Explaining the Torque vs TSR curve in a Fully Resolved Setting on a Mega Watt Size Wind Turbine.

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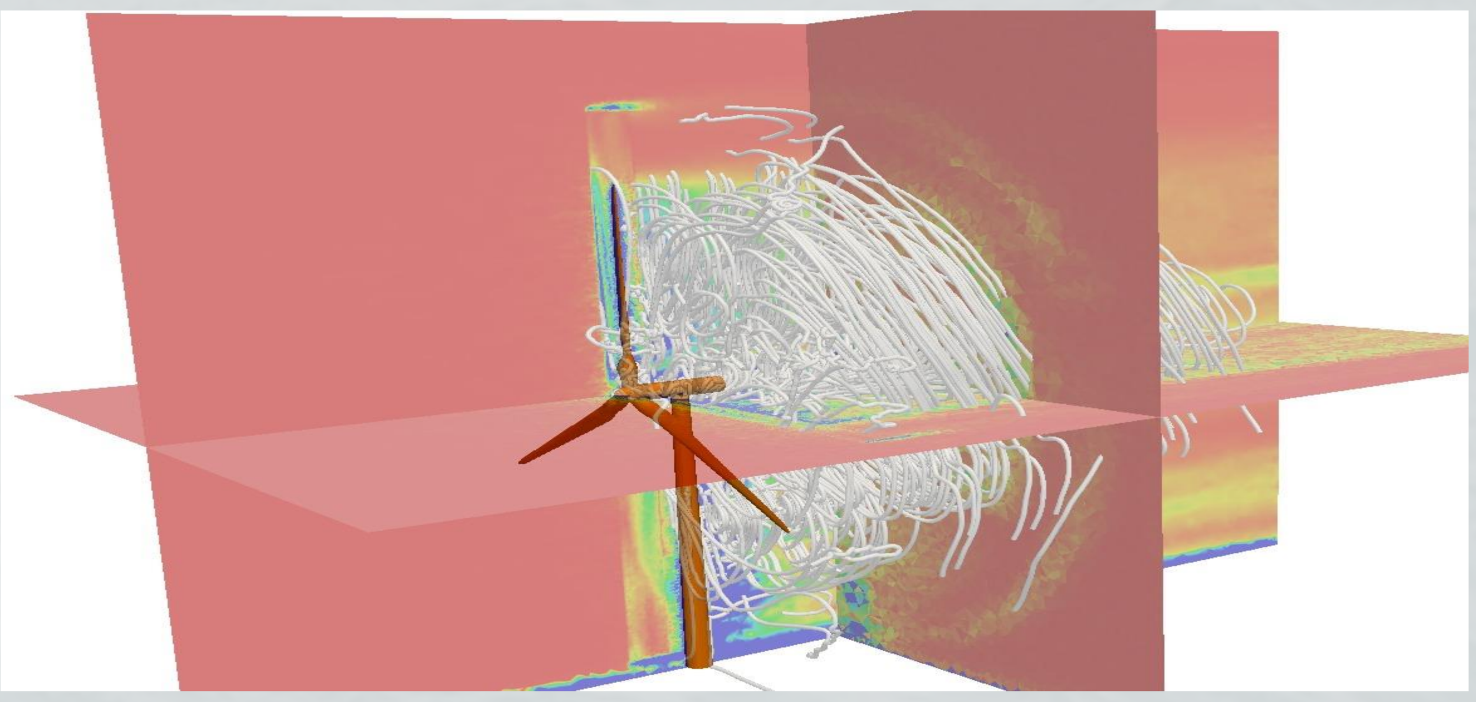
INTRODUCTION

A fully resolved Sliding Mesh Interface(SMI) and Multiple Reference Frame (MRF) techniques are implemented to predict the aerodynamic performance and wake distribution of a complete wind machine. The present study identify the predictive capabilities of both numerical techniques against the experimental results to study the performance of wind turbine under various Tip Speed Ratio's(TSR). NREL 5MW reference wind turbine design is employed as the baseline model. Performance predictions are studied in terms of overall torque produce by the turbine. We also analysed the velocity deficit behind the turbine, along with the estimate of the profiles of turbulent fluctuations in the wake behind the wind turbine.



METHODOLOGY

The computational model employed to simulate the flow behaviour is shown in Figure 3 with the corresponding boundary conditions. Complete wind turbine is modeled including the support structure. A hybrid finite element mesh with structured hexahedral elements close to the rotor and structure surface and tetrahedral mesh elsewhere is used.

