Linear Regression Algorithm Results for a PV Dual-Axis Tracking-Type System

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***Abstract*—A photovoltaic (PV) module converts solar energy into electrical energy. In order to increase the output power of any PV module, several factors including tilt angle, orientation angle, load profile, environmental condition, latitude of the location site, and energy management techniques should be considered. It is essential to continuously deliver the highest possible power to a load for a given day, which may be achieved by using a tracking-type system as compared to a fixed-type system. The purpose of this paper is to present the results of an algorithm that may be applied to a dual-axis system located in an elevated plateau of the interior of South Africa in order to sustain a high output power. Two identical 310W PV modules were used for a fixed-type and tracking-type system. The fixed-type system was installed at a tilt angle of Latitude minus 10° serving as a baseline to the tracking-type system. A LabView user interface was developed to record and display the voltage and current measurements from the PV modules. Results indicate that the dual-axis tracking-type system extracted more power (on average 39.32% more power) as compared to the fixed-type system. A key recommendation is to use a linear regression algorithm with a tracking-type system to enable a higher output energy yield for a given day.**

***Index Terms*—Photovoltaic, tilt angle, orientation angle, Latitude, LabVIEW**

I. Introduction

In a world of ever-increasing population and pollution, there exists a demand for more energy. Different types of renewables, or green energy resources, exist, such as hydropower, wind power, biomass and solar energy [1]. Economic growth depends heavily on the long-term availability of energy that is affordable, accessible, and environmentally sustainable. Research into renewable energy has therefore included finding more efficient and feasible methods to add to the existing energy supply [2]. This has included research into various energy monitoring and management systems.

Monitoring and managing Photovoltaic (PV) module performance facilitates preventive maintenance and fault detection [3], that can lead to a higher sustained yield of energy over a prolonged period of time. These management systems often contain a hardware and software section. Software that includes a customizable user interface is often used, and can be built in LabVIEW [4], where various parameters can be monitored and managed, including the output power and alignment of a PV module.

The output power of a PV module is influenced by a number of factors, including its installation (its alignment to the sun), varying atmospheric conditions and abnormal module degradation [5]. The installation can either be fixed, or variable (tracking-type), where the PV module is constantly aligned to the direct beam radiation of the sun by using either a single-axis or dual-axis system. Research has shown that tracking-type systems produce more power than fixed-type systems. One study showed that a single-axis system can produce 13% more power than a fixed-axis system [6] while a dual-axis system can produce 18% more power than a single-axis system. This suggests that a dual-axis system can produce around 31% more power than a fixed-axis system, as noted by Akbar, Siddiq and Aziz [7] who did their study in Iraq. However, would this percentage improvement hold true for all dual-axis systems that experience varying atmospheric conditions based on their location?

The purpose of this paper is to present the results of an algorithm that may be applied to a dual-axis system located in an elevated plateau of the interior of South Africa in order to sustain a high output power. A theoretical overview of fixed-type and tracking-type systems is firstly presented. Secondly, the experimental setup is outlined followed by the research methodology. Subsequently the results are listed and analyzed. Lastly the conclusion completes the paper.

II. Literature Study

Efficient operation of PV modules depends on many factors, including its installation [8]. The optimum installation for a fixed-type system involves placing a PV module at an orientation angle of 0° North (if in the Southern Hemisphere) and changing the tilt angle to be close to the Latitude angle of the site. The orientation angle is defined as the angle between true South (or true North) and the projection of the normal of the PV module to the horizontal plane [9]. The tilt angle is defined as the angle between the PV module surface and the horizontal plane. The tilt and orientation angles of a PV module are shown in Fig. 1. The angle of the sun differs between different hours of the day and the various seasons of the year resulting in the introduction of solar tracking-type

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systems. A tracking-type system follows the sun's daily motion (from east to west), by constantly trying to ensure a perpendicular direct beam radiation of the sun onto the glass surface of the PV module. Solar tracking-type systems do consume energy during operation [10], as either actuators or motors are used to change the alignment of the PV module to the direct beam radiation of the sun throughout the day.

However, they yield more energy that compensates for the higher construction, operations and maintenance costs [11]. Furthermore, its overall efficiency can also be influenced by the type of control algorithm that is used to control the actuators or motors, which can include linear regression [12].

