Hybrid Photovoltaic-Thermoelectric generator for compensating variability in solar illumination

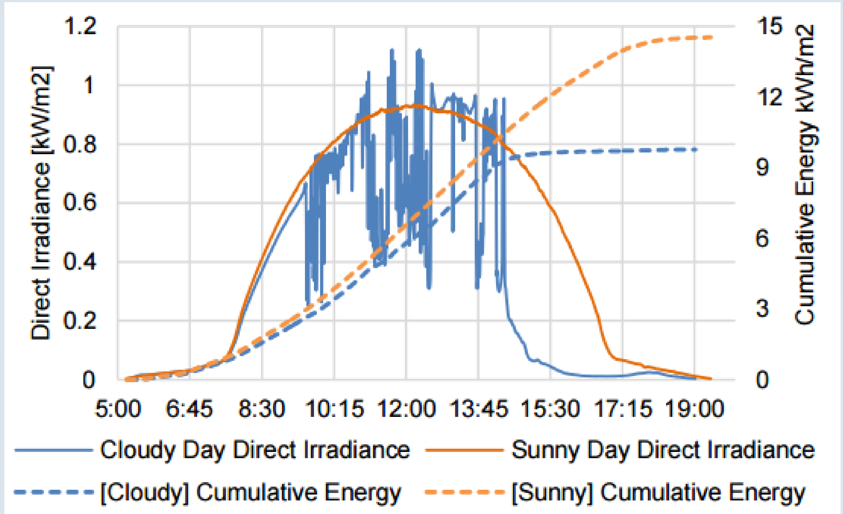
Raphael Perci[a,b,c,d], Silvana Ayala[a], Yuechen Wu[a] ,Raymond Kostuk[a,b]
The University of Arizona: Department of Electrical and Computer Engineering[a] and College of Optical Sciences[b]
Universidade do Estado do Rio de Janeiro (Departamento de Engenharia elétrica)[c] and CAPES Foundation , Ministry of Education of Brazil[d]

Introduction

Transient clouds create solar intermittency, directly affecting the output of **photovoltaic systems (PV)** and making them unreliable for power grid applications. One approach to mitigate this problem is a **hybridization between PV and thermoelectric devices (TE).** The longer time constant of TE devices makes them less susceptible to transient illumination effects. In this work a model is proposed and built to investigate the properties affecting the performance of such a system. In our model, a thermal storage element absorbs solar radiation to power a thermal electric device during periods of cloud obscuration. Different materials including water, aluminum, and zeolite are evaluated and compared for use as thermal storage systems to extend the operating times of TE devices in the hybrid conversion system.

The storage materials were evaluated in terms of their absorption, emissivity, heat capacity, and density which impact their thermal energy storage capacity. The design goal was to produce the greatest temperature differential between the front and back surfaces of the TE device. The performance of the combined thermal energy storage and TE power generation is modeled and evaluated for offsetting power loss of PV generation systems. An experimental hybrid PV/TE/thermal storage system was designed, implemented, and used to collect data for comparison with model predictions. There was good agreement between the model and experimental results and shows that intermittency of PV system output can be mitigated for periods of several minutes. The overall system can be improved with optical concentration to increase storage system temperatures and will be investigated in future work.

Keywords: Solar intermittency, Solar energy, Photovoltaic, Thermoelectric, Hybrid PV Systems



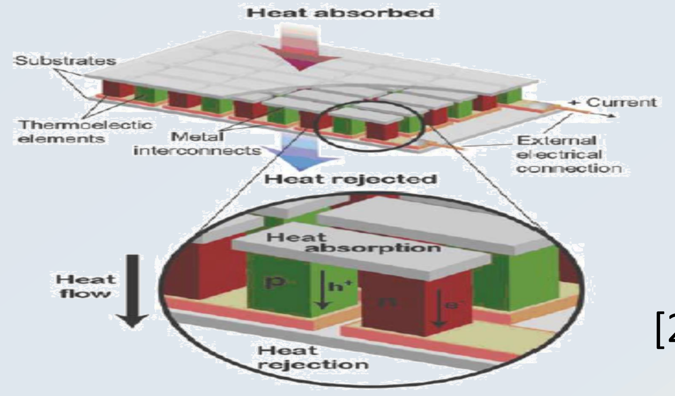
Solar irradiance comparison between a cloud day and a sunny day . Cumulative energy is shown with dashed lines for both sunny and cloud day.

