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A Study of Methods to Improve the Efficiency of Photovoltaics Systems

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Abstract:

Solar panels have zero emissions in terms of power production and therefore help to combat climate change. However, commercial solar panels have an efficiency that is less than 20%. Therefore, the researcher endeavored to examine various ways to improve the performance of photovoltaic systems. This includes the use of optimum tilt angles and tracking devices to secure maximum radiation, and the cooling of photovoltaic panels. Using a polycrystalline photovoltaic solar panel equipped with a Versatile Data Acquisition System (VDAS) hardware, studies of how Peak Power, Efficiency and Intensity of Irradiance varied at tilt angles of 7°, 10°, 15°, 20°, 25°, and 30° were conducted and the optimum tilt angle determined. The solar panel was located at the University of Guyana, Faculty of Engineering and Technology, Turkeyen Campus.

Empirical studies reveal an optimum tilt angle of 7^0 where the maximum peak power is produced. This was consistent with that recommended by literature Amin et al. (2018) because it was the latitude of the location. Deviation from the optimum tilt angle can produce a significant reduction in power production and efficiency. A deviation of 3^0 from the optimum tilt angle caused a reduction in average peak power production of as much as 28 % and a 16% reduction in average efficiency. Further studies conducted in this research showed that solar panels that have cooling mechanisms can deliver as much as 14% more energy. Additionally, empirical data also reveal that tracked arrays are useful and can produce 25.5% more power than fixed arrays to meet energy needs.

Keywords **—Tilt angle, efficiency, photovoltaic.**

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I. INTRODUCTION

Since around the 1850's, the global utilization of fossil fuels has dominated energy supply, leading to a rapid increase in carbon dioxide emissions with negative environmental effects. The IPCC Fourth Assessment Report concluded that "Most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" [1]. Fossil fuel has remained the main energy source in the world's energy supply. Their use for power production has resulted in global warming through Green House Gas (GHG) emissions. In 1990, the GHG emitted in terms of volume was approximately 30, 423 MtCO2e, compared to 2012 this was increased to 47, 598.55 MtCO2e which represents a 2.06 percent annual growth [2]. Guyana is heavily dependent on fossil fuel to meet its energy needs and therefore has an urgent need for sustainable energy sources. Sustainable energy is the concept of establishing methods of generating energy and providing that energy to meet the needs of the current generation but not compromising the needs of the future generations [3].

Solar photovoltaic power production has a surging potential for reduction of greenhouse gas emissions but commercial solar panels still have an efficiency of less than 20%. Various methods of improving the efficiency of solar photovoltaic power systems are investigated in this research, including the use of optimum tilt angle, tracking devices to secure maximum radiation, and the cooling of photovoltaic panels. In this research, the variation of peak power, efficiency, and intensity of irradiance at tilt angles of 7°, 10 °, 15°, 20°, 25°, and 30° is studied using a polycrystalline solar panel facing south located at the Faculty of Engineering and Technology. Data is collected for the months of May, June, and August and the optimum tilt angle is determined. The recommended optimum tilt angle is determined by the latitude of the geographical location, but research must be done to verify the value of the optimum tilt angle. When solar panels are positioned at the optimum tilt angle there is maximum power production and maximum efficiency.

The panel is equipped with a Versatile Data Acquisition System (VDAS) Hardware which enables the user to view and record data in real time with the use of a computer. Furthermore, empirical studies reveal an optimum tilt angle of 7^0 where the maximum peak power is produced. Deviation from the optimum tilt angle can produce significant reduction in power production and efficiency. A deviation of 3^0 fromthe optimum tilt angle caused a reduction in average peak power production of as much as 28 % and a 16% reduction in average efficiency.

The literature review provides a sound mathematical analysis of the calculation of efficiency and maximum power production of a solar cell, which is necessary for the determination of the optimum tilt angle. The efficiency of a typical solar cell is defined by the ratio of the maximum power production to the intake or incoming power. Maximum power production is defined as the product of maximum current I_{mp} and Voltage V_{mp} or(I_{mp} x V_{mp}). The values for the maximum current I_{mp} and Voltage V_{mp} are obtained at the maximum power point(MPP) which is found when array curves for current versus voltage and power versus voltage were plotted for the environmental conditions at the time of the test. Thepeak power of the array is the maximum power (W) shown on the array curve showing power versus voltage. The peak power was divided by surface area to produce peak intensity (W/m^2). The efficiency of the array was found by dividing peak intensity by the solarimeter reading. The solar array used in this research consisted of a commercially accessible polycrystalline photovoltaic solar panel which was made up of thirty-six series connected cells. The literature review provides the integral foundation needed for the appreciation of other methods of improvement of efficiency of photovoltaics systems such as cooling and tracking. It also determines the most economical solar cell which is the polycrystalline solar cell.