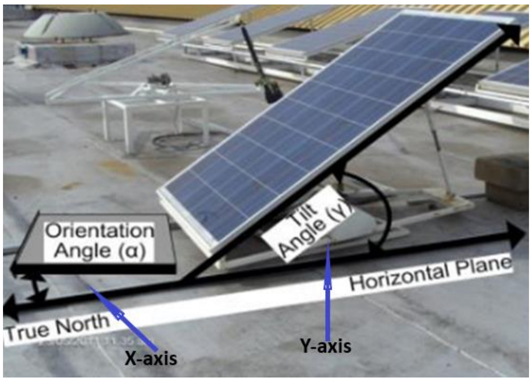

Fig. 1. Tilt and orientation angles of a PV module [9].

III. Experimental Setup

The output characteristic of a PV system is nonlinear and varies with ambient temperatures and solar irradiance levels [13]. However, a linear regression algorithm can be used as a way of fitting a straight-line model to observed data [14]. The relationship between the independent variable *X* (time of day) and the dependent variable *Y* (output voltage of the PV m module) can be modelled to enable a higher output power from a PV system. In this research, two identical PV modules of 310W are used along with a logging interface circuit that links to a LabVIEW user interface. Polycrystalline modules (YL310P-35b) are used with a rated voltage of 36.3V, open circuit voltage of 45.6V, rated current of 8.53A and a short circuit current of 8.99A.

The logging interface circuit connects to a load comprising 5 resistors (4 by 0.82Ω resistors in series with a 1Ω resistor (100W)). One of the PV modules (a fixed-type system) was set to an orientation angle of 0° North and tilt angle of 16°. Previous research has suggested using the Latitude of the installation side, or then Latitude +10° or Latitude –10° depending on the season of the year [8]. This 16° is 10° less than the Latitude value of the installation site of the Science Campus of the University of South Africa (UNISA). This campus lies on an elevated plateau of the interior of South Africa (Highveld) that is well-known for its spectacular thunderstorms. The climate is subtropic with a high-altitude plateau of extensive grasslands located about 1700 m above sea level. The temperature ranges between 15℃ and 26℃ in summer and between 4℃ and 16℃ in winter periods. Brief afternoon thunderstorms and rainfall are common in summer whereas winters are crisp and dry, with frost occurring in the southern areas. The wind speed is generally light ($4 m \cdot s^{-1}$) except during thunderstorms, and average evaporation rate ranges between 109 and 246 mm $month^{-1}$) [15].

The second 310W PV module (a tracking-type system) was controlled by a linear regression algorithm that was developed in LabVIEW. The development of this algorithm was published in 2018 [16]. The system block diagram is illustrated in Fig. 2 while a photo of the modules is shown in Fig. 3.

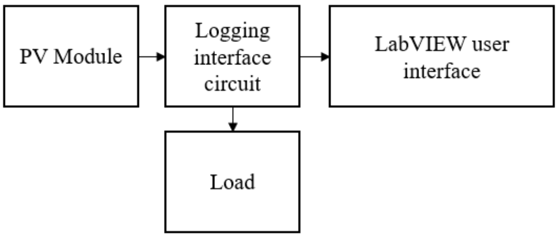

Fig. 2. Block diagram of the system.

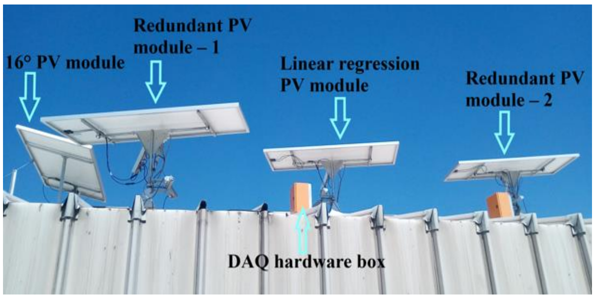

Fig. 3. Experimental setup showing fixed 16°, linear regression algorithm PV modules and DAQ hardware box.

The data logging interface circuit provides signal conditioning between the PV modules and specific data acquisition (DAQ) equipment from National Instruments (NI). It was installed close to the PV modules and connected to a remote personal computer using a network cable. The DAQ was also used with other PV modules that do not form part of this study. Voltage and current measurements from the PV modules were relayed to LabVIEW where the output power is calculated, and the result visually displayed in graph form. The main function of the data logging interface circuit is to scale down the output voltage of the PV module to a value less than 10V, being the maximum input voltage to the DAQ equipment.

Fig. 4 illustrates the resistor configuration used in the load (see Fig. 5 for a photo of them). These are high power resistors that are chosen to satisfy the voltage divider rule. An economic viable load for considering output power results from identical PV modules can include the following [17]:

- Batteries with a solar charger;
- Batteries with a maximum power point tracker (MPPTs);
- Regulated and non-regulated light emitting diode (LED) lamps; and
- Fixed load resistors.

