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THE EFFECT OF SUN IRRADIANCE AND TEMPERATURE ON THE SOLAR ENERGY GENERATION SYSTEM.

[1*]Augustine O. Folorunso, [2]Olamide O. Olusanya, [3]Oladimeji O. Fasipe
Email: *folorunsoaustine@gmail.com/ booolusanya@bellsuniversity.edu.ng/ Oladimeji.fasipe@bellsuniversity.edu.ng

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Abstract
The need for clean, sustainable energy sources is growing worldwide, which has prompted much research and development into solar power exploitation. The full modeling and simulation of a cutting-edge solar energy generating system intended to maximize efficiency and solve issues with conventional photovoltaic technology is the main emphasis of this paper.

The model considers solar irradiance and temperature as the primary variables influencing the power output, with a temperature correction factor accounting for the temperature-dependent efficiency. Simulations were conducted to analyze how sun irradiance and temperature profile variations impact overall energy generation over time. Real-world data from Bells University of Technology, Ota Ogun State, Nigeria geographical locations and climatic conditions validate the model's accuracy. The results reveal the intricate relationships between solar panel performance and environmental factors, highlighting the need for adaptive solar energy system design strategies. This study also investigates the influence of these variables on the long-term reliability and maintenance requirements of solar installations. The research proposes mitigation strategies to enhance system resilience under varying conditions by integrating advanced technologies such as predictive control algorithms and adaptive thermal management systems. The findings contribute valuable insights to solar energy engineering, offering a deeper understanding of the challenges posed by sun irradiance and temperature variations. The developed model and simulations provide a robust framework for assessing and improving solar energy generation systems in diverse climates.

[1,3]Department of Electrical/Electronics and Telecommunication Engineering, Bells University of Technology, Ota, Ogun State. Nigeria.
[2] Department of Computer Engineering, Bells University of Technology, Ota, Ogun State. Nigeria

1. INTRODUCTION

Environmental factors, particularly sun irradiance and temperature. Sun irradiance, the amount of solar energy received per unit area, is directly affected by factors such as time of day, season, weather conditions, and geographical location. Higher irradiance levels result in increased electricity generation [2]. Temperature also plays a crucial role in the performance of solar energy systems. Solar panels operate more efficiently at lower temperatures because excessive heat can decrease the efficiency and output. The "temperature coefficient" phenomenon, where the efficiency of solar cells decreases with increasing temperature, impacts overall system performance[3].
Understanding the relationship between sun irradiance, temperature, and solar energy generation is essential for optimizing the design, operation, and maintenance of solar PV systems. Techniques to enhance performance include using advanced materials with higher temperature tolerance, incorporating cooling mechanisms, and implementing tracking systems [4]. Accurate forecasting models are being developed to predict solar irradiance and temperature patterns, enabling better system management and resource planning.
This study aims to explore the influence of sun irradiance and temperature on solar energy generation systems in the Ota area of Ogun state, Nigeria, proposing innovative solutions to enhance system efficiency and reliability