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PHOTOVOLTAIC SYSTEM MODEL CALIBRATION USING MONITORED SYSTEM DATA

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ABSTRACT

Accurate calibration of photovoltaic (PV) system models currently requires PV modules to be individually characterized outdoors on a 2-axis tracker. Significant cost savings could be realized if accurate calibration could be achieved using data obtained outdoors at fixed tilt and orientation. We present new methods for calibrating PV performance models using IV curves and module temperature measured outdoors on fixed tilt arrays and show that model prediction accuracy is comparable to that achieved by models calibrated using data obtained on a two-axis tracker.

1. INTRODUCTION

We present methods to calibrate two popular performance models, the Sandia Photovoltaic Array Performance Model (SAPM) [1] and the De Soto model [2], using data collected outdoors for modules at fixed tilt orientation. Calibration of a photovoltaic (PV) module performance model currently relies on measurements of electrical output taken outdoors with the module on a two-axis tracker [3], or indoors using a solar simulator [4]. By contrast, measuring electrical performance for systems outdoors on fixed racking is substantially cheaper, yet no method currently exists to translate these measurements to model coefficients.

SAPM comprises empirical expressions for short-circuit current, open circuit voltage, and the maximum power point. The De Soto model uses a single diode equivalent circuit to represent a module's IV curve. The popular software package PVsyst [5] also represents a PV module as a single diode equivalent circuit albeit with some differences from the De Soto model. Calibration of each model determines a set of module specific coefficients, including estimates for reflection losses at the module surface when the module is not normal to the sun and the variation in current due to the spectral content of incident irradiance.

2. MONITORED SYSTEM DATA

Five PV modules, representing a range of cell technologies, were used to test our methods. I-V curves were measured every 5 minutes outdoors at Los Alamos, NM, USA, over the course of 9 months, concurrent with module back-surface temperature, plane-of-array (POA) and global horizontal irradiance (using EKO MS-802 pyranometers), direct normal irradiance, air temperature and wind speed. Field data are filtered to exclude IV curves indicating measurement issues, e.g., when POA irradiance and I_{SC} do not conform closely to a linear relationship. Cell temperature is not measured; rather, it is estimated from the module back-surface temperature using methods described in [1]. The filtered data are divided into in-sample data used to calibrate the model and out-of-sample data used for model validation.

2. CALIBRATION METHODS

When calibrating the SAPM and the De Soto models using fixed tilt data, the primary challenge is establishing a relationship between the available irradiance measurements and I_{SC} for the SAPM and the light current for the De Soto model. Both models normally require beam and diffuse irradiance as inputs. Beam irradiance is reduced using an angle of incidence (AOI) dependent function $f_2(AOI)$ to account for reflection losses and irradiance reaching the cell is adjusted by an airmass-dependent function, $f_1(AMa)$, to represent the effects of variation in solar spectrum. For this work, however, we assume that only POA irradiance measurements are available and consequently we simplified both models to require only POA irradiance E as input. For the SAPM we set $I_{SC} = I_{SC0}\, E/E_0\, f_1(AMa)\left(1+\alpha_{Isc}\left(T_C - T_0\right)\right)$ and we set $I_L = E/E_0 f_1(AMa)\left(I_{L0}+\alpha_{Isc}\left(T_C - T_0\right)\right)$ for the De Soto model. By doing so, reflection losses are essentially made part of the empirical term $f_1(AMa)$. For comparison we also calibrated SAPM using measured DNI and a representative $f_2(AOI)$ function.

The calibration techniques and parameter descriptions used in this paper are described in more detail in [6, 7]. For the SAPM, parameters are generally estimated by rearranging the equations and using regression techniques. For the De Soto model a two-step procedure is required: first, the single diode equation is fit to each IV curve, then diode equation parameters are related to irradiance and temperature by regression.

Temperature coefficients are not determined directly from monitored data. Rather values from module datasheets are used for preliminary calibration and are later adjusted using an iterative procedure, after which the SAPM and De Soto models are re-calibrated to be consistent with the adjusted temperature coefficients.

3. RESULTS AND CONCLUSIONS

The calibrated SAPM and De Soto models for each module were used to predict the out-of-sample data. For each model, the predictor variables are POA irradiance and module back-surface temperature. We computed I_{SC}, I_{MP}, V_{OC}, V_{MP}, and P_{MP} using the calibrated models and compared the predictions with the measured values.

Table I lists the 90th percentile for the P_{MP} prediction error (percent of measured P_{MP}) for each model. For both the SAPM and the De Soto models, P_{MP} prediction error is similar to what is observed for module performance models calibrated to data obtained using a two-axis tracker or an indoor simulator [4]. For comparison Table I lists prediction errors for models for other module with similar cell technology. Prediction errors are generally greater for the De Soto model; we suspect these greater errors result from less accurate modeling of module output at low light levels. The greater prediction errors for either model for the Kaneka tandem a-Si module are not surprising, given that this module is effectively a two-junction device, whereas both models represent the module as a single junction device.

Table I: 90th percentile P_{MP} prediction error for the SAPM and the De Soto models using different data.

Fixed tilt data	SAPM	De Soto
Sharp mono-Si	1.92%	1.55%
Sunpower mono-Si	2.01%	2.73%
Kyocera poly-Si	1.83%	2.83%
Solar Frontier CIS	1.58%	3.14%
Kaneka tandem a-Si	4.09%	8.35%
Two-axis tracker data	**SAPM**	**De Soto**
Solar World mono-Si	0.81%	1.33%
Yingli poly-Si	0.96%	3.19%
Solar Frontier	0.62%	2.58%

Fig 1. illustrates the adjustment of the temperature coefficient for V_{MP} using the Kyocera poly-Si module. When we first fit the model using a datasheet value, a bias in predicted V_{MP} is evident (Fig 1, left panel). To adjust the datasheet value, a regression line was fit to the scatterplot and its slope is used to scale the datasheet temperature coefficient. The adjusted temperature coefficient is then used to re-calibrate the models and the process is repeated if predicted V_{MP} still shows bias. After 2-3 iterations the temperature coefficients stabilize. This updating process removes systematic biases we found primarily in the V_{OC} and V_{MP} predictions. The prediction errors in Table 1 result from models which incorporate adjusted temperature coefficients.

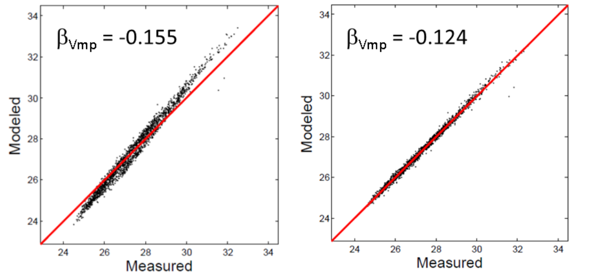

Figure 1: Prediction in V_{MP} before (left) and after (right) the temperature coefficient adjustment.

Our results demonstrate that reasonably accurate models for predicting output from PV modules can be obtained using data typically recorded for monitored PV systems. Our methods could greatly expand the ability to rapidly characterize as-built PV system performance.

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