JÜLICH
FORSCHUNGSZENTRUM

Modelling bi-coupled concentrating solar collectors

September 30, 2010 | Yosef Meller

Outline

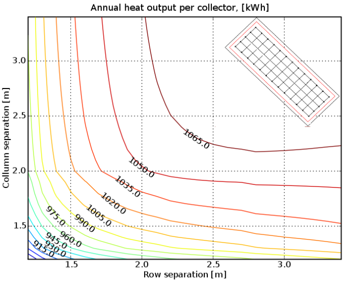
- The problem.
- The existing model.
- Problems with the existing model.
- The new model.
- Non-linear solver technicalities.
- Some results.

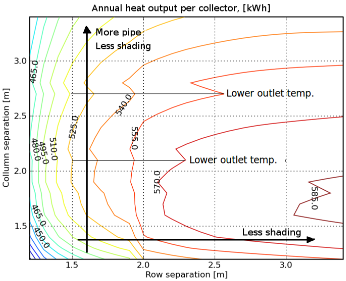
Small-scale CSP fields

- CSP - Concentrating Solar Power.
- Small area of highly efficient PV cells.
- Use heat close to source.

Double interconnection

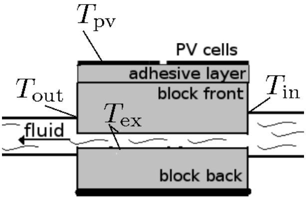
- Thermal series connection: achieve temperature goal.
- Electric series connection: achieve high voltage to reduce wire losses.
- Transverse connections!





Heat/Electricity interplay

- Energy that was not converted by the PV cells moves on to the heat exchanger (active cooler).



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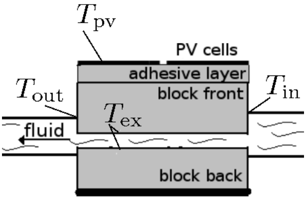
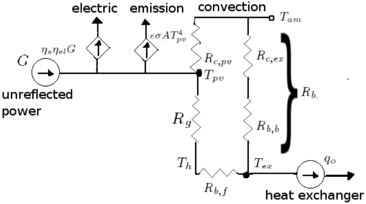


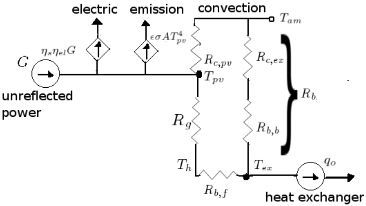
- Conversion efficiency → exchanger temperature.
- Exchanger temperature → conversion efficiency.

The existing model

- For each receiver, a thermal network can be solved given inlet temperature.
- Propagate temperature along thermal series



The existing model



- For each receiver, a thermal network can be solved given inlet temperature.
- Propagate temperature along thermal series
- Parallel thermal strings must have the same pressure drop
- Pressure-drop $\leftrightarrow$ flow-rate feedback link. Use a non-linear equation solver.

Electric string issues

Efficiency model

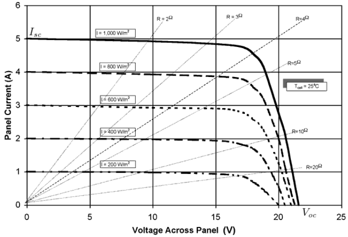
- Existing model employs a linear temperature-dependent efficiency model,

$$\eta_{\mathrm{el}} = \eta_{\mathrm{cons}} + T_{\mathrm{pv}}\eta_{\mathrm{lin}}$$

- η_{lin} is negative, usually small.
- Both coefficients can be presented as function of concentration.
- this model is receiver local.

Electric string Issues

How real PV cells behave

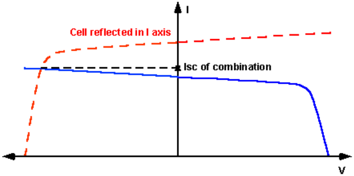


Source: PowerFromTheSun.net

- Efficiency depends on load (I/V ratio), insolation, temperature in a non-linear way.
- If maximum-power point can be maintained for a cell, the simple model works.

Electric string issues

Mismatch and bias



Source: pvcdrom.pveducation.org

- A weakly-illuminated cell will be reverse-biased.
- Excess energy unloaded on weak cell!
- Strong cells also less efficient.
- Mitigation: bypass diode.