The temperature rise of a solar panel adversely affects its photoelectric conversion efficiency. The temperature of a solar panel can be as high as 80°C and its efficiency is therefore significantly reduced [4]. Further studies conducted in this research show that solar panels that have cooling mechanisms can deliver as much as 14 % more energy, thus increasing its efficiency.

A standard solar array consisting of polycrystalline solar cells will require an estimated area of 10 m^2 to generate 1 KW of peak power. Some applications do not permit enough room for larger array areas but still need to provide sufficient power to attain the desired energy requirement. Tracking is therefore useful in such a situation because this type of array allows panels to capture light from all angles and allows for maximum production [5]. A solar tracker is a mechanism that is used on solar panels to follow the sun's movements throughout the day. A fixed array is usually installed at the angle of latitude and cannot capture maximum radiation all day. Power production can be improved with the use of tracking. Solar trackers are also useful in commercial installations where there is economic justification despite the large initial investment required [6].

Information provided by this research can prove to be valuable to policy makers, end users, and students as Guyana seeks to scale up its use of solar photovoltaic power systems for power production as it endeavors to meet its ambitious goal of reducing our carbon emissions by 70 per cent by 2030.

II. OPTIMUM TILT ANGLE, USE OF TRACKING AND COOLING MECHANISM

The various methods of improving the efficiency of solar photovoltaic power systems are examined, including the use of optimum tilt angles, tracking devices to secure maximum radiation, and the cooling of photovoltaic panels. The variation of peak power, efficiency, and intensity of irradiance at tilt angles of 7°, 10 °, 15°, 20°, 25°, and 30° is studied using a polycrystalline solar panel facing south located at the Faculty of Engineering and Technology. Data is collected for the months of May, June, and August and the optimum tilt angle is determined. May and June usually present rainy weather conditions while August present dry weather conditions. Hence, these months were chosen as the months of interest for data collection. The panel is equipped with a Versatile Data Acquisition System (VDAS) Hardware which enables the user to view and record data in real time with the use of a computer. Please see Fig 4.5 and Fig 4.6. The procedure for measuring the efficiency and peak power at tilt angles 7^o, 10^o, 15^o, 20^o, 25^o and 30^o is outlined. The efficiency of a typical solar cell is defined by the ratio of the maximum power production to the intake or incoming power. Maximum power production is defined as the product of maximum current I_{mp} and Voltage V_{mp} or(I_{mp} x V_{mp}) [7]. The values for the maximum current I_{mp} and Voltage V_{mp} are obtained at the maximum power point(MPP) which is found when array curves for current versus voltage and power versus voltage were plotted for the environmental conditions at the time of the test. Thepeak power of the array is the maximum power (W) shown on the array curve showing power versus voltage. The peak power was divided by surface area to produce peak intensity (W/m^2). The efficiency of the array was found by dividing peak intensity by the solarimeter reading.

The solar array used in this research consisted of a commercially accessible polycrystalline photovoltaic solar panel which was made up of thirty-six series connected cells. Data such as peak power, efficiency, solar intensity, and peak intensity was collected in the months of May, June, and August and presented appropriately. An analysis of empirical data reveals an optimum tilt angle of 7^o where the maximum peak power is produced. Deviation of as little as 3^o fromthe optimum tilt angle can cause a reduction in peak power production of as much as 16 %.

A solar tracker is a mechanism that allows solar panels to follow the sun's movements throughout the day. Maximum assimilation of energy by solar panels can be achieved as a result of tracking, which causes the panel to be positioned perpendicular to the sun therefore maximizing the power generated by the solar array [6]. The procedure is outlined where PV-Watts modelling is used to show the advantage that a track array has over a fixed array. PV-Watts simulation tool was created by the National Renewable Energy Laboratory (NREL) and is an internet-dependent platform designed for the approximation of electrical energy produced by grid-connected photovoltaic (PV) systems. This research shows that tracked arrays are useful and can produce 25.5 % more power than fixed arrays to meet energy needs.

The temperature rise of a solar panel adversely affects its photoelectric conversion efficiency. The temperature of a solar panel can be as high as 80^0C and its efficiency is therefore significantly reduced [4].

