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Evaluating Seasonal Variations of selected Photovoltaic (PV) Parameters of Solar Energy System

Chikwudo Ogonna Nwoye[1*], Anthony Osita Chibuike Nwokoye[2]

[1] Department of Physics and Industrial Physics, Solar Energy Physics,
Nnamdi Azikiwe University, Awka, Anambra State, PMB 5025, NIGERIA

[2] Department of Physics and Industrial Physics, Solar Energy Physics,
Nnamdi Azikiwe University, Awka, Anambra State, PMB 5025, NIGERIA

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ABSTRACT

This study evaluated the seasonal variations of selected photovoltaic (PV) parameters of solar energy system. Specifically, it investigated if the degree of variations of daily Temperature, daily Output Current and daily Open Circuit Voltage in the rainy and dry season is statistically significant. The field study was carried out in Uruana, Nibo Community in Awka South Local Government Area of Anambra State, Nigeria was conducted between May 1, 2025 –February 28, 2026 (a ten months period). The realtime performance data of the selected three (3) solar performance parameters such as Temperature (T), Output Current (I), and Open Circuit Voltage (Voc) were collated on hourly basis from 0600hours – 1800hours daily across the Rainy season (May 1, 2025 – September 30, 2025) and Dry season (October 1, 2025 – February 28, 2026). These data were further analysed using graphs with the aid of Microsoft excel 2016 package and IBM SPSS version 16 utilizing One Way ANOVA statistical tool. It was found that the degree of variations of daily Temperature (T) performances were statistically significant in the Rainy and Dry seasons recording 40°C consistently from May 2025 – September 2025 between 0900hours and 1600hours but 35.7 ^{o}C – 45.8 ^{o}C from October 2025 -February 2026 between 1000hours – 1500hours (p-values 0.000 and 0.004). It also discovered that the degree of variations of daily Output Current (I) performances were statistically significant in the Rainy and Dry seasons recording its highest at 1400hours (9.0 Amperes) in June 2025 and at 9.4 Amperes in November 2025 respectively (p-values 0.001 and 0.000). Finally, the degree of variations of daily Open Circuit Voltage (Voc) performances in the Rainy and Dry seasons was however statistically insignificant (p-values 0.655 and 0.464). The study therefore concludes that while seasonal variations in the performances of the solar energy system in the Rainy and Dry seasons persist, observations made prove that the extent of such variations or differences in its performances was not statistically significant to undermine the reliability of the solar energy system in the Rainy season..

1. Introduction

Energy is considered very essential in any Society, especially as it is a major factor that drives all sectors and global economies into unprecedented productive activities, growth and consequent development [1]. Unfortunately, lack of reliable energy that will support adequate and/or consistent power supply has continued to slow down the pace of industrial and non-industrial productivity [2], even in Nigeria, thus frustrating the growth, recovery and sustenance of the nation's fragile economy. Further disturbing was the hike in electricity tariff, effective April 2024. This sharp hike in electricity tariffs for Band A Users, amidst the highly unstable and inadequate hydro power and gas-based electricity supply, has added more significant financial strain to Nigeria's industrial, service, health sectors and educational research-based institutions such as public universities, forcing many into darkness due to

*Corresponding author: con.nwoye@unizik.edu.ng

unpaid electricity tariff debts. With energy costs rising by over 100% - 250%, production industries, services firms, Tourist corporate organisations, public and private hospitals, and of course educational institutions of Universities based such as the University of Lagos, Ahmadu Bello University, Nnamdi Azikiwe University et cetera, have faced disconnections [3] from the national grid again and again, impacting their productivity, profitability, going concern status, as well as academic calendars and jeopardizing operations.

As a result of the aforementioned energy dilemma in Nigeria, relentless efforts in recent times have been intensified by the private sector to resolve this "life threat" associated with the persistent reliance on energy from fossil fuels by most private sector establishments, and the after-effect of the hydro power energy source (*often also leading to destructive flooding of rural and urban areas in Nigeria*). This has presented mankind with renewable energy sources which is void of noise pollution and other emissions that usually poison the air, tree and water consumed by human beings. According to [4], this alternative renewable energy is also referred to as solar energy; a non-conventional energy sources and has several benefits among which are its unlimited availability and accessibility that will not run out amidst extensive exploitation.

