DETACHED-EDDY SIMULATIONS OF ATMOSPHERIC FLOW OVER COMPLEX TERRAINS

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Introduction

As the growing requirement from renewable energy, especially for wind energy, more and more on-shore wind farms has been constructed on the mountain ridges and plateaus. In contrast to the off-shore or flat terrain wind farms, reliably modelling the atmospheric flow over the complex terrains is a big challenge. A separation bubble, induced by the rolling hills includes low wind speed and high turbulence intensity. If the wind turbine happened to be located in this region, a low annual energy production (AEP) and fatigue failure of the wind turbine will be caused. Negative wind shear, which means the wind speed in the lower part of the turbine is higher than that in the higher part, will cause the turbine blade collide with the turbine tower, resulting the broken of the blade. Such unfavourable wind conditions will cause a finance loss, resulting a big risk of the project.

Currently, Reynolds-Averaged Navier Stokes (RANS) with two-equation turbulence model (k-ε model) is a standard process for the wind resource assessment and the siting optimization. By considering the measured met mast data and a standard post-processing form IEC, the wind resource file can be obtained and will be used to represent a 20 years mean value for the siting engineers. A following siting optimization and AEP calculation can be done to evaluate the risk of the project. However, it has been reported that steady RANS failed to accurately predict the flow features when flow separation occurs[1]. Large-Eddy Simulation, which only model the sub-grid scale turbulence, is a promising method to increase the accuracy when solving the wind farm. But due to the consuming of the calculation, it usually used to simulate the turbine-scale flows, such as SOWFA[2]. Detached-Eddy Simulation (DES), which will use RANS method in the near wall region and switches to LES method in the turbine region, can provide us more information than the traditional RANS method. It can be used to investigate the unsteady features in the wind farm, such as the possibility of the negative turbine wind shear and wind veer [3]. Compared with RANS method, DES method shows better performance when solving the hill induced separation[4].

Greenwich CFD (GWCFD), is a wind resource assessment CFD software developed by Envision Energy based on OpenFOAM. It integrates the pre-processing of the wind farm engineering, such as map and mast data clean, mesh generation and the post-processing, like cross-checking and the annual energy production (AEP). The primary workhorse of Greenwich CFD is the neutral RANS solver with k-ε closure, which carries 90% of the internal workload from the operational siting engineers in Envision Energy. In addition, Greenwich CFD has developed advanced models, such as thermal stratification model of atmosphere boundary layer, forest model, actuator line/disk model, as well as meso/micro scale coupling model.

Description of the case

In this paper, a wind farm in China is selected to investigate as shown in Figure 1. Wind turbines with hub height of 44m are located along the hill. The length of the plateau is about 1000m from southeast to northwest and about 10km from southwest to northeast. The hill elevation ranges from 1100m to 1700m. A met mast is located on the northeast of the wind farm. The wind rose at the measured met mast is shown in Figure 2, with the main wind direction of about 135degree (The direction of the wind from north is defined as 0 degree). The hill slope is about 30deg in the windward side. Based on the result from RANS, the predicted wind speed (or AEP) on the upwind side of the turbine group is higher than that on the downwind side. While the operating data from Year 2012 to Year 2015 shows the AEP on the upwind side is 30% lower than predicted. A detached-eddy simulation method with the standard K-Omega SST model [5] is used to review this case. Parameters in the turbulence model are carefully selected to make them consistent with the RANS k-Epsilon model [6]. Wind conditions at the problematic turbines will be fully considered.

Results and Discussion

The computational domain is 20km*20km, with the horizontal mesh resolution of 12.5m and the first wall normal mesh of 1m, resulting a total mesh size of about 70million. A log law inflow profile is used to simulate the neutral atmosphere boundary layer[1,3]. A rough wall function is used to model the near wall roughness effect [7]. Flow features in the dominant wind direction (135 degree) is simulated and analysed in this paper.

Figure 3 shows the flow pattern along the main wind direction near the problematic wind turbine. A separation bubble is observed in the leeside of the hill. The flow is disturbed on the plateau. The zoomed-in result at four time steps are shown in Figure 4. The turbine suffers unsteady wind conditions during the operation. The history of the wind speed variation at the upwind and downwind turbines is recorded during the simulation. Two probes at turbine bottom (H=20m) and turbine top (H=60m) are used to check the wind speed difference on the turbine disk as shown in Figure 5. The wind shear defined as (dU/dz), is analysed based on the probe data. It is found that the possibility of the negative wind shear is 65% for the upwind turbine and only 19% for the downwind turbine. Since large negative wind shear can cause the turbine blade collide with turbine tower, It is a high risk for the wind turbine in the upwind side.
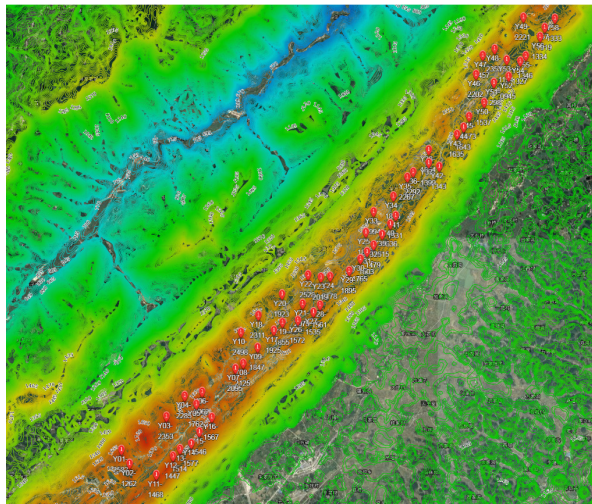

