ABSTRACT

The worldwide photovoltaic (PV) installation capacity has expanded in recent decades to meet the increase in energy demand and to address sustainable development goals with a shift from conventional to renewable energy sources. In different existing modeling approaches of theoretical PV performance analysis solar irradiance, temperature and environmental parameters are considered as the governing factors. However, the role of spectral variation of solar irradiance over the day and seasons are found to be ignored. This might lead to lesser accuracy in modeling results. Furthermore, the effect of integrated approach of environmental parameters and solar spectrum need to be explored for reliable estimation of PV performance analysis. The existing literatures have reported non-transient study; although the factors affecting PV performance are dynamic and change over time and season during outdoor operating conditions. The increase in cell temperature is a major concern in estimating PV output. However, the integrated approach of spectral response of solar cell, transient nature of ambient temperature and cell temperature is found to be less prominent in earlier modeling. So, a dynamic temperature response model accountable to these factors provides justified solution. Though, an immutable correlation is expected between soiling and environmental parameters, however, the interdependency of soiling with environmental parameters and solar spectral need to be investigated. To address these concerns, this thesis presents integrated modeling approach through the analysis of spectrum dependent electrical-thermal model considering the soiling effect.

A real-time solar spectrum under varying meteorological parameters is generated using SMARTSv2.9.5. This transient solar spectrum is fed as an input to the developed electrical and thermal model. The one diode electrical model is developed in MATLAB and the electrical output of the PV module is estimated using environmental parameters and spectral response of the solar cells in the PV module. The unused part of the solar spectrum is fed into the thermal model developed in 'COMSOL Multyphysics'. The different spectral, thermal, and electrical models were integrated using COMSOL MATLAB Livelink. The transient nature of the solar cell temperature and its effect on the electrical output of the PV modules is considered

through iterative methods for higher accuracy of the model and reliable estimation of the PV output.

The developed spectrum-based electrical-thermal model is experimentally validated for various seasons using $50W_p$ monocrystalline silicon (m-Si) and $50W_p$ polycrystalline (p-Si) modules mounted at a fixed 26° slope angle in outdoor conditions. The experiments are conducted on various days of the season under clear-sky conditions, and for the validation, a typical day of the season is considered. The RMSE of back surface temperature and power output from m-Si PV module ranges from 1.67-2.59°C and 1.83-2.92 W, respectively, and the same for p-Si PV module ranges from 1.93-2.29°C and 1.70-3.63 W, respectively. The MAE of the short-circuit current and open-circuit voltage varies between 0.10-0.29 A and 0.41-0.58 V, respectively, for m-Si, 0.13-0.43 A and 0.39-0.52 V, respectively, for p-Si PV modules. Therefore, considering the simulated and experimental data along with error analysis it is found that the developed model can precisely estimate the PV performance even with seasonal variability.

The effect of soiling on PV module in different seasons is experimentally analyzed using transmittance of the cover glass samples (using glass coupons) mounted horizontally in the outdoor conditions and the cleaning cycle requirements for optimum yield of PV module during different seasons in 'warm and humid' climatic condition are investigated. The transmittance of horizontally-mounted glass coupons exposed in outdoors conditions is used to evaluate seasonal soiling correlations with environmental factors and effectiveness of different cleaning cycles using linear regression models and statistical (F- and t-test) analysis respectively. The statistical analysis revealed that weekly cleanings during winter and post-monsoon seasons; and monthly cleanings during south-west monsoon and pre-monsoon seasons are optimal for a 'warm and humid' climate like Assam, India. The transmittance of the PV glass surface is found to be more than 80% during winter and post-monsoon seasons and above 90% during south-west monsoon and pre-monsoon seasons. Furthermore, the transmittance loss due to soiling is incorporated in the developed integrated spectrum-based electrical-thermal model to evaluate the energy loss due to soiling.

The energy yield evaluation without soiling and with soiling is analyzed using the developed model. The deviation between the simulation and experimental typical energy yield during various seasons is found to be within the range of 2.40-8.06% and

1.10-10.9%, respectively, for clean m-Si and p-Si PV modules. The developed model has potential benefits for the scientific community and the installers for precise estimation of the PV performance. The maximum reduction in energy yield of both m-Si and p-Si PV modules due to soiling (without any manual cleaning) is found to be 26%, that is, during winter, followed by 20% during post-monsoon, then pre-monsoon with 16%, and the least during SW monsoon with 7%. The cleaning cycle recommendations are made based on the effect of soiling analysis during different seasons in a warm and humid location.

Keywords: photovoltaic, solar spectrum, electrical, thermal, temperature, power, soiling, transmittance loss, environmental parameters, linear regression, statistical analysis, simulation, experimental.