Visualising the effect of different tilt angles on the switch-on time of small PV modules using a simplified measuring approach

Arthur James Swart
Dept. of Electrical, Electronic and Computer Engineering
Central University of Technology
Private Bag X20539, Bloemfontein, South Africa, 9300
Email: drjamesswart@gmail.com

***Abstract*—Renewable energy systems are receiving more and more attention, as governments and industry seek to reduce fossil fuel usage and provide more clean energy. PV systems fall into this category, and are especially sought after in countries that enjoy sufficient annual solar radiation. It has been scientifically proven that both the tilt and orientation angles, along with variable atmospheric conditions, impact significantly on the optimum output power of PV modules used in these systems. The purpose of this paper is to present a simplified measuring approach to validate this fact when considering the tilt angle. Research is not always about discovering new aspects, but also involves using various scientific methods to test and re-test current findings. This simplified measuring approach is a re-test of current findings that indicates that a PV module with a high tilt angle starts operating earlier than a PV module with a lower tilt angle for winter periods in South Africa. However, the simplified approach costs less than 25% of traditional measuring approaches, providing a visual dimension and perspective in validating current research findings.**

***Keywords*— Webcam; motion-detection; solar panels; performance;**

I. Introduction

"It is paradoxical, yet true, to say, that the more we know, the more ignorant we become in the absolute sense, for it is only through enlightenment that we become conscious of our limitations". These words, by Nickola Tesla, well illustrate that the more we know about ourselves, the more we become aware of our own limitations. This applies equally well to science and technology! The more we discover, the more we realize how small and insignificant we really are in a gigantic universe. Nevertheless, we press on with our discovery and research, hoping to contribute in some small way to the contribution of scientific knowledge that may lead to humanity's benefit. Moreover, this process often leads to the discovery of further questions or problems that requires satisfying answers or sustainable solutions.

Scholarly research is defined by the Australian Research Council [1] as the creation of new knowledge and/or the use of existing knowledge in a new and creative way so as to generate new concepts, methodologies and understandings. These words imply that research does not always have to provide anything new, but should also be used to further our understanding of the material world. In fact, Chen [2] states that research is not always about discovering new aspects, but also involves using various scientific methods to test and re-test current findings.

A current scientifically accepted finding, with regard to photovoltaic (PV) modules, is that the tilt angle of installation plays a significant role in the optimum output power of such a module [3-6]. Research reporting on these results often involves the use of complex and expensive data logging equipment to establish these facts. However, previous research has also shown that inexpensive simplified measuring approaches are also scientifically acceptable to re-test current findings. These simplified measuring approaches have been used to validate the acceptance zone of a PV module and to correlate the difference between the switch-on time of identical PV systems [7, 8].

The purpose of this paper is to present a simplified measuring approach that visually demonstrates the effect of different tilt angles on the switch-on time of two identical PV systems. Switch-on time is defined as the time when a PV module starts to generate at least 15% of its rated peak output power. The target area of this research is located in the heart of South Africa (Bloemfontein, Free State) in the Southern Hemisphere, which is classified as a semi-arid region with temperatures reaching well beyond 40°C in December. Traditional measuring approaches, with regard to PV module systems, will firstly be reviewed. The practical setup and methodology will then be substantiated. Descriptive results, in the form of sketches and tables, will be presented, along with succinct conclusions.

II. Traditional Measuring Approaches

A plethora of measuring approaches exist today that may be used to determine or verify specific results. Key measurements associated with PV modules include voltage, current and temperature readings. Power calculations are often derived from these measurements, and are used to determine hourly, daily and monthly power generation. These power

978-1-5386-2774-7/17/$31.00 ©2017 IEEE

calculations may be performed within the software package that is used to monitor and record the data to a computer hard drive, or it may be processed in MS EXCEL after having been recorded. The DAQPRO 5300 [9] is a stand-alone data logger (approximate cost R12 000) that monitors and records data to its internal memory. This data may then be downloaded to a computer, and further processed in MS EXCEL. The PICOLOG 2016 data logger [10] and ARDUINO UNO microcontroller board [11] may also be used to monitor specific data. However, they do not have large sized internal memories to support data recording, and must therefore be permanently connected to a computer running specific software. This software is then used to define the measurements which are required and to automatically process specific calculations, such as power calculations.