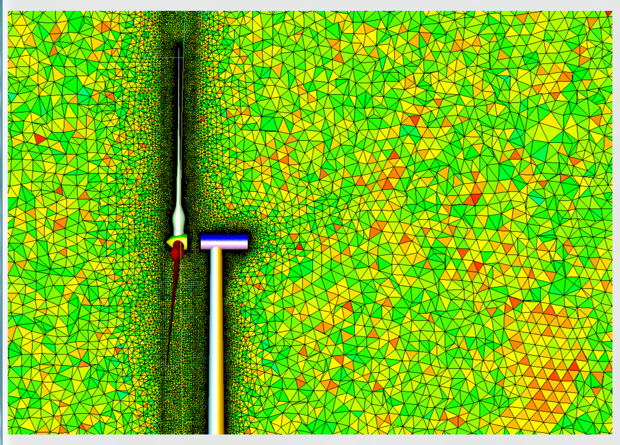


Figure 1: Mesh domain

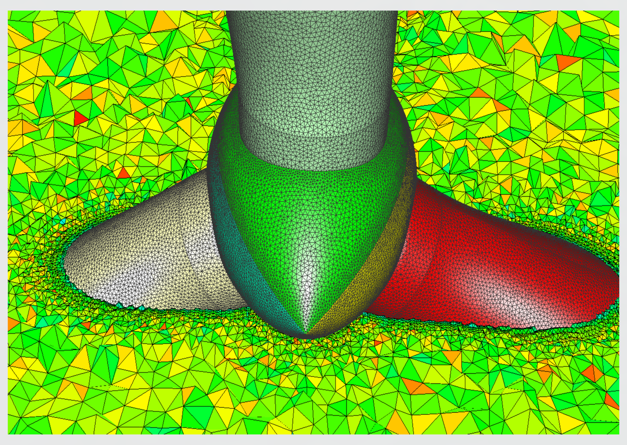


Figure 2: Mesh rotor

Two different approaches are implemented to model the rotating turbine: a)computationally expensive but supposedly more accurate Sliding Mesh Interface (SMI), b)faster but less reliable Multiple Reference Frame (MRF). Eventually, MRF, is used to evaluate the performance of a full scale turbine under different TSR.

