SUMMARY

The performance of photovoltaic (PV) modules in terms of their ability to convert incident photon to electrical energy (efficiency) depends mostly on the spectral distribution of incident radiation from the sun. The incident spectrum finally perceived by the module depends strongly on the composition of the medium in which it has traveled. The composition of the earth's atmosphere, which includes, amongst others, water vapour, gases such as carbon dioxide and oxygen, absorbs or scatters some of the sunlight. The incident solar spectrum is also modified by the diffuse aspect of radiation from the sky which strongly depends on aerosol concentration, cloudiness and local reflection of the earth's surface. Although it is well known that the changes in outdoor spectrum affect device performance, little work has been conducted to support this theory. This is probably due to lack of spectral data or in certain instances where data is available, little knowledge of interpreting that data. The outdoor spectral data that one obtains in the field does not come clearly for just simple interpretation. Different analytical interpretation procedures have been proposed, all trying to explain and quantify the spectral influence on PV devices.

In this study an assessment methodology for evaluating the effects of outdoor spectra on device performance parameters during the course of the day, seasons and or cloudy cover has been developed. The methodology consists of developing a device dependant concept, Weighted Useful Fraction (WUF) using the outdoor measured spectral data. For measuring PV module's performance parameters, a current-voltage (I-V) tester was developed in order to monitor the performance of six different module technologies. The Gaussian distribution was used to interpret the data. For hot-spot analysis, different techniques were used, which include Infrared thermographic technique for identifying the hot-spots in the solar cells, SEM and EDX techniques. The AES technique was also used in order to identify other elements at hot-spots sites that could not be detected by the EDX technique.

Results obtained indicate that multicrystalline modules performance is affected by the changes in the outdoor spectrum during summer or winter seasons. The modules prefer a spectrum characterized by WUF = 0.809 during summer season. This spectrum corresponds to AM 2.19 which is different from AM 1.5 used for device ratings. In winter, the mc-Si module's WUF (0.7125) peaks at 13h00 at a value corresponding to AM 1.83. Although these devices have a wider wavelength range, they respond differently in real outdoor environment. Results for mono – Si module showed that the device performs best at WUF = 0.6457 which corresponds to AM 1.83 during summer season, while it operates optimally under a winter spectrum indicated by WUF of 0.5691 (AM2.58). The seasonal changes resulted in the shift in WUF during day time corresponding to the "preferred" spectrum. This shift indicates that these devices should be rated using AM values that correspond to the WUF values under which the device operates optimally. For poly-Si, it was also observed the WUF values are lower than the other two crystalline-Si counterparts. The pc-Si was observed to prefer a lower AM value indicated by WUF = 0.5813 during winter season while for summer it prefers a spectrum characterized by WUF = 0.5541 at AM 3.36.

The performance of the single junction a-Si module degraded by 67% after an initial outdoor exposure of 16 kWh/m² while the HIT module did not exhibit the initial degradation regardless of their similarities in material composition. It was established that the WUF before degradation peaks at 15h00 at a value of 0.7130 corresponding to AM 4.50 while the WUF after degradation "prefers" the spectrum (WUF = 0.6578) experienced at 15h30 corresponding to AM value of 5.57. Comparing the before and after degradation scenarios of a-Si:H, it was observed that the device spends less time under the red spectrum which implies that the device "prefers" a full spectrum to operate optimally. The degradation of a-Si:H device revealed that the device spectral response was also shifted by a 7.7% after degradation. A higher percentage difference (61.8%) for spectral range for the HIT module is observed, but with no effects on device parameters.

Seasonal changes (summer/winter) resulted in the outdoor spectrum of $CuInSe_2$ to vary by ΔWUF = 1.5%, which resulted in the decrease in I_{sc}. This was ascertained by

analyzing the percentage change in WUF and evaluating the corresponding change in I_{sc}. The analysis showed that there was a large percentage difference of the module's I_{sc} as the outdoor spectrum changed during the course of the day. This confirmed that the 17% decrease in I_{sc} was due to a ΔWUF of 1.5 %.

In mc-Si solar cells used in this study, it was found that elemental composition across the entire solar cell was not homogenously distributed resulting in high concentration of transition metals which were detected at hot spot areas. The presence of transition metals causes hot-spot formation in crystalline solar cells. Although several transition elements exist at hot-spot regions, the presence of oxygen, carbon, iron and platinum was detected in high concentrations. From this study, it is highly recommended that transition elements and oxygen must be minimized so as to increase the life expectancy of these devices and improve overall systems reliability.

Keywords: *Photovoltaic modules, hot-spots, spectral distribution, light-induced degradation, air mass, transition metals.*