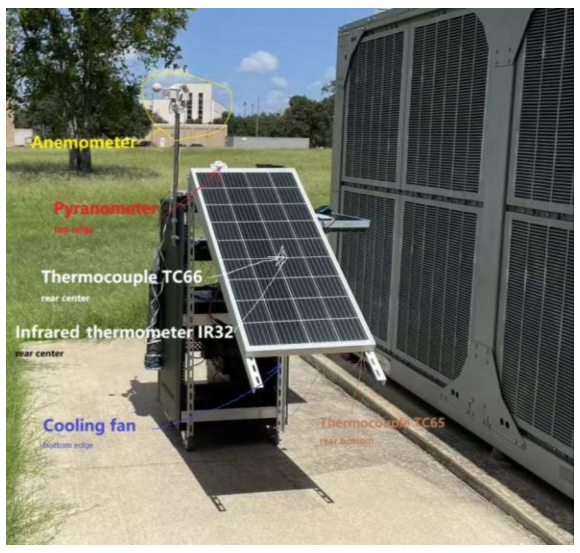
Assessing Transient Thermal Models for Photovoltaic Modules Using High-Time-Resolution Outdoor Measurements

Bitian Jiang, Christi K. Madsen
Department of Electrical and Computer Engineering
Texas A&M University, College Station, TX, USA

Introduction

PV module temperature strongly affects efficiency and model accuracy. Most thermal models (e.g., Faiman) assume steady-state conditions. However, real outdoor irradiance and wind vary rapidly, causing transient temperature behavior.

Experimental Setup



High-time-resolution (~2 Hz) outdoor measurements capture irradiance, wind, and module temperature using both thermocouples(TC65,TC66) and IR sensors(IR32), enabling analysis of sensor-dependent transient response and thermal lag.

Fig. 1 Outdoor PV Measurement Setup

Results

Large thermal time constants prevent steady-state behavior.

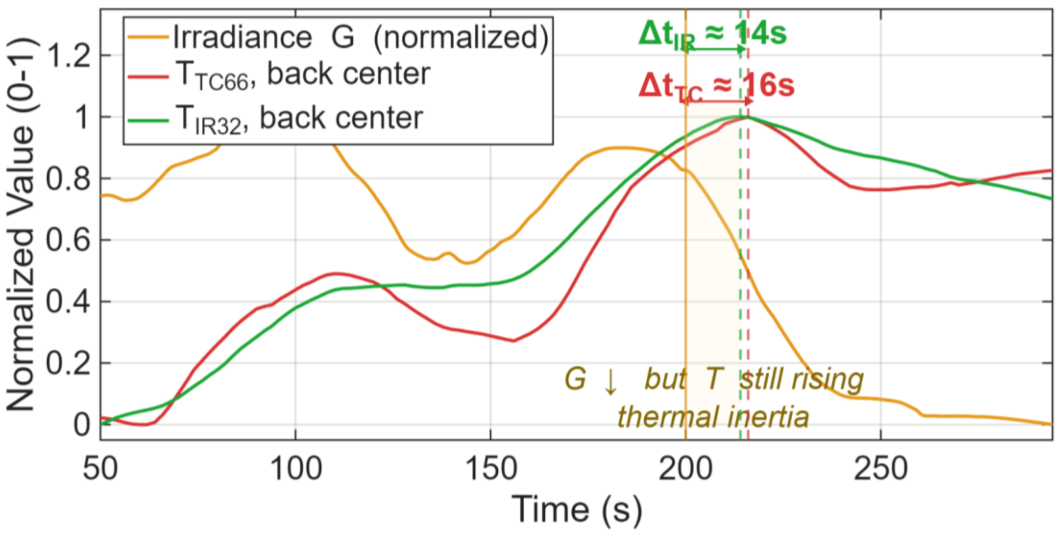


Fig. 3 PV temperature rises after irradiance drop. G peak at t ≈ 200 s; TC66 and IR32 lag irradiance by ~16 s and ~14 s, respectively, much smaller than τ ≈ 340 s, indicating thermal inertia–dominated behavior.

