Thermal and Mechanical Interactions Between Utility Scale PV Plants and the Atmospheric Surface Layer

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The Goal of This Research

This research seeks to build a better understanding of thermal and mechanical interactions between utility-scale PV plants and the atmospheric surface layer. Utility-scale PV plants act as surface roughness elements that interact with the atmosphere and affect thermal transport processes. This study aims to build fundamental concepts and develop concrete equations that describe these interactions. The ultimate goal is to develop simple parametric models to represent utility-scale PV plants' impact as a drag force coefficient and an overall heat transfer coefficient. Developing such models makes it possible to insert these large-scale canopies into weather models.

Copper Mountain Solar Facility, Nevada
4,000 Acres

Background

We know that the atmospheric surface layer is greatly influenced by what lies beneath it. Thermal and mechanical interactions between the atmospheric boundary layer and earth surface govern the atmosphere's mechanics. Different environments lead to different effects, but the atmospheric surface layer is always affected by the background canopy, whether it is grass, bare soil, buildings, dessert, ocean, PV plants, etc.

What Do Previous Studies Say About Thermal Interactions between PV-Plants and Atmosphere?

Previous studies agree that PV plants produce a significant effect on the atmospheric surface layer's thermal properties; however, these studies are somewhat divided with their results. Some claim an increase in near ground temperature, while others suggest the near-ground temperatures would decrease.

What Do Previous Studies Say About Mechanical Interactions PV-Plants and Atmosphere?

Many studies describe the atmospheric mechanics of flows over various canopies. Concrete equations have been developed to describe flows over surfaces such as the ocean, low plant canopies, forests, deserts, bare soil, and many more, but no concrete equations have been developed for describing characteristics of the surface layer above utility-scale PV-plant canopies.

Building On the Previous Studies

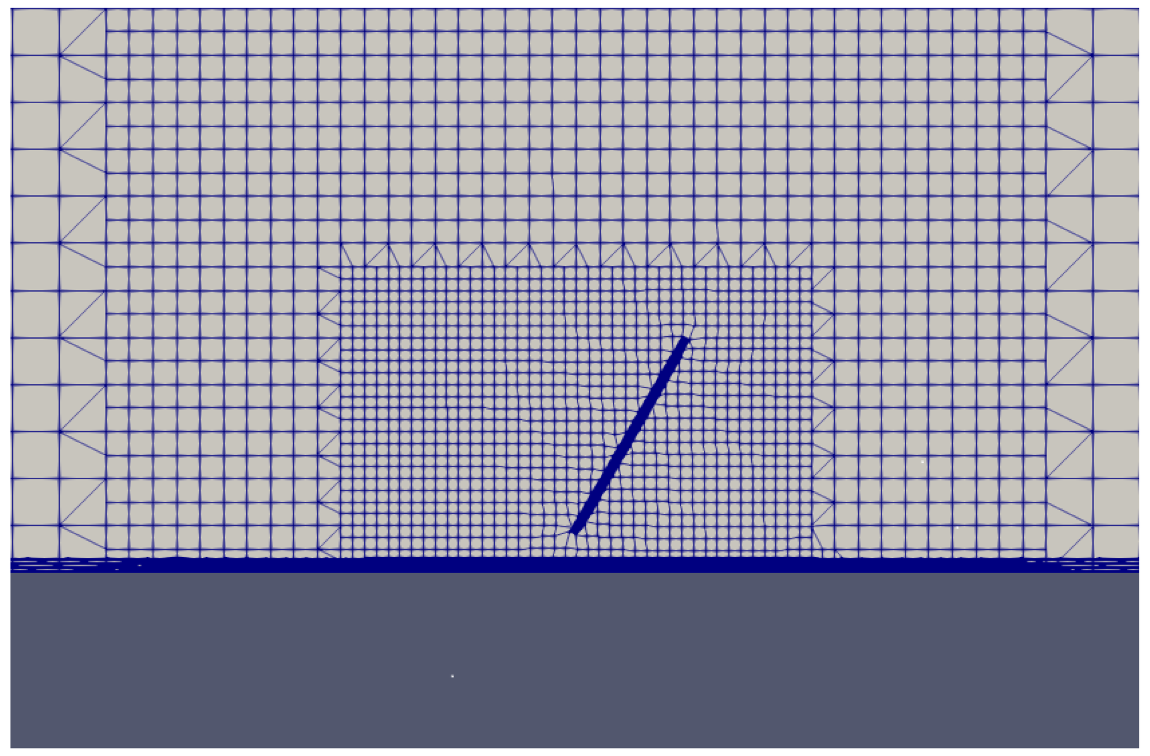
The previous studies that describe the thermal effects of PV plants were all based on limited physical experiments. Hence, information could only be recorded at a few limited locations where sensors were placed. Physical experiments also introduce outside variables that cannot be perfectly controlled. CFD (Computational Fluid Dynamics) offers a significant advantage in addressing these problems. In CFD simulations, information is recorded at every location within the domain, and essential variables can easily be controlled.