Background

Thermoelectric generators convert heat into electricity through the **Seebeck effect .** It can be seen as a voltage source that depends on the temperature difference between the cold and the hot surfaces of the device

$$V = S\Delta T$$

$$V = \int_{t1}^{t2} (S_b(T) - S_a(T))dT$$



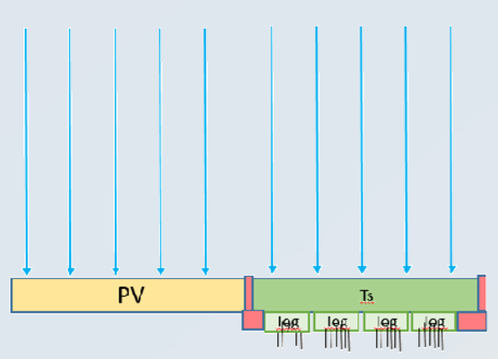
[2]

Assuming that PV and TE devices are independently operated, the equation below shows the ideal output power of a hybrid PV-TE System . [1,4]

$$P_{PV,max=I_{sc}V_{oc}FF}$$

$$P_{TE,max} = \frac{1}{4}\frac{(V_{TE})^2}{R_i}, R_i = N\left(\frac{\rho_n l}{A_n} + \frac{\rho_p l}{A_p} + R_c\right)$$

$$P_{out\,TE} = P_{out\,PV} = I\,\eta_{PV} A$$



Energy model mechanism

$$Q_b(t) = Q_{in} + Q_b(t-1) - \left(P_{TED}(t) + P_{Conv}(t) + P_{rad}(t)\right).\delta t$$

TE Power

$$P = \eta \Delta Q/\Delta t$$

TE Efficiency

$$\eta = \frac{\Delta T}{T_h}\frac{\sqrt{1+ZT}}{\sqrt{1+ZT}}\frac{-1}{+{T_c}/{T_h}}$$

$$ZT = \frac{S^2 T}{\rho\kappa}$$

(Dependent material properties)

Experiment

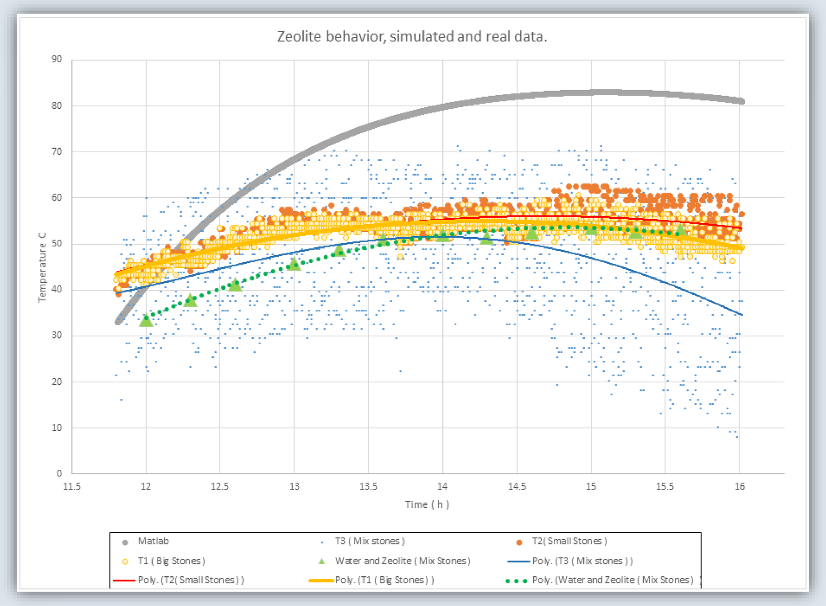
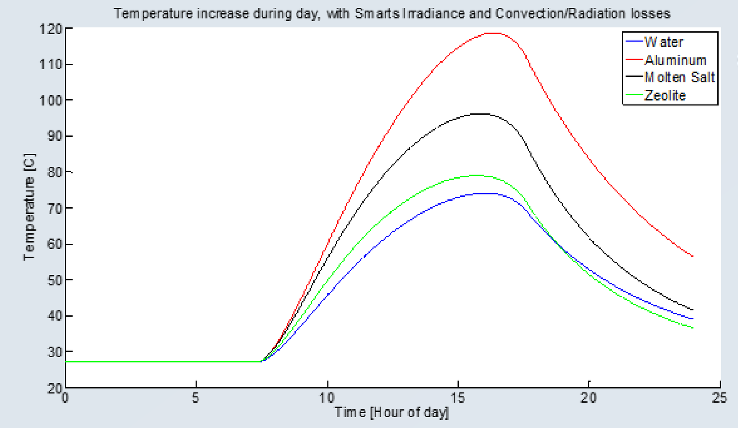