III. Description of Photovoltaic System Research Equipment

A Photovoltaic System Research Equipment follows a normal configuration of a Photovoltaic System and can be seen in Fig. 1. and Fig 2. The Control Cabinet was energized by the mains and was linked to the Solar Array with a long cable for convenient and safe operation. A detached small power battery can be attached to the Control Cabinet and used for tests that have small duration. The solar array consisted of a commercially accessible polycrystalline photovoltaic solar panel which was made up of thirty-six Series Connected Cells. It was equipped with a reinforced high transmission glass cover. This category of panel provided the utmost dependability and needed minimal upkeep. It had a high aversion to water, corrosion, and other environmental effects. The peak power of the solar array was 40 W and its maximum open circuit voltage was 21.8V. The current at peak power was 2.31A and the short circuit current was 2.54 A with a nominal voltage of 12V. The panel was affixed to a frame with wheels that permitted it to be positioned at an angle of 0^o to 90^o with respect to the light source. A solarimeter was attached to the frame to permit evaluation of incident radiation in order to compute the efficiency of the system. See Fig. 1. below. The solarimeter was used to evaluate the irradiation intensity and evaluated both direct and indirect radiation as one radiation level without any differentiation. Direct radiation travels in a straight line and indirect radiation is non-directional. The solarimeter consisted of a sequence of thermocouple junctions shielded by a hemispherical dome. The instrument was calibrated to produce a reading proportional to the total incoming radiation. The Solarimeter was affixed straight overhead of the Array, so that it is exposed to the same irradiation just like the array. This enabled it to provide an accurate indicator of the total incident radiation, direct plus indirect, that strikes the exterior of the array.

Fig. 1Polycrystalline Photovoltaic Solar

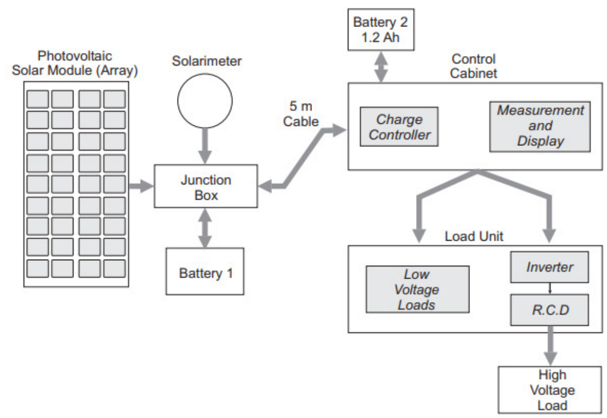

Fig. 2 Configuration of Photovoltaic System

A long cable linked the junction box on the Solar Array Frame and the Control Cabinet so that connection was made amongst the Battery 1, the Array, and the Solarimeter. See Fig. 4. This permits the utilization of the frame outdoors, at the same time the control cabinet that is powered by the mains remains indoor, in a sheltered condition. The control cabinet consisted of a charge controller that managed the flow of current backward and forward from the batteries. It incorporated a link for a display that revealed the production of the panel and the battery storage arrangement. The display showed values for: Battery output voltage and current (current is shown as negative as an indication of the battery being charged); Array output voltage and current; Output voltage and current to loads (from Output 2) and Solarimeter signal (radiation intensity) Wm^{-2}. The output voltage and current consisted of the total voltage and current measured at the Output 2 sockets, which is roughly the total of the Battery and Array voltages and currents. This value is more precise because of the loss in voltage from Battery 2 at large loads as a result of the volt loss across the 5 m lead. The battery and array currents incorporated a minor value of current (< 0.1A)that was utilized by the circuits and relays of the Charge Controller and therefore was not recorded at the Output 2 sockets. Please see Fig. 2. and Fig. 3.

Output 1 was utilized primarily for experiments that require a “direct” link to the Array. Two LEDs positioned on the front panel of the Control Cabinet indicated the two conditions of the Charge Controller, “LOAD CUT” and “FLOAT MODE”. The “LOAD CUT” LED showed that the load has been disengaged by the Charge Controller because the battery voltage has gone too low, so the battery is protected from additional drain. The “FLOAT MODE” LED showed that the battery is at a nominal voltage and is being charged by the Array with a small (float) current. The battery current is shown negative when it is being charged

Switches SW1 and SW2 permitted the option of the solar array/ charge controller output/ battery alternatives. Each switch had three locations and the middle location indicated ‘off’. Please see Fig. 3. below for the arrangements of the switches as they link the array to the charge controller and batteries. On the back of the panel of the control cabinet were located connections for the long cable to the Array, the smaller battery (Battery 2), power for the fan on the Load Unit (IEC female).

