Simulating single turbine and associated wake development - comparison of computational methods (Actuator Line Vs Sliding Mesh Interface Vs Multiple Reference Frame) for an industrial scale wind turbine

Mandar Tabib[1], Adil Rasheed[1], M. Salman Siddiqui, Trond Kvamsdal

[1]Mathematics and Cybernetics, SINTEF Digital, Strindveien 4, 7035, Trondheim, Norway.

INTRODUCTION AND OBJECTIVES

Accurate modelling of turbine behaviour will lead to an accurate assessment of loading and wake behaviour, which helps in obtaining better assessment of power generation capability and better designing of turbines. Wakes generated from turbines can influence power production in multi-turbine wind farm set-up. Amongst various computational models, a wind farm performance can be simulated in a computationally efficient way using Actuator line model (ALM) and is popularly used to do so. An improved understanding of accuracy of ALM through comparison with more accurate but computationally exhaustive methods (like sliding mesh interface (SMI)) will be helpful in quantifying uncertainties associated with ALM. The objective of this work is to evaluate and compare predictive capability of various computational methods: ALM, SMI and Multiple Reference Frame (MRF) for a single industrial scale turbine.

METHODOLOGY

The methodology involves simulating behaviour of a popular three bladed industrial scale wind-turbine, the NREL 5 MW industrial scale turbine, using three different computational techniques (ALC, SMI, MRF). The 5MW NREL turbine consists of three 63m long blades, with each blade comprising of 8 airfoils at different locations away from the hub (see Table 1).

Airfoil profile	Thickness (t/c)	Distance from the center (m)	Chord (m)	Twist angle(°)
Cylinder1	100%	2.00	3.542	0.000
Cylinder2	100%	5.60	3.854	0.000
DU40-A17	40.50%	11.75	4.557	13.308
DU35-A17	35.09%	15.85	4.652	11.480
DU30-A17	30.00%	24.05	4.249	9.011
DU25-A17	25.00%	28.15	4.007	7.795
DU21-A17	21.00%	36.35	3.502	5.361
NACA64-A17	18.00%	44.55	3.010	3.125

Regarding the three approaches used in this work : the Sliding Mesh Interface (SMI) (Geometry and mesh in figure 1) captures the unsteady flow by explicitly modelling the blades and its rotation using a dynamic mesh, while Multiple Reference Frame (MRF) (in Figure 2) captures a steady state flow as it employs a frozen rotor hypothesis (i.e. static blade) and involves use of Coriolis and centrifugal forces in momentum equation to account for rotation. A 120^0 sector geometry is used with rotational periodicity employed across two boundary. On other hand, the Actuator Line Model (Figure 3) is a transient model where the blades are not modelled explicitly but each blade is resolved as a rotating line (made of N actuator segments), over which the forces are computed. The ALM model relies on input blade aerofoil data to compute lift and drag coefficient at each segment. This non-explicit way of resolving blade in ALM leads to use of coarser mesh and efficient computation, as there is no need to resolve boundary layers and no rotating mesh.

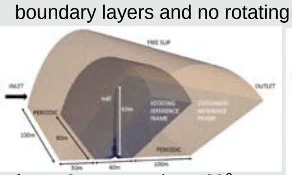


Figure 2 . MRF using 120^0 sector with rotational periodicity.

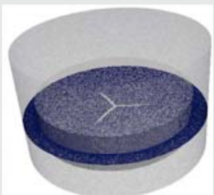
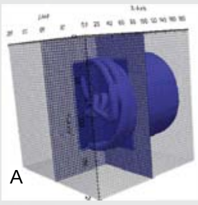


Figure 1. SMI geometry and mesh used.



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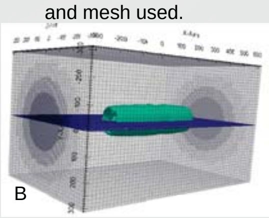

B

Figure 3 Actuator line model. (A) Finer mesh near turbine and (B) Coarser mesh with wider geometry.