Fig 1 . Comparison between Experimental data and simulated data to the Zeolite

- Different materials **including water, aluminum, and zeolite** were evaluated and compared for use as thermal storage systems.
- An automated data acquisition system was created to acquire the voltage and temperature from the thermoelectric devices for further research.
- Computational system models were also created in order to simulate and predict the behavior of the prototype.
- The I-V characteristic of the TE were experimentally investigated in order to evaluate the power available to a load powered for a TE.

(a)



(b)

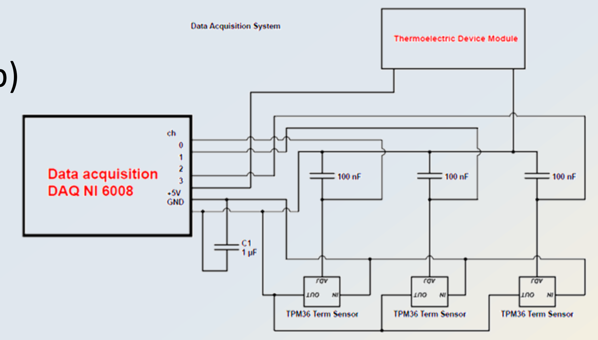


Fig 2 . (a) Model to predict the temperature of the materials during the day with Smarts irradiances. (b) Data acquisition circuit.