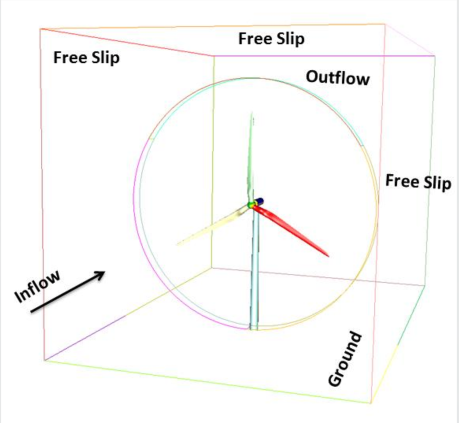


Figure 3: Computational setup

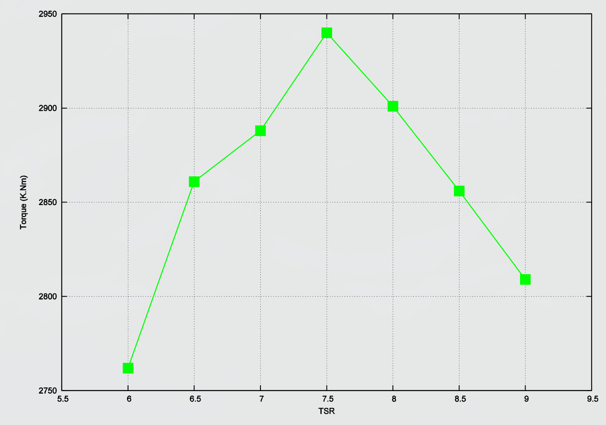


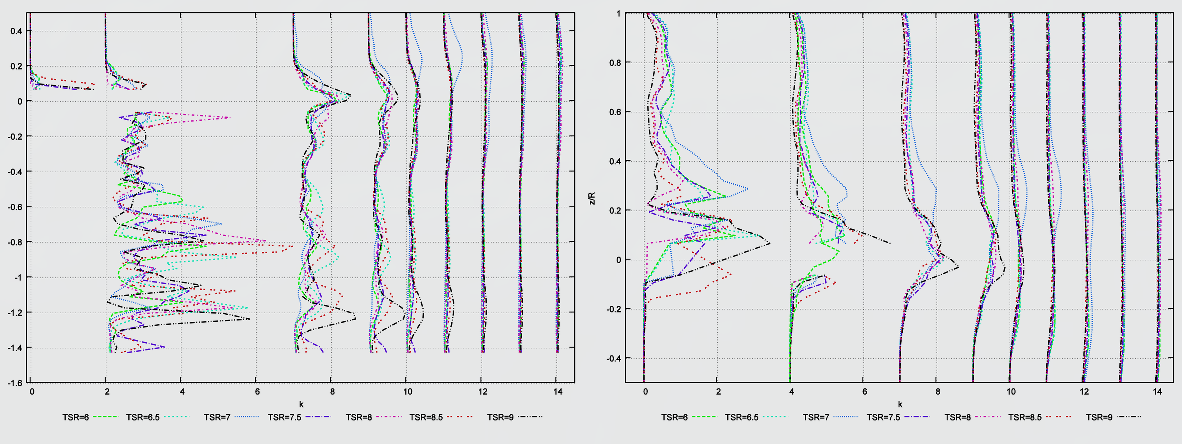
Figure 4: Torque vs. TSR

Effect on wake

Rotation of wind turbine leads to distortion of field variables in the downstream direction. In order to parametrize the behavior we have plotted the wake distribution in terms of turbulent kinetic enegry behind the wind turbine in the vertical and lateral directions.

The support structure is found to disrupt the flow field, especially, the presence of tower cause a significant increase in the turbulent levels in the vertical direction. Oscillatory behavior of profiles are observed adjacent to the tower, however, the eddies emanating gets adverted and loses their energy due to turbulent mixing and wake diffusion.

Where as, in the lateral direction, sharp gradients of turbulent kinetic energy are observed on one side, which is attributed to the deflection of wake behind the trailing edge of turbine blade.



Turbulent kinetic energy in vertical direction TSR=7.5

Turbulent kinetic energy in lateral direction TSR=7.5

Fig 7 : Wake structure

RESULTS AND DISCUSSION

Impact of TSR on torque generated

AT low TSR values (6.5 or 6), wind starts impinging on the top of the blade section instead of the leading edge, resulting in massive flow separation. This is true for all the cross sectional profiles along the blade(Figure6). The arrival of stall at lower TSR values than the optimal TSR is the cause of under performance of a wind turbine at low TSR values. An opposite trend is observed when one approaches a TSR of 9. The flow becomes more symmetric relative to the blade and hence the lift generated diminishes resulting in a lower torque generation. . It also suggest that the cross sectional geometry tends to get more aerodynamically shaped away from the hub and towards the blade edge and since a big contribution of torque comes from the outer section of the blade

