ABSTRACT

Analysis of the effect of tracking is made upon collection of solar radiation in solar system without concentration, and in non-tracking system with conventional and bifacial photovoltaic solar panel. A simple model is developed to account for daily variation of solar irradiance. For the experiments, an original 2-axis Sun tracker was developed. The tracking effect calculated and measured shows an increase in energy collection around 30 – 40%; bifacial panel with a small reflector collecting solar radiation for the rear face gives the corresponding increase of 50 – 60% for the same panel area.

Keywords: Photovoltaic Solar Panel, Bifacial Panel, Sun Tracking, Irradiance Variations.

1. INTRODUCTION

The problem which is constantly in focus of attention of scientists and technologists in the field of solar energy conversion by photovoltaic (PV) panels is the restricted conversion efficiency. One of its many aspects is the concentration of solar radiation and/or tracking of the Sun, to increase the efficiency as well as the total energy collected for conversion. Essential progress achieved in the field (see, for example, [1-3]) was mainly due to employment of semiconductor high technology and high degree of concentration, and is clearly connected with high cost of the devices developed. The purpose of this paper is to analyse the possibilities to increase the efficiency of utilization of solar energy in more practical way, using traditional and bifacial PV panels, low concentration systems and economic Sun trackers. The basis for the investigation made was the study of the daily variations of Solar radiation intensity in conditions of Querétaro, México, with the North latitude close to 23°.

These variations were found experimentally at the time of summer solstice (around June 22) when the position of the Sun at noon at this latitude is practically vertical, also at equinox time and at winter solstice. The calculated and measured increase of the total energy collected by Sun-tracking panel in comparison with the immobile one is around 35%; the larger effect could be obtained by using bifacial panels with sufficient illumination of their rear part.

2. MODEL FOR DAILY IRRADIANCE VARIATIONS

Variation of Solar irradiance during the day caused by the change of the angle \( \phi \) between the Sun radiation flux and zenith (and of the corresponding atmospheric air mass) was theoretically modelled in many publications (see [4-9]). As a rule, these models demand very detailed information about the state of atmosphere to be used (like light dispersion and absorption caused by water vapor, ozone layer, aerosols, etc.), which makes their utilization for quick estimations practically impossible. We constructed a simple model to calculate the dependence of irradiance upon the position of the Sun in relation to the zenith. The data known for the radiation intensity at different air mass: AM0 (1367 W/m\(^2\)), AM1 (925 W/m\(^2\)), AM1.5 (844 W/m\(^2\)) and AM2 (691 W/m\(^2\)), to serve as the reference points for calculations.

We consider the losses in solar radiation intensity \( I \) during passing through atmosphere as the result of absorption and scattering in it which we characterize with the summary coefficient \( \alpha \); the radiation loss \( (-dl) \) at the differential pass \( dx \) could be written as

\[
dl = -I(x) \alpha \, dx
\]
which in very rough approximation of $\alpha = \text{const}$ (“uniform atmosphere”) gives the following intensity variation with the distance “x”

$$I = I_C \exp(-\alpha x) \quad (2)$$

Here $I_C$ is the cosmic solar radiation (right outside the Earth’s atmosphere, the AM0 value). When “x” is the total path of radiation in atmosphere ($x = d$), then $I$ is the irradiation of Earth’s surface. The shortest path (the Sun position at zenith, $\phi = 0$, see Fig. 1) is equal to effective thickness of atmosphere $h$; depending on the angle $\phi$, the value of $d$ will change according to law

$$d = R \cos \phi [ (1 + 2h/R \cos^2 \phi)^{1/2} - 1] \quad (3)$$

which could be easily obtained by application to sketch given in Fig. 1 of the theorem related to intersection of a khorde with diameter, and taking into account that $h << R$ (the Earth’s radius). At relatively small angles, when $2h/R \cos \phi << 1$, (3) is converted to $d \approx h/\cos \phi$, which could be written immediately if one neglects the Earth’s curvature. In this case

$$I = I_C \exp(-\alpha h/\cos \phi) \quad (4)$$

In the case of exponential dependence of atmospheric absorption/scattering coefficient upon the distance from the Earth’s surface $h$ ($\alpha = \alpha_S \exp(-ah)$ where $\alpha_S$ is the coefficient value at $h = 0$, and $a$ is the barometric constant), with account of the relation found between $h$ and $x$ (the expression (3) with “d” substituted by “x”), the differential equation (1) is transformed into

$$\frac{df}{I} = -\alpha_S e^{-ax^2/2R} dx \approx -\alpha_S e^{-ax^2}(1 - ax^2/2R)dx \quad (5)$$

the last approximation being valid when

$$ax^2/2R << 1. \quad (6)$$

Integration of (5) in its last form along the whole atmosphere (in this case, from $x = 0$ to $\infty$) gives the irradiation of Earth’s surface