This unique energy involves transforming light from the sun into electricity such that sunlight is collected directly or indirectly by using photovoltaic or concentrations of solar power [5][6]. It is against this backdrop that this study is envisaged to evaluates the seasonal variations of selected photovoltaic (PV) parameters of solar energy system.

The research is therefore based on these hypothses which were stated in their null and alternate forms.

1. H_o: The degree of variations of daily Temperature in the rainy and dry season is not statistically significant.
   H_i: The degree of variations of daily Temperature in the rainy and dry season is statistically significant.
2. H_o: The degree of variations of daily Output Current in the rainy and dry season is not statistically significant.
   H_i: The degree of variations of daily Output Current in the rainy and dry season is statistically significant.
3. H_o: The degree of variations of daily Open Circuit Voltage in the rainy and dry season is not statistically significant.
   H_i: The degree of variations of daily Open Circuit Voltage in the rainy and dry season is statistically significant.

However, further studies showed:

[7] in their study investigated how various solar parameters influenced the open circuit voltage (Voc) of an organic solar cell (OSC) and how Voc impacts the conversion efficiency of cell's power. Among the solar parameters utilized are reverse saturation current, open circuit voltage (Voc), charge carrier mobility ratio, recombination, charge carrier density, temperature, and light intensity. The study found out that the Voc can theoretically reach a value of about 2.34 V when light intensity, charge-carrier density ($1 \times 10^{18} cm^{-3}$), charge carrier mobility ratio [10] and cell temperature (320 K) are optimal. It is shown that the open circuit voltage (Voc) is negatively impacted by recombination (up to 30 Ω). Lastly, the power conversion efficiency is predicted to be 20 % at 0.63 V and can reach a theoretical value of 37 % at a Voc of 1.0 V, at a power intensity input of 6.578 w/m2, and a fill factor of 0.89 (max for silicon).

[8] in their study explored the how temperature affects the performance of photovoltaic (PV) modules in tropical Indonesia. The study was descriptively conducted using interviews, sampling 5 solar energy professionals. Key environmental factors such as high temperatures, humidity, and rainfall were taken into consideration as significant influencers of PV module efficiency. The study observed that thermal losses are recorded when there is increase in temperature beyond the standard test condition rate, while efficiency was drastically affected by reduction in irradiance and high humidity and rainfall that result in dust accumulation.

[9] in their study considered the variation in the short circuit current to that in the temperature, Open circuit tension, Voltage at the maximum power point et cetera. The study observed that the maximum power generated in a PV panel varies according to irradiation and temperature such that increasing irradiation increases voltage while increasing temperature results in a reduction in voltage. It is possible to verify that the irradiation and temperature variations result in changes in the modules' voltage to guarantee that the panel's power is maximum.

[10] carried out a research on the Influence of Light Intensity on Solar Cell. They obtained the output voltage and current of the maximum power point by analyzing its relationship with influencing factors, the impact analysis on the power generation performance of photovoltaic cells was realized. The experimental results show that the open circuit voltage, short-circuit current, and maximum output power of solar cells increase with the increase of light intensity. Therefore, it was known that the greater the light intensity, the better the power generation performance of the solar cell.

[11] conducted an investigative study to measure the solar energy using Arduino Board technology. During the 3 days measurement of the solar energy system, four parameters were deployed to achieve that purpose namely temperature measured using temperature sensor, light intensity measured using light dependent resistor (LDR) sensor, voltage using the voltage divider because the voltage generated by the solar panel are large for the Arduino as receiver and the current measured using the current sensor module that can sense the current generated by the solar panel. The project used polycrystalline type of the panel solar with 12V, 250mA, 3W as a source. The size of the panel was 145mm X 145mm. Simulation results obtained showed that at Sunrise position, the highest light intensity was 950 Lux at 1200hours, while the lowest light intensity was 830 Lux at 1700hours. They also found out that at the Upward position, the higher the light intensity, the higher the voltage value. Summarily, the solar panel in upward position records the highest voltage of 13.11V at 1000hours with light intensity peaking at 929 Lux and the lowest voltage recording 6.3V