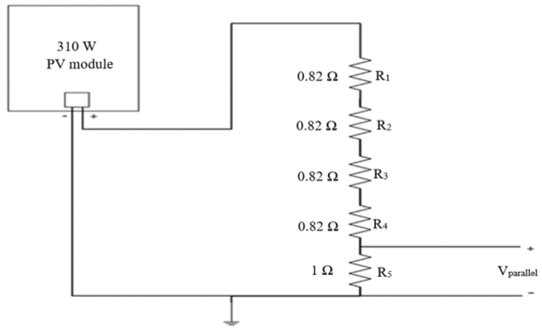

Fig. 4. Circuit diagram of the load resistance.

Fig. 5. System's load.

Using fixed load resistors is an effective and easy method to start loading PV modules located outdoors for measurement purposes. They can greatly reduce costs and complexity; however, the disadvantage is that there is no way to implement maximum power tracking (MPT). Fixed load resistors in this study form a typical voltage divider circuit, where five resistors are connected in series across a source voltage. As the source voltage is dropped in successive steps through the series resistors, any desired portion of the source voltage may be "tapped off" to supply individual voltage requirements [18]. The voltage divider circuit provides signal conditioning, as the maximum power point voltage of the PV module is rated at 36.3V which is much higher than the allowed input voltage to the NI DAQ unit which is limited to 10V. Using three 0.82Ω and 1Ω resistors (100W) in series enables the input voltage to the NI DAQ to be less than 10V.

IV. Research Methodology

This section describes the research methodology that was followed for this study. An experimental research approach was used where one PV module was set to a fixed position (Latitude minus 10° (16°)) and the other one was used to track the sun throughout the day, using a linear regression algorithm. The data was collected for a period of six months (November 2018 to April 2019).

The calibration of the systems was verified on 3 February 2019 between 12 noon and 1 pm. Both were set to the same orientation angle of 0° North and to a tilt angle of 26° (Latitude) (reference to Fig. 6). Voltage and current measurements were taken to observe if there was any significant difference between the two systems. Results showed no significant difference which then required no calibration adjustments to the system. Subsequently, the two PV modules were then set back to their respective positions (fixed-type and tracking-type system) (see Fig. 7).

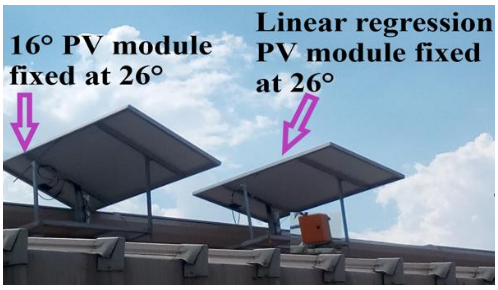

Fig. 6. Fixed-type and tracking-type systems fixed at a 26 °tilt angle.

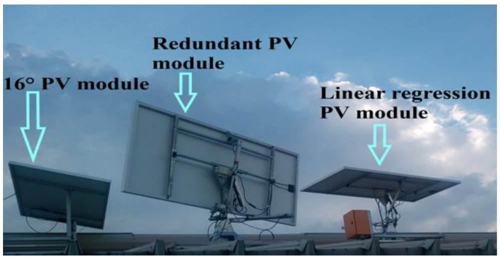

Fig. 7. PV modules used in this study.

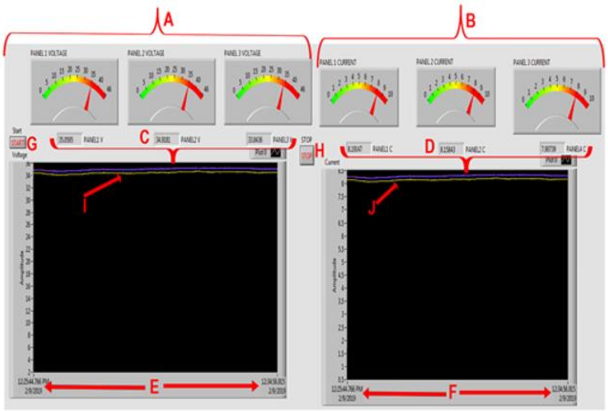

Fig. 8. LabVIEW front panel.

V. Results and Discussions

This section provides results regarding the different output powers measured from the fixed-type and tracking-type systems. Fig. 8 shows the LabVIEW user interface that was used to display voltage and current readings.