$$I = I_C \exp[-(\alpha_S/acos\phi)(1 - 1/Racos^2\phi)] \quad (7)$$

Fig. 2 presents the results of calculations according to expressions (7) (the curve) and (4) (squares), the constants in the expressions used were taken to get better adjustment of calculations with the known data for different air mass. It could be seen that the barometric atmosphere approximation agrees with the data mentioned in interval 0 – 60° with an accuracy better than 3 %, and even the uniform atmosphere approximation neglecting Earth curvature gives a good agreement for angles 0 – 45°, but for larger angles the calculated points are too low. Thus, we take expression (7) as reasonable theoretical approximation to treat the experimental results. For actual comparison of calculated results given in Fig. 2 with experiment, the relation between the angle $\phi$ and the time should be defined, based on the latitude of the observation point and the
specific season of the year. To discuss the data obtained with the Sun-tracking PV panel, the curve in Fig. 2 must be used; for an immobile panel oriented in most profitable manner, the irradiance found from the corresponding curve must be multiplied by the value of \( \cos \phi \), \( \phi \) being angle of incidence (see examples below).

3. EXPERIMENT: RESULTS AND DISCUSSION

3.1 Two-Axis Solar Tracking

The two axis tracking system designed and made uses the solar panel composed in our laboratory from c-Si cells elaborated by Russian plant “Solar Wind” (Fig. 3). The system is equipped with two geared servo motors (Colman EYQF-33300-661 and Globe 407A-350); 2 pairs of phototransistors (1 pair for each axis) are positioned in such a way that the difference of photoresponse in each pair is zero when the panel is orientated normally to the Sun radiation flux, and grows with an increase of angle of desorientation. The system monitoring is based on microcontroller PIC16F877 with 4 input channels (one for each sensor); the input analog signals in each channel are digitalized with resolution of 8 bits, the differential signal for each pair is calculated, and the proportional output PWP (pulse width modulated) signal is applied to the motors, until the correct position is reached. After that, the system enters the “sleeping state” for the time interval \( X \) which could be chosen depending on the accuracy of tracking necessary. In our case, the value of \( X = 20 \) min was taken, giving the tracking accuracy (i.e. deviation of radiation intensity from maximum) better than 0.5 %: the largest corresponding variation of angle \( \phi \) during this interval (at summer time) is 6 grad, and \( \cos 6^\circ = 0.995 \).

To calculate the total solar energy captured daily by the Sun-tracking panel, it is necessary to change the horizontal axis in Fig. 2 from angle \( \phi \) to corresponding time \( t \), find the area under the \( I(t) \) curve and double it. Experimental conditions which correspond to calculation presented (i.e. with the maximum corresponding to \( \phi = 0 \)) could be realized at summer time, around June 22 (summer solstice), in geographical points with North latitude close to \( \theta = 23.5^\circ \), like Guadalajara, Leon or Querétaro in Mexico. Our measurements were made in Querétaro on June 19, 2003, the results are shown in Fig. 4 (triangles with tracking, circles without it). Fig. 1 gives the scheme of experiment: line A-A denotes the Earth rotation axis, Sun radiation comes from the right (dashed arrows), the vertical line B-B indicates the boundary between illuminated and dark parts of Earth (day-night), \( O_3 \) is the observation point at noon; with time this point changes its position in relation to Sun following the circular line \( O_3 - O \), the solar day ends when \( \phi = 90^\circ \) (corresponds to the point \( O_1 \)). To estimate the duration of a solar day the time interval above 12 hrs, to be exact, we have to calculate the distance between the points \( O_1 \) and \( O_2 \) of the circle mentioned; a reasonable approximation could be made on the basis of triangle \( O_1O_2C \), neglecting the Earth curvature in the corresponding region. Thus we get \( l = O_1O_2 = R \sin \theta \ tg \theta \), and the duration of the day in hours \( t_s = 12 + 24 \cdot l/2\pi R \cos \theta = 12 + 24 \cdot \tan^2 \theta/\pi \). In the case considered, the day duration is 13.44 hrs.

![Fig. 3: Automatic two-axis Sun tracking system.](image1)

![Fig. 4: Experimental and calculated irradiance (see text).](image2)
lower than the experimental data at large angles \( \phi \). For non-tracking panel placed horizontally, the irradiation at arbitrary angle \( \phi \) is proportional to \( \cos \phi \). The ratio of the corresponding areas is 1.354 which means that the calculated tracking effect in the case examined (i.e. that of the vertical Sun orbit) constitutes 35.4 %. The experimental effect of tracking in this case (i.e. the ratio of areas under the upper and lower curves in Fig. 4) is 1.4, reasonably close to the calculated one.

For the case of winter insolation at the same latitude (winter solstice, illumination from the left in Fig. 1) our analysis gives the daytime of \( t^* = 10.56 \) hrs; the maximum irradiance corresponds to the angle of 47° in Fig. 2, and the part of the curve between 47 and 90 grad corresponds to dependence of insolation upon time from noon until the end of the day. The calculated dependence for the radiation flux captured by the tracking system is shown in Fig. 5 by squares (the curve starting at irradiance 825 W/m²), here \( \Delta t \) is the time difference from noon.

