ACTUAL OPTICAL AND THERMAL PERFORMANCE OF PV-MODULES

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ABSTRACT

Actual efficiency of photovoltaic generators is often lower than predicted by standard test conditions (STC [1]) or standard operating conditions (SOC). This is caused mainly by an underestimation of reflection losses and solar cell temperature in the module. To get more accurate results in predicting the performance of PV-modules, the parameters influencing incoming (optical parameters [3]) and outgoing power flow (electrical and thermal parameters [4]) were investigated by simulation and some verifying experiments at the University of New South Wales and the Australian desert [5].

OPTICAL PARAMETERS

Losses by reflection at glass surface laminated PV-modules are 4-5 % only at perpendicular incidence of sun-radiation. For most applications incidence angles can vary significantly from normal, which results in increased reflection losses according to FRESNEL's laws [2] at each slab (see Fig.1).

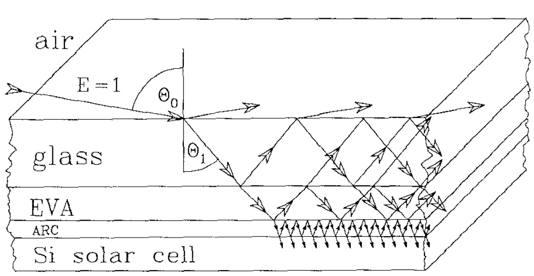

Fig. 1. Ray tracing through the module layers.

Also non-homogenous diffuse components (Fig.3) [7] and polarization of skylight (Fig.4) [6] have been accounted for. The difference to previous models is quite significant. As shown in Fig.2, the usually used perpendicular incidence gives only a peak value of the real transmittance of the encapsulation system during a day, especially if only the air/glass transition is regarded.

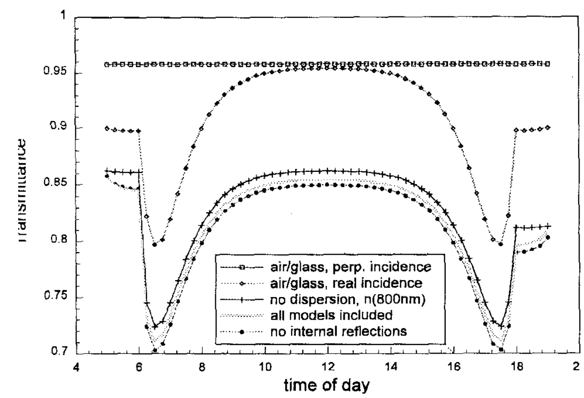

Fig. 2. Transmittance of an encapsulation of a standard PV module (PQ 40/50) over a day (21/3 at 34°S) calculated with different models.

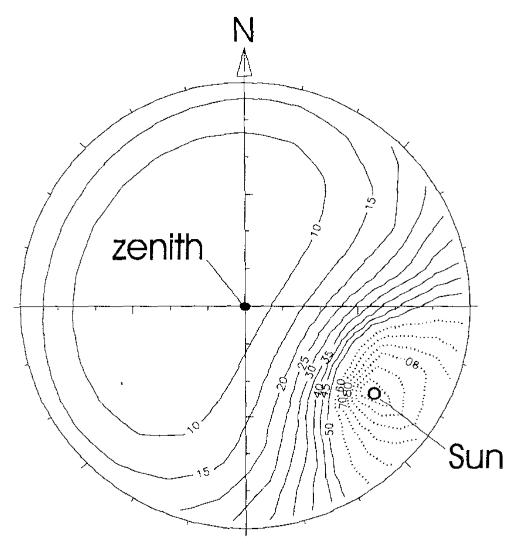

Fig. 3. Non-isotropic distribution of diffuse irradiance (according to DIN 5034) for a sun elevation of 30° and clear sky conditions in W m^{-2} sr^{-1} (projection from sky sphere).