Equations can be developed to describe the mechanical interactions using the information or data available throughout the domain and methods from previous studies. Previous studies show how to develop equations for characteristics such as drag force (Cd), a crucial factor influencing the atmospheric surface layer's mechanical structure.

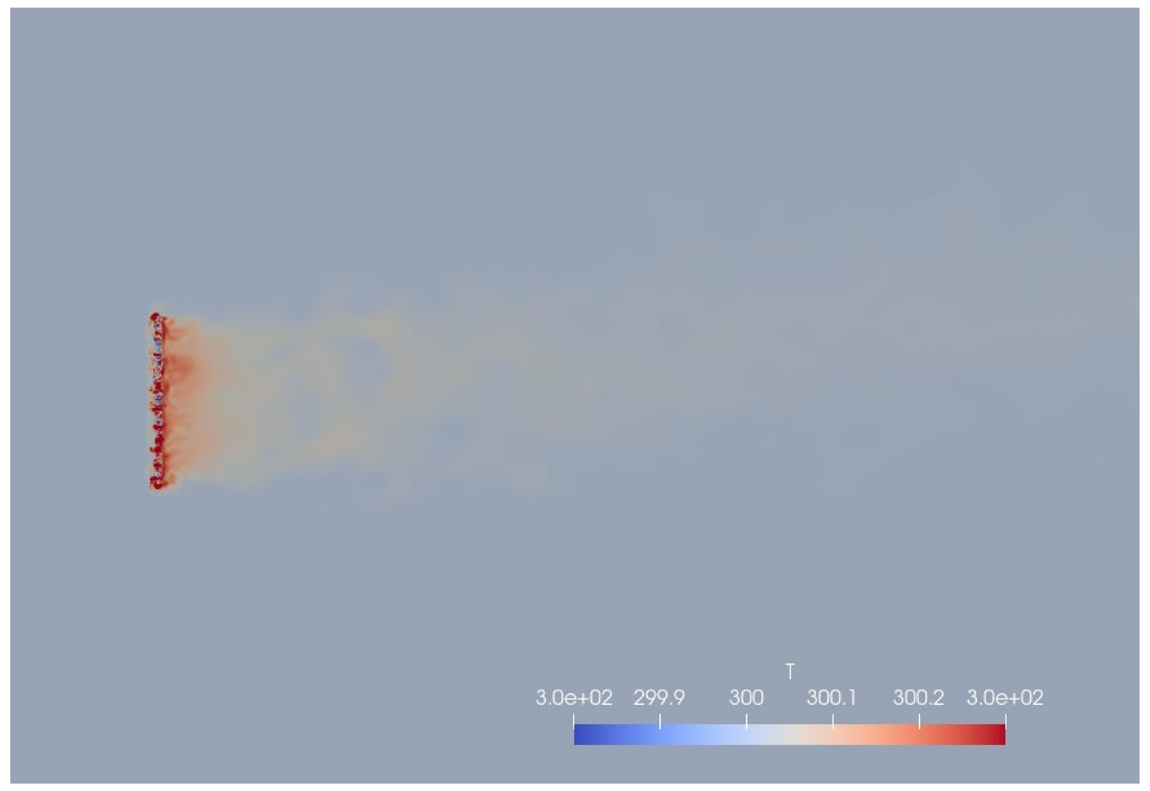
CFD Setup

The CFD software used for this research consists of OpenFOAM coupled with the SOWFA. OpenFOAM is a very powerful CFD solver that is capable of handling extensive atmospheric-scale models, and SOWFA is a sub-library within OpenFOAM that was developed by the National Renewable Energy Laboratory (NREL). The purpose of SOWFA is to simulate realistic atmospheric flows and properties.