at 1700hours when light intensity peaked at 357 Lux. This outcome contradicted the outcome obtained at sunset position where the highest voltage recorded was 12.57V at 1300hours with light intensity at 964 Lux and the lowest voltage recording 11.19V at 0900hours with light intensity of 931 Lux. The study concluded that the best position of the solar panel energize was the sunrise position with the highest voltage value which is 14.75V at time 1100hours. The researchers noted that at this time the light intensity was 954 lux and the temperature was at 34.32℃.

1.1 Experimental Procedures and Materials

This study was conducted at Uruanna area of Nibo Community in Awka South Local Government Area of Anambra State, Nigeria, under daily real time condition. To achieve the purpose of this study under daily real time sunlight situation, a robust and functional solar energy system was set up using the following materials such as Digital Lux Meter (range up to 200,000), two Photovoltaic Panels (250W), POWMi MPPT Solar Charge Controller, Fidelity Solar 12V Battery for Power, Digital Multi-meter (DMM) , Inverter (i-verter, LGS1100I-EX), Circuit Breaker (63 Amps), two (2) Electrical Change-Over Switch (OPEC, 200 Amps) and Twain and Single Cables. Real time daily readings of selected solar energy parameters were recorded on hourly basis. Thus, the study involved manual collation of target parameters' data on hourly basis, and this lasted for a period of ten months which equitably cut across the rainy season (1st May 2025 – 30th September, 2025) and dry season (1st October 2025 – 28th February, 2026). A total of 304 days was covered (that is, 153 rainy season days and 151 dry season days respectively) at hourly interval from 0600hours – 1800hours (a total of twelve hours daily).

2. Materials and Methods

This study adopted experimental research design. This design was considered appropriate because it allowed the researcher to set up the relevant solar energy system infrastructure collate the hourly performance readings of the selected solar energy parameters To achieve the purpose of this study under daily real time sunlight situation, a robust and functional solar energy system was set up using the following materials such as two Photovoltaic Panels (250W) which were installed southward, POWMi MPPT Solar Charge Controller, Fidelity Solar 12V Battery for Power, Digital Multi-meter (DMM), Inverter (i-verter, LGS1100I-EX), Circuit Breaker (63 Amps), two Electrical Change-Over Switch (OPEC, 200 Amps) and Twain and Single Cables. The study involved manual collation of target parameters' real time performance data on hourly basis from 0600hours to 1800hours, and this lasted for a period of ten months which was equitably cut across the Rainy season (1st May 2025 – 30th September, 2025) and Dry season (1st October 2025 – 28th February, 2026). For effective control purposes, the Panels were installed on accessible roof top where the Panels were cleaned periodically during the Dry season from dusts and soilings. furthermore, the solar energy system was connected to active load that ensured that the battery was duly controlled to avoid full charge. This measure ensured that the hourly real time performance readings obtained were very much reliable.

The daily hourly performance data obtained were analysed, first, by means of tables and thereafter graphs using the Microsoft Excel version 16 package. This was to allow for a clear appreciation of the trends and performance levels of the solar energy system in the Rainy and Dry seasons. These were further evaluated by way of statistical analysis using the One Way Analysis of Variance (One Way ANOVA) statistical tool to test the various hypotheses formulated in the study. The choice of the One way Analysis of Variance (ANOVA) statistical tool in this study was to enable it ascertain if there was any statistical significant difference in solar energy performance within a group (for instance, a given solar parameter) across different seasons (Rainy and Dry seasons) as well as the solar energy performance between groups (for instance, two different solar parameters) during a given season compared to another season.

2.1 Decision Rule

2.1.1 General Rule on Level of Significance

Accept the Alternate hypothesis if p-value is equal to or less than 0.05, indicating that there is a statistically significant difference between performances of the selected solar energy parameters in the Rainy and Dry seasons.

