- Realizing the need for forecasting wind characteristics data due to their limited availability, a novel heuristic-free optimal design algorithm for building nonlinear deep learning-based system-identification techniques has been proposed. Also, the abilities of generative models like Gaussian Processes and Variational Autoencoders are utilized in combination with a clustering-based generative model for accurately modelling the uncertain nature of wind.

- The novel ideas developed in the lab have led to 14 high-impact peer-reviewed publications of international repute and two high-value Government projects worth INR 1 crore with international collaboration for the establishment of large-scale efficient wind farms. The funding agencies include DST - National Supercomputing Mission, SPARC – MHRD, and special fund by British Council UKIERI through the international collaboration with the University of Exeter, UK (Department of Computer Science).

- Methods for modelling turbulent wake effects in wind farms are focused on next. Here, machine learning-driven accurate models are developed, which would be fast as compared to high fidelity CFD-based models.

- As a whole, the wind farm layout optimization problem turns out to be NP-hard MINLP formulation. To convert such a large-scale problem to a small scale, an auto-encoder-based strategy is proposed, which assists efficient usage of combinatorial, evolutionary, and hybrid optimization algorithms for micrositing.

- To make it realistic, wind state uncertainty in the micrositing formulation is considered and solved using Robust Optimization. Moreover, wind farm control studies using reinforcement learning are performed.

Research Diary

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Wind Energy Research at IIT Hyderabad

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Wind energy is one of the fastest-growing sources of renewable energy worldwide and in India. Per MNRE, the installed capacity in India exceeds 40 GW as of late-2020. Despite this, there are several issues that preclude the widespread penetration of wind into the Indian and global energy mix. The importance of harnessing energy in a clean and efficient manner leads to several exciting interdisciplinary research opportunities, targeted towards, e.g., making accurate wind forecasts; designing aerodynamically efficient, less noisy, and structurally robust wind turbines; & designing better wind-farm layouts and optimal control strategies that maximize energy generation and minimize maintenance/repair costs. Our group at IITH studies fluid dynamics associated with several of the challenges outlined above. The primary tools employed are high-fidelity large-eddy simulations (LES) of the turbulent flow over wind turbines and wind farms embedded in the atmospheric boundary layer (ABL). Due to the wide range of length and time scales involved, these simulations are extremely expensive, requiring extensive use of supercomputing resources (available in India via NSM-funded clusters at IITH, IISER Pune, etc., and internationally).

These large-scale LES are accompanied by the development of simplified analytical, statistical, or semi-analytical models that reproduce the key results (e.g., mean wind speed or average power production) at a fraction of the cost of the LES.

A turbine located in the wake (in the wind shadow) of an upstream turbine sees lower wind speeds and increased turbulence. Consequently, the downstream turbine generates lower power than the upstream turbine; this phenomenon is termed 'wake losses'. Minimizing wake losses is key to ensuring effective utilization of the wind resource. Wake losses are inherently tied to wind-farm design and operating parameters as well as features of the incoming ABL flow. Some challenges specific to the Indian context are the effect of non-flat/undulating/hilly terrain and the effect of surface heterogeneities. Some key results obtained in the last few years are provided below (see Figure 7).

(1) Multi-rotor wind turbines, wherein four three-bladed rotors are mounted on a single tower, is a relatively new turbine configuration with structural and aerodynamic benefits over the conventional single-rotor configuration. Our recent work quantifies the reduced wake losses that are observed in finite-sized wind farms of multi-rotor turbines (Ref. 1), and in very large wind farms, and develops an analytical method to predict the mean wind speed accurately.

(2) Differences in land use and land type (agricultural/fallow; urban/ rural; forested/ semi-arid), or type of surface (water/ land), affect the wind patterns over it. The flow is known to accelerate or decelerate over a surface transition. We have developed a fully predictive analytical model that captures the strength of this acceleration/deceleration of the flow for different transitions (Ref. 2). Current efforts are aimed at understanding how and why wind farms located on such heterogeneous surfaces behave very differently as compared to those on homogeneous surfaces.

In summary, the field of wind energy offers several exciting interdisciplinary research opportunities for students in various disciplines ranging from fluid dynamics, structural mechanics, atmospheric sciences to control theory, optimization, and data-driven approaches.

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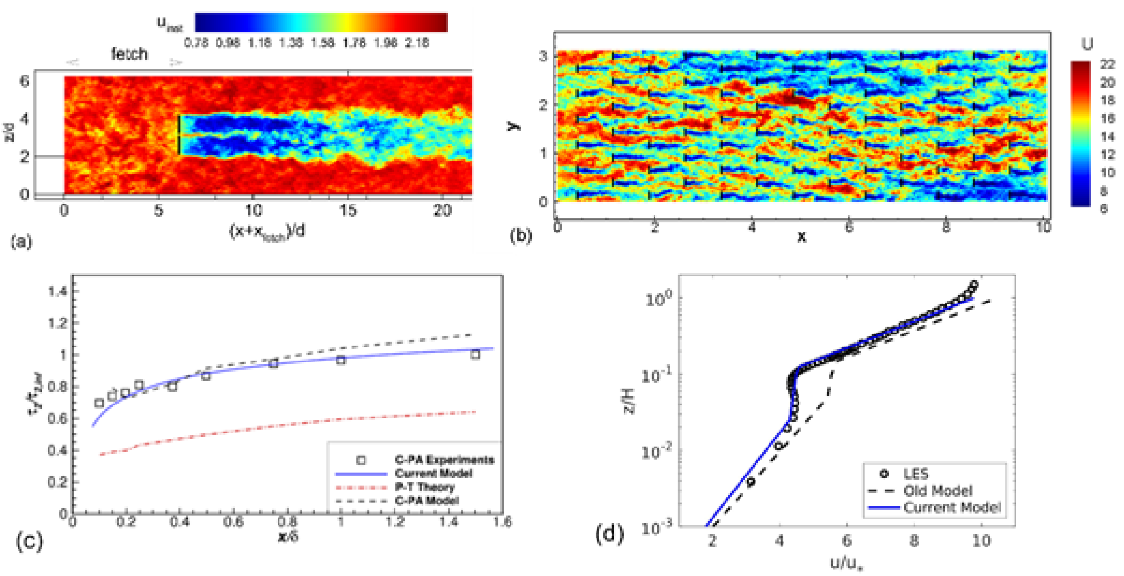

Fig. 8: Contours of the instantaneous velocity field behind (a) a stand-alone multi-rotor wind turbine, (b) a very large wind farm. Thick black lines denote turbine rotors. Analytical model predictions for (c) the shear stress behind a surface roughness jump compared to previous models and experiments and (d) mean velocity profile in very large wind-farms compared to a previously proposed model and LES results