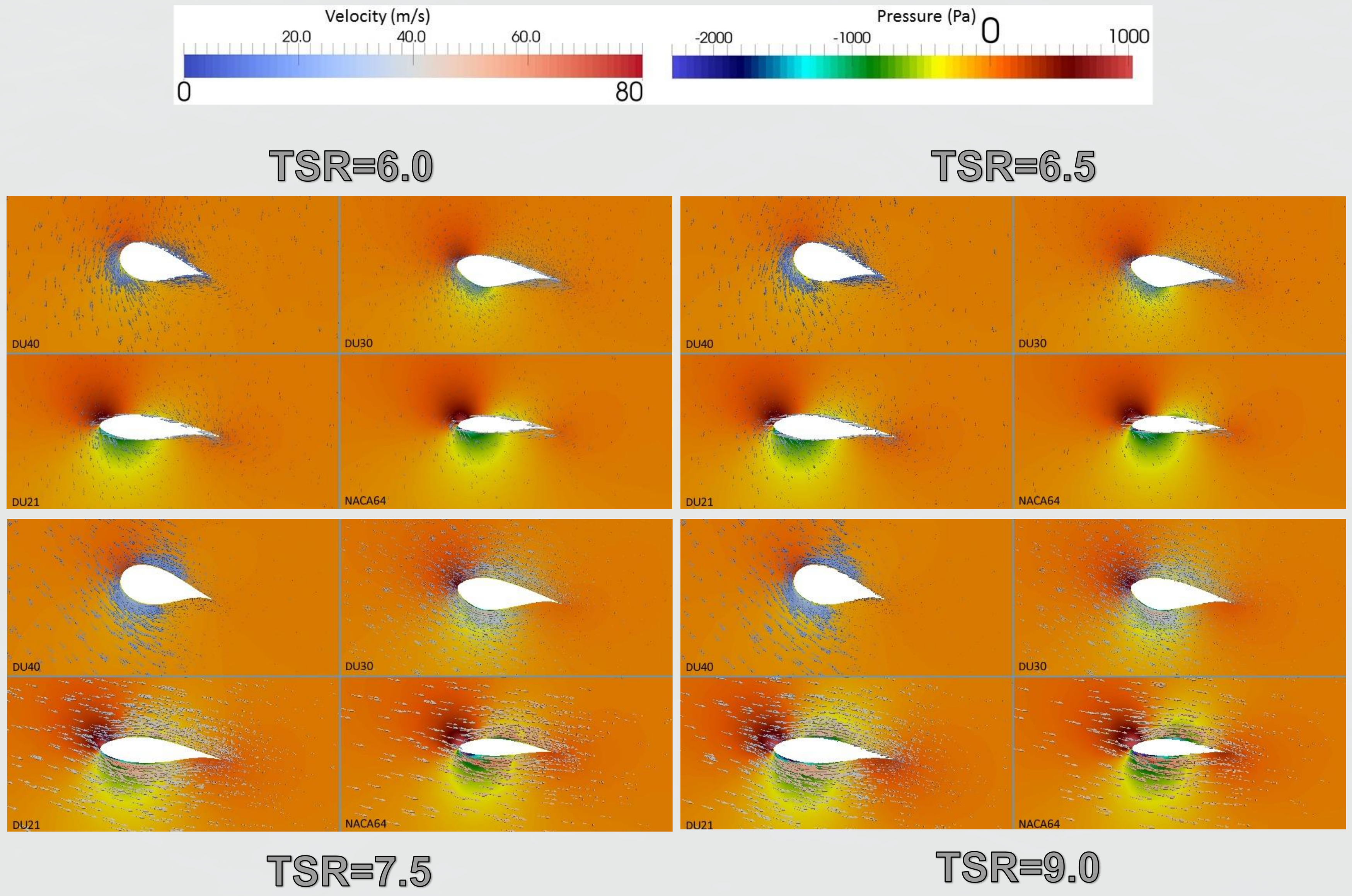


Fig 5: Velocity and pressure contour along the blade

The contours of velocity deficit behind the wind turbine is plotted to highlight the characteristics of wake distribution at certain distances in downstream direction at optimal TSR=7.5

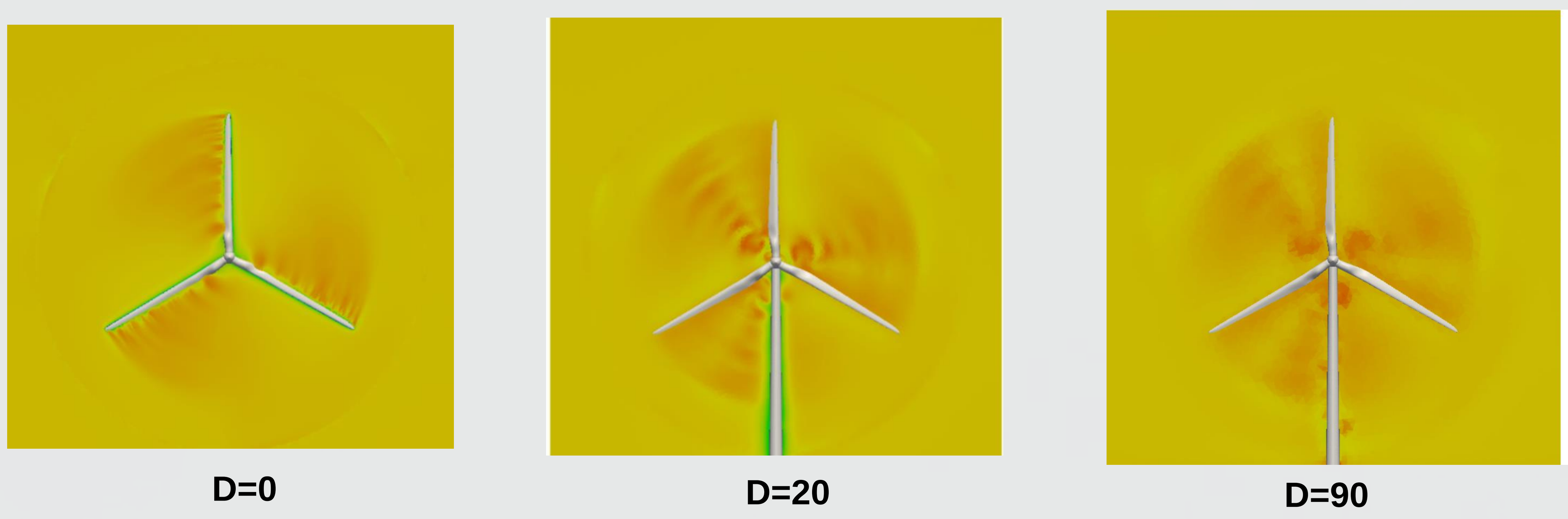


Fig 6 : Wake distribution pattern in the downstream direction

CONCLUSION

- Flow simulation around a full scale 5MW NREL reference turbine is conducted with SMI and MRF approach using turbulence models. The performance of turbine operating at different TSR are evaluated using MRF.
- The variation of torque at various tip speed is qualitatively explained using the contours of pressure magnitude imposed with velocity vector field at various cross sections in the spanwise direction, which identified the flow distribution which alter the torque characteristics.
- TSR 7.5 corresponds to the maximum torque. Below this TSR, the performance degrades due to stall experienced by the outer sections of the blade. Above the optimal value of TSR, the incoming flow becomes symmetric relative to the blade section and this results in smaller magnitude of generated lift and hence the torque.

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