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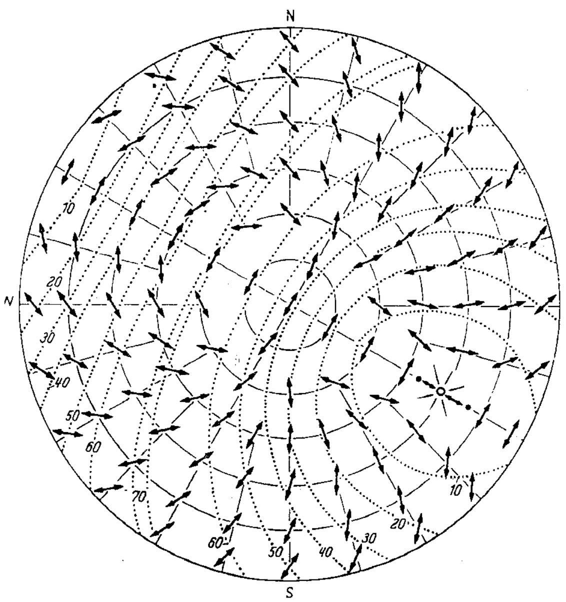

Fig. 4. Degree of polarization (in %) and directions of planes of polarization (arrows) of diffuse irradiance at a sun elevation of 30° (projection from the sky sphere).

Total reflection losses of the optical system consisting of module encapsulation and solar cell are in the vicinity of 20 % (Fig. 5 and Fig. 6).

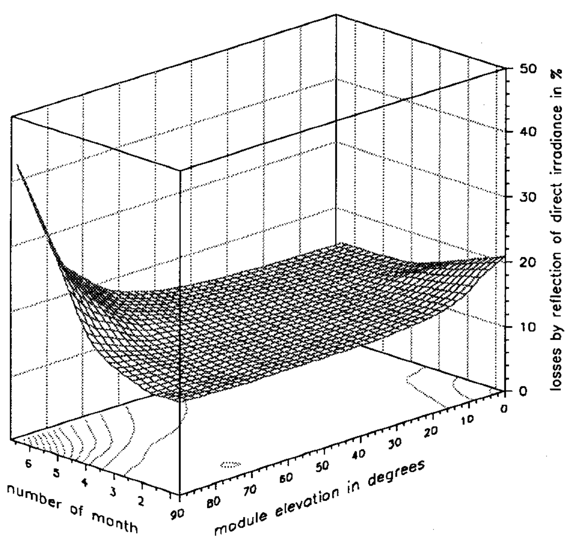

Fig. 5. Daily reflection losses of a non-tracking module for direct irradiance (Site: 34.5°N, Module: PQ 40/50, tilted southward).

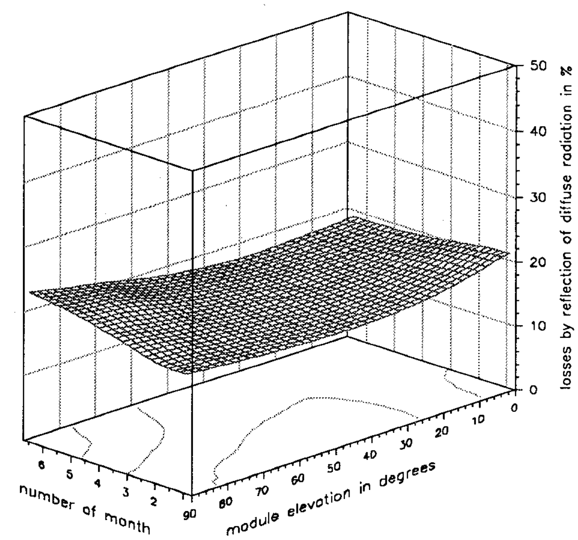

Fig. 6. Daily reflection losses of a non-tracking module for diffuse irradiance (Site: 34.5°N, Module: PQ 40/50, tilted southward).

An optimal matching of the refractive indices of the front layers allows an improvement of 4 % of PV output generated over a day [3]. To decrease further reflection losses, a V-structure on the surface is suggested [9].

THERMAL PARAMETERS

PV modules loose voltage and efficiency at elevated cell temperatures by 0.4-0.5 % K^{-1} for crystalline silicon solar cells. The cell temperature at a certain heat flow (absorbed irradiance minus generated PV power) is determined by the heat radiation exchange (among module and environment) and the convective heat transfer coefficient (see Fig. 7.).