For a similar way, we obtain the irradiance at equinox time, when the smallest value of \( \varphi \) at the latitude chosen is 23.5°, and the solar day time is 12 hrs. The calculated data are shown in Fig. 5 by diamonds (the highest curve starting at irradiance 910 W/m²) for tracking module, and by the curve with crosses starting at the same points for non-tracking one, orientated at 23.5° to the surface and normal to solar flux at noon. Two other curves in Fig. 5 (triangles up and down) are experimental ones (Querétaro, Mexico, March 23, 2004); they go a little lower than the calculated curves, but reasonably close to them. The experimental tracking effect is 33 % (theoretical one – 31 %).

3.2 Non-Tracking System with Bifacial PV Panel

There exists another possibility to get more power from PV solar panel of a fixed area – to use bifacial panels [10] sensitive to illumination from both sides; the rear face is able to give up to 60 % of the power produced by the front one. These panels demand some arrangements to collect solar radiation for the rear face (for example, to use the diffuse reflectance from surfaces below the panel, and to paint them correspondingly [11]). The method mentioned needs relatively large areas of reflecting surfaces, which may be not practical; besides, the paint usually lasts less than the PV panel. We employed the technique demanding smaller area, which in fact is small concentrating reflector placed below the PV panel (ideally it should be a cylindric or spherical mirror, with the panel placed in its focal point, at half a radius from the optical center). We used the concentrator made of stainless steel plates, with area about twice as big as the area of panel. The bifacial panel employed was made in OKBZ “Krasnoe Znamya”, Russia, the front side power at AM1.5 illumination was 60 W, and that of the rear side – 40 W. Thus an effect of the rear panel face is around 60 % (in different bifacial panels, it is between 50 and 60 %), which is better than the data given above for the tracking effect.

Fig. 5: Irradiance at different periods (see text).

The lowest curve in Fig. 5 gives the irradiance at winter solstice of non-tracking system orientated in the most favorable way – normal to the solar flux at noon, i.e. at 47° to the Earth surface. During the day, the angle of incidence of this flux to the panel varies between \( \phi = 0 \) at noon and \( \phi = 90^\circ \) (dawn, evening); multiplication of the former curve by corresponding \( \cos \phi \) gives the irradiance. In this case, the calculated tracking effect is 1.28, i.e. is lower than in summer, in good agreement with our experiment (not shown) performed on December 20, 2003.

In a similar way, we obtain the irradiance at equinox time, when the smallest value of \( \varphi \) at the latitude chosen is 23.5°, and the solar day time is 12 hrs. The calculated data are shown in Fig. 5 by diamonds (the highest curve starting at irradiance 910 W/m²) for tracking module,
(the total peak power of photovoltaic panels 200 W), having corresponding battery bank, charge controller and DC-AC converter, was installed in one of the rural schools in the state of Querétaro, Mexico, in August 2002 (Fig. 6 presents photo of the panels with reflectors on the roof of the school), and since then it is constantly used providing enough energy for functioning of the receptor of the satellite educational programs and TV-video set during 6 hours a day. At the moment, 85 solar electric systems of this kind having peak power 300 W each are installed in rural schools of the state of Querétaro, in places which do not have access to the electric network, with more systems to follow.

4. SUMMARY

Investigations made lead us to the conclusion that the use of solar tracking PV panels in absence of solar concentration gives relatively small (30 – 35 %) increase in the solar energy collection and electric energy production, and therefore could be practical only with very economic tracking systems. Larger effect could be achieved with bifacial PV panels, which production cost is not much higher than that of standard panels of the same area, and an increase in energy production caused by effective use of a rear face with a simple system of flat mirrors could be 50 – 60 %.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support by CONACYT of Mexico and CONCYTEQ, Queretaro. We are greatly indebted to Dr. Gabriel Siade Barquet and Lic. Alvaro Martinez Ezeta whose participance in rural school electrification program was most active, most valuable and most successful.

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J. Zubizarreta and M. Nicklas, Innovative Design Inc. and P. Morante, Rensselaer Polytechnic Institute, USA

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S. Leal, C. Tiba, E. Barbosa and R. Melo, Universidade Federal De Pernambuco, Brazil

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SUSTAINABILITY

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E. Löwendahl, Chalmers University of Technology and Göteborg University; J. Swahn, Chalmers University of Technology and H. Eek, IVL Swedish Environmental Research Institute, Sweden

G. Wolfson, Solar Alternatives, USA

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J. Ndegwa, Rural Friends Kenya/IRDD Univ of Reading, United Kingdom and M. Githinji, Rural Friends Kenya

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C. Abbate, Rensselaer Polytechnic Institute, USA and AeV Abbate e Vigevano Architects, Italy

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M. Ross and T. Wilson, Sandia National Laboratories, USA and A. Romero Paredes, Ecoturismo y Nuevas Tecnologias, Mexico
Photovoltaic for Sustainable Livelihoods in Off-Grid Areas of Bangladesh
F. Ahmed PPRE, C.v.O. University, Germany; J. Aman and M. Islam, Bangladesh Power Development Board, Bangladesh