The measured voltage and current values were used to calculate the output power ($P = VI$). It must be noted that the readings for Panel 3 do not form part of this study. The LabVIEW user interface provides the following information:

- Analog instantaneous value of voltage for each PV module (point A);
- Analog instantaneous value of current for each PV module (point B);
- Digital instantaneous value of voltage for each PV module (point C);
- Digital instantaneous value of current for each PV module (point D);

- Execution date and time of the system (point E and F);
- Manual start of the measuring system ignoring the set system's start time (G);
- Manual stop button function to control the while loop execution (point H);
- Voltage curve for each PV module (point I); and
- Current curve for each PV module (point J).

The readings highlighted in Fig. 9 show the physically measured voltage of 34.9V and current of 8.29A on the digital multimeters taken on 3 February 2019 as part of the calibration process. These values correlated well with the rated value of the PV module (rated voltage of 36.3V and rated current of 8.53A) and with those shown on the LabVIEW user interface as shown in Table I, which also presents the percentage difference between the digital multimeter and LabVIEW readings. The highest error percentage for voltage occurred for the fixed-type system PV module (being 0.57%). Identical PV systems can be calibrated to produce the same results, with variability of less than 1% being excellent [4]. A consistent percentage (0.24%) error was also determined between the multimeter and LabVIEW user interface. No adjustment to the calibration settings of the system were thus required. All subsequent measurements were thus deemed valid and reliable.

Fig. 9. Rish multi 16S True RMS multimeter

TABLE I: CALIBRATION RESULTS

Systems	LabVIEW Current (A)	Multimeter Current (A)	Current Error percentage (%)	LabVIEW Voltage (V)	Multimeter Voltage (V)	Voltage Error percentage (%)
Fixe-type system	8,27	8,29	0,24	34,7	34,9	0,57
Tracking-type system	8,27	8,29	0,24	34,4	34,5	0,29

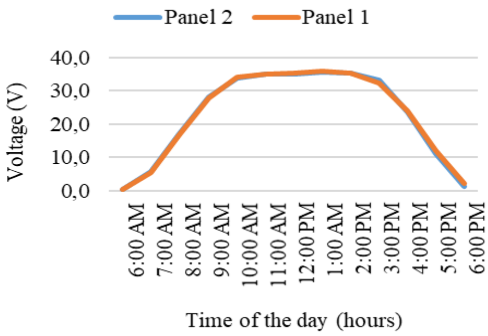

Fig. 10. Two PV modules fixed at 0 °orientation and 26 °tilt angles for calibration purposes.

The voltage measured for one day was utilized to plot a graph as illustrated in Fig. 10 where the two PV modules (Panel 1 – fixed-type system and Panel 2 – tracking-type system) were fixed at the same tilt and orientation angles (0 ° and 26 °) for calibration purposes. The PV modules behaved similarly throughout the day. From 10 am to 15:00 pm the PV modules were aligned to the larger portion of the solar radiation which is normally maximum at 12 noon. The PV modules were producing the same output voltage which was nearly the maximum rated voltage. The purpose of the calibration was to determine any invariability between the two systems. None existed, resulting in a valid setup where subsequent measurements or results were reliable.

Table II lists the daily average hourly power and the total hourly power for the tracking-type (Panel 2) and the fixed-type system (Panel 1). Panel 2 extracted power from the sun by tracking it in both axes (dual axis) while Panel 1 extracted power fixed at tilt angle of 16 °. The percentage difference (41 %) is evident at the bottom of the table. This suggests that Panel 2 extracted 41 % more energy than Panel 1 for this specific day in the summer season. The table was also used to plot a graph as illustrated in Fig. 11, where one day (1 December 2018) of instantaneous power (in watts - W) for both fixed-type and tracking-type systems is shown. It is evident that the tracking-type system performed better than the fixed-type system from 6 am to 10:00 am and from 3 pm to 6:00 pm. However, from 11 am to 2 pm, the PV modules produced constant output voltage which was nearly maximum. This was due to the fact that the PV modules were aligned to the larger portion of the solar radiation which is normally maximum at 12 noon.

