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Precision Manual Sun Tracker Control

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Although traditional photovoltaic (PV) installations use fixed-tilt or single-axis tracking modules, little research has been accomplished in evaluating the outdoor measurement uncertainties and biases of using myriad solar radiation sensors in the different module orientations.

Thermopile pyranometers can be spectrally flat, temperature compensated, and have good cosine responses; however, the signal is not directly indicative of the energy available for power production based on the spectral selectivity of the PV material. In addition, thermopile pyranometers are viewed to be expensive within the industry. Some PV sites use photodiode based pyranometers. These sensors are less expensive but have spectral, temperature, and angle of incidence issues that are very difficult to parse from the data. These effects can be intensified when placed on a tracking PV system. Lastly, many users decide to install PV reference cells. These devices have the potential to provide the most accurate estimate of the available power the PV modules are receiving because they are matched materials and technologies. However, the reference cells cannot be used for an accurate irradiance measurement based on the spectral selectivity of the detector and sensor materials. So which sensor is correct for the application? Many researchers and engineers around the world have argued this point. Recently, collaboration between researchers at the National Renewable Energy Laboratory (NREL) and the University of Oregon has begun to fully understand the real-world biases of each sensor type.
But how can this seemingly tough task be accomplished? How can someone parse out the different biases?

Many papers have been published on fixed global horizontal irradiance (GHI) measurements as well as fixed plane of array (POA) measurements. But what about two-axis tracking or even one-axis tracking and the associated measurement biases? NREL took the lead in providing a proof of concept. To accomplish this, NREL needed a solar tracker that could be manually controlled. This tracker system would, of course, need to have very good pointing accuracy, reliability and be controllable via a PC or data logger.

Image 1. Various sensor types installed on the EKO tracker | Courtesy of Mike Dooraghi of NREL

Image 2 . Tracker installation | Courtesy of Mike Dooraghi of NREL

Image 3. Tracker installation, detail | Courtesy of Mike Dooraghi of NREL

Not many trackers can accomplish this task. Combine those features with the need to mount many sensors (high payload) and the possible tracker choices reduces greatly. The EKO Instruments STR-32G was selected as a platform to install the sensors on and provide the researchers with the ability to move the equipment into any orientation. Photographs of the NREL installation are shown above in images 1, 2 and 3. In addition to this unique research topic, NREL also uses the EKO STR-32G before the Broadband Outdoor Radiometer Calibration (BORCAL) season to establish the diffuse irradiance reference for the measurements season using the shade/unshaded method [1] [2]. As of the latest BORCAL (2018), the tracker shade/unshaded procedure was added to the BORCAL software (RCC) [3]. By using the STR-32G, NREL was able to completely automate the shade/unshaded processes by using RCC to control the tracker and shading arm position. In prior years, NREL would have to perform this operation manually, removing/installing the shading ball, and rotating the radiometer position. The STR-23G was able to rotate and move to multiple positions fast enough to perform the shade/unshade procedure. Each shade/unshade procedure is repeated several dozen times throughout a given day.

As shown in images 2 and 3, various sensor types were installed on the tracker as well as two EKO spectroradiometers. The total equipment installed is as follows: two reference cells, four photodiode pyranometers, a traditional thermopile pyranometer, the fast response EKO MS-80 pyranometer, EKO MS-710 (UV-VIS) spectroradiometer, and EKO MS-712 (NIR) spectroradiometer. By measuring the spectrum and controlling the sensor orientation, the spectral effects as well as angle of incidence effects of each sensor can be parsed out of the data. These measurements along with those present at NREL, informed previous papers from Vignola et al presented at the 2017 and 2018 IEEE PV Specialists Conferences [4] and the 2017 American Solar Energy Society Conference.

Under normal operation, the EKO tracker reads the tracker location from a global positioning system (GPS) receiver. Internally, the tracker calculates the sun's position and moves the tracker throughout the day. Often a sun sensor is combined, providing feedback to the tracking algorithm and allowing the tracker to point with an accuracy of <0.01°. However, a unique feature of the EKO STR series trackers is the Manual mode operation. In this mode, the user can point the tracker to a specified orientation.