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A. Schüler, E. De Chambrier, C. Roecker and J. Scartezzini, Ecole Polytechnique Fédérale de Lausanne EPFL, Switzerland; D. Dutta, Indian Institute of Technology IIT, India and G. De Temmerman and P. Oelhafen, University of Basel, Switzerland

Study on Two-Phase Heat Transfer Mechanism from Heating Surface of Solar Collector to the Fluid
J. Kim, Korea Institute of Energy Research and M. Kim, University of Science and Technology, Korea (South)

Optimization of Solar Energy Collection Using SOCOL
J. Garrison, San Diego State University, USA

Application of Finite-Difference Time-Domain Method to Solar Light Absorption Coating of Al-N Films with Surface Roughness
H. Iijima, K. Katazakai and T. Iishiguro, Nagaoka University of Technology, Japan

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S. Maneewan and S. Chindaruksa, ISES and Naresuan University and J. Waewsak, ISES and Renewable Energy System
Synthesis by Concentrated Solar Radiation of Fluorit-Like Solid Solutions on the ZrO$_2$-CaO (MgO) -Gd$_2$O$_3$ Systems and Their Properties
D. Gulamova, S. Gornostaeva, T. Ismailova, J. Turdiev, M. Zufarov and A. Lejebokov, Uzbekistan Academy of Sciences, Uzbekistan

Bi-Dimensional Study of Heat and Mass
E. Aroudam, University Abdelmalek Essaadi, Morocco

Performance Evaluation Techniques and Tools

Performance of Flat-Plate Collectors with Two-Positional Active Tracking
T. Tomson, Tallinn University of Technology. Estonia and G. Tamma, United States Military Academy, USA

Thermal Performance Comparisons of the Glass Evacuated Tube Solar Collectors of Different Absorber Tubes
Y. Kim and T. Beom Seo, Inha University; Y. Heack Kang, Korea Institute of Energy Research and G. Young Han, Sungkyunkwan University, Korea (South)

Mechanical Performance of Polymer Tubes Intended for Use in Solar Heat Exchangers
A. Freeman, S. Mantell and J. Davidson, University of Minnesota, USA

Investigation and Comparison of Different Model Equations
K. Vajen, E. Frank and C. Jipp, Universität Kassel, Germany

Analysis of the Collector Test Procedures for Steady State and Quasi Dynamic Test Conditions in View of the Collector Coefficients Uncertainties and Model Stability
M. Kratzenberg, Federal University of Santa Catarina, Brazil; H. Beyer, University of Applied Science Magdeburg-Stendal, Germany; S. Colle, Federal University of Santa Catarina, Brazil; A. Albertazzi, Federal University of Santa Catarina, Brazil; S. Güths, Laboratory of Porous Means and Thermo-physic Properties, Brazil; D. Fernandes, P. Oikawa and R. Machado, Federal University of Santa Catarina, Brazil and D. Petzoldt, University of Applied Science Magdeburg-Stendal, Germany

Design, construction and testing of a parabolic trough solar collector for a developing-country application
M. Brooks and I. Mills, Mangosuthu Technikon and T. Harms, University of Stellenbosch, South Africa; Campbell, J. Coots and B. Mar, Sandia National Laboratories, USA

SOLAR COLLECTOR TECHNOLOGIES (continued)
Performance Evaluation Techniques and Tools (continued)

Experimental Investigation of Two-Phase Closed Thermosyphons with a Liquid Retention Structure for SDHWs
S. Abreu, J. Destri and S. Colle, Universidade Federal de Santa Catarina, Brazil

Test and Simulation of Solar Thermal Collectors with Multi-Axial Incident Angle Behavior
S. Fischer, W. Heidemann and H. Mueller-Steinhagen, Universität Stuttgart, Germany

Performance Model for Solar Thermal Collectors Taking into Account Degradation Effects
E. Streicher, S. Fischer, W. Heidemann and H. Mueller-Steinhagen, Universität Stuttgart, Germany

Design, Manufacture and Installation of a Solar Simulator for the Green Laboratory at Pontificia Universidade Católica De Minas Gerais in Brazil
C. Zahler, F. Lugingländ and A. Haeberle, PSE GmbH, Germany; E. Marques and D. Pereira, GREEN / PUC Minas, Brazil
Concentrating Solar Collectors

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S. Gallagher and B. Norton, Dublin Institute of Technology, Ireland and P. Eames, University of Ulster, N-Ireland

Quantum Dot Solar Concentrator Device Characterisation Using Spectroscopic Techniques
S. Gallagher, B. Rowan, J. Doran and B. Norton, Dublin Institute of Technology, Ireland

Numerical Simulation of Heat Losses by Natural Convection and Surface Thermal Radiation in an Open Tilted Shallow Cavity
J. Hinojosa, University of Sonora; C. Estrado, Universidad Nacional Autónoma de México; G. Alvarez, CENIDET and R. Cabanillas, University of Sonora, Mexico