The Charge Controller was located within the Control Cabinet and adjusted the charging current from the Array to Battery 1 or Battery 2 so that a large current flowed when the battery is greatly dispensed. It also ensured a small (‘Float’) charging voltage when the battery has reached its nominal voltage. The Charge Controller shields the battery from impairment when it disengages the battery from the load (‘Load Cut”) when the voltage level of the battery is low.

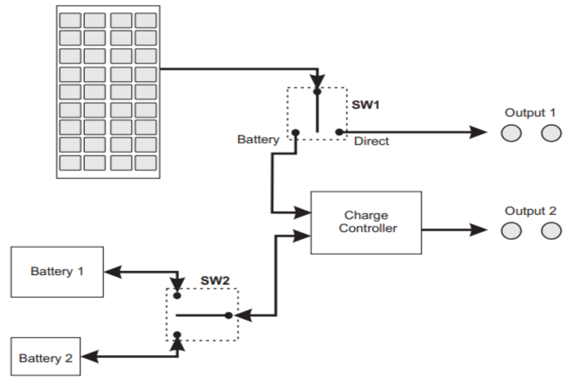

Fig. 3 SW1 and SW2 Circuits

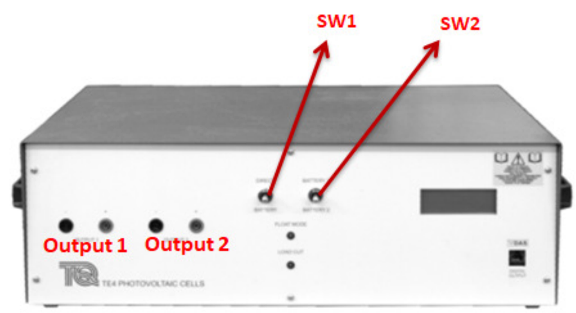

Fig. 4 The Control Cabinet

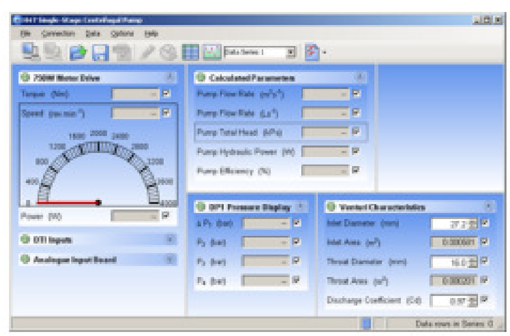

Fig. 5 VDAS Experiment Window

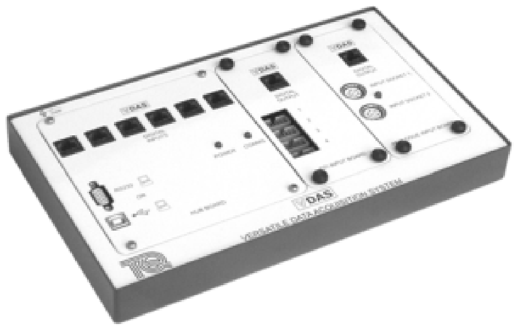

Fig. 6 VDAS-B Hardware

IV. MEASUREMENT OF PEAK POWER, EFFICIENCY, SOLAR INTENSITY AND PEAK INTENSITY AT TILT ANGLES 7^0, 10^0, 15^0, 20^0, 25^0 AND 30^0

The solar array was situated at the Faculty of Engineering and Technology, University of Guyana which has a latitude of 6.81^0 according to Google Maps. Data was collected in the months of May, June, and August. May and June presented rainy weather conditions while August presented dry weather conditions. At tilt angles 7^0, 10^0, 15^0, 20^0, 25^0 and 30^0, the variation of the following variables with time is studied: peak power, efficiency, solar intensity and peak intensity.

V. RESULTS FOR VARIATION OF PEAK POWER WITH TIME AT TILT ANGLE 7^0, 10^0, 15^0, 20^0, 25^0 AND 30^0

The solar panel was used to collect data at the Faculty of Engineering and Technology, University of Guyana, Turkeyen Campus which has a latitude of 6.81^0 according to Google Maps. Data was collected in the months of May, June and August 2022 for tilt angle 7^0, 10^0, 15, 20^0, 25^0 and 30^0. May and June presented rainy weather conditions while August presented dry weather conditions.

