow channel requires more focused distribution of amplified wind source to achieve more power at higher amplification factor.

![Fig. 14 Increment in free stream wind velocity at WARP module](image1)

![Fig 15 Wind amplification factor of WARP module](image2)

5. CONCLUSION

1. There is close agreement between flow analysis of WARP module using CFD –ACE for present configuration and results obtained from published paper.
2. An average increase of 30% wind speed results in 120% increase in power output of turbine, which is enough to encourage concept in power generation.

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