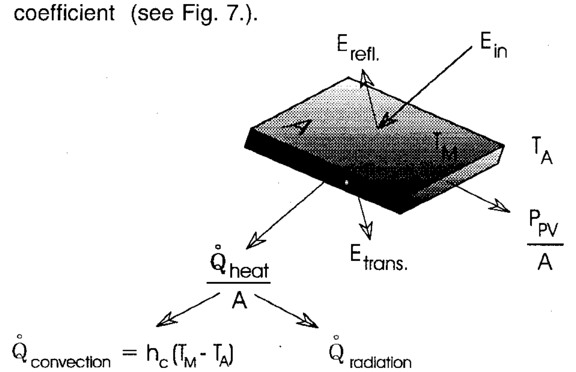

Fig. 7. Balance of energy flows at a PV module

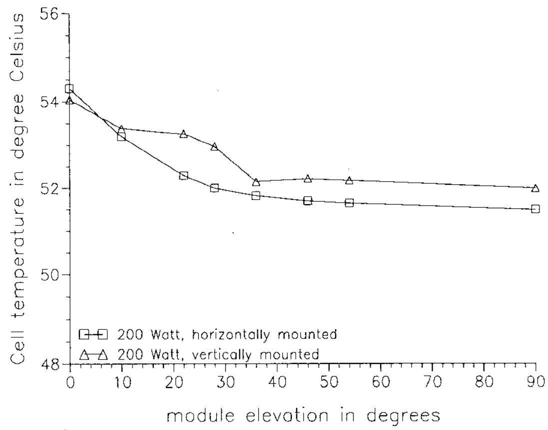

Fig. 8. Cell temperature at a heat flow of 200 W in a M 55 module (400 W m^{-2}) for $T_{ambient}$ = 24.9 °C.

The elevation angle of the module has little influence on the natural convective heat transfer coefficient in the 20°-80° elevation angle range (< 0.2 %). However, at almost horizontal position (0°-20° angle of elevation) the energy output of the module decreases by approximately 0.7 % due to elevated cell temperature. Horizontal, instead of vertical mounting of a standard module increases efficiency by 0.3 % (see Fig. 8). Heating was done by forcing an electrical power dissipation in the cells (using cells as diodes in forward direction).

SIMULATION

The process of insolation, absorption, power dissipation by electrical load, heat transfer to the front and back surface of the module, heat dissipation by radiation exchange with the ground and the sky, natural and forced convection was simulated by a computer program [5]. The results for a simulation of the module efficiency during a day are shown in Fig. 9.

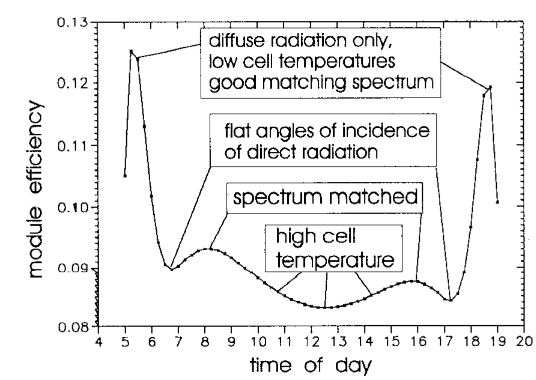

Fig. 9. Module efficiency during a day (21/6 at 34.5°N, PQ 40/50).

For every solar position during a day, each point on the sky sphere was described by its specific spectrum, polarization and incidence angle towards the module surface. All components were traced separately until their absorption in the solar cell. After adding up of all absorbed components the balance of energy flows was carried out.

VERIFICATION

The model used for the determination of the cell temperature was verified by measurements in the Australian desert. For the simulation a constant wind speed of 2 m/s was used as input and the ambient temperature as shown in Fig. 9. It can be seen that the predicted cell temperature follows accurately the actual measured one with a peak deviation of 3 K, which occurred only when the actual wind speed was quite different from 2 m/s.

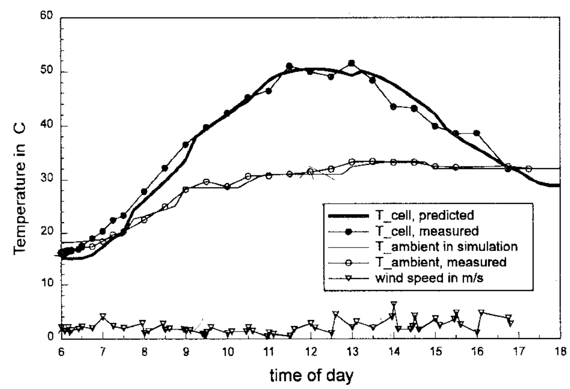

Fig. 10. Measured cell temperatures versus simulation at 4/3/94 in Fowlers Gap (31°5'S, 141°40'E, module elevation: 30°).