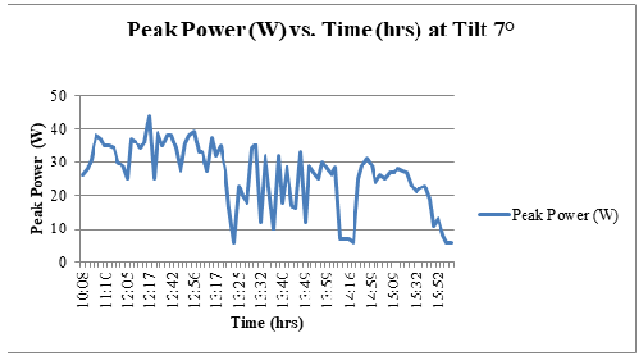

Fig. 7 Peak Power (W) vs. Time (hrs.) at Tilt 7^0

At tilt angle 7^0, a maximum peak power of 43.9W occurred at 12:17 hrs. with a minimum value of 6W occurring at 13:25 hrs. The average peak power was 26.1W with a standard deviation of 9.6.

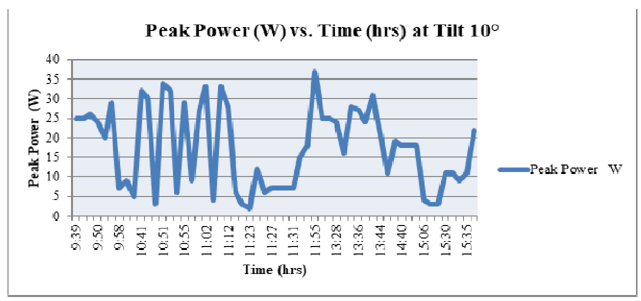

Fig. 8 Peak Power (W) vs. Time (hrs.) at Tilt 10^0

At tilt angle 10^0, peak power 37W occurred just before 11:55 hrs. Minimum power of 2W occurred at 11:23 hrs. There was an average peak power of 18.7W with a standard deviation of 10.7.

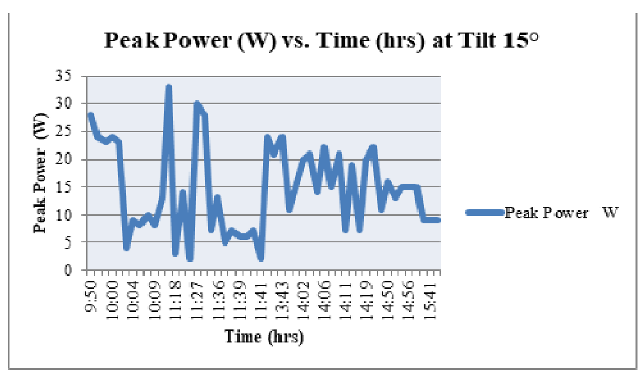

Fig. 9 Peak Power (W) vs. Time (hrs.) at Tilt 15^0

At tilt angle 15^0, a peak power of 33W occurred at 10:35 hrs. Minimum power of 2W occurred at 11:41 hrs. The peak power average was 14.4W with a standard deviation of 7.6.

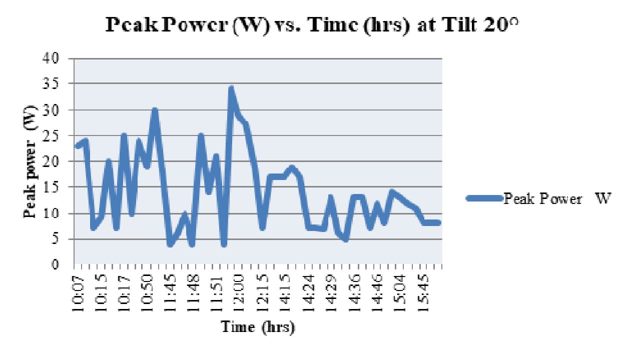

Fig. 10Peak Power (W) vs. Time (hrs.) at Tilt 20^0

At tilt angle 20^0 a peak power of 34W occurred at 11:55 hrs. A minimum power of 4W occurred at 11:53 hrs. illustrating the fluctuating weather conditions of Guyana. The Peak Power average was 14.1W with a standard deviation of 7.8.