Numerical Simulation of Heat Losses by Natural Convection in an Open Tilted Cubic Cavity
J. Hinojosa, University of Sonora; C. Estrado, Universidad Nacional Autónoma de México and G. Alvarez, CENIDET, Mexico

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S. Vasylyev, S.V.V. Technology Innovations, Inc., USA and V. Vasylyev, ISES-Ukraine, Ukraine

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R. Cabanillas, J. Perez and H. Munguia, Universidad De Sonora; C. Villegas and C. Iriarte, CIBNOR-Hermosillo and J. Hinojosa, Universidad De Sonora, Mexico

Description and Performance of a TRNSYS Model of the Solargenix Tracking Power Roof
T. Cleveland, North Carolina Solar Center, USA

Stationary Focus Tracking Solar Concentrators for Cooking and Process Applications
D. Gadhia, Gadhia Solar Energy Systems Pvt. Ltd., India and T. Shah, Prime Resources LLC. USA

Optimal Design of Stationary Nonevacuated CPC Solar Concentrator with Fully Illuminated Wedge Receivers
C. Tiba, N. Fraidenraich and B. Brandao, Universidade Federal De Pernambuco, Brazil

Thermal Performance of Composed Pipe in a Parabolic Trough Collector
A. Torres, R. Lugo and J. Zamora, Universidad Autónoma Metropolitana, Mexico

Theoretical Analysis of a Conical-Bucket Solar Concentrator for Fluid Heating
M. El-Refaie, Cairo University, Egypt

Features of Properties of Materials Synthesized in Solar Furnace
D. Gulamova, Uzbekistan Academy of Sciences, Uzbekistan

Flow Distribution in a Solar Collector Panel with Horizontal Fins
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Vacuum Collectors

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Long Term Performance and Reliability of Two Evacuated Collectors
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Numerical Investigations of an All-Glass Evacuated Tubular Collector
L. Shah and S. Furbo, Technical University of Denmark, Denmark

SOLAR COLLECTOR TECHNOLOGIES (continued)

Vacuum Collectors (continued)

Performance and Reliability Evaluation of the Sacramento Demonstration Novel ICPC Solar Collectors
W. Duff and J. Daosukho, Colorado State University; R. Winston, University of California at Merced; J. O’Gallagher, University of Chicago Enrico Fermi Institute; J. Bergquam, Sacramento State University and T. Henkel, Solar Enterprises International, USA

Theoretical Investigations of Differently Designed Heat Pipe Evacuated Tubular Collectors
L. Shah and S. Furbo, Technical University of Denmark, Denmark

Study on the Residual Gas in All-Glass Evacuated Collector Tubes
X. Zhou, Tsinghua Solar Ltd.; Z. Yin and G. Dong, Tsinghua University and S. Zheng, Tsinghua Solar Ltd., PR China

Long Term Thermal Performance of Evacuated Tubular Solar Collector System for Industrial Process Heat in Korea
H. Kwak, Korea Institute of Energy Research and C. Choi Jeonju University, Korea (South)

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TiO$_2$/SiO$_2$ Nanocomposite Electrode Prepared by Electrodeposition for Dye-Sensitized Solar Cells
T. Nguyen, H. Lee, K. Kim and O. Yang, Chonbuk National University, Korea (South)

Industrial Design Way of DSCS Panel with High Efficiency
S. Dai, J. Weng, Y. Sui, S. Chen, S. Xiao, Y. Huang, F. Kong, X. Pan, L. Hu, X. Fan, et. al., Chinese Academy of Sciences, PR China

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M. Yamaguchi, Toyota Technological Institute; T. Takamoto, Sharp Corporation and K. Araki, Daido Steel Corporation, Japan

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I. Kaulach, Institute of Physical Energetics LAS; I. Muzikante, Institute of Solid State Physics University of Latvia and P. Shipkevs, J. Ekmanis and G. Kashkarova, Institute of Physical Energetics LAS, Latvia

Obtaining Heterostructures with Quantum Dots for Solar Cells
A. Minailov and T. Kupriyanova, Kherson State Technical University, Ukraine

Externally Unbiased Electron Injection from Copper Oxide to Porous
E. Vigil, University of La Habana, Cuba; J.A. Ayllón, Autonomous University of Barcelona, Spain; B. González, I. Zumeta and L. Curbelo, University of La Habana, Cuba

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S. Sun, Norfolk State University, USA

Solar Cell Materials & Manufacturing

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A. Black, OnGrid Solar Energy Systems, USA

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G. Oreski, Polymer Competence Center Leoben GmbH and G. Wallner, University of Leoben, Austria

