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Joshua Pearce, Adegboyega Babasola, Rob Andrews

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Joshua M. Pearce, Michigan Technological University and Queen's University
Adegboyega Babasola, St. Lawrence College
Rob Andrews, Queen's University

ABSTRACT

Eighteen organizations have formed a partnership to produce the Open Solar Outdoors Test Field (OSOTF), which has been designed to provide critical data and research on solar photovoltaic (PV) systems optimization in the public domain. Unlike many other projects, the OSOTF is organized under open source principles. All data and analysis, when completed, will be made freely available to the entire photovoltaic community and the general public. This paper documents how teamwork between educational institutions and industry has resulted in one of the largest systems in the world for this detailed level of analysis of PV systems performance in real-world conditions. The challenges to this approach will be addressed and appropriate models for garnering industrial teamwork will be discussed. Conclusions will be drawn about how to scale other opportunities for the sharing of data to assist in improved optimization of socially beneficial appropriate technologies.

Introduction

Solar photovoltaic (PV) technology, which converts sunlight directly into electricity, is one of the fastest growing Renewable Energy Technologies (RETs) in the world (REN21 2010; Kirkegaard et al. 2010). The PV industry, one of the most aggressive intellectual property battlegrounds in the global business sector, is growing at an unprecedented rate.[1] With growth came an increased demand for solar systems design and optimization in realistic outdoor environments as both large and small-scale PV systems are deployed at an increasing rate throughout the world. Yet high-quality PV system performance data and optimization routines are normally closely-guarded trade secrets. This results in sub-optimal PV system deployment and concomitant reductions in solar electricity generation and greenhouse gas emissions reductions. The efforts of governments, such as RETScreen,[2] developed in Canada, and the National Renewable Energy Lab's SAM, developed in the US,[3] to correct this problem have met with some success, but core unanswered questions on basic loss mechanisms remain, and thus most PV installations are sub-optimized even when the best commercial and/or free software is used.[4] To address this problem, the Open Solar Outdoors Test Field (OSOTF) was designed to provide critical data and research on PV systems optimization to the public domain. The partnership contains both academic and industry stakeholders, as seen in Table 1.

1 Consider that from 2000 to 2010, global solar PV deployment has increased from 0.26 GW to 16.1 GW1 (Mints 2011) with an annual growth rate of more than 40% (REN21 2011; IEA 2010).

2 The **RETScreen Clean Energy Project Analysis Software,** provided free-of-charge, can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability, and risk for various types of renewable-energy and energy-efficient technologies (RETs). The software (available in multiple languages) also includes product, project, hydrology, and climate databases, a detailed user manual, and a case study based college/university-level training course, including an engineering e-textbook. Available: http://www.retscreen.net/.

3 The System Advisor Model (SAM) is a performance and economic model designed to facilitate decision-making for people involved in the renewable energy industry. Available: https://www.nrel.gov/analysis/sam/.

4 A more complete list of available solar photovoltaic software can be found here: http://www.appropedia.org/Solar_photovoltaic_software.

Advanced Solar Investments Ltd.	PV system developer
AYA Instruments	Electricity monitoring company
Calama Consulting	Photovoltaic consulting firm
Dupont Canada	Chemical company
eIQ Energy	Power optimization systems manufacturer
Heliene Inc.	Photovoltaic manufacturer
KACO New Energy Inc.	Inverter manufacturer
Nanofilm	Nanotechnology company
Michigan Tech's Open Sustainability Technology Lab	University research group
Photovoltaic Performance Labs Inc.	Photovoltaic consulting firm
Schueco Canada	Photovoltaic manufacturer, supplier, and developer
Silfab Ontario	Photovoltaic manufacturer
Soventix Canada Inc.	Photovoltaic manufacturer
Sustainable Energy Applied Research Centre at St. Lawrence College	College Research Centre
Sustainable Energy Technologies Ltd.	Inverter manufacturer
Queen's Applied Sustainability Group	University research group
Queen's Innovation Park	University affiliated institution to stimulate commercialization and economic development
Universidad Privada Boliviana	University
Uni-Solar Ovonic LLC	Photovoltaic manufacturer

Table 1. Partners in the Open Solar Outdoors Test Field

Unlike many other projects, the OSOTF is organized under open source principles.5 All data and analysis, when completed, will be made freely available to the entire photovoltaic community and the general public. Live images are currently available from two of the three OSOTF sites on the web6 and the full documentation for the project is available7 and is already being utilized to build a similar system by the Center for Evaluation of Clean Energy Technology in Cortland, New York.