However, the ARDUINO UNO required specific software packages, such as LabVIEW, which is very expensive to purchase. These three aforementioned loggers have been used to monitor and record specific measurements relating to PV modules over lengthy periods of time. This has enabled the calculation of direct sun hours [12], daily power generation [13] and battery state of charge [14, 15]. It has also enabled the correlation between empirical and simulation data [16-18] and the verification of the sustainability of a given PV system [16, 19]. Two key studies, using these aforementioned data loggers, focused on the effect of different tilt angles on the output power of a PV module [5, 9]. Figures 1 – 3 highlight some key results from the latter study conducted in 2015, where Figure 1 highlights NO visual difference between the output powers of the three PV modules set to the same tilt angle. Similar power sample counts (1369, 1359 and 1354) attest to this calibration process.

The 2011 study [9] revealed that the tilt angle of a PV module must be set to Latitude + 10° for optimum annual power generation in a pollution intensive area. The 2015 study [5] revealed that the tilt angle should be varied in accordance with seasonal changes for a semi-arid region. This latter study further revealed a noteworthy result. The various tilt angles produced different PV module output powers primarily during in the early morning and late afternoon. Figures 2 and 3 illustrate this result.

In Figure 2, the different tilt angles (set to Latitude, Latitude + 10° and Latitude - 10°) produced the same power curve, but well separated by a specific power margin. This power margin tended to reduce at approximately 11:00 in the morning. This suggests that the incident angle onto the various tilted PV module produces the greatest variation in output power among these modules during the early morning and late afternoon. From 11:00 to 15:00, the incident angle on the various tilted PV modules does not produce such a large variation in output power. This effect is noticed in August 2015 (see Figure 2) and in May 2016 (sees Figure 3).

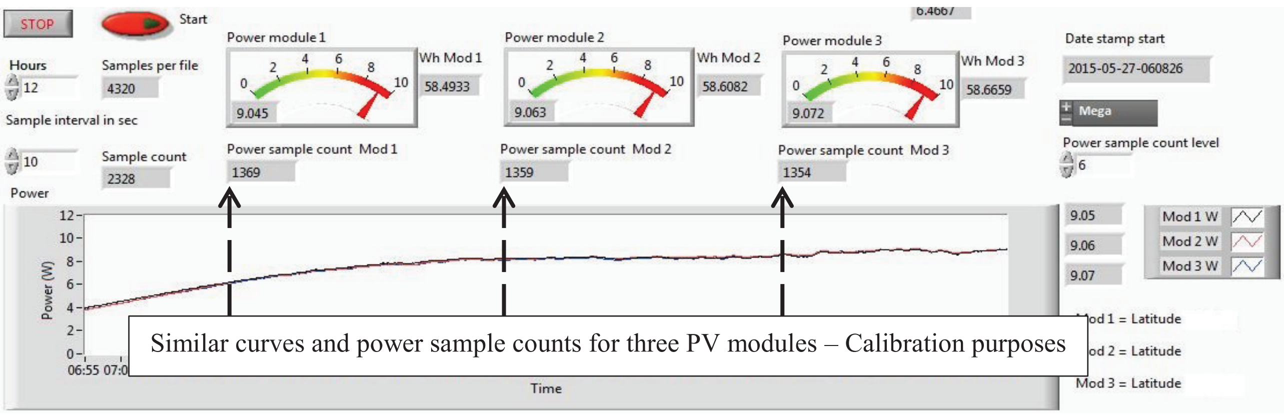

Fig. 1: LabVIEW interface showing identical power curves for three PV modules set to the same tilt angle of 29 Degrees.

