Theoretical and Operational Thermal Performance of a 'Wet' Crystalline Silicon PV Module under Jamaican Conditions

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Overview of Presentation

- Problem Statement
- Attempted Solutions to Problem
- My Approach to Solution
- Conclusions from my approach
- Questions???

Problem Statements

- **The conversion of light energy to electrical energy (conversion efficiency) of photovoltaic (PV) cells is reduced as the working temperature of the cells is elevated.**
- **The Power Output (conversion efficiency) of the cells is further reduced when the cells operate in low latitude conditions such as those in Jamaica, West Indies**

What affects Power Output (Conversion Efficiency) of the Cells, especially those of c-Si?

- $V_{oc} \approx U_T ln(I_{sc}/I_o)$

Where, V_{oc}, = open circuit voltage

I_0 = saturation current

But

I_0 proportional to T^4

Where T is working temperature of cell

Therefore,

cool cells = higher efficiency

Attempted Solutions to Problem (Applied Cooling Techniques)

- **Cells laminated on copper fin absorber with water tube welded on the back is used by Brogren and Karisson**

- **Heat spreader made of aluminum plate attached to cells is proposed by Araki et al.**

Cooling Techniques cont'd

- Farahat employs evaporative cooling based on heat pipes theory
- Increasing thermal mass of modules by attaching them to small water filled tanks is used by Ronnelid et al.; and Krauter
- Sweelem et al. blows air across the back of the cell through an adjustable air-gap.

Most Efficient Cooling Solution

- **Circulating water over the back surface of the cell proves to be the most effective (Brogren and Karisson).**

  Drawback: This system needs a circulating pump which requires power to run; so the pump becomes a power drain on the PV system.

Other Solutions

- Furushima and Nawata employed siphonage with controller for valve-openings, utilizing city water to supply tank on top of the building. No need for circulating pump

  Drawbacks: Complex; Hard to keep siphonage; Some level of maintenance is needed.