Effect of Magnetic Field on Bifacial Silicon Solar Cell Studied in Modeling: Capacitance and Space Charge Region Width
Determination
S. Madougou, Université Abdou Moumouni de Niamey, Niger; I. Barro, Université Cheikh Anta Diop de Dakar, Dakar (Sénégal) and G. Sissoko, Université de Ouagadougou, Burkina Faso
Ellipsometric Analysis of Cobalt-Oxide Solar Selective Coatings on Different Substrates
E. Barrera and J. Martinez, Universidad Autónoma Metropolitana-Iztapalapa and A. Avila and M. Ortega CINVESTAV del IPN, Mexico

Coefficient of Performance of Mono- and Multi-Crystalline Silicon Photovoltaic Panels
M. Bahadori and K. Zamzamian, Sharif University of Technology, Iran

Effect of Stainless Steel Substrate Thickness on the CIGSS Thin Film Solar Cell
A. Kadam, A. Jahagirdar and N. Dhere, Florida Solar Energy Center, USA

Review of Rapid Thermal Process and Setup for Fabrication of Absorber Layer for CIGSS Solar Cells by RTP
N. Dhere, S. Kulkarni, J. Shirolkar and M. Nugent, Florida Solar Energy Center, USA

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E. Belov, N. Efimov, E. Lebedev, Y. Zadde, A. Pinov and D. Strebkov, INTERSOLARCenter, Russia and K. Touryan and D. Blake, National Renewable Energy Laboratory, USA

The Effect of the Growth Rate on Polycrystallinity
T. Razykov and K. Kouchkarov, Physical-Technical Institute, Uzbekistan

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Solar Cell Materials & Manufacturing (continued)
The Graded Optical Band Gap (GBG) in Hydrogenated Nanoamorphous Silicon (Na-Sih) Solar Cell Prepared by Plasma Enhance Chemical Vapor Deposition (PECVD)
Y. Huacong, C. Rongqiang, M. Fanying and Z. Zhanxia, Shanghai Jiaotong University; W. He and Y. Hong, Xi’an Jiaotong University and H. Yuliang, Jiangsu Weifu Nanometers Science & Technology Ltd., PR China
Performance Enhancement of CIGSs Absorber Layer on Glass Substrate
A. Kadam, A. Jahagirdar and N. Dhere, Florida Solar Energy Center, USA

Gigawatt-Scale Manufacturing of Discrete Flexible CIGS Solar Cells as a Near-Term Catalyst for the Transition to a “Solar Economy”
J. Tuttle and T. Schuyler, DayStar Technologies, Inc., USA

PV Applications
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Integrating PV/Thermal Concentrator Systems into Buildings
D. Strebkov, P. Litvinov, Y. Kuzhmurov, E. Tveryanovich and I. Tyukhov, All-Russian Research Institute for Electrification of Agriculture, Russia and S. Kivalov, Renewable Energy Research, USA

Renewable Hydrogen Based Off-Grid Power System Control System
S. Uppapalli, University of Nevada; R. Denis, Donovan Sustainable Energy Solutions; B. Wood, Utah State University and R. Jacobson and M. Wetzel, Desert Research Institute, USA

Performance of Photovoltaic and Thermal Hybrid Air Collectors
S. Ito, K. Sato and N. Miura, Kanagawa Institute of Technology, Japan

Effect of Photovoltaic Cover on Urban Surface Energy Balance
S. Nagpal and S. Shah, Arizona State University, USA
Application of Wind Tunnel Testing and Finite Element Analysis to Development of a Photovoltaic Module Mounting System
M. Bowler and M. Huber, Eastwood Energy Corporation and M. Lobo, NovaComp Engineering, Inc., USA

Peer-reviewed Abstracts
PV Research and Technological Development in Russia
D. Strebkov and A. Irodionov, All-Russian Research Institute for Electrification of Agriculture (VIESH), Russia

Two Decades of PV Lessons Learned in Latin America
R. Foster, New Mexico State University, USA and A. Cota, Universidad Autónoma de Ciudad Juárez, Mexico

Solar Lanterns for Remote Areas
S. Tavaranan and J. Duffy, University of Massachusetts Lowell, USA

Validated Simulation of the Influence of Insolation and System Sizing on the Performance of PV Pumping Systems
I. Odeh and Y. Ychaniş, University of Ulster, Northern Ireland, UK and B. Norton, Dublin Institute of Technology, Ireland

Development of Hybrid Photovoltaic-Wind System for Academic Purposes
R. Soler-Bientz, Autonomous University of Yucatan, Mexico

Amorphous-Silicon Photovoltaic/Thermal Solar Collector System in Thailand
S. Jaikla, T. Nualboonrueng and P. Sichanugrist, National Science and Technology Development Agency, Thailand

Disasters: Photovoltaics for Special Needs
W. Young, Jr., Florida Solar Energy Center, USA

Experimental Performance of a Frequency Converter Driving a PV Pumping System
R. Melo, N. Fraidenraich and O. Vilela, Universidade Federal de Pernambuco, Brazil

Electrification of Villages: A Case Study of Mustung Village near Quetta (Pakistan)
S. Ilyas, S. Nasir and S. Raza, University of Balochistan, Pakistan