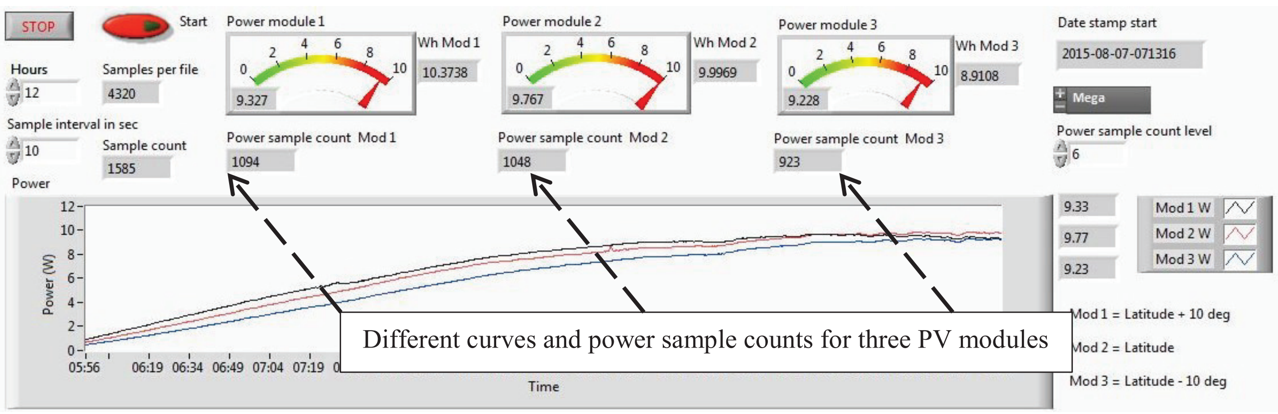

Fig. 2: LabVIEW interface showing different power curves for three PV modules set to tilt angles relating to the Latitude of the installation site.

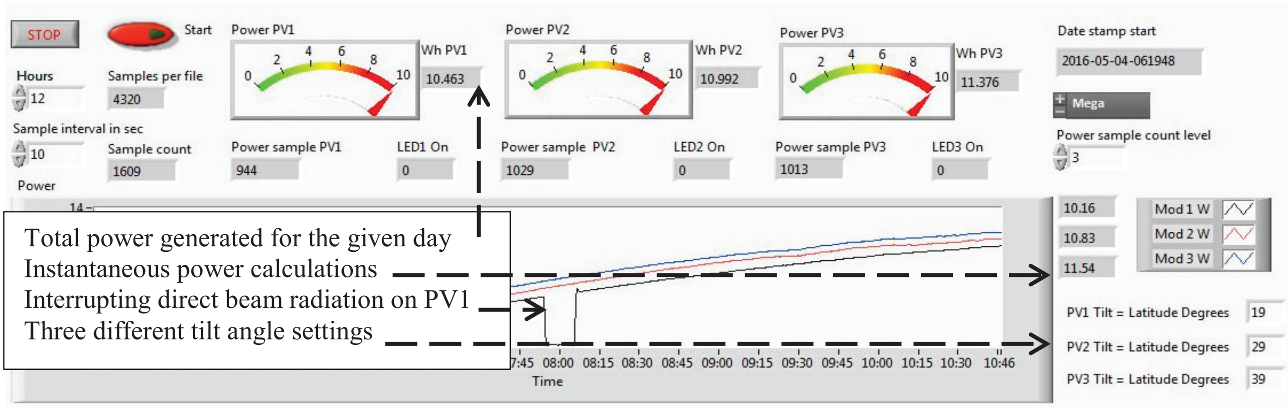

Fig. 3: LabVIEW interface showing different power curves for three PV modules set to separate tilt angles (19, 29 and 39 Degrees).

Figure 3 further reveals that a dove was sitting on PV1, due to the significant dip in output power around 08:00 the morning. The variations in the power sample count (set to 6 W in August 2015 and to 3 W in May 2016) further attest to this effect. PV1, in Figure 2, reached the 6 W mark quicker, and therefore enjoyed a longer time period above this mark (being 1094) as compared to PV3 (being 923). Each of these samples was 10 seconds in duration, indicating a difference of 28.5 minutes or 1710 seconds (1094 – 923 / 6). This means that PV1 enjoyed a better direct beam radiation component for at least 28:30 minutes as compared to PV3. The average difference was found to be 18:03 minutes.

This time difference may further be discerned by determining the switch-on time of two PV modules set to a tilt angle of 19° and 39° respectively. Determining this switch-on time is made possible using a simplified measuring approach, outlined in the following section.