To control the tracker, NREL wrote a CR Basic program running on a Campbell Scientific CR3000® Micrologger. While the EKO STR trackers can be

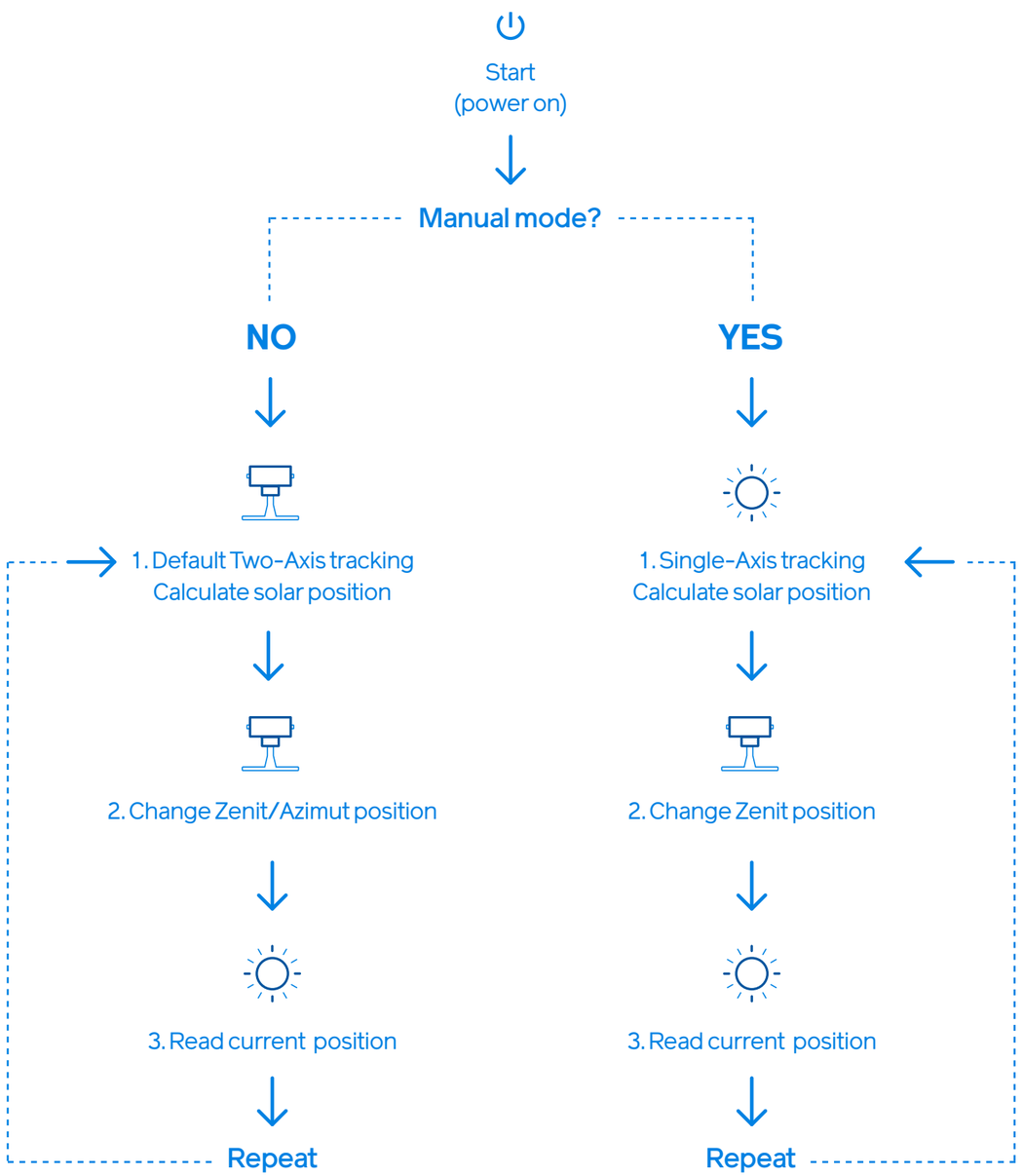
[1] *I. Reda, "Method to Calculate Uncertainties in Measuring Shortwave Solar Irradiance Using Thermopile and Semiconductor Solar Radiometers" NREL/TP-3B10-52194 July 2011*

[2] *I. Reda, A.M. Andreas, "Calibration Procedure of a Modified Hukseflux SR25 as an Example to Establish the Diffuse Reference for the Outdoor Broadband Radiometer Calibration" NREL/TP-1900-68999 August 2017*

[3] *A.M. Andreas, S.M. Wilcox, "Radiometer Calibration and Characterization (RCC) User's Manual: Windows Version 4.0," NREL/TP-3B10-65844, 2016.*

[4] *ignola, Frank & Peterson, Josh & Kessler, Rich & Dooraghi, Mike & Sengupta, Manajit & Mavromatakis, Fotis. (2018). Evaluation of Photodiode-based Pyranometers and Reference Solar Cells on a Two-Axis Tracking System. 2376-2381. 10.1109/PVSC.2018.8547299.*

Image 4 . Flow diagram of the NREL program.