Solar Roof Špansko-Croatia, First Year of Operation

Hybrid Solar Generation for Rural Decentralized Electrification in the Semi-Arid Northeast of Brazil
E. Barbosa, R. Oliveira, C. Tiba, N. Fraidenraich and E. Vieira, Federal University of Pernambuco, Brazil

Photovoltaic Reincarnation – Using Salvaged PV in the Eco Office
V. Sami, and J. Nicolow, Lord, Aeck and Sargent Architecture and A. Campolucci, Southface Energy Institute, USA

Characteristics of PV power generation system in Japan
N. Mori, Taisei Corporation; H. Fukao, M. Saito, M. Nakamura and Y. Sato, Taisei Corporation Technology Center and M. Morita, Taisei Corporation, Japan

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PV Balance-of-Systems

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Quantitative Design and Implementation of Two-Stage Grid-Connected PV Inverter With DSP-Based Controller
S. Chiang, National United University; Y. Lai, Material Research Lab, ITRI; K. Chai, HsinChu Research Center, Sysgration LTD. and Y. Tzou, Chiao Tung University, Taiwan

An MPPT Control Method to Acquire the Maximum Power over All Types of Irradiations Various Changing with Weather Conditions
N. Mutoh, M. Ohno and T. Inoue, Tokyo Metropolitan Institute of Technology, Japan

Optimal Reliability Design Method for Remote Solar Systems
N. Suwapaet and J. Duffy, University of Massachusetts Lowell, USA

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Innovative Micro-Inverter for the AC PV Building Block or AC Modules
W. Bower, Sandia National Laboratories; A. Dickerson, Bluepoint Associates and R. West, Distributed Power, USA

Review of PV Inverter Technologies for Practical Implementation
A. Wang, B. Chen and Y. Tzou, National Chiao Tung University, Taiwan

Characterization and Measuring in Test Facilities PV Grid Connected Inverters
L. Davila, Polytechnic University of Madrid; M. Castro, A. Colmenar, J. Carpio and J. Peire, Spanish University for Distance Education and R. Jiménez, University of Cadiz, Spain

Development of a Low Cost Control System for a Solar Tracker
F. Monteiro, O. Vilela and N. Fraidenraich, Universidade Federal de Pernambuco, Brazil

A Side by Side Comparison of Maximum Power Point Tracking Charge Controllers for a Stand-Alone PV System
F. Collins and J. Kreider, University of Colorado, USA

Development of High-Frequency Transformer Inverter Topologies for Small-Power Grid-Connected PV Inverters
K. Chai, Y. Lin, J. Hsu and Y. Tzou, National Chiao Tung University, Taiwan

Modeling and Simulation of Stand-Alone Power Photovoltaic System Using Artificial Neural Network
A. Mellit, University Center of Médéa and A. Benghabem, University of Sciences and Technology Houari Boumediene (USTHB), Algeria

Grid-connected PV System Performance

Peer-reviewed Papers
An Alternative Method to Regression Analysis for PV System STC Rating
J. Bing, New Energy Options, Inc. USA; E. Kern Jr., Irradiance Inc., USA and C. Sumaoy, CEPALCO, Philippines

Experimental Validation of Algebraic Methods to Predict the Outdoors Electrical Performance of Monocrystalline Silicon PV Modules in Southern Europe Climates
M. Fuentes, G. Nofuentes, J. Aguilera and D. Talavera, Universidad de Jaén and M. Castro, UNED – Ciudad Universitaria, Spain

Comparative Analysis of the Influence of the Climatic Conditions in Europe on the Efficiency of a Grid-Connected Photovoltaic System
G. Lopez, Sociedad para el Desarrollo Energético de Andalucía and I. Lillo, Universidad de Sevilla, Spain

Economic Analysis of Grid Connected PV Systems in South East Queensland
K. Khouzam, Queensland University of Technology, Australia

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Performance Monitoring of 900 Individual Photovoltaic Systems in Sacramento
O. Bartholomy, Sacramento Municipal Utility District and M. Sheridan, MSEE, USA

Results from the California PV Testing and Evaluation Project: A Third-Party Evaluation of Currently Available PV Systems
W. Brooks, J. Newmiller, T. Townsend and C. Whitaker, Behnke, Erdman, and Whitaker Engineering, Inc., USA

One Megawatt Photovoltaic Plant Completes Twenty One Years of Successful Operation
G. Nelson, Sacramento Municipal Utility District and A. Rosenthal, Southwest Technology Development Institute, USA

Multi-Year Performance Assessment of Two PV Installation Clusters
S. Wiese, Conservation Services Group and CSGServices Inc. and L. Moore and C. Hanley, Sandia National Laboratories, USA

A 10 kWp Photovoltaic Grid Connected System – Planning and Checking the System Components
I. Farkas and I. Seres, Szént István University and L. Koksis, Hungarian Academy of Sciences-SIU, Hungary

PV Technologies, Systems and Applications (continued)

Grid-connected PV System Performance (continued)