III. Practical Setup

The simplified measuring approach used in this research consisted of two identical PV modules (10 W polycrystalline PV), two 60 LED Lamps (MR16, rated 4 W at 12 V), an aluminum frame, a singular protractor, a notebook, a Webcam (Prestigio) and a software package for motion detection (Yawcam). The 60 LED Lamp is chosen in order to adjust its threshold operating voltage, by means of a series resistor, to ensure that a higher output power from the PV module would be required to activate it. A 22 Ω series resistor was used [20], which requires that the output voltage from the PV module be at least 50% of its maximum power voltage and its output current be at least 33% of its maximum power current. This means that the PV module would be operating at an output power of more than 1.5 W, which is 15% of its peak output power. Bear in mind that 4 W is the maximum power rating of the 60 LED Lamp, which does activate at lower power values.

The aluminum frame was used to securely mount the PV module at a tilt angle of 29º, that equates to the latitude value of CUT [5]. This frame was kept inside an air-conditioned room with a large north facing window, where the temperature was kept constant at 25^{0}C. This was to prevent excess temperature degradation that has a significant impact on the output voltage of a PV module [21]. The protractor was primarily used to verify the direction of the sun with regard to the switch-on time of the PV modules, which would point to due North at 12:00 noon.

The notebook was connected to the Webcam that was focused on the two 60 LED Lamps, in order to take a snapshot when signaled by the motion detection option available in the Yawcam software package. This motion detection is based on the activation of the 60 LED Lamp when the PV module produces more than 1.5 W of its peak output power. The sensitivity of the motion detection was set to 75% with a tolerance value of 15%. The time period of interest was from 23 May to 6 August 2016, corresponding to the winter months in South Africa. Each snapshot contains a timestamp value that was visually observed and recorded in an MS EXCEL sheet to enable the analysis of the collected data.

IV. Research Methodology

An experimental research design is used to gather quantitative data (timestamp information) from the data collection instrument (Webcam and Yawcam). The timestamp was set in the software to be included at the top of each snapshot (photo) which was then viewed in Microsoft Explorer. The switch-on time for each 60 LED Lamp was then recorded in a MS EXCEL sheet, along with the specific date. Data was recorded over a four-month period in the winter season, where lower solar irradiation and cloud cover would be expected (23 May to 06 August 2016). This would prevent severe interruptions in the continuous collection of data, as more clear sky conditions would exist.

Initially, PV1 was connected to the left hand 60 LED Lamp, with PV2 being connected to the right hand 60 LED Lamp (this was done for the first two months of the stipulated time period (see Figure 4). Then, on 9 August 2016, PV1 was connected to the right hand 60 LED Lamp, with PV2 being connected to the left hand 60 LED Lamp. This reversal was to ensure that the PV modules were being analyzed, and not the LED lamp in series with the 22 Ω resistor.

The setup was installed in an air-conditioned office with a large North facing window to ensure that the ambient temperature never exceeded 25ºC. Motion detection was limited to a specific area (only the 60 LED Lamp) defined in the software package in order to avoid numerous snapshots of unrelated or erroneous events. Sufficient black colored paper was wrapped around different parts of the aluminum frame, so as to prevent the flooding of the Webcam by an overexposure of sunlight. The analyzed results are presented next in a series of graphs.

V. Quantitative Results

Figure 4 shows the practical setup where the two 60 LED Lamps are visible, along with the 10 W PV modules and Webcam. The setup is facing due North during the winter time period for Bloemfontein in 2016.

Figure 5 presents the results of the switch-on time for each of the identical modules between 23 May 2016 and 06 August 2016. The GREY highlighted areas represent the PV module set to a high tilt angle of 44 Degrees. The BLACK highlighted areas represent the PV module set to a low tilt angle of 22 Degrees. These represent tilt angles above and below the research site's latitude angle of 29 Degrees. Reasons for using a 15 Degree higher tilt angle relates to research done by Asowata et.al [14] who used +15 Degrees about latitude to establish the validity of using a 0 Degree orientation angle for optimum output power from a PV module. The 22 Degree angle was simply chosen to be 50% of the higher tilt angle, being 44 Degrees. Figure 6 highlights the difference between the switch-on times of the two identical PV modules set to different tilt angles.