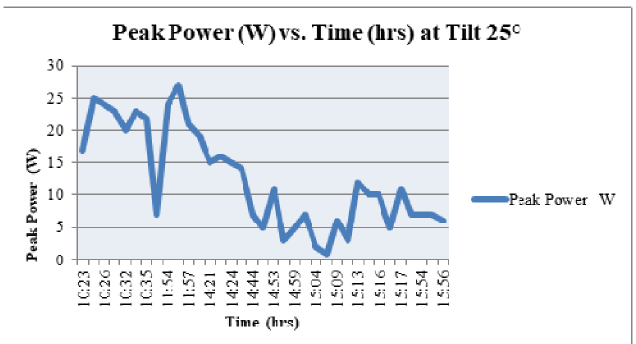

Fig. 11 Peak Power (W) vs. Time (hrs.) at Tilt 25^0

At a tilt angle of 25^0 a maximum peak power of 27W occurred at 11:55 hrs. A minimum power of 1W occurred at 15:09 hrs. The peak power average was 12.5W with a standard deviation of 7.7.

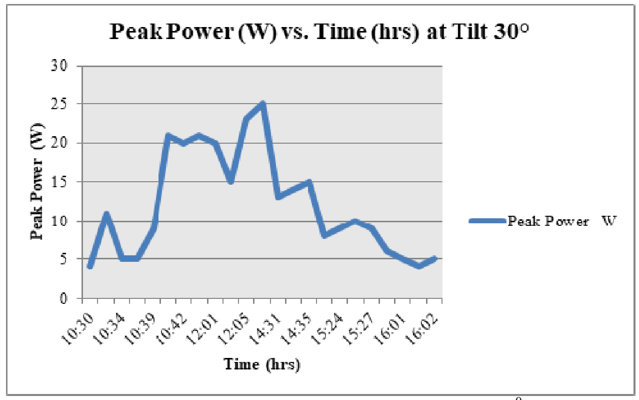

Fig. 12 Peak Power (W) vs. Time (hrs.) at Tilt 30^0

At a tilt angle of 30^0 a peak power of 25W occurred at 12:07 hrs. Minimum power occurred at 4W at 16:02 hrs. The average peak power was 12W with a standard deviation of 6.8.

TABLE I
SUMMARY OF RESULTS-PEAK POWER REDUCTION VERSUS TILT ANGLE

Tilt Angle (Degrees)	Peak Power (W)	Percentage Reduction in Peak Power
30	25	43.1
25	27	38.5
20	34	22.6
15	33	24.8
10	37	15.7
7	43.9	0

VI. VARIATION OF EFFICIENCY WITH INTENSITY AT TILT ANGLES

The Optimum Tilt Angle was found to be 7^0 as expected from literature, because this is the latitude of the location. At this tilt angle, the highest maximum efficiency of 15.4 % was recorded at irradiance of 518 W/m^2 with the highest average efficiency of 12.6 % and the lowest standard deviation. This means that the efficiency of the solar panel is most consistently high at tilt angle 7^0. However, maximum efficiency significantly decreases as the tilt angle deviates from 7^0. At tilt angle 10^0, which is a 3 o deviation from the optimum tilt angle produces an 8 % reduction in maximum efficiency and a 16 % reduction in average efficiency. At tilt angle 15^0 there is a 7^0 deviation from the optimum tilt angle produces a 22 % reduction in average efficiency and a 13 % reduction in maximum efficiency. At tilt angle 20^0, a 13^0 deviation from optimum tilt angle causes a 23 % reduction in average efficiency and a 19 % reduction in maximum efficiency. At tilt angle 25^0, a 13^0 deviation from optimum tilt angle causes a 28 % reduction in average efficiency and a 10 % reduction in maximum efficiency. Finally, at tilt angle 30^0, a 23^0 deviation from optimum tilt angle causes a 29 % reduction in average efficiency and a 23 % reduction in maximum efficiency. Therefore, it can be said that the efficiency of the solar panel is significantly affected by tilt angle.

TABLE 2
SUMMARY OF RESULTS-VARIATION OF EFFICIENCY WITH TILT ANGLES

Tilt Angle (Degrees)	Max Efficiency (%)	Average Efficiency (%)	Reduction of Max Efficiency (%)	Reduction of Average Efficiency (%)
7	15.4	12.6	0.0	0.0
10	14.2	10.8	7.8	15.8
15	13.5	9.8	13	22.2
20	12.5	9.7	18.8	23.0
25	13.8	9.1	10.4	27.8
30	11.8	8.9	23.4	29.4

The tilt angle of a solar panel had a significant effect on the efficiency of the solar panel. The efficiency of the solar panel was most consistently high at tilt angle 7^0 which is the optimum tilt angle. Therefore, there was maximum power production at this tilt angle. However, maximum efficiency significantly decreased as the tilt angle deviated from 7^0. At tilt angle 10^0, which was a 3^0 deviation from the optimum tilt angle, an 8 % reduction in maximum efficiency and a 16 % reduction in average efficiency were achieved. Therefore, there was an 8 % reduction in maximum power production at tilt angle 10^0.