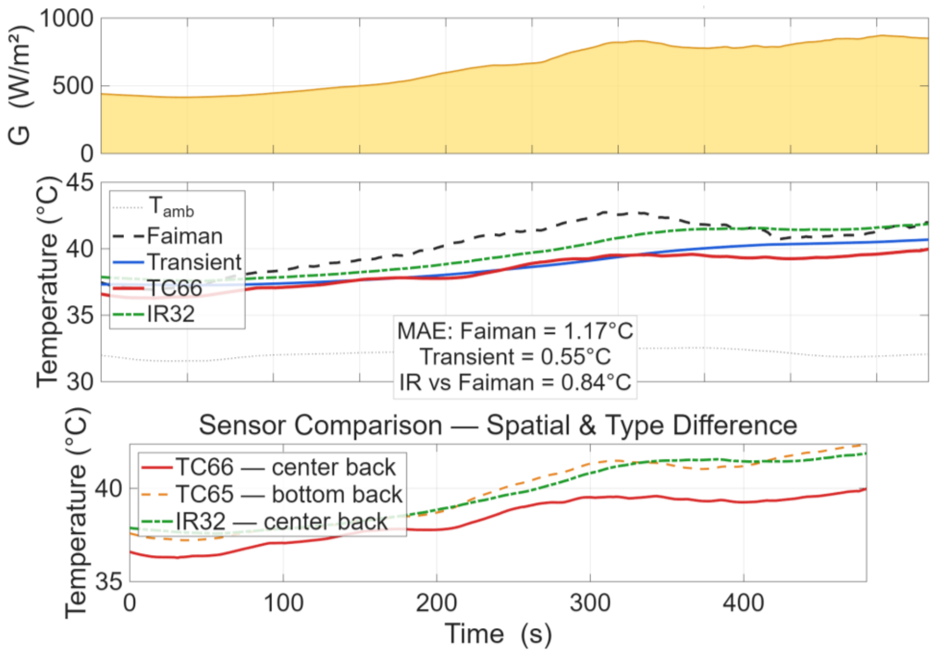


Fig. 4 Transient model matches measurements; steady-state model deviates under dynamic conditions (mean wind speed = 23.3 mph).

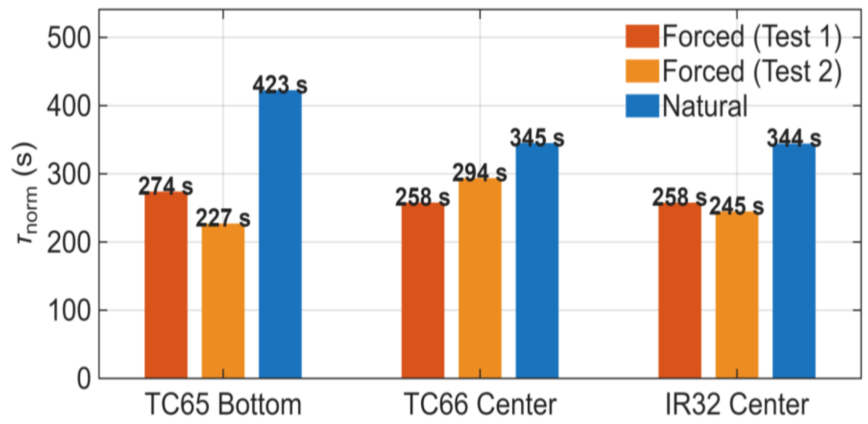


Fig. 2 Thermal time constant τ ≈ 230–420 s indicates slow cooling under shading, highlighting strong thermal inertia in PV modules.