Figure 5 indicates that the PV module set to a 44 Degree tilt angle consistently switches on earlier than the PV module set to a 22 Degree tilt angle. Both PV modules switch on after 09:30 in the morning, indicating low solar radiation due to the winter period. The annual solar radiation cycle peaks in summer and undergoes a trough in winter time [22], when in the southern hemisphere. Cloudy conditions in the morning primarily contributed to certain days having no switch-on time, and are thus shown as gaps in Figure 5 (for example, 12 – 17 July 2016).

Figure 6 reveals a large time difference between 17 June and 07 July 2016, with a maximum difference on 20 June 2016 (55 minutes). Small time differences were found after 3 August 2016. The average difference between the two PV modules (between a 44 Degree and 22 Degree tilt angle) was found to be 23:30 minutes. This is near to the once off measurement of 28:30 minutes derived from Figure 2, which was determined by Hertzog and Swart [5] when using their LabVIEW program in conjunction with an ARDUINO board and data logging interface circuit.

A Pearson correlation ($r = 0.739$ with $p = 0.000$) reveals a statistically significant relationship between the switch-on times of the two identical PV modules. This correlation indicates reliability [23], as numerous multiple measurements provided similar time difference results. The average percentage difference between the two PV modules set to different tilt angles was calculated to be 39.2% for the 48 valid samples obtained over the 3-month time period.

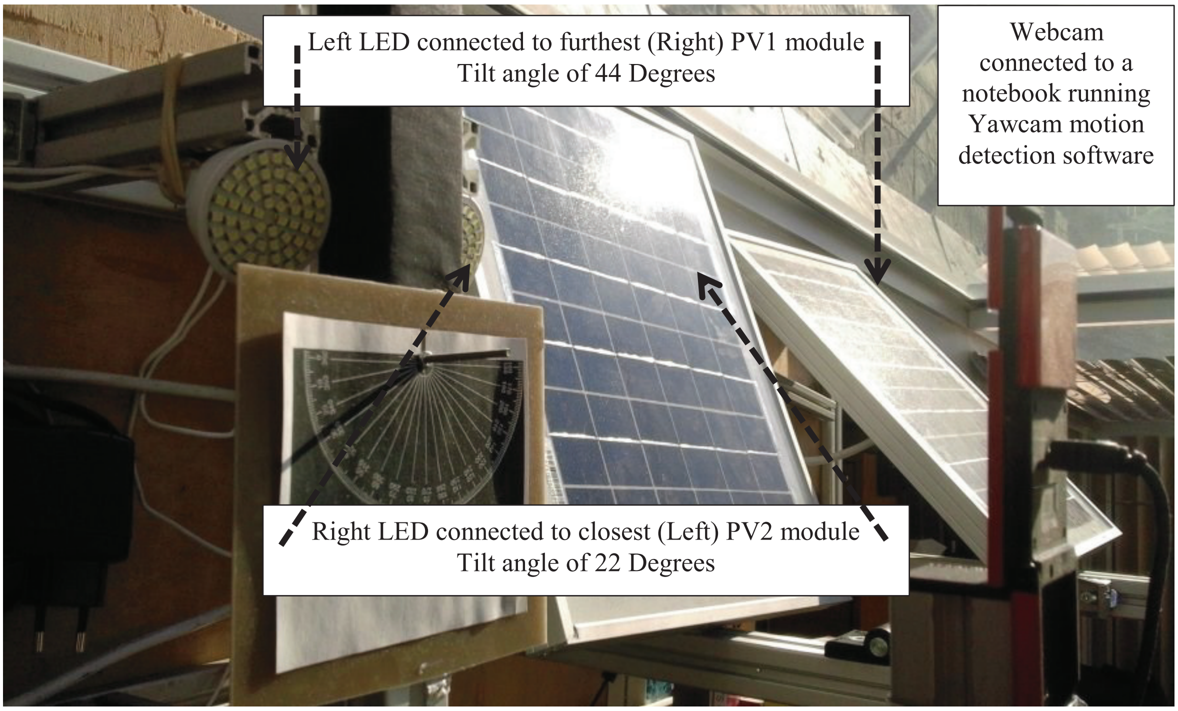

Fig. 4: Practical setup for PV1 (Left – 44 Degree tilt angle) and PV2 (Right – 22 Degree tilt angle) from 23 May to 06 August 2016

