CALCULATED SOLAR CELL ISC SENSITIVITY TO ATMOSPHERIC CONDITIONS UNDER DIRECT AND GLOBAL IRRADIANCE

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ABSTRACT

Using a new solar spectral irradiation computer model, a procedure has been devised which allows the calculation of short-circuit current (Isc) sensitivity to atmospheric variables. This procedure, which has applications for photovoltaic reference cell calibrations, clearly shows the Isc sensitivity to spectral distribution changes without the influence of the total irradiance level. Example outputs are presented for four different solar cell types.

METHODOLOGY

The short-circuit current of a linear, single-junction solar cell can be expressed as

\[ I = A \int E_i(\lambda) R(\lambda) \, d\lambda \]

where \( A \) is the active area of the device, \( E_i(\lambda) \) is the spectral irradiance (W/m²/nm), and \( \lambda \) the wavelength (nm). Varying \( E_i(\lambda) \) in equation 1 will show variations in \( I_{sc} \), but the resulting \( I_{sc} \) changes will be due to both spectral and total (integrated) irradiance changes. To isolate the two effects, equation 1 can be divided by the total irradiance, or

\[ CN = \frac{A \int E_i(\lambda) R(\lambda) \, d\lambda}{\int E_i(\lambda) \, d\lambda} \]

where \( CN \) is the normalized calibration number and \( E_{ref}(\lambda) \) is the spectral irradiance which corresponds to the reference atmospheric conditions. Notice that the active area has been eliminated and all spectral quantities appear in both the numerator and the denominator. Therefore, changes in \( CN \) which occur from varying \( E_i(\lambda) \) are due to spectral changes alone and are relative to \( E_{ref}(\lambda) \).

Figure 1. External quantum efficiency vs. wavelength for silicon (+), GaAs (x), CdS/CuInSe2 (diamond) and a-Si:H (box) devices used in this study.
Figure 2. \( \tau \) vs. water vapor, turbidity at 0.5 \( \mu \)m, and zenith angle (degrees) for silicon device under direct irradiance.

Figure 3. \( \tau \) vs. water vapor, turbidity at 0.5 \( \mu \)m, and zenith angle (degrees) for silicon device under global irradiance.

Figure 4. \( \tau \) vs. water vapor, turbidity at 0.5 \( \mu \)m, and zenith angle (degrees) for GaAs device under direct irradiance.

Figure 5. \( \tau \) vs. water vapor, turbidity at 0.5 \( \mu \)m, and zenith angle (degrees) for GaAs device under global irradiance.
Figure 2. Efficiency vs. water vapor, turbidity at 0.5 μm, and zenith angle (degrees) for silicon device under direct irradiance.

Figure 3. Efficiency vs. water vapor, turbidity at 0.5 μm, and zenith angle (degrees) for silicon device under global irradiance.

Figure 4. Efficiency vs. water vapor, turbidity at 0.5 μm, and zenith angle (degrees) for GaAs device under direct irradiance.

Figure 5. Efficiency vs. water vapor, turbidity at 0.5 μm, and zenith angle (degrees) for GaAs device under global irradiance.
Figure 6. \( M \) vs. water vapor, turbidity at 0.5 µm, and zenith angle (degrees) for CdS/CdSe device under direct irradiance.

Figure 7. \( M \) vs. water vapor, turbidity at 0.5 µm, and zenith angle (degrees) for CdS/CdSe device under global irradiance.

Figure 8. \( M \) vs. water vapor, turbidity at 0.5 µm, and zenith angle (degrees) for a-Si:H device under direct irradiance.

Figure 9. \( M \) vs. water vapor, turbidity at 0.5 µm, and zenith angle (degrees) for a-Si:H device under global irradiance.
Figure 6. \(\text{CC} \text{ vs. water vapor, turbidity at } 0.5 \mu m\) and zenith angle (degrees) for CdS/CdS rings device under direct irradiance.

Figure 7. \(\text{CC} \text{ vs. water vapor, turbidity at } 0.5 \mu m\) and zenith angle (degrees) for CdS/CdS rings device under global irradiance.

Figure 8. \(\text{CC} \text{ vs. water vapor, turbidity at } 0.5 \mu m\) and zenith angle (degrees) for a single device under direct irradiance.

Figure 9. \(\text{CC} \text{ vs. water vapor, turbidity at } 0.5 \mu m\) and zenith angle (degrees) for a single device under global irradiance.
PROCEDURE
The computer model which was used to vary $E(t)$ outputs both a direct beam and a global spectrum for a given set of input atmospheric variables (1). It was possible to obtain simultaneously the global and direct sensitivities for a given solar cell. The model provides for a large number of variables to be input such as atmospheric turbidity, surface air pressure, water vapor and ozone content, solar zenith angle, and ground albedo for a cloudless sky. In order to restrict the input to three independent variables, it was necessary to fix all other variables except the water vapor content, atmospheric turbidity, and the solar zenith angle. Fortunately, most of the other variables except the air pressure either do not vary much or have a rather small effect on the spectrum. The reference conditions chosen for this study are water vapor, 1.42 cm; atmospheric turbidity at 500 nm, 0.27; air pressure, 1013.25 mb (sea level); ozone, 0.34 cm; ground albedo, 0.2; and zenith angle, 48.19° (corresponding to air mass 1.5) (2).

Four measured spectral responses were chosen for study, and the quantum efficiencies of these devices are presented in figure 1. The input variable matrix used consisted of 21 values of turbidity, 29 zenith angles, and four water vapors, which resulted in 1,872 different spectra. These were used in equation 3 with the spectral responses to calculate the normalized calibration number for each case. The resulting 33,168 CN's are presented in figures 2-9. Each CN was sorted into bins as follows:

- CN 0.9800 to 0.9867;
- CN 0.9867 to 0.9933;
- CN 0.9933 to 1.0000;
- CN 1.0000 to 1.0067;
- CN 1.0067 to 1.0133;
- CN 1.0133 to 1.0200.

Therefore, each character maps a location where the CN is within a given range of unity and on any given plot, the total area marked shows the region where CN is within 2% of unity.

DISCUSSION
Some major trends are evident upon examination of Figs. 2-9. From the total number of points marked in each series, it is seen that silicon is the least sensitive while a-Si is the most sensitive. GaAs is very similar to silicon although it is slightly more sensitive. In terms of outdoor performance measurements, this means that silicon will perform more uniformly than a-Si, which has a larger variation in sensitivity to atmospheric conditions. GaAs is similar to silicon, although it is slightly more sensitive. These results indicate that silicon and GaAs are the most promising materials for terrestrial use, while a-Si is the least promising.

Since $E(t)$ is variable among solar simulators (indoor) and varies with air mass and atmospheric conditions (outdoors), all of the device performance relationships shown above are affected by variations in spectral irradiance. The purpose of this paper is to describe models and instruments used to produce data sets of spectral irradiance. This paper describes conditions for particular spectral irradiance conditions. Specific PV device models can be combined with spectral irradiance models to predict PV device efficiency and power output for a range of air mass and atmospheric conditions, or to optimize device performance for particular irradiance conditions. Careful design and operation of instrumentation is required to ensure high-quality measurements of spectral irradiance for PV device testing, model validation, and development of an empirical data base.

SOLAR IRRADIANCE MODELS, DATA, AND INSTRUMENTATION FOR PV DEVICE PERFORMANCE ANALYSIS

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REFERENCES

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