At tilt angle 15^0, a 7^0 deviation from the optimum tilt angle produced a 22 % reduction in average efficiency and a 13 % reduction in maximum efficiency. Therefore, there was a 13% reduction of maximum power produced at this tilt angle.

At tilt angle 20^0, a 13^0 deviation from optimum tilt angle, a 23 % reduction in average efficiency and a 19 % reduction in maximum efficiency were achieved. Therefore, at this tilt angle there was a 19% reduction of maximum power produced compared to that produced at tilt angle 7^0.

At tilt angle 25^0, a 13^0 deviation from optimum tilt angle, a 28 % reduction in average efficiency and a 10 % reduction in maximum efficiency were the results. Therefore, at this tilt angle there was a 28% reduction of average power produced compared to that produced at tilt angle 7^0.

Finally, at tilt angle 30^0, a 29 % reduction in average efficiency and a 23 % reduction in maximum efficiency were determined. Therefore, at this tilt angle there was a 29% reduction of average power produced compared to that produced at tilt angle 7^0. The tilt angle had a significant effect on the efficiency and power production of the solar panel.

VII. USE OF PV WATTS MODELING TO SHOW THE EFFECT OF COOLING ON PV POWER PRODUCTION

The PV Watts modelling was used to show the effect of cooling on PV power production. PV Watts is an Internet-connected simulation tool for providing a quick approximation of the electrical energy produced by a stand-alone crystalline silicon photovoltaic (PV) system. The location of the Faculty of Engineering and Technology, University of Guyana was selected and the nearest weather station data source was used together with the provided PV system parameters. PV-Watts performed an hour-by-hour simulation of monthly and annual alternating current (AC) energy production in kilowatts and energy value in dollars. Some of the system parameters that may be specified include AC rating and size, local electric costs, PV array type (fixed or tracking), PV array tilt angle, and PV array azimuth angle. The tool is available on the National Renewable Energy Laboratory (NREL) website [8].

The PV Watts modelling for the simulation used a 4 KW roof mounted standalone system. System losses of 12.2 % were chosen to represent a system with cooling and system losses of 24.2 % were selected to represent a solar panel system without cooling. This resulted in a 13.9 % increase in power production, as shown below as a result of cooling. In the month of December, there was a negligible difference in power production due to cooling because of the prevailing rainy weather conditions of that month.

TABLE 3
PV-WATTS SIMULATION OF THE 4 KW POWER SYSTEM: FIXED (ROOF MOUNTED) WITHOUT COOLING

Month	**Solar Radiation (kWh / m^2 / day)**	**AC Energy (kWh)**	**Value ($)**
January	5.64	452	20 792
February	6.12	441	20 286
March	6.34	505	23 230
April	5.92	461	21 206
May	5.39	431	19 826
June	5.25	411	18 906
July	5.48	434	19 964
August	6.09	481	22 126
September	6.48	490	22 540
October	6.23	491	22 586
November	5.80	447	20 562
December	5.25	419	19 274
Annual	5.83	5463	251 298

TABLE 4
PV-WATTS SIMULATION OF THE 4 KW POWER SYSTEM: FIXED (ROOF MOUNTED) WITH COOLING

Month	**Solar Radiation (kWh / m^2 / day)**	**AC Energy (kWh)**	**Value ($)**
January	4.99	466	21 436
February	5.60	470	21 620
March	6.17	574	26 404
April	6.05	548	25 208
May	5.71	531	24 426
June	5.67	517	23 782
July	5.91	544	25 024
August	6.33	582	26 772
September	6.40	564	25 944
October	5.82	536	24 656
November	5.15	464	21 344
December	4.58	426	19 596
Annual	5.70	6222	285 212

PV systems that have cooling mechanisms can provide as much as 14 % more energy.

VIII. PV-WATTS MODELING OF TRACKED ARRAY AND FIXED ARRAY

Maximum assimilation of energy by solar panels can be achieved as a result of tracking, which causes the panel to be positioned perpendicular to the sun, therefore maximizing the power generated by the solar array. Using PV-Watts Modeling, a study was done to show the edge that a tracked array has over a fixed array.

