Mechanical Engineering Doctoral Defense

Understanding the interaction of wind farms and turbulent atmoshperic boundary layer in a large eddy simulation framework: from periodic to LIDAR based mean data driven cases

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abstract

This thesis focuses on an improved understanding of the dynamics at different length scales of wind farm in atmospheric boundary layer (ABL) interaction using a series of visualization studies and Fourier, wavelet and POD based spectral analysis using high fidelity large eddy simulation (LES) with near wall model. For this purpose, we begin by developing a robust LES based neutral ABL model at very high Reynolds number using higher order exponentially accurate spectral element methods and validated against previous experimental/numerical studies. This ABL methodology has been used as a building block to drive large wind turbine arrays or wind farms residing inside the boundary layer in our subsequent work. Our studies involving massive periodic wind farms with neutral ABL inflows have indicated towards the presence of large scale coherent structures that contribute to the power generated by the wind turbines via downdraft mechanisms which are also responsible for the modulation of near wall dynamics.This seminal idea about the modulation of large scales have seen a lot of promise in our application of flow past vertically staggered wind farms with turbines at different scales. Eventually, our studies involving wind farms are progressively evolved in a framework of inflow-outflow where the turbulent inflow is being fed from the precursor ABL using a spectral interpolation technique. This methodology has been used to enhance our understanding related to the multiscale physics of wind farm ABL interaction, where phenomenon like the growth of the inner layer, and wake impingement effects in the subsequent rows of wind turbines are important owing to the streamwise heterogeneity of the flow. Finally, we have also investigated the presence of realistic geophysical effects on the turbulent inflow in influencing the flow past the wind turbine arrays. Some of the geophysical effects that have been considered include the presence of Coriolis forces as well as the temporal variation of mean wind magnitude and direction that might occur due to some mesoscale effects. This study have been compared against field experimental results which gives an important step towards understanding the capability of our LES methodology in predicting realistic flow structures.

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