This paper documents how the teamwork between educational institutions and industry has resulted in one of the largest systems in the world (as seen in figures 1-3) for this detailed level of analysis of PV systems performance in real-world conditions. The challenges to this approach will be addressed, and appropriate models for garnering industrial team work will be discussed. Conclusions will be drawn on how to scale other opportunities for the sharing of data to assist in improved optimization of socially beneficial appropriate technologies.

The Open Solar Outdoors Test Field

The Open Solar Outdoors Test Field (OSOTF) consists of discreet test beds, the largest of which is located on the roof of the new Wind Turbine and Trades building at St. Lawrence College and which has room for 60 commercial PV panels, which are divided between eight angles of 5, 10, 15, 20, 30, 40, 50, and 60 degrees as seen in Figure 1. The second test field is located on a flat rooftop at St. Lawrence College and consists of two commercial flat roof ballasted systems as seen in Figure 2. In addition, the Queen's Innovation Park Test Site was developed as part of a preliminary study on the effects of snow on photovoltaic performance funded by Sustainable Energy Technologies.

5 Historically, "open source" has referred to a method of development in the software industry which allows software code to be published for other users to see, modify, and use, instead of being copyrighted or patented (Mockus et al. 2002). Here open source is further expanded to ideas concerning experimental designs and protocols, systems design, data, and even hardware designs.

6 http://snowstudy.ati.sl.on.ca/ and http://snowstudyballast.ati.sl.on.ca/.

7 SEARC OSOTF Design and Operations Manual http://www.appropedia.org/SEARC_OSOTF_Design_and_Operations_Manual.

It consists of 16 panels mounted at angles from 0 to 70 degrees, with two each at increments of 10 degrees.

Figure 1. Representative image of the first test field located at the roof of the Wind Turbine and Trades building at St. Lawrence College

Figure 2. Representative image of second test field located on a flat rooftop at St. Lawrence College

Figure 3. Representative image of Queen's Innovation Park test site

The OSOTF is one of the premier PV test beds in North America, and the experimental capabilities of this test bed are shown in Table 2.

Table 2. OSOTF Experimental Capabilities

Solar Radiation-Direct	CMP-22 Pyranometer	The highest quality secondary standard device, calibration directly traceable to the World Radiometric Reference in Davos, Switzerland.	<1%
Solar Radiation-Diffuse	CMP-22 Pyranometer	The highest quality secondary standard device, calibration directly traceable to the World Radiometric Reference in Davos, Switzerland, fitted with an adjustable shadow band.	<1%
Solar Radiation-Albedo	CMP-11 Pyranometer	Secondary standard device, calibration directly traceable to the World Radiometric Reference in Davos, Switzerland.	<2%
Wind Speed and Direction	RM-young wind monitor	WMO standard integrated wind speed and direction sensor.	+/- 3 m/s +/- 3 °
Temperature/RH	Rotronic HygroClip	Integrated temperature/RH sensor with radiation shield.	RH: +/- 1.5% Temp: +/- 0.2 C
Snow Depth	SR50 ultrasonic snow depth sensor	Provides accurate readings of snow on ground using calibrated ultrasonic pulses. Can give total snow depth and accumulation/settling rate.	+/- 0.4%
Data Acquisition System	Campbell Scientific CR1000	The industry standard for high-accuracy environmental monitoring. Expanded with multiplexers to accept 106+ point measurements.	+/- 0.12%
Photographs	StarDot NetCam IP camera	High resolution camera, photographing array at 5 minute intervals. Photos will be used with customized image analysis software to give: covered area, accumulation rate, sliding rate.	3 megapixel sensor
Panel Temperature	Custom T-type thermocouple	Monitoring of panel temperature profiles using Special Limits of Error T-type thermocouple wire. Attached to solid-state multiplexers with integrated cold-junction compensation.	+/- 0.5 C
Panel Power Monitoring	Custom Transducers with MPPT	The panels are monitored using a proprietary DC power transducer, calibrated using instrumentation traceable to NIST. This transducer measures Vmp and Imp at the regular collection intervals. The use of a 99.7% efficient MPPT device ensures that the DC maximum power point of the panel under any real world condition is known.	<1%
Spectral Distribution	Avantes 1105019u2 & 1105020U2 spectrometer	High quality spectrometer allows for monitoring of spectral effects within the range of PV sensitivities. This can be extremely useful when monitoring practical performance ratios and when investigating the effects of Albedo on PV performance.	>99.8 % corrected linearity, spectral range 200nm-2500nm