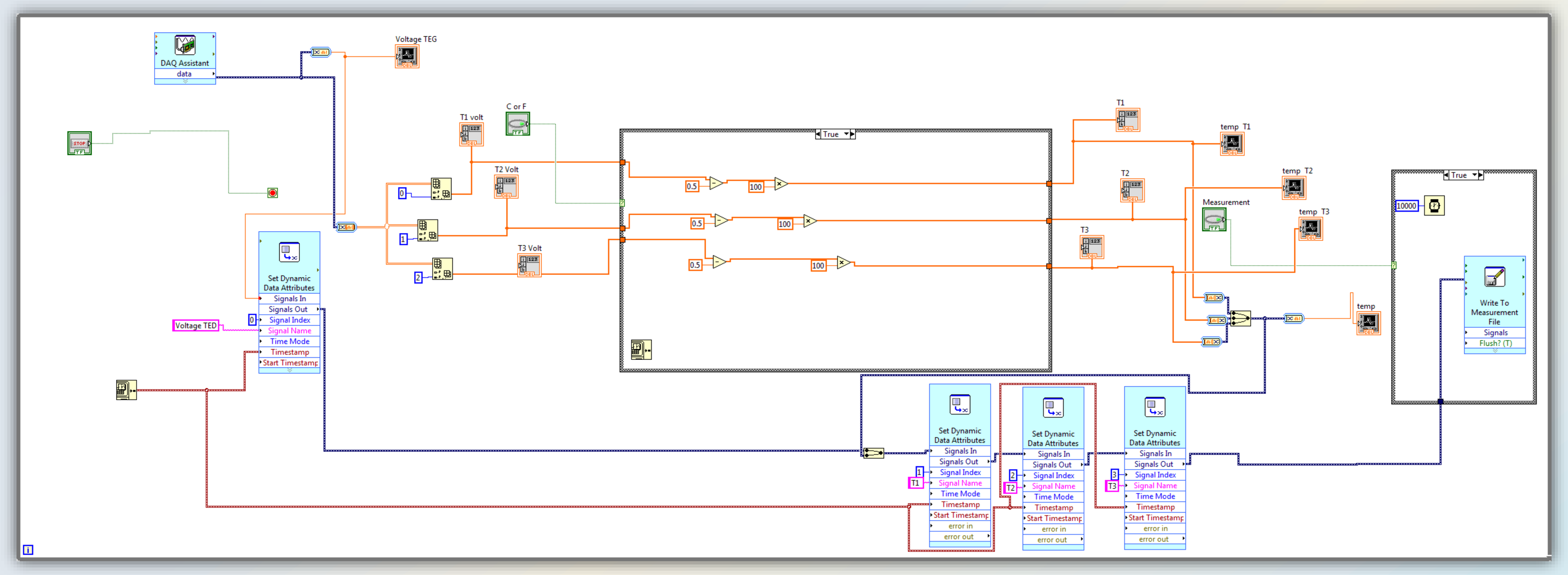


Fig 3 . Automated data acquisition system to acquire voltage and temperature

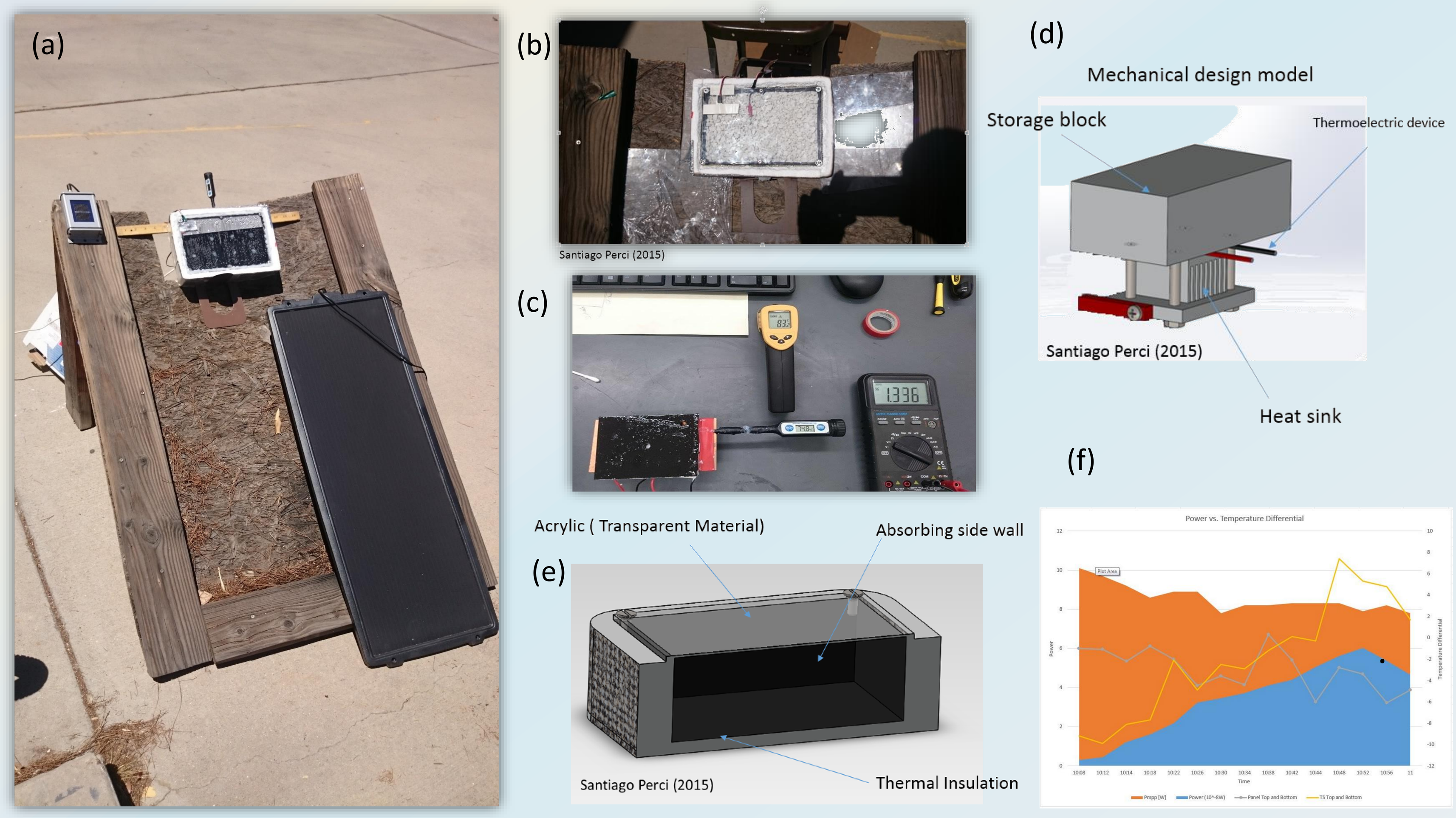
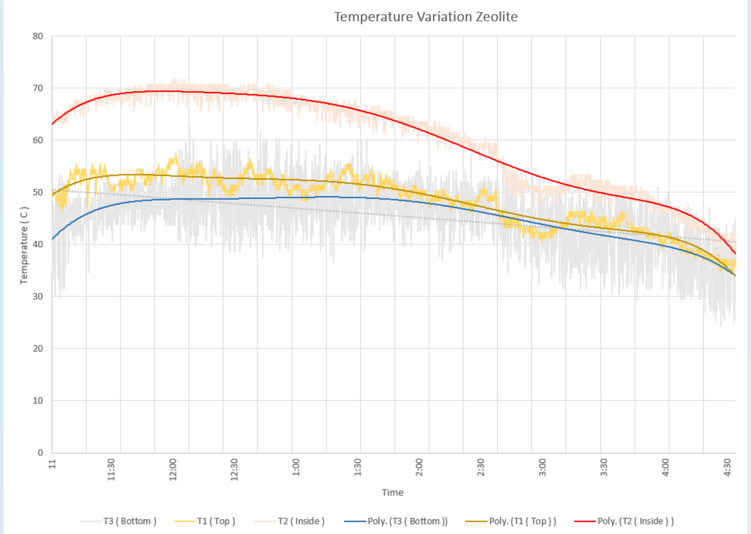


