16.3 CURRENT VERSUS VOLTAGE MEASUREMENTS

A solar cell can be modeled as a diode in parallel with a current generator, whereas a module is a series-parallel network of solar cells, as discussed in Chapter 7. Measurements of cell or module $I-V$ behavior allow the diode characteristics to be determined, along with other important parameters including the maximum-power point, $P_{\max}$. A typical $I-V$ measurement system is composed of a simulated or natural light source, test bed to mount the device under test, temperature control and sensors, and a data acquisition system to measure the current and voltage as the voltage across the device or current through the device is varied with an external load or power supply.

16.3.1 Measurement of Irradiance

Irradiance measurements are made with respect to a reference spectral irradiance or the prevailing solar spectral irradiance. The measurement of the irradiance, E_{tot}, incident on the PV device in equation (16.1) is typically performed with a thermal detector (pyranometer, cavity radiometer) for outdoor measurements and reference cells for simulator-based measurements. If the goal is to determine the PV efficiency or power with respect to standardized or different reference conditions, then a spectral error will exist. Outdoor measurements of PV systems or modules are often made with respect to the prevailing or total irradiance incident on the module. If a broadband thermal detector with a constant spectral responsivity is used, then the spectral error is zero. If a silicon-based pyranometer is used to measure the performance based on the total irradiance, then there will be a spectral error because Si does not respond over the entire spectrum. For PV measurements with respect to a reference spectrum, the spectral error in the measured short-circuit current I_{SC} of a PV device can be written in general as [2]:

$$I'_{\text{SC}} = \frac{I_{\text{SC}}}{M} = I_{\text{SC}} \frac{\int_{\lambda_1}^{\lambda_2}\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} E_{\text{Ref}}(\lambda,\theta,\phi) S_{\text{T}}(\lambda,\theta,\phi)\,\mathrm{d}\lambda\mathrm{d}\theta\mathrm{d}\phi}{\int_{\lambda_1}^{\lambda_2}\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} E_{\text{Ref}}(\lambda,\theta,\phi) S_{\text{R}}(\lambda,\theta,\phi)\,\mathrm{d}\lambda\mathrm{d}\theta\mathrm{d}\phi} \times \frac{\int_{\lambda_1}^{\lambda_2}\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} E_{\text{S}}(\lambda,\theta,\phi) S_{\text{R}}(\lambda,\theta,\phi)\,\mathrm{d}\lambda\mathrm{d}\theta\mathrm{d}\phi}{\int_{\lambda_1}^{\lambda_2}\int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} E_{\text{S}}(\lambda,\theta,\phi) S_{\text{T}}(\lambda,\theta,\phi)\,\mathrm{d}\lambda\mathrm{d}\theta\mathrm{d}\phi}, \tag{16.16}$$

where the spectral responsivity of the device under test (S_{T}), spectral responsivity of the reference detector (S_{R}), reference spectral irradiance (E_{Ref}), and source spectral irradiance (E_{S}) are a function of wavelength (λ) and incident azimuth (ϕ) and zenith (θ) angles. This general form allows the reference detector to be noncoplanar with the device under test and the source angular distribution of the source spectrum to be nearly arbitrary. In practice, the test device and reference detector used to measure the total irradiance are usually coplanar to minimize errors associated with measuring the orientation. The