The PV-Watts simulation tool was created by the National Renewable Energy Laboratory (NREL) and is an internet-dependent platform designed for the approximation of electrical energy produced by grid-connected photovoltaic (PV) systems. The simulation tool is available on NREL's website and takes several parameters, most of which are hidden from the user, into consideration in order to produce its results. It was used to create an illustration of a 0.05KW power system to demonstrate the advantage that a tracked array has over a fixed array.

The location of the Faculty of Engineering and Technology, University of Guyana was selected and the nearest weather station data source was used together with the provided PV system parameters. PV- Watts performed "an hour-by-hour simulation of monthly and annual alternating current (AC) energy production in kilowatts and energy value in dollars. Some of the system parameters that may be specified include AC rating or size, local electric costs, PV array type, PV array tilt angle, and PV array azimuth angle (Rutstrum & Carl, 2000). The results, as shown below, illustrate that the tracked array produces more power (25.5% more) than the fixed array.

TABLE 5
PV-WATTS SIMULATION OF THE 0.05 KW POWER SYSTEM: FIXED (ROOF MOUNTED)

Month	**Solar Radiation (kWh / m^2 / day)**	**AC Energy (kWh)**	**Value ($)**
January	4.99	6	262
February	5.60	6	264
March	6.17	7	323
April	6.05	7	308
May	5.71	6	299
June	5.67	6	291
July	5.91	7	306

August	6.33	7	327
September	6.40	7	317
October	5.82	7	301
November	5.15	6	261
December	4.58	5	239
Annual	5.70	77	3498

TABLE 6
PV-WATTS SIMULATION OF THE 0.05 KW POWER SYSTEM: AXIS TRACKING

Month	**Solar Radiation (kWh / m^2 / day)**	**AC Energy (kWh)**	**Value ($)**
January	6.16	7	331
February	7.11	7	342
March	7.70	9	410
April	7.32	8	378
May	6.74	8	358
June	6.72	8	349
July	7.26	8	383
August	7.84	9	412
September	8.03	9	406
October	7.23	8	381
November	6.45	7	334
December	5.70	7	305
Annual	7.02	95	4389

It can be seen from Table 5 and Table 6 that 25 % more power is produced by tracked arrays compared to a similarly sized fixed array. This value would remain the same regardless of the size of array used.

IX. CONCLUSIONS

The optimum tilt angle of the polycrystalline solar panel located at the University of Guyana, Faculty of Engineering and Technology at latitude 6.81^0 was 7^0. The efficiency of the solar panel is most consistently high at tilt angle 7^0 which is the optimum tilt angle. Therefore, there will be maximum power production at this tilt angle. However, maximum efficiency significantly decreased as the tilt angle deviated from 7^0. At tilt angle 10^0, which is a 3^0 deviation from the optimum tilt angle, an 8 % reduction in maximum efficiency and a 16 % reduction in average efficiency are produced. Therefore, there was an 8 % reduction in maximum power production at tilt angle 10^0.

At tilt angle 15^0, a 7^0 deviation from the optimum tilt angle, a 22 % reduction in average efficiency and a 13 % reduction in maximum efficiency were produced. Therefore, there was a 13% reduction of maximum power produced at this tilt angle.

At tilt angle 20^0, a 13^0 deviation from optimum tilt angle, a 23 % reduction in average efficiency and a 19 % reduction in maximum efficiency were the results. Therefore, at this tilt angle there is a 19% reduction of maximum power produced compared to that produced at tilt angle 7^0.

At tilt angle 25^0, a 13^0 deviation from optimum tilt angle caused a 28 % reduction in average efficiency and a 10 % reduction in maximum efficiency. Therefore, at this tilt angle there was a 28% reduction of average power produced compared to that produced at tilt angle 7^0.

Finally, at tilt angle 30^0, a 23^0 deviation from optimum tilt angle, caused a 29 % reduction in average efficiency and a 23 % reduction in maximum efficiency. Therefore, at this tilt angle there was a 29% reduction of average power produced compared to that produced at tilt angle 7^0.

The tilt angle of a solar panel has a significant effect on the efficiency and power production of the solar panel. Under conditions when space is limited and also when economically justified, tracked arrays are useful and can produce 25.5 % more power than fixed arrays to meet energy needs. Moreover, PV systems that have cooling mechanisms can provide as much as 14 % more energy. More income can be available because of increased energy production, and PV systems can last longer with lower maintenance costs.

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