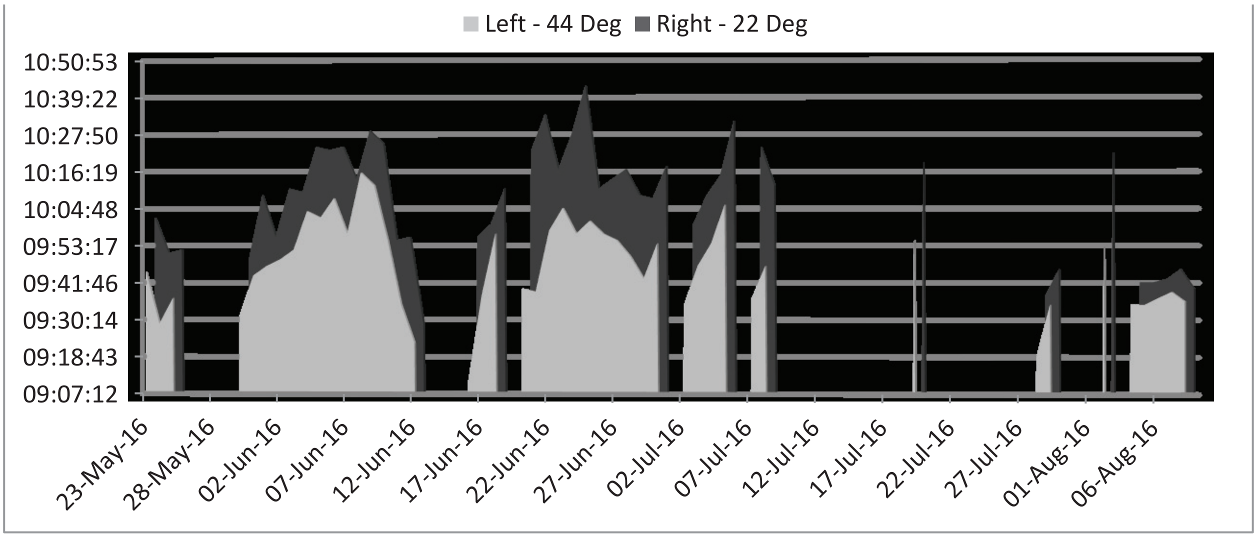

Fig. 5: Switch-on time data for PV1 (Left – 44 Degree tilt angle) and PV2 (Right – 22 Degree tilt angle) from 23 May to 06 August 2016

