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Advancing Solar Farm Resilience: CFD-Driven Wind Load Optimization

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ADVANCING SOLAR FARM RESILIENCE

CFD-DRIVEN WIND LOAD OPTIMIZATION

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INTRODUCTION

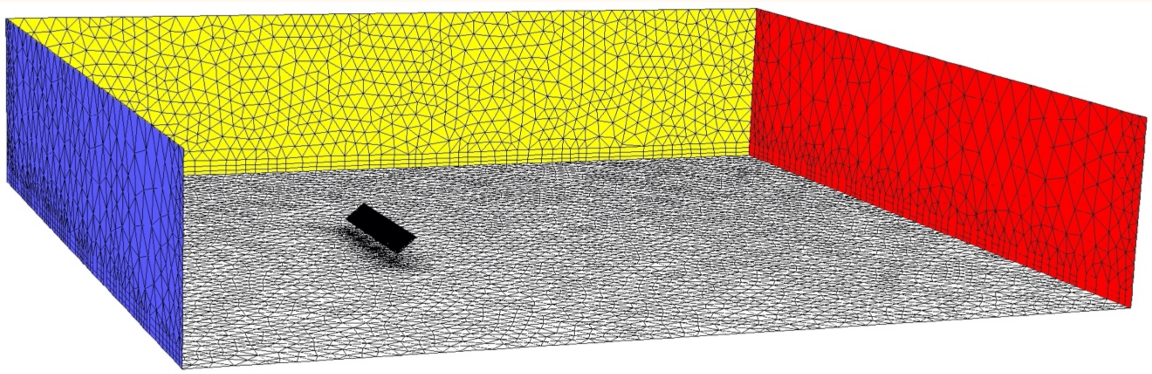
The global solar energy market continues to experience significant growth, driven by declining technology costs and strong policy support across major economies, yet extreme weather events like Hurricane Maria—which significantly destroyed Puerto Rico's solar capacity—reveal critical vulnerabilities in current design practices. This white paper bridges the gap between Computational Fluid Dynamics (CFD) simulations and ASCE design standards to optimize wind load predictions for ground-mounted solar arrays, balancing safety and cost-efficiency.

Urgency and Scope

- Hurricane Maria's Impact: A case study of a Puerto Rican solar farm—built in two phases with identical panels but differing elevations/tilt angles—showed 75% failure in Phase 2 versus 25% in Phase 1, underscoring the need for aerodynamic optimization.
- Economic Stakes: Post-storm rebuilds cost 50% more than original installations, while proactive design upgrades would have added much less to initial costs.
- Standards Gap: ASCE 7-2016 provisions still underestimate CFD-predicted loads, exposing systemic risks in static design approaches.
- Economic impact: Damaged solar farms can lead to millions in repair costs and lost energy production

METHODOLOGY

- CFD simulations using ANSYS Fluent, chosen for its advanced turbulence modeling capabilities
- Turbulence models:
    - Reynolds Stress Model (RSM): Provides detailed anisotropic turbulence information
    - k–ε model: Widely used for industrial applications
    - Large Eddy Simulation (LES): Offers high-fidelity results for transient flows
- Comparison with ASCE Standard calculations
- 3D modeling of solar panel arrays to capture realistic wind flow patterns



KEY FINDINGS

KEY FINDINGS #1

First row of array panels experienced higher pressures than subsequent rows. LES outperforms RANS models (RSM, *k*-ε) in accuracy but is computationally expensive.

KEY FINDINGS #2

Phase 1 panels (higher elevation/tilt) experienced 20–40% greater wind loads than Phase 2. ASCE 7-2010 increased design wind pressures by 48% vs. 2005, but 2016 provisions still underpredict CFD results.

KEY FINDINGS #3

Cost-benefit analysis favors upfront structural reinforcement (+2% cost) over post-failure rebuilds (+50%).

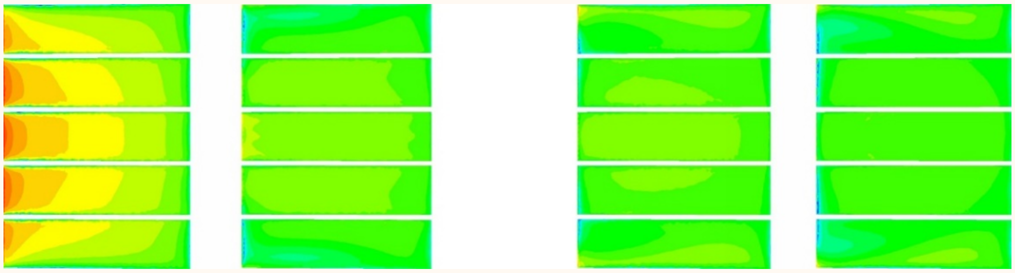
VISUAL DATA

(a) Phase 1, and (b) Phase 2 Post Hurricane Maria [1]; (c) Reden Solar Phase 2 Destruction Post Hurricane Maria [2]; (d) Pressure Coefficient (Top Surface) for Phase 2 Array; and (e) Velocity Magnitude [3].

(a)

(b)

(c)



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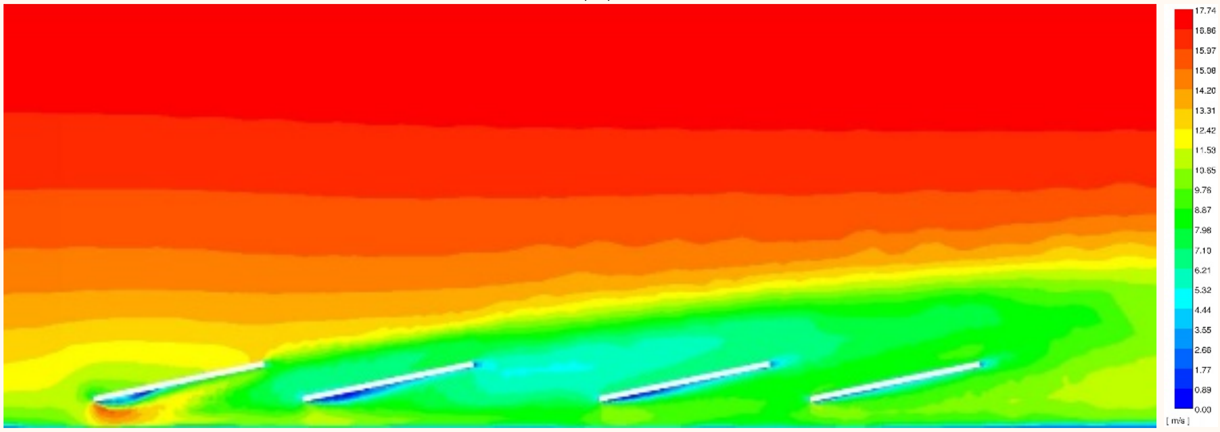

(e)

CONCLUSION

By incorporating advanced CFD simulations and updated design standards, we can create more resilient solar installations that better withstand extreme weather events. The minimal cost increase for stronger structural systems offers significant long-term savings and improved energy security.

KEY TAKEAWAYS

1. Reinforce first-row panels to withstand higher wind loads, leveraging sheltering effects for subsequent rows.
2. CFD simulations exceed ASCE standard predictions, exposing critical gaps in current wind load design methodologies.
3. Proactive structural upgrades (e.g., stronger framing) increase upfront costs by 2% but can reduce rebuild costs by 50% in the event of failure due to wind forces.
4. LES delivers high-fidelity wind load analysis; RSM balances accuracy and efficiency for mean pressure estimates.

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