Accept the null hypothesis if p-value is greater than 0.05, indicating that there is no statistically significant difference between performances of the selected solar energy parameters in the Rainy and Dry seasons.

3. Results and Discussion

3.1 Data Analysis and Hypotheses Testing

This section clearly presents the output of the relevant analysis carried out in testing the hypothesis formulated for the study. We now determine:

3.1.1 Hypothesis One

H_o: The degree of variations of daily Temperature, in the rainy and dry season is not statistically significant.

Using the performance data readings of Temperature as measured on daily basis from 0600hours – 1800hours over a ten months period (May 1, 2025 – February 28, 2026), the hypothesis was tested for scientific proof of concept and statistical evidence. The analysis output is as presented in Table 1 respectively.

Table 1 - ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Temperature RAINY	Between Groups	12434.099	319	38.978	1.369	.000
	Within Groups	46622.455	1638	28.463		
	Total	59056.554	1957			
Temperature DRY	Between Groups	10710.776	319	33.576	1.252	.004
	Within Groups	43975.935	1640	26.815		
	Total	54686.711	1959			

Source: IBM SPSS ver 26

Inferring from the analysis results in Table 1, it became obvious that the observed cell temperature daily performances of the two 250Watts Panels installed and directly exposed southwards to the sunlight, indicated that the degree of variation of daily Temperature (T) performances in the Rainy and Dry seasons were statistically significant as the p-value (Sig) recorded in both seasons were 0.000 and 0.004, which are evidently less than 0.05. The implication is that the cells of the Panels received quality moderate sunlight during the cooler or Rainy season (May 1, 2025 –September 30, 2025), just as the Dry season or hotter period of the study (October 1, 2025 –February 28, 2026) presented a similar result pointing out a state of statistically significant variation of daily Temperature performances.

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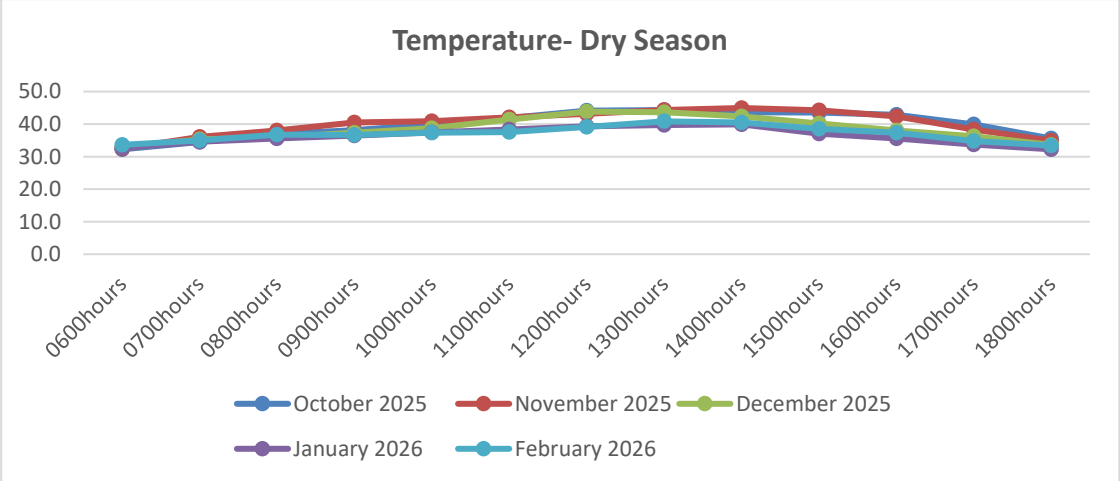

Fig. 1: Average Daily Readings of Temperature (T) in the Dry Season

This perhaps, could be as a result of the unusual state of the October 1, 2025 –February 28, 2026 Dry season which was hot but not as hotter and harmattan-oriented as in previous years' Dry season (see Figure 1). This may also be as a result of the flow of electrons during the hotter days of the Dry season which may have been hindered due to the heat up of the Panels that also led to the intense activeness of atoms in the Panels. The implication is that, under the latter circumstances, the overall efficiency of the Panels dropped, thus contradicting the widely anticipated belief that the hotter the sunlight and the higher the Temperature (T), leads to higher performance of the solar Panel in generating electricity.