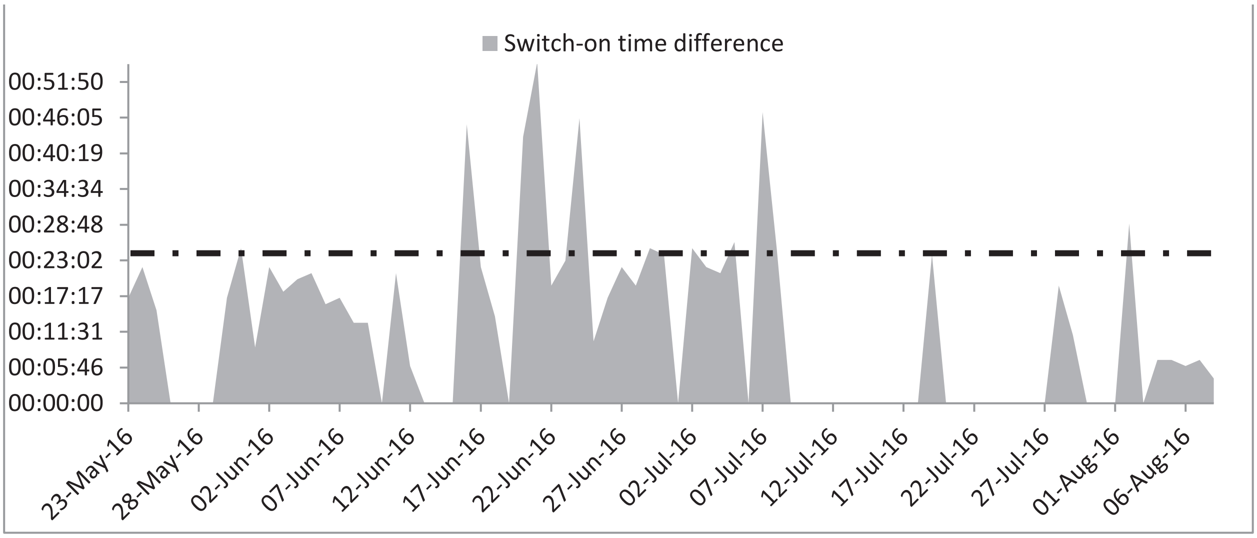

Fig. 6: Switch-on time differences between PV1 and PV2 from 23 May to 06 August 2016

VI. Conclusions

The purpose of this paper was to present a simplified measuring approach that visually demonstrates the effect of different tilt angles on the switch-on time of two identical PV systems. Traditional measuring approaches monitor and record numerous measurements over a lengthy period of time, using expensive data logging equipment (DAQPRO 5300 costing around R12 000 while the ARDUINO UNO board and its data logging interface circuit may cost around R600 while still requiring expensive software packages such as LabVIEW). In contrast, this simplified measuring approach costs approximately R200, requiring only a Webcam with free motion detection software. Moreover, this approach provides visual images of the switch-on time of the PV modules, which may be used for demonstration purposes to undergraduate engineering students enrolled for renewable energy modules.

A key limitation is the fact that this measuring approach is not suited to deterring the output power of a PV module. However, it has the potential of being used to re-test current findings from a visual perspective. The simplified measuring approach may be used in other applications, such as verifying the acceptance zone of PV modules [7] and determining the switch-on time of two identical PV modules set to the same tilt angle [8]. It proves to be a valid, reliable and inexpensive method of collecting specific data using motion detection.

Acknowledgment

This work is based on the research supported in part by the National Research Foundation (NRF) of South Africa. Any opinions, findings, conclusions or recommendations expressed in this material are that of the author(s) and the NRF does not accept any liability in this regard.

REFERENCES

[1] Australian Research Council. (2015, 17 August). *ERA 2015*. Available: http://www.arc.gov.au/era-2015-key-documents

[2] Y.-W. Chen, "A Network approach to the study of the World Uyghur Congress' global outreach: a methodological note," *Journal of Chinese Political Science,* vol. 17, pp. 77-88, 2012.

[3] S. Armstrong and W. G. Hurley, "A new methodology to optimise solar energy extraction under cloudy conditions," *Renewable Energy,* vol. 35, pp. 780-787, 2009.

[4] O. Asowata, A. J. Swart, H. C. Pienaar, and R. M. Schoeman, "Optimizing the output power of a stationary PV panel," presented at the SATNAC 2013, Stellenbosch, South Africa, 2013.

[5] P. E. Hertzog and A. J. Swart, "Determining the optimum tilt angles for PV modules in a semi-arid region of South Africa for the summer season," presented at the SATNAC 2015, Arabella, Hermanus, Western Cape, 2015.

[6] P. E. Hertzog and A. J. Swart, "Validating the optimum tilt angle for PV modules in the central region of South Africa for the winter season," presented at the ECTI-CON, 13th International Conference on Electrical Engineering, Electronics, Computer and Information Technology, Chiang Mai, Thailand. ISBN: 978-1-467-39749-0, 2016.

[7] A. J. Swart and P. E. Hertzog, "Validating the acceptance zone for PV modules using a simplified measuring approach," presented at the ECTI-CON, 13th International Conference on Electrical Engineering, Electronics, Computer and Information Technology, Chiang Mai, Thailand. ISBN: 978-1-467-39749-0, 2016.