Fig 4. (a) Experiment setup using water as a storage element. (b) Experiment using Zeolite as a storage element. (c) TE Calibration. (d) Aluminum block as a storage element. (e) Thermal storage recipient design. (f) Temperature differential and power comparison of PV and TE system.

Results and Future Works

More field experiments with the TE devices are currently undergoing in order to verify the agreement between the simulated data from the model and the experimental data.

- Studies have been made in order to find the optimum load matching for a PV-TE system. In our experiments , using a variable load ranging from 2 Ώ to 48.5 Ώ, a single TED produced 0.08 W. Considering an array of 692 TEDs in 1 m^2, it is possible to reach ~70 W. This is approximately 1/3 of what is expected from a solar panel.
- These studies still having to be improved in order to find the optimum load point defined by the resistivity of these TE devices. It is expected that an array of this size should be able to produce up to 600 W[5].
- A new design of packed bed solar energy storage system was designed and tested using different materials as a storage element. Insulation was added to the system as well as black paint absorber on its surfaces, improving the absorption and reducing the thermalization losses.
- Zeolite showed to be a really good material for storage heat purposes. The Zeolite combining with the water can provide a better thermal contact, what makes possible to store more energy in a long period of time. After a two hour exposition to the sun, the system yielded temperatures of 70ºC. This results match the simulation values.
- A further improvement to be explored in the system is finding the optimum ratio of zeolite stones of different diameters to ensure good conduction on top of its proven excellent storage capacity.



- The data modeled and gathered on our PV-TE system supports our proposal of using the system to offset fluctuations in the PV output. Using the information learned about the efficiency and power available by thermoelectric devices , the next step of this project would be to implement an array of TE.

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