- **My Solution**

My Solution

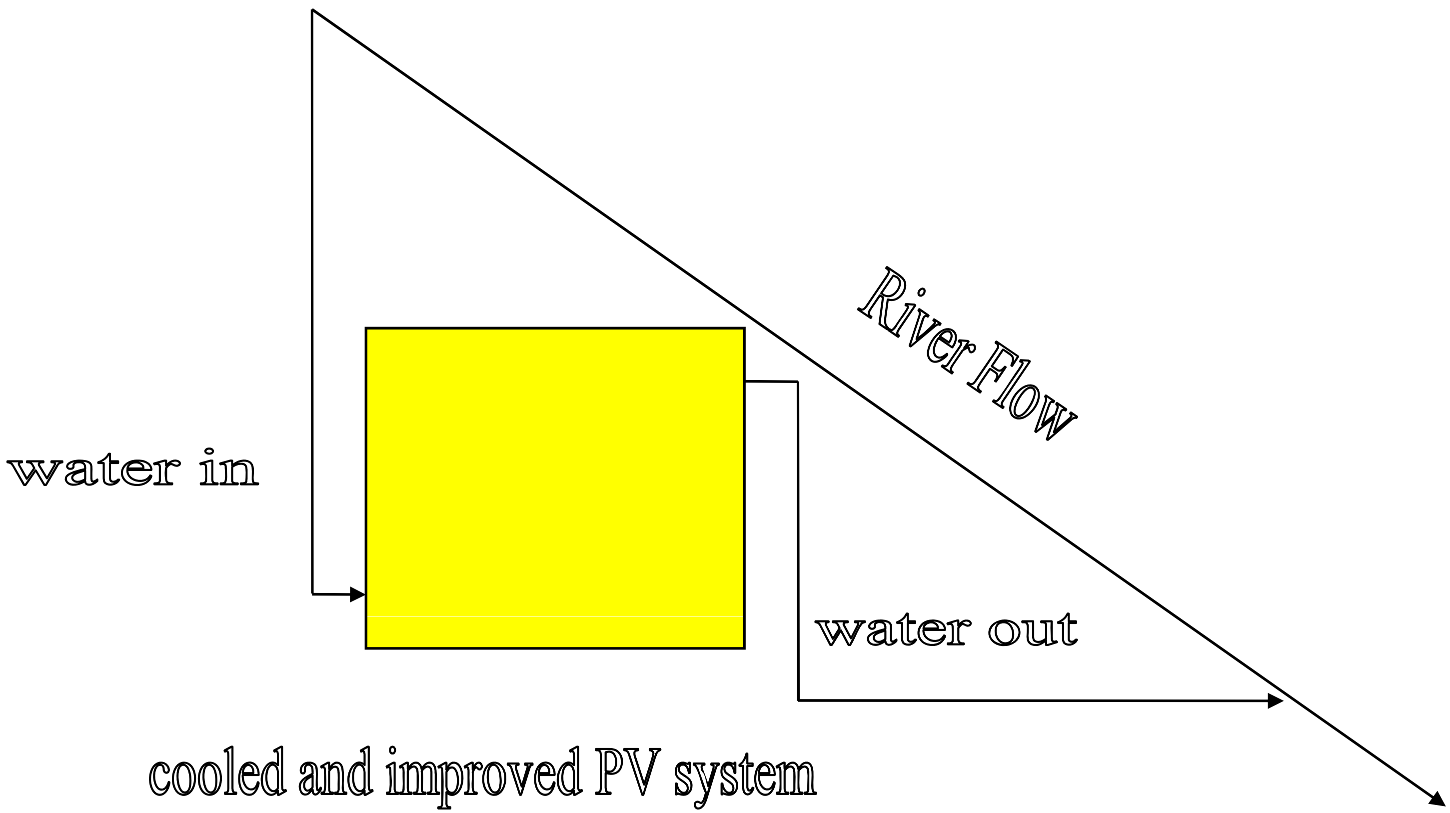
- **Gravity-Fed Technique**

  Water being diverted from upstream a source such as a river, channeled across the back of a PV module ('wet' module), cools the module and returns to the river downstream.

  The power required to drive the water through the system comes from the hydraulic head of the flow stream under gravity, due to the difference in elevation.

Drawback: **Limits the system to regions that have water supply. Hence use in remote or semi-remote PV power generation**

Schematics of a Gravity-Fed Cooling (GFC) System

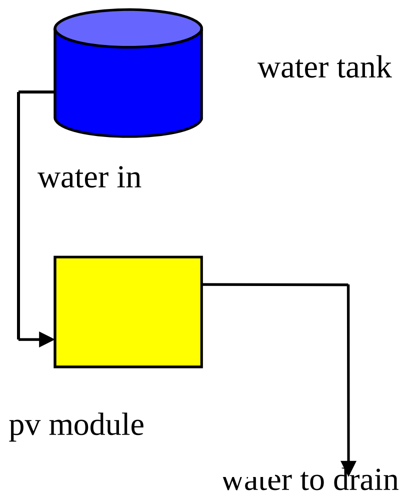


Theoretical Consideration
(Performance Modeling)

- How does the temperature (U) across a cell varies with position (x) and time (t)

$$U_{(x,t)} = \left[U_L + \frac{q_0}{k}(L - x)\right] + \sum_{n=1}^{\infty}\left\{\left[F_n Cos\,\frac{(2n-1)\pi x}{2L}\right] \times Exp\left[\frac{-\alpha(2n-1)^2\pi^2 t}{4L^2}\right]\right\}$$