The accuracy of any CFD simulation is dependent on the accuracy of the setup. One critical element is the proper implementation of boundary conditions. A good mesh must be produced, and the thermal and mechanical conditions must be set (e.g., heat fluxes and surface temperatures). The thermal boundary conditions must be accurate. For this reason, the boundary conditions simulated will be fed by actual field data. This data will be recorded from a small-scale setup and then used to drive the simulation's boundary conditions.



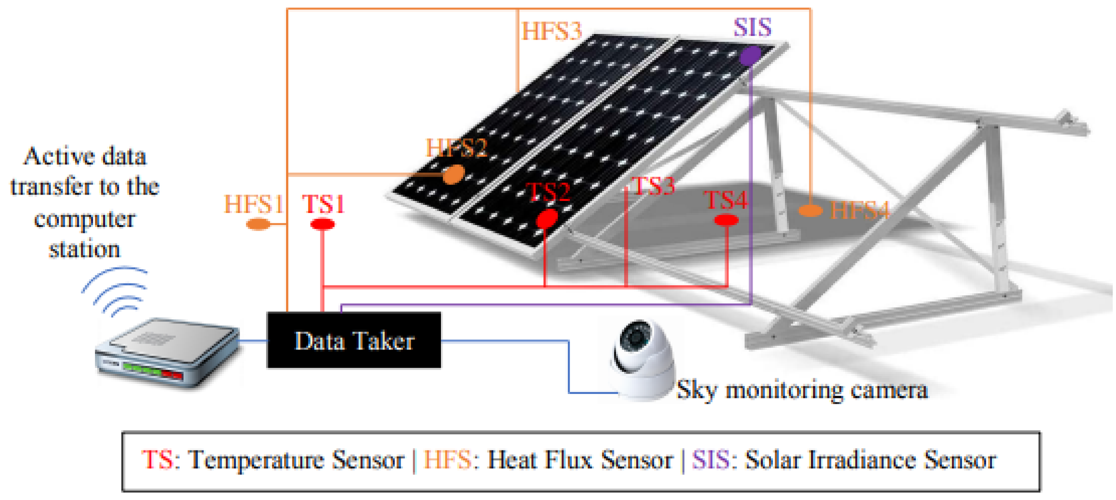
Mesh Cross Section Of A Single Panel Row



Temperature Contour As Seen From Above

Physical Setup

A small-scale physical setup will be constructed for this project. It will consist of a few panels mounted on an adjustable base, which will allow changes in panel height and tilt. This setup will also be mobile, enabling the location to be varied to study different background canopies' effects. Temperature flux sensors will be placed in several locations, such as the panels' front side, the rear side of the panels, the unshaded ground region, and the shaded ground region. The setup will be funded by the 2021-2022 Faculty Research Grant.



Experimental Setup to collect time-varying boundary conditions to feed the CFD simulations

Obtaining Results

After the CFD boundary conditions are setup to model the physical data, many simulations can be studied. Using Tennessee Tech's High Performance Computing Cluster (HPC), many simulations can be run at the same time. Different elements of the simulation can easily modified or adjusted. Among other aspects, this research will look into the effects of PV plant size, PV plant layout, panel height, panel tilt, atmospheric structure and stability (time of day), wind speed, wind direction, and the background canopy.

Conclusion

The outcome of this research will be a better understanding of how PV plants affect the atmospheric surface layer. Equations will be developed to describe the atmospheric flow over these surfaces, including equations for drag force coefficient and overall heat transfer coefficient.

Acknowledgments such as state, federal, industry, university, or other support go here.