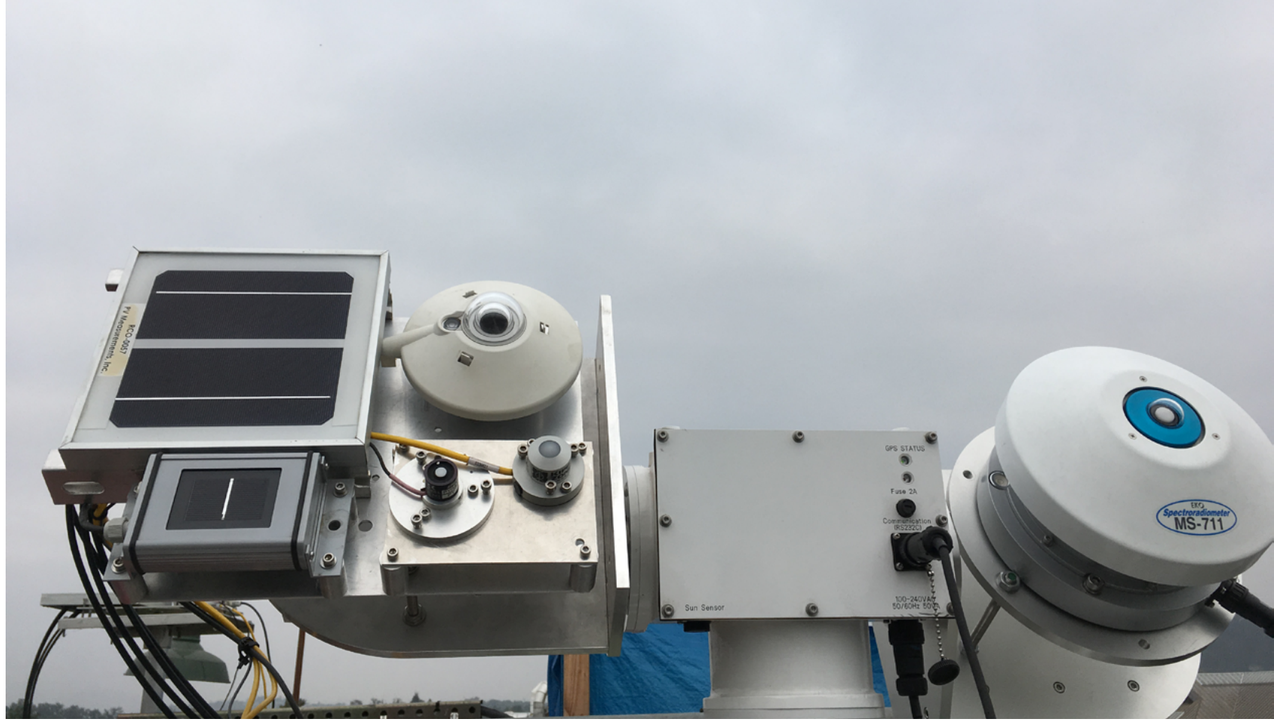


Image 5 . University of Oregon, Eugen installation | Courtesy of Mike Dooraghi of NREL

communicated with over RS-232 and RS-422. NREL wrote the CR Basic program to query and control the tracker over RS-232. Commands for the tracker can be provided to each user, please contact your regional EKO Instruments offices. The CR Basic program has been written in a way that allows for multiple modes, including normal two-axis tracking, one axis tracking, fixed angle (GHI or POA) as well as an option to simply point the system to any user specified location. A simplified flow diagram of the NREL program is shown on the left (image 4).
Following the proof of concept experiment at NREL, a similar system was deployed at the University of Oregon in Eugene. By installing similar equipment in two different climatic regions, the research team will be able to investigate a wider variety of conditions especially different solar spectra. An image of the Eugen installation is above (image 5).
This application will prove incredibly valuable to the PV community in truly understanding the differences in the various sensor technologies. We look forward to supporting this research and all other research related to PV, atmospheric science, and beyond. Special thanks to NREL members Mike Dooraghi, Afshin Andreas, Peter Gotseff, Bill Marion and Ibrahim Reda as well as University of Oregon members Frank Vignola, Josh Peterson, and Richard Kessler.

Image 6. Picture includes (from the right): Frank Vignola of the University of Oregon, Mike Dooraghi of the National Renewable Energy Laboratory, Josh Peterson and Richard Kessler of the University of Oregon. Not pictured and providing remote assistance is Afshin Andreas of NREL.

This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by [applicable Department of Energy office and program office, e.g., U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office]. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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