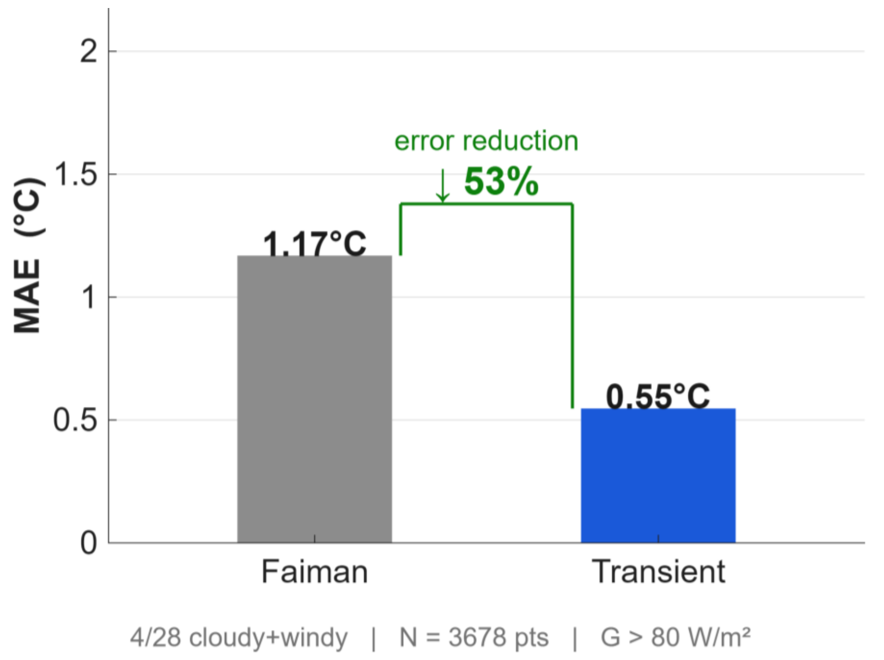


Fig. 5 Prediction error: Transient model reduces prediction error by 53%.

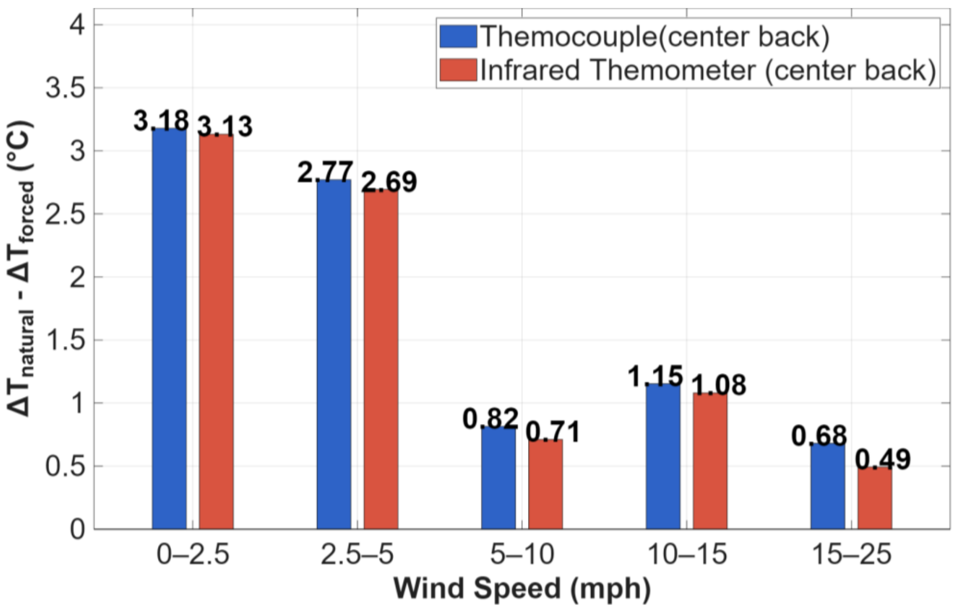


Fig. Cooling benefit ($\Delta T_{natural} - \Delta T_{forced}$) decreases with increasing wind speed under moderate irradiance (G ≈ 400–480 W/m²).

Conclusion

- Thermal inertia limits steady-state modeling for PV modules under real outdoor conditions.
- Transient models are more accurate and better suited for predicting temperature changes in dynamic environments.
- Optimizing cooling strategies based on wind speed is crucial for improving PV system performance.

Discussion

- Thermal time constants (τ ≈ 230–420 s) prevent steady-state modeling under real outdoor conditions.
- The transient model improves temperature accuracy by 53%, outperforming steady-state models.
- Fan cooling is effective at low wind speeds but diminishes as wind speed increases, highlighting the importance of ambient airflow.

What's Next?

- Validate transient models across different climates.
- Evaluate cooling technologies and their impact on efficiency.
- Future models should optimize cooling strategies based on environmental conditions.

Reference

1. *Goodfriend, W.; Pieters, E.B.; Tsvetelina, M.; et al. Development and Improvement of a Transient Temperature Model of PV Modules. Prog. Photovoltaics 2024, 32, 399–405. doi:10.1002/pip.3785.*
2. *Faiman, D. (2008). Calculation of the energy loss due to temperature in photovoltaic modules. Solar Energy, 82(7), 665-674.*