[8] A. J. Swart, "Correlating the switch-on time of two identical PV modules using a simplified measuring approach," presented at the ECTI-CON, 13th International Conference on Electrical Engineering, Electronics, Computer and Information Technology, Chiang Mai, Thailand. ISBN: 978-1-467-39749-0, 2016.

[9] O. Asowata, J. Swart, and C. Pienaar, "Optimum Tilt Angles for Photovoltaic Panels during Winter Months in the Vaal Triangle, South Africa," *SGRE, Smart Grid and Renewable Energy,* vol. 3, pp. 119-125, 2012.

[10] A. Ozemoya, J. Swart, and H. C. Pienaar, "Experimental Assessment of PV Module Cooling Strategies," presented at the SATNAC 2014, Boardwalk Conference Centre, Nelson Mandela Bay, Eastern Cape, South Africa, 2014.

[11] P. E. Hertzog and A. J. Swart, "The Use of An Innovative Jig to Stimulate Awareness of Sustainable Technologies Among Freshman Engineering Students," *Sustainability,* vol. 7, pp. 9100-9117, 2015.

[12] A. J. Swart, H. C. Pienaar, and R. M. Schoeman, "Assessing the effect of variable atmospheric conditions on the performance of photovoltaic panels: A case study from the Vaal Triangle," presented at the Southern African Energy Efficiency Convention, SAEEC 2011, Emperor's Palace Convention Centre, Johannesburg, 2011.

[13] R. M. Schoeman, A. J. Swart, and H. C. Pienaar, "Negating temperature on photovoltaic panels," presented at the AFRICON 2013, Mauritius, 2013.

[14] O. Asowata, J. Swart, and C. Pienaar, "Evaluating the effect of orientation angles on the output power of a stationary photovoltaic panel," *JRSE, Journal of Renewable and Sustainable Energy,* vol. 6, pp. 1-9, 2014.

[15] O. Asowata, A. J. Swart, and H. C. Pienaar, "Evaluating the effect of a stationary PV panel on the charging rate of Deep-Cycle Valve-Regulated Lead-Acid Batteries," presented at the AFRICON 2013, Mauritius, 2013.

[16] A. J. Swart, R. M. Schoeman, and H. C. Pienaar, "Ensuring sustainability of PV systems for a given climate region in South Africa," presented at the AFRICON 2013, Mauritius, 2013.

[17] P. E. Hertzog and A. J. Swart, "A Case Study: Validating a LabVIEW simulation model's presentation of fundamental principles in emerging renewable energy systems," presented at the EMERGITECH 2016, The 2016 IEEE International Conference on Emerging Technologies and Innovative Business Practices for the Transformation of Societies, Mauritius. ISBN: 978-1-5090-0706-6, 2016.

[18] O. Asowata, A. J. Swart, and H. C. Pienaar, "Correlating the power conversion of a PV panel to the solar irradiance obtained from Meteonorm," presented at the ICIT 2013, International Conference on Industrial Technology, Pavilion Clock Tower Conference Centre, Waterfront, Cape Town, 2013.

[19] P. E. Hertzog and A. J. Swart, "The impact of atmospheric conditions on the sustainability of a PV system in a semi-arid region: A case study from South Africa," presented at the ECTI-CON, 13th International Conference on Electrical Engineering, Electronics, Computer and Information Technology, Chiang Mai, Thailand. ISBN: 978-1-467-39749-0, 2016.

[20] A. J. Swart and P. E. Hertzog, "Quantifying the Effect of Varying Percentages of Full Uniform Shading on the Output Power of a PV Module in a Controlled Environment," presented at the SATNAC 2014, Boardwalk Conference Centre, PE, South Africa, 2014.

[21] A. Ozemoya, J. Swart, H. C. Pienaar, and R. M. Schoeman, "Factors impacting on the surface temperature of a PV panel," presented at the SATNAC 2013, Stellenbosch, South Africa, 2013.

[22] M. Duan and X. Zhou, "Stochastic dynamic simulation of the 100-kyr cycles in climate system," *Science China Earth Sciences,* vol. 58, pp. 420-428, 2015.

[23] M. Kolich and P. White, "Reliability and validity of a long term survey for automobile seat comfort," *International Journal of Vehicle Design,* vol. 34, pp. 158-167, 2004.