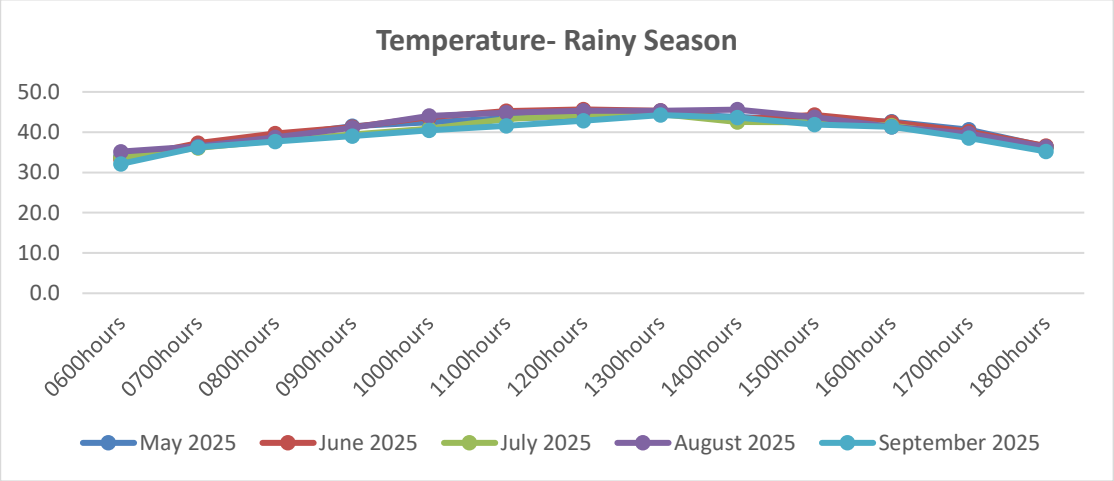

Fig. 2: Average Daily Readings of Temperature (T) in the Rainy Season

Aligning this with the average real time daily cell Temperature readings observed, it was discovered that average daily Temperature performance was at its highest at 1200hours and 1400hours in the months of June 2025 and August 2025 respectively (recorded 45.6 ºC each) during the Rainy season (see Figure 2). This is more as cell Temperatures that were above 40ºC was consistently observed throughout the months of May 2025 – September 2025 between 0900hours and 1600hours. This however contradicts the situation observed in the Dry season where the average daily Temperature performance was at its highest at exactly 1400hours in the month of November 2025 (recorded 45.8 ºC). Moreso, high cell Temperature performances fluctuated between the time frame of 1000hours – 1500hours with performance values that fell between the ranges of 35.7 ºC – 45.8 ºC within the months of October 2025 and February 2026 (Dry season). While these daily temperature performances are considered normal for 250 watts Panels whose temperature's standard test condition is 25 ºC, it pertinent to state that at 45 ºC, a 250 watts Panel is likely to witness approximately 6% - 7% drop in the peak power it generates.

Decision: Since p-values of daily Temperature performances in the Rainy and Dry seasons (0.000 and 0.004) were less than 0.05, the study concludes that the degree of variations of daily Temperature (T) performances was statistically significant in the Rainy and Dry.

Hypothesis Two

H_o: The degree of variations of daily Output Current in the rainy and dry season is not statistically significant.

Using the performance data readings of the Output Current as measured on daily basis from 0600hours – 1800hours over a ten months period (May 1, 2025 – February 28, 2026), the hypothesis was tested for scientific proof of concept and statistical evidence. The analysis output is as presented in Table 2 respectively.