IMPROVEMENTS

A tilt of the module azimuth towards east allows a better performance in the morning time while lower ambient temperatures occur (maximum at + 0.4 % for 35°).

A gain of 2.6 % was achieved by attaching a small water tank (12.3 l) to the backside of a module to increase the total heat capacity. During a day the minimum of efficiency is then delayed two hours from the maximum of insolation at lower peak temperatures. A latent heat storage foil is under development and should allow an improvement of 8-10 %.

Continuous studies led us to the TOEPVIS-module (Thermal and Optical Enhanced PV module with Integrated Stand). Here the thermal capacity, a water tank made out of recycled PE, was enlarged in such a way, that the tank also serves as the module stand. The cell temperatures are lowered decisive, which results in a gain of energy output of 11-14 % (see Fig. 11). A photo of the prototype module is shown in Fig. 12.

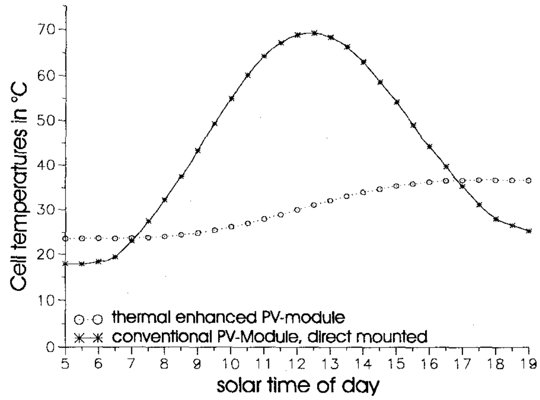

Fig. 1. Cell temperatures of a conventional PV module compared to TOEPVIS module during a day.

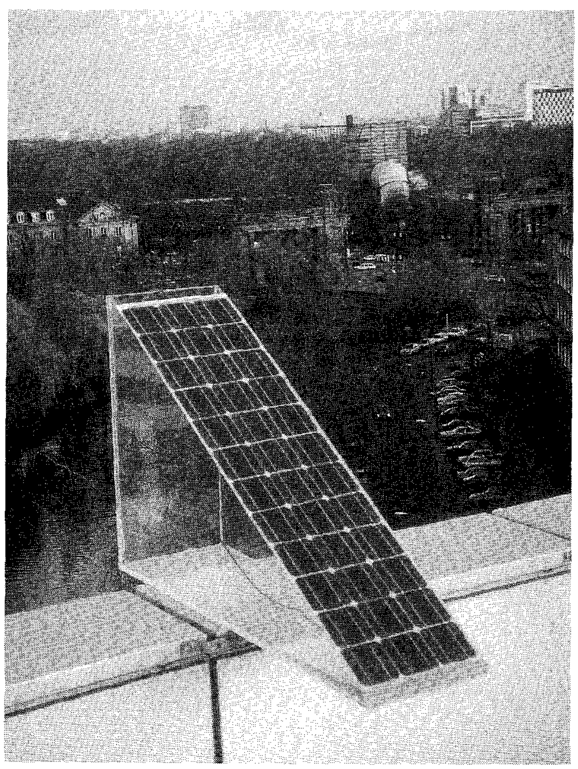

Fig. 12. TOEPVIS prototype

Together with an encapsulation with better matched refractive indices and a partial surface structure [9] an increased energy output of 18 % under arid conditions is possible. Comparing the costs of a conventional PV installation with framing, mounting, installation and fundament, the TOEPVIS installation will cost only 60-80 % of it. In total the TOEPVIS module will allow a cost reduction of 10-15 %, plus an increased output, so a total gain in the 30 % region could be achieved.

CONCLUSIONS

The model and the simulation program developed allow us to predict optical and thermal performance under realistic operating conditions, and they are promising tools for evaluating PV power plants with the aim of increasing efficiency.

LITERATURE

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