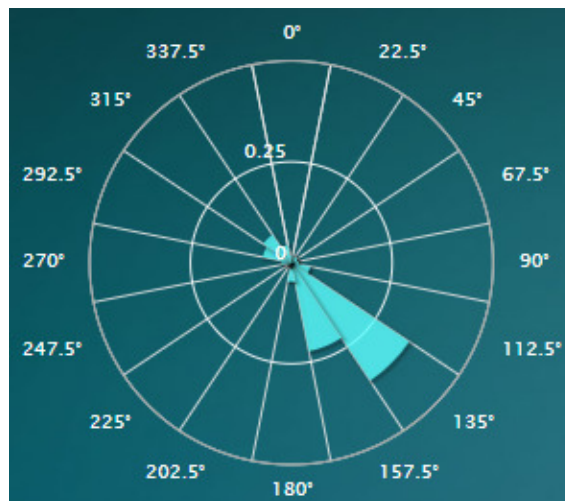Figure 1. Terrain information of the site
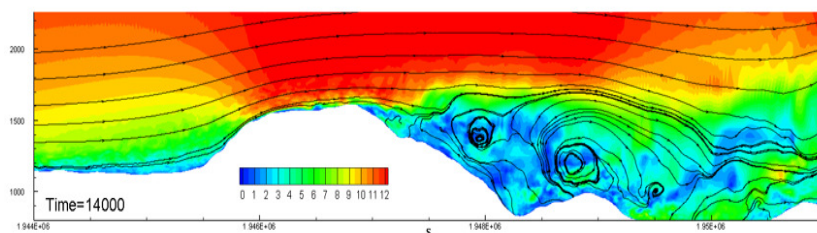

Figure 2. Wind rose of the Met mast

Figure 3. Flow pattern along the problematic wind turbine plane.
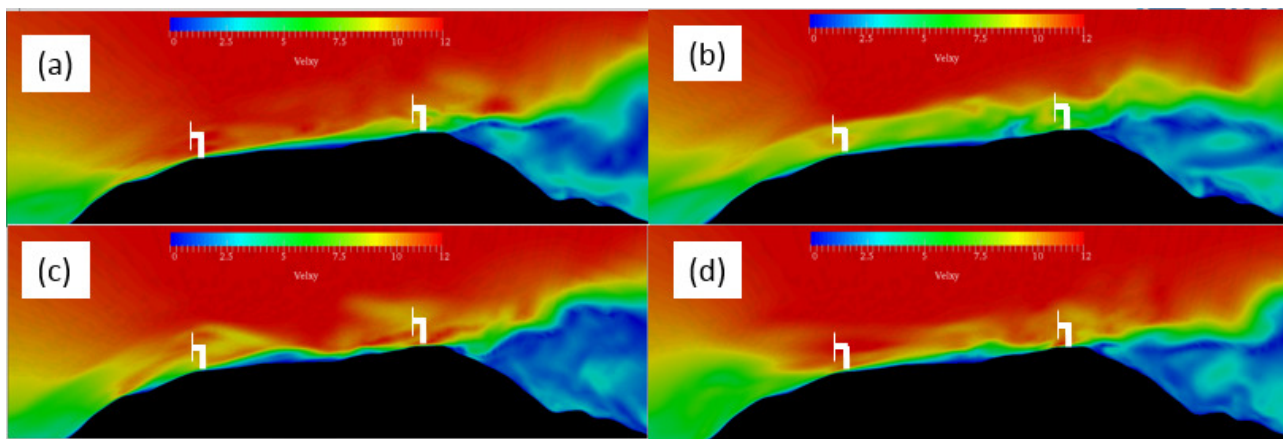
Figure 4. Zoomed-in flow patterns at different time near the problematic turbines.
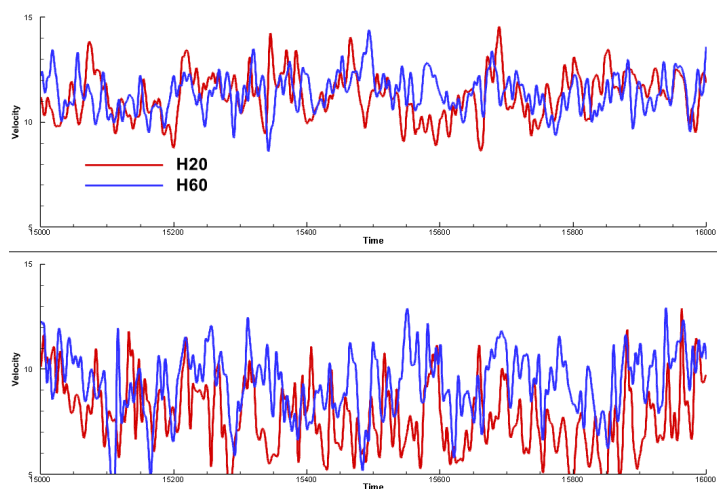

Figure 4. Time history of the wind speed variation at the upwind and downwind turbines.

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