Table 2 - ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OutputCurrent RAINY	Between Groups	5401.890	319	16.934	1.301	.001
	Within Groups	21333.819	1639	13.016		
	Total	26735.708	1958			
OutputCurrent DRY	Between Groups	5733.353	319	17.973	1.387	.000
	Within Groups	21257.248	1640	12.962		
	Total	26990.602	1959			

Source: IBM SPSS ver 26

Clear glance at Table 2 showed statistical evidence that the degree of variation in daily performances of Output Current (I) during the Rainy season from May 1, 2025 – September 30, 2025 and the Dry season from October 1, 2025 – February 28, 2026, were statistically significant (p-values 0.001 and 0.000 which were both less than 0.05). This equally agrees with the existing scientific belief that Output Current (I) rises slightly or remains stable as the Temperature of the Panel's cell (*which degree of variation in the Rainy and Dry seasons under hypothesis one and Table 1 were also statistically significant*) rises.

The result from the table showed statistical evidence that the degree of variation in daily performances of Output Current (I) during the Rainy season from May 1, 2025 – September 30, 2025 and the Dry season from October 1, 2025 – February 28, 2026, were statistically significant (p-values 0.001 and 0.000 which were both less than 0.05). This equally agrees with the existing scientific

belief that Output Current (I) rises slightly or remains stable as the Temperature of the Panel's cell rises. More observations revealed that the daily performance of Output Current was least at 0600hours in the Rainy and Dry seasons (ranges between 0.2 Amperes – 0.4 Amperes) indicating that the 250 watts Panels with a standard test condition of 7 – 8 Amperes were generating below its expected potential power at 0600hours, and highest at 1400hours (9.0 Amperes) in June 2025 and at 9.4 Amperes in November 2025 respectively (see Figures 3 and 4).