New model

Electric constraints

Expand non-linear equation system:

- Existing model solves for flow-rates based on pressure drop.
- Add solving for cell electric state based on electric-circuit rules.
  - Current equality.
  - Target current,

$$I_i = \sum V / R_{\mathrm{inv}}$$

New model

Thermal constraints

- Add solving for cells' temperature using energy conservation law.
  - Calculate power into coolant in a top-down order:

$$q_0 = q_{\mathrm{el}} - q_{\mathrm{losses}}$$

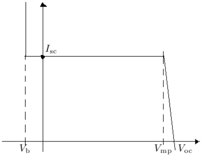
  - Calculate power in a left-right order using inlet temperature:

$$q_o^* = \dot{m}C_{\mathrm{p}}\left(1 - e^{-UA/\dot{m}C_{\mathrm{p}}}\right)(T_{\mathrm{ex}} - T_{\mathrm{in}})$$

  - Correct solution: $q_o = q_o^*$
  - Thermal constraints depend an all previous receivers in string.

Rotating the I-V curve

A PV cell’s I-V curve in an simplified way:



- A constant-current part.
- A constant-voltage part.
- A nearly-constant-voltage part.s

Over which variable to iterate?

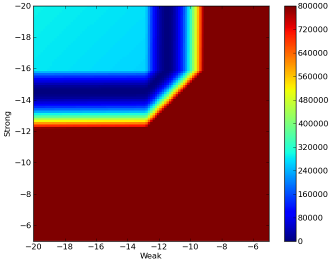
Rotate the curve:

$$b = V - R_{\mathrm{eq}} I$$

Initial values

The problem

- For mismatched cells, the error landscape of the electric constraints exposes a long ditch.
- On those points, the currents can't get much closer without changing the target current significantly.



Initial values

Possible solutions

Continuation methods:

- Start with something you can solve.
- Use its solution as the initial value for a problem closer to the area of difficulty.
- Move closer and closer.
- This method is used in circuit simulators (spice).
- Slow but sure.

Initial values

Possible solutions

Problem analysis:

- Derive an initial solution from problem features.
- In this case, directly solve using the linear I-V curve model.
- Problem-specific.

Solver considerations

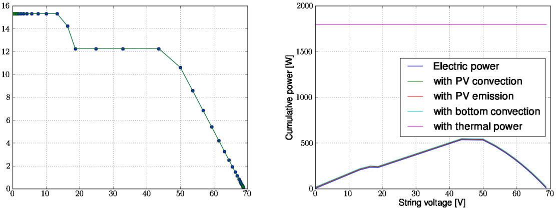
- Algorithm:
  - Levenberg-Marquardt (LM) replaces BFGS.
  - Result: running time and number of function calls reduced by over a half!

Solver considerations

- Algorithm:
  - Levenberg-Marquardt (LM) replaces BFGS.
  - Result: running time and number of function calls reduced by over a half!
- Constraints:
  - An $n \times n$ matrix for n constraints, each a function of n flow-rates
  - Bordered constraints: $c_i = \Delta P_i \left(\vec{\dot{m}}\right) - \Delta P_0 \left(\vec{\dot{m}}\right)$
  - Banded constraints: $c_i = \Delta P_i - \Delta P_{i-1}$
    - No noticable effect.
  - Average constraints: $c_i = \Delta P_i - \overline{\Delta P}$
    - Introduces an extra constraint.

Results

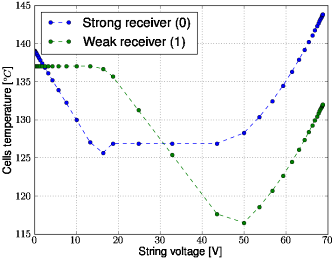
Validation



- Reproduces the well-known I-V curve for an active/bypassed pair.
- Reproduces the P-V curve for the same case.

Results

Temperatures



- Trough-points in temperature correspond to PV module’s peak-power point.
- Unloading of excess energy on the weak receiver is visible.

Results

Benchmark

- Benchmark: generate the two-receiver I-V curve.
- 50 points: 0.721
- Projection to 500 annual simulations on 4 cores: 1.75 hours
- Still lots of Python code involved.

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