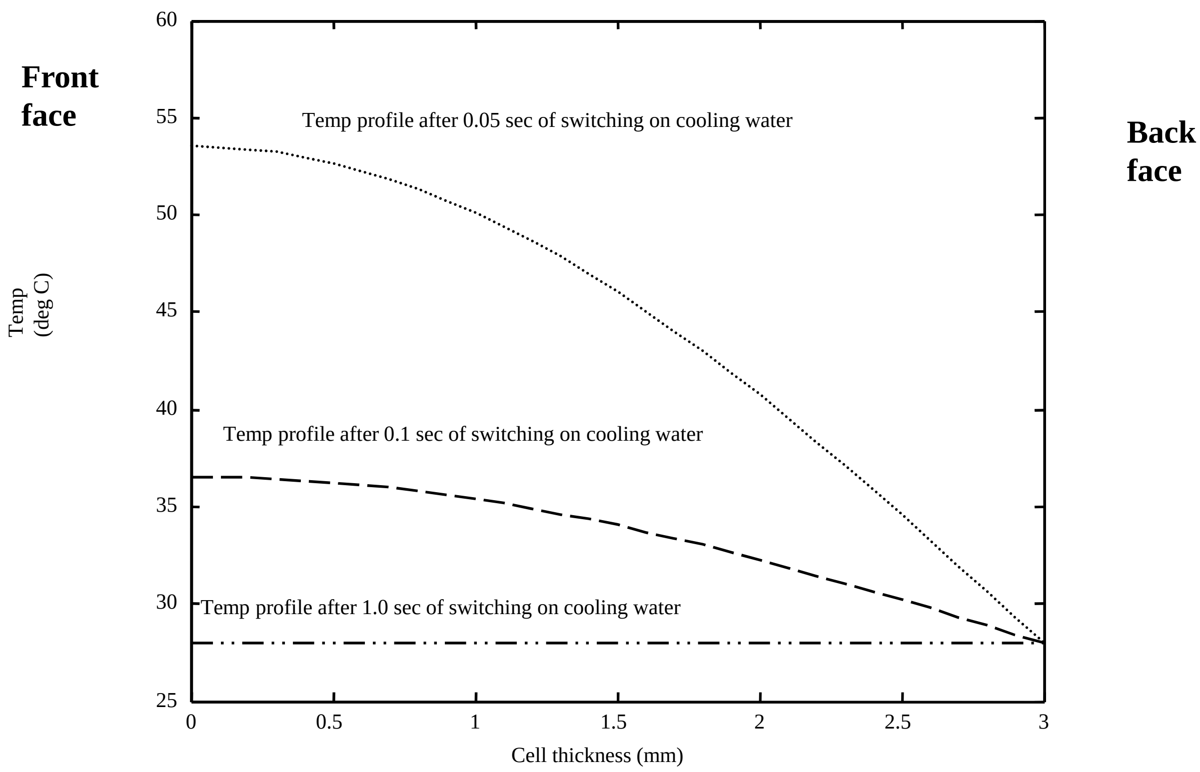
Operational Performance
(experimental setup)