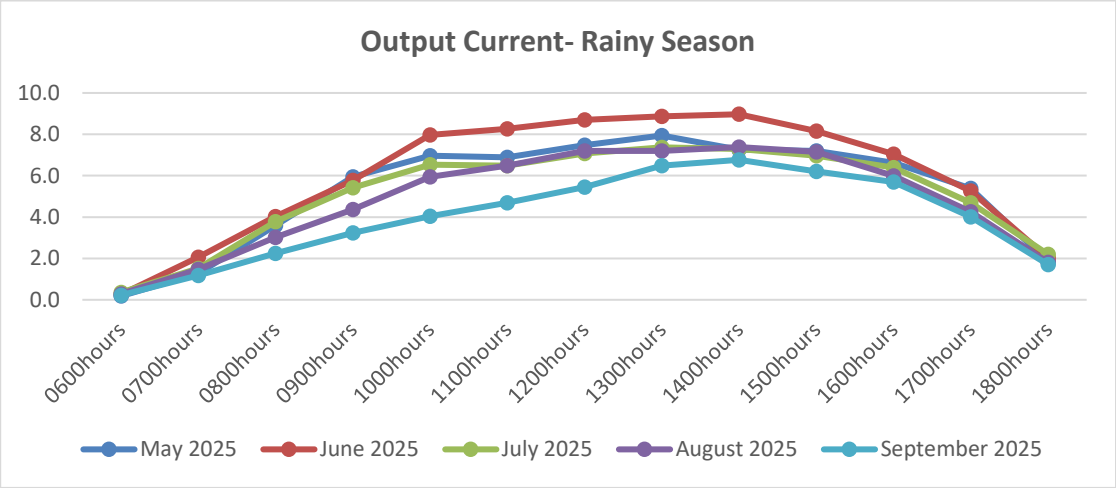

Fig. 3: Average Daily Readings of Output Current (I) in the Rainy Season

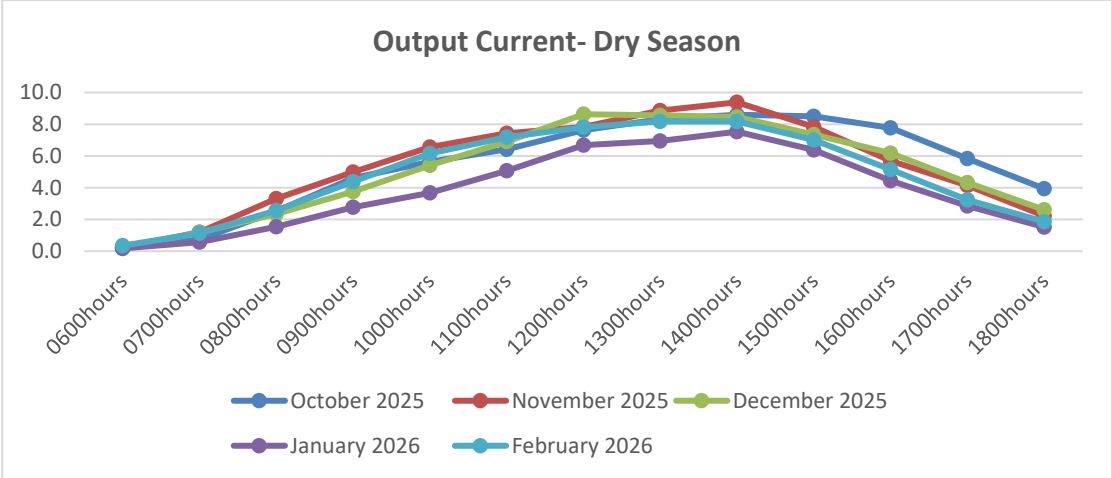

Fig. 4: Average Daily Readings of Output Current (I) in the Dry Season

Decision: Since the p-values of daily Output Current performances in the Rainy and Dry seasons (0.001 and 0.000) were less than 0.05 respectively, the study concludes that the degree of variations of daily Output Current (I) performances was statistically significant in Rainy and Dry seasons.

Hypothesis Three

H_o: Degree of variations of daily Open Circuit Voltage in the rainy and dry season is not statistically significant.

Using the performance data readings of the Open Circuit Voltage (Voc) as measured on daily basis from 0600hours – 1800hours over a ten months period (May 1, 2025 – February 28, 2026), the hypothesis was tested for scientific proof of concept and statistical evidence. The analysis output is in Table 3.

Table 3 - ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OpenCircuitVoltage RAINY	Between Groups	79274.049	319	248.508	.964	.655
	Within Groups	422384.069	1639	257.708		
	Total	501658.118	1958			
OpenCircuitVoltage DRY	Between Groups	76894.464	303	253.777	1.006	.464
	Within Groups	417369.077	1655	252.187		
	Total	494263.541	1958			

Source: IBM SPSS ver 26

Closer consideration of the Voc analysis in Table 3 indicated that the degree of variation in the daily performances of Voc from 0600hours – 1800hours during the May 1, 2025 – February 28, 2028 study was rather statisticall insignificant in the Rainy and Dry seasons (p-values 0.655 and 0.464 which are greater than 0.05). It is important to note that the state of the Voc in a solar energy system (whether high or low) affects the performances of the whole solar energy system particularly the quality of power output and watts produced by the Panels even when the Output Current performances is good or commendable.