Grid-Connected Photovoltaics in Brazil

R. Ruther, LABSOLAR - Universidade Federal de Santa Catarina; W. Regus – CELESC – Centrais Elétricas de Santa Catarina; M. Dacoregio, LABSOLAR - Universidade Federal de Santa Catarina; P. Knob, C. Jardim and I. Salamoni; LabEEE - Universidade Federal de Santa Catarina; R. Ricardo; LABSOLAR - Universidade Federal de Santa Catarina and A. Diniz; CEMIG - Companhia Energética de Minas Gerais, Brazil

California's Self-Generation Incentive Program PV Systems: Measured Performance and Actual Costs

K. Scheuermann and P. Lilly, Itron, Inc. and P. Landry, Southern California Edison, USA

Analysis of PV System Performance Versus Modeled Expectations Across a Set of Identical PV Systems

J. Perlman, A. McNamara and D. Strobino, Big Apple Solar Installation Commitment (BASIC), USA

Predicting the Performance of Photovoltaic Cells Using a 5-Parameter Model

W. de Soto, S. Klein and W. Beckman, Solar Energy Laboratory, University of Wisconsin-Madison, USA

4.872 kW Grid-Connected PV System Results and Testing at Rajamangala University of Technology (RMUT), Thailand

N. Watjanatepin and C. Boonmee, Rajamangala University of Technology (RMUT), Thailand

Fundamental Studies of Electrical Detection of Failed Modules in PV Array

T. Takashima, K. Otani and K. Kato, Research Center for Photovoltaics, AIST, Japan

Characterization of Photovoltaic Modules Via Artificial Neural Networks

L. Vilhena, L. Zárate and D. Scares, Pontifical Catholic University of Minas Gerais and A. Diniz; Energy Company of Minas Gerais (CEMIG), Brazil

Solar Electric Concentrators

Peer-reviewed Paper

Prismatic Stationary Concentrators in the Photovoltaic Modules

S. Kivalov, Renewable Energy Research, USA and D. Strebkov and E. Tver’yanovich, All-Russian Research Institute for Electrification of Agriculture (VIESH), Russia

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A Novel 500W Photovoltaic Concentrator

S. Vasylyev, S.V.V. Technology Innovations, Inc., USA

A Miniature Building-Integrated Spherical Collector PV System

A. Kribus, J. Appelbaum and M. Arenson, Tel Aviv University, Israel; G. Grossman and I. Capeluto, Technion-Israel Institute of Technology; A. Kudish, Ben Gurion University, Israel; F. Martelli, University of Florence, Italy and T. Caselli, Solar Heat and Power, Italy

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D. Kaftori, DiSP – Distributed Solar Power Ltd. and A. Kribus, Tel Aviv University, Israel

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S. Flores Larsen, Universidad Nacional de Salta – CONICET; C. Filippin, CONICET and G. Lesino, Universidad Nacional

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B. Bauer, T. Williamson and P. McEntee, Thermomax Ltd., Northern Ireland, UK

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V. Fernández-Quero and R. Osuna, Solàcar Energia, S.A.; M. Romero and M. Sánchez, Ciemat/PSA and V. Ruiz and M. Silva, Escuela Superior de Ingenieros, Spain

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K. Datye, Society for Advancement in Renewable Materials and Energy Technology, India; N. Pandit, International Institute of Energy Conservation-North America, USA and P. Ashtunkar, Society for Advancement in Renewable Materials and Energy Technology, India

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U. Jordan and K. Vajen, Universität Kassel, Germany
Energy Conservation and Electric Energy Peak Reduction Potential During Peak Hours for a Group of Low-Income Residential Consumers of a Brazilian Utility
J. Salazar, S. Abreu and S. Colle, Universidade Federal de Santa Catarina, LABSOLAR/EMC/UFSC and W. Reguse, Centrais Eléctricas de Santa Catarina S.A (CELESC), Brazil

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T. Schmidt, Solar- und Wärmetechnik Stuttgart (SWT) and J. Nußbicker and S. Raab, Universität Stuttgart, Germany

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K. Sumathy, University of Hong Kong, Republic of China

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Broadband Model Performance for an Updated National Solar Radiation Data Base in the United States of America

D. Myers, S. Wilcox, W. Marion, R. George and M. Anderberg, National Renewable Energy Laboratory, USA

Validation of DNI Estimations in Brazil Using Brazil-SR Model

F. Martins and E. Pereira, Brazilian Institute of Space Research and S. Abreu, University of Santa Catarina, Brazil

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S. Wilcox, National Renewable Energy Laboratory; R. Perez, State University of New York at Albany; R. George, W. Marion, D. Meyers and D. Renné, National Renewable Energy Laboratory; A. DeGaetano, Northeast Regional Climate Center; C. Gueymard, Solar Consulting Services; F. Vignola, University of Oregon and P. Stackhouse, National Aeronautics and Space Administration, Et al, USA

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K. Guthrie, Sustainable Energy Authority Victoria, Australia

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E. Tsioliaridou and G. Bakos, Democritus University of Thrace (DUTH), Greece

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