Simulated GFC System

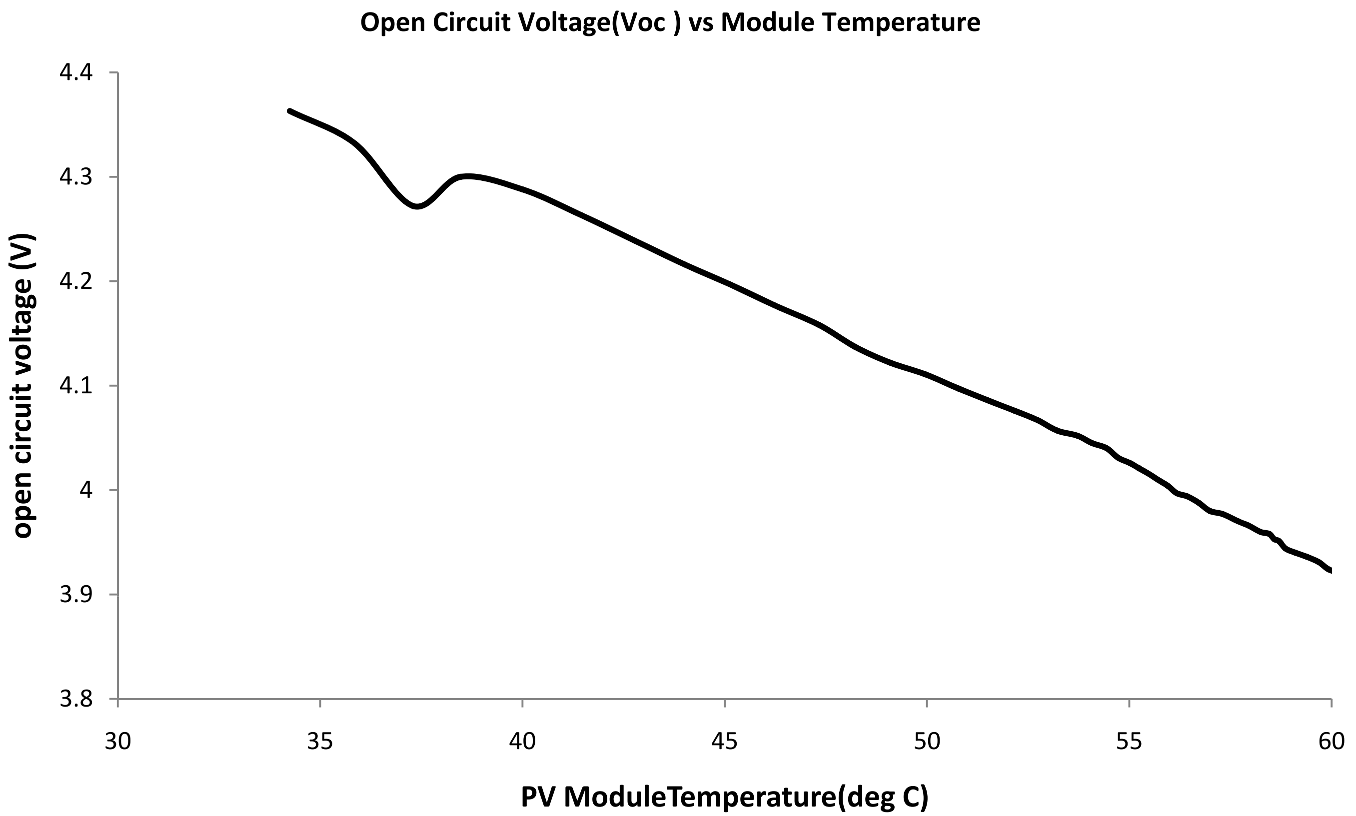
Picture of Photo-voltaic (PV) Module

Results from Mathematical Modeling



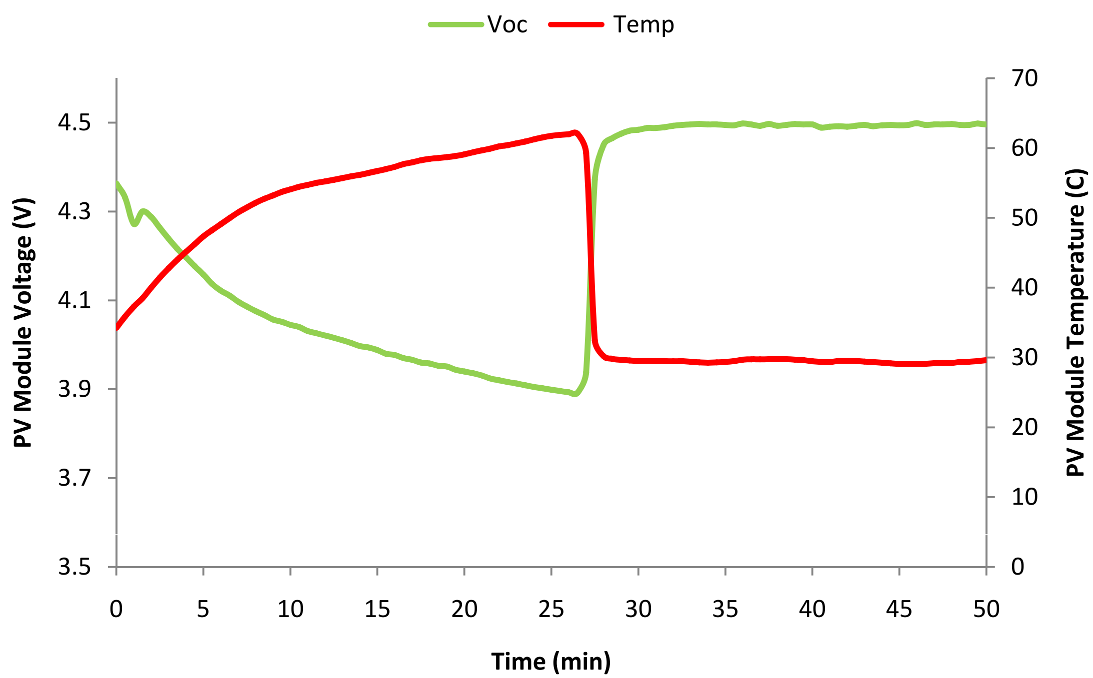
Time-Steps of Temperature profiles for a modelled 3mm thick 'wet' PV cell with irradiance of 1000 W/m^2 incident on front face and back face held at water temperature of 28 ^oC

Results from Experiments



Impact of elevated temperature on open circuit voltage of a PV module

Results from Experiments Continues



Voltage and Temperature profiles of a 'wet' PV module with cooling water switched on at 25.5 minutes.

Conclusions

The following are the conclusions drawn from the investigation of the impacts of a Gravity Fed Cooling (GFC) system on a PV cell/module

- **The GFC system increases the conversion efficiency (power output) of a PV cell/module by 12.8%**

Conclusions Continues

- **The system demonstrates that cooling a PV array can be achieved without the use of a circulating pump**.

- **The GFC system keeps the operating temperature of the module from rising above 5 ^{0}C of the designed temperature.**

Conclusions Continues

- **The increase in power, obtained by the 'wet' PV module, is a 'true' increase as none is utilized to circulate water.**
- **The mathematical model results show very close agreement with those from the experiments and therefore the model can be used as a "predictive" tool to determine temperature profiles across PV modules.**

QUESTIONS