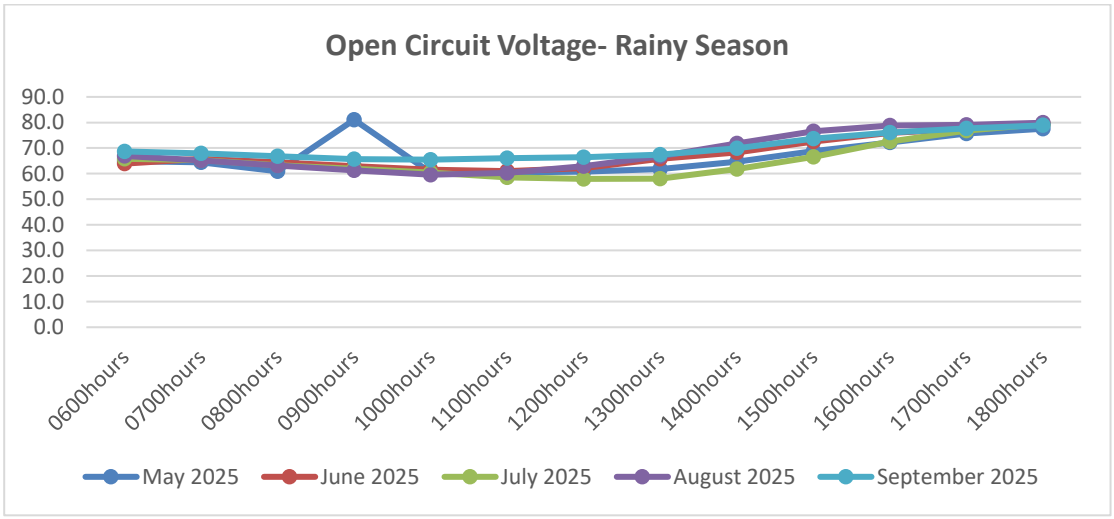

Fig. 5: Average Daily Readings of Open Circuit Voltage (Voc) in the Rainy Season

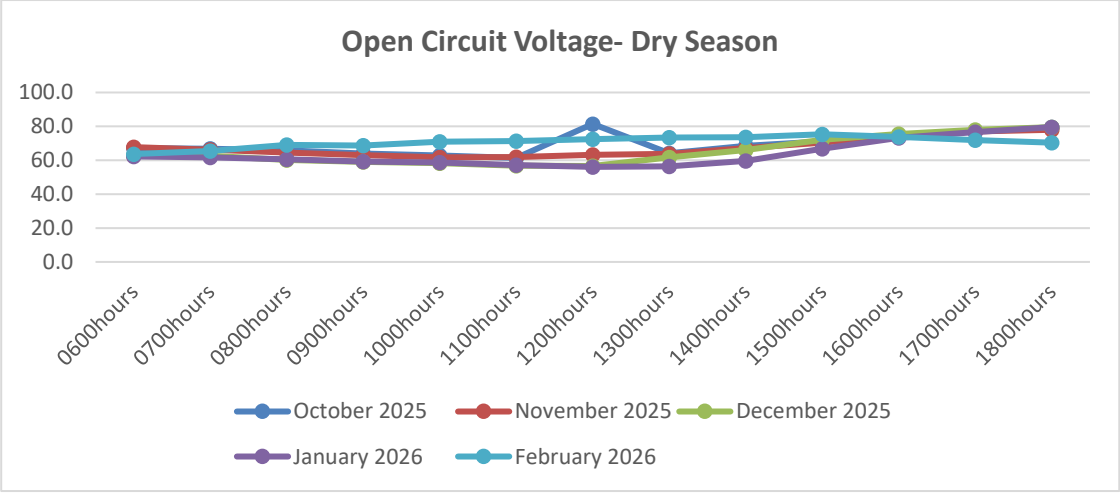

Fig. 6: Average Daily Readings of Open Circuit Voltage (Voc) in the Dry Season

Trend outlook of Figures 5 and 6 also showed that the degree of variations of Voc daily performances in the Rainy and Dry seasons exist but it was observed not to be so significant, particularly between 1000hours and 1300hours.

Decision: Since the p-values of Open Circuit Voltage performances in the Rainy and Dry seasons (0.655 and 0.464 respectively) was greater than 0.05, the study concludes that the degree of variations of daily Open Circuit Voltage (Voc) performances in the Rainy and Dry seasons was insignificant.

4. Conclusions

The study therefore concludes that while seasonal variations in the performances of the solar energy system in the Rainy and Dry seasons persist, observations and findings made prove that the extent of such variations or differences in its performances is not statistically significant to undermine the reliability of the solar energy system in the Rainy season.

These findings agree with the research outcomes of prior related studies as [12] who observed that irradiance has a linear effect on Current and log linear effect on Voltage; [13] pointed out that too high Temperature leads to slow down in the flow of electricity within each solar cell; [7] observed that Open Circuit Voltage can theoretically reach a value of 2.3V when Light intensity and cell Temperature are optimal. [14] found out that energy produced in the dry season is more than the energy produced in the rainy season; [9] reported that increase in irradiance increases Voltages even as increase in Temperature reduces Voltage;

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