RESULTS– COMPARISON OF THREE METHODS

Figure 4 shows predictions of Wake deficit (*X-axis*) by 3 models at TSR of 7.5 along a vertical line perpendicular to the axis of the turbine (z/*R*, on *Y axis*) for six locations located downstream of turbines i.e. 0.15R downstream, 0.30R 0.45R, 0.60R, 0.90R, 1.30R). R is the radius of turbine diameter (=63 m).

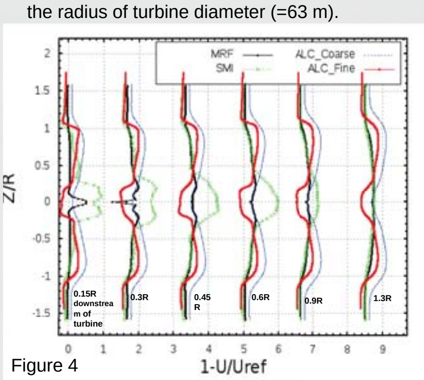

Figure 4

The ALC models is seen to differ from MRF and SMI models in 2 major ways,

A. In all downstream regions near the hub axis (0.25>z/R>-0.25), ALC models suggest no wake deficit as the hub is not modelled.
B. At all downstream locations in range (1>z/R>0.3), the ALC models predict higher wake deficit than MRF and SMI. In other words, the MRF and SMI models show faster wake recovery.

Figure 5A below shows influence of tip speed ratios (as predicted by the 3 models) on wake deficit for six locations located downstream of turbines i.e. 0.15R downstream, 0.30R 0.45R, 0.60R, 0.90R, 1.30R). R is the radius of turbine diameter (=63 m).

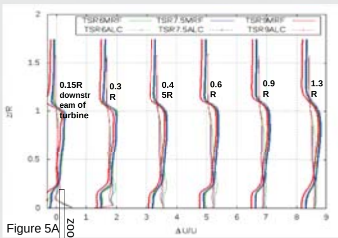

Figure 5A

zoomed

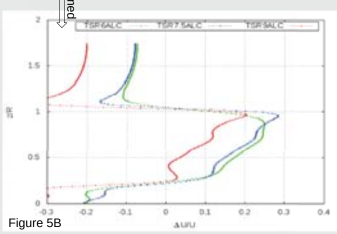

Figure 5B

As observed earlier in Figure 4, the ALC for all three TSR's in Figure 5 too show higher wake deficit between range (1>z/R>0.3) as compared to the corresponding TSRs from MRF method.

Like MRF (Figure 5A), The ALC (Fig 5A and zoomed figure in Figure 5B), shows that at TSR=6, the wake deficit is largest while at TSR=9, the wake deficit is the lowest wake. The reason for this is attributed to the change in angle of attack of flow with TSR. As TSR reduces below 7.5, the flow becomes separated leading to enhanced wake effects and lower coefficient of power, while as TSR increases to 9, the flow becomes more symmetric relative to the blade and hence the lift generated diminishes resulting in a lower power coefficient. As reported by Jonkman, the optimal TSR of 7.55 has highest Cp.

CONCLUSION

The three models have been compared at three different tip speed ratio (at optimum TSR of 7.55, at below the optimum TSR, TSR=6 and at higher than optimum TSR, TSR = 9). The comparison reveals the regions in which the models differ in their predictions and some similarities in qualitative estimation of trends. The differences in quantitative values predicted by the three models can be attributed to the inherent limitations of the ALC model. Despite these limitations, the ALC model is popularly used in wind farms involving multiple turbines due to its computational efficiency. Future work involves comparison of turbulence quantities and flow-pattern analysis as predicted by the 3 models.

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Contact: Mandar.Tabib@sintef.no

SINTEF NTNU Norwegian University of Science and Technology FFI Forsvarets forskningsinstitutt Meteorologisk institutt TrønderEnergi windsim Statoil KJELLER Forskningsrådet