TABLE II: FIXED-TYPE (PANEL 1) AND TRACKING-TYPE (PANEL 2) PV MODULES AVERAGE HOURLY POWER READINGS (W) AND THE TOTAL WH FOR 1 DECEMBER 2018

Time	Panel 2	Panel 1
6AM-7AM	171,76	4,78
7AM-8AM	262,22	39,8
8AM-9AM	254,96	127,04
9AM-10AM	256,64	233,28
10AM-11AM	271,21	271,23
11AM-12PM	274,41	274,81
12PM-13PM	289,74	291,14
13PM-14PM	282,3	279,65
14PM-15PM	269,79	269,69
15PM-16PM	253,02	187,05
16PM-17PM	234,47	91,39
17PM-18PM	112,15	14,93
Total Wh for the day	2942,67	2084,79
Percentage difference	41%	

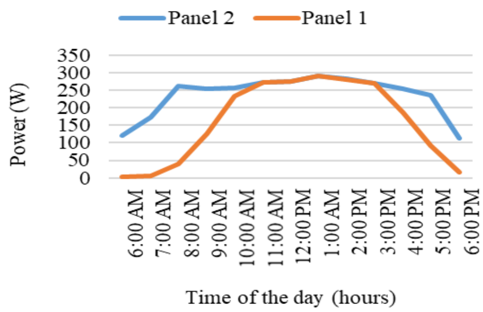

Fig. 11. Fixed-type (Panel 1) and tracking-type (Panel 2) PV modules average daily power output.

TABLE III: TRACKING-TYPE AND FIXED-TYPE MODULES INSTANTANEOUS POWER READINGS FOR SIX MONTHS

Time	Panel 2	Panel 1
Nov-18	6277,87	4727,85
Dec-18	8254,22	5849,14
Jan-19	6780,27	4822,38
Feb-19	6035,62	4280,27
Mar-19	4262,09	3022,07
Apr-19	1630,26	1156,51
Total 6 Months Ave. Wh	33240,33	23858,22

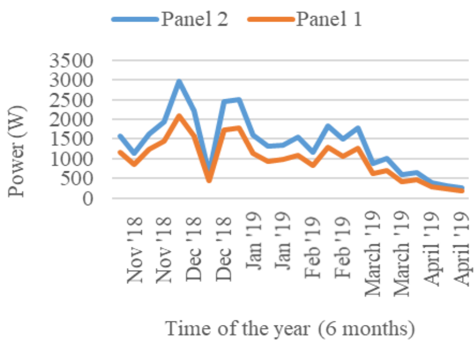

Fig. 12. The tracking-type (panel 2) and fixed-type (panel 1) system's output power for 6-months.

Table III lists the results of the instantaneous average power for a period of six months, being November, December 2018, January, February, March and April 2019 for both systems. These results were used to plot a graph as illustrated in Fig. 12. The total average Wh is listed at the bottom of the table.

It is evident from Fig. 12 that the tracking-type system outperformed the fixed-type system for the whole six months with an average difference of 39.32 %. Dual-axis tracking-type systems usually produce more than 30 % output power as compared to a fixed-type system [7] The power output was high in the months of November and December 2018. However, the results show that from the month of January to the month of April 2019 the output power started decreasing due to the seasonal change in South Africa. The solar radiation curve is higher between November and February (its peak being in December) and starts declining from February to May reaching its lowest point in June in South Africa [19].

VI. CONCLUSION

The purpose of this paper was to present the results of an algorithm that may be applied to a dual-axis system located in an elevated plateau of the interior of South Africa in order to sustain a high output power. A fixed-type system, set at a tilt angle of Latitude minus 10 ° (Panel 1), served as a baseline to a tracking-type system (Panel 2). The PV modules were installed at the Science Campus of UNISA that is characterized as having a subtropic climate, located on a high-altitude plateau of extensive grasslands about 1700 m above sea level. Its climate differs significantly from Iraq, where another study also contrasted a dual-axis tracking-type system to a fixed-type system [7]. That Iraq study was conducted for only one month and revealed a maximum output power improvement of 30% for their tracking-type system that used a microcontroller.

This South African study revealed an average output power improvement of 39.32% over a 6-month period. The main results indicated that Panel 2 (tracking-type system) outperformed Panel 1 (fixed-type system) by 41% for 1 December 2018 and by 39.32% in a six-month period.

The reliability and validity of these results was established by having the two PV module set to the same tilt angle for one day. A variability of less than 1 % between their respective output powers was established indicating a higher level of similarity between the performances of the two modules.

It is important to state that possible limitations of this study include the fact that only one research installation site was used, and that data has not yet been collected for a whole year. It is vital to obtain results for a whole year as varying environmental conditions always exist. Based on the results of this study, it is recommended to use a linear regression algorithm for dual-axis tracking-type systems, as it performs well in perpendicularly aligning the glass surface of a PV module to the direct beam radiation of the sun throughout the day.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Mr. Lehloka conducted the research as part of his postgraduate study; Prof Swart provided guidance on structuring the paper and edited it; Prof Hertzog provided review comments and edited specific sections of the paper; all authors had approved the final version.

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