The OSOTF originated because in northern regions with significant snowfall, concentrating a much larger focus on PV development, there is a keen interest and concern about the effects of snow cover on solar energy yield. From small scale residential to large multi-MW ventures, developers are interested in the effect of snow on the performance of different types of panels and on the optimization of racking angles. There have been very few comprehensive studies performed which attempt to quantify the effects of snowfall, and none which provide universally applicable estimations of snow-related losses (Brench 1979; Ross 1995; Yoshio, Toshiyuki, and Makoto 1999; Yoshioka et al. 2002; Marion et al. 2005; Becker et al. 2006; David et al. 2009; Marion, Rodriguez, and Pruett 2009). Thus, the first goal of the study is to attempt to gain a better understanding of the effects of snowfall on PV performance, and to provide some recommendations for reducing these losses. By monitoring panel output, solar influx, snowfall, and meteorological factors, a loss due to snowfall can be determined for a general system at a variety of angles. In addition, thermal panel measurements lead to a better understanding of snow shedding mechanisms. A series of analysis algorithms have been developed which allow for constant data mining to determine factors such as snow coverage ratio using image analysis, performance ratio, and estimated losses/gains due to snowfall. These results are currently being prepared for publication in technical journals and, once passing peer review, will be open sourced along with all of the raw data.

Partnerships

Previous work has attempted to understand how openness can be conducive to industry. For example, Garud and Kumaraswamy (1993) studied how Sun Microsystems' open systems strategy from the 1980s and 1990s resulted in their share of the workstation market increasing from 15% to lead the industry in 1989 with 28%. Other authors, such as Heller and Eisenberg (1998) and Benkler (2004) have even made the case that strong and restrictive intellectual property (IP) protection and patents actually slow the pace of innovation at universities and institutions in the United States and create a tragedy of anti-commons. This type of intellectual straightjacket is particularly important when a new drug or treatment has the possibility to save numerous human lives around the world, but cannot be mass-manufactured due to patents and copyrights. Thus, several authors have argued for open source strategies to decrease drug prices (Maurer, Rai, and Sali 2004 ; Kapczynski et al. 2005). Finally, the application of open sourcing in fields such as nanotechnology (Bruns 2001; Mushtaq and Pearce 2011) and the less explored appropriate technology for international development (Pearce and Mushtaq 2009; Buitenhuis, Zelenika, and Pearce 2010) were found to be promising. However, there has been no examination of the application of openness in the technology of solar PV.

Currently, traditional proprietary models of design and innovation are the norm in the solar PV industry. Innovations in the PV industry, in general, are created within the research and development labs of universities and research centres, turnkey suppliers, and manufacturers. Sometimes, universities work together with suppliers and manufacturers; however, the fast pace of innovation, investment pressure, and rapid growth forces companies to fiercely maintain their intellectual property (Margolis, Mitchell, and Zweibel 2006). Although IP has been shown to limit innovation in other fields, there is no literature specifically related to intellectual property protection in PV as a large barrier for innovation.

However, evidence that patents may start to act as barriers to innovation is apparent in the recent patent ruling against the Swiss firm Oerlikon Solar AG. Oerlikon had exclusive rights on a patent covering the manufacturing process for micromorph thin film modules. The micromorph PV cell is a tandem solar cell made of two layers: amorphous silicon and microcrystalline silicon. Having two layers enables the cell to reach higher efficiencies than standard thin film silicon-based PV. This is because these two materials have nearly optimal bandgaps for a double junction solar cell under AM1.5 illumination (Meier et al. 1998). Oerlikon filed a patent infringement lawsuit against a module manufacturer, Sunfilm AG (Papathanasiou 2009). If the patent had not been challenged and overturned, research and innovation would have slowed down in the amorphous silicon thin film PV field significantly, due to the large monopoly that Oerlikon would have held over all companies. It is possible that as the thin film industry matures, more cases of patent infringements will arise, hindering rates of innovation and thus the overall uptake of solar PV.

In order to continue to accelerate PV innovation, a methodology for developing partnerships for the evolution of the OSOTF project was developed that attempted to take into account the conflicting interests of industry and accelerated open source research. The largest barrier to entry of all the industry partners was concern over a negative result, which could be derived from the open sourced data set of the OSOTF. In response to this challenge, a hybrid open source methodology was used, where data which would allow the test site to be utilized for academic research are released openly, while keeping proprietary information that could be utilized for commercial purposes confidential for each company.

For example, in the case of PV modules that were donated for the OSOTF (PV modules were often donated by their respective manufacturers, but other companies outside of manufacturing also donated modules), the power rating, technology/material, glass type, and all relevant physical properties of the panel are released publicly, while the model number and manufacturer of the panel is kept confidential. In this way, the public, academia, and the industry benefits from a rich data set containing all the information required for academic study and generalizable systems optimization information, while the industrial realm benefits from high-quality performance data about their specific product and are protected from a negative result influencing their future commercial success. In this way, open academic research can continue in parallel with applied industrial research and development, contained within an open source framework.

Overcoming Challenges to an Open Source Approach

The open source approach has challenges in bringing valuable and critical data to the public domain to promote innovation and improve products and processes. This is mainly due to industrial concerns about sharing proprietary information and losing competitive advantage. There are also fears of collaborating with post secondary institutions and academic researchers and giving them free access to commercial products and data for research and development, which again may assist industrial competitors. Thus, valuable information that could enhance innovation for the entire technical sector is kept "close to the chest" and all companies in the sector are hurt.

The collaborating partners in the Open Solar Photovoltaic Systems Optimization project were willing to overcome the challenges of open source because they saw value in having free access to critical research data that would be useful for product improvement and reductions in system losses. Building a community of partners was critical for the data set to be as useful as possible and the community worked well because the partners were committed to the open source approach. A large number of enthusiastic partners pledged their commitment to openness by signing of a memorandum of understanding (MOU) agreeing to the open sharing of the project results. In signing the MOU, the organizations jointly affirmed that intellectual integrity; freedom of enquiry and exchange of ideas; and equal dignity of all persons would govern the actions of all members of the organizations. In addition, the organizations also agreed that any intellectual property rights arising from any program or activity that have been established under the signed MOU would be determined in good faith and in writing between the organizations in relation to particular projects. In principle, the organizations agreed that such rights would be determined based on each organization's inventive contribution. The MOU achieved an acceptable level of confidence among the partners and enabled the open source project--the largest of its kind in the world--to take place.

Conclusions

A successful open source partnership has formed between 18 organizations to produce the OSOTF, which provides critical data and research in the public domain for solar PV systems optimization. This paper documented how the teamwork between educational institutions and industry has resulted in one of the largest systems in the world for this detailed level of analysis of PV systems performance in real-world conditions. The primary barrier to the open source methodology from industry was found to be concern over a negative result that might be derived from the data set of the OSOTF. In response to this challenge, a hybrid open source methodology was used, where data which would allow the test site to be utilized for academic research and generalizable results are released openly, while proprietary information that could be utilized for commercial purposes is kept confidential for each company. In this way, the public, academia, and industry all benefit. Using this methodology, open academic research and development can continue in parallel with applied industrial research and development, contained within an open source framework. Finally, this methodology can be scaled to other industries where opportunities exist for data sharing to assist in improved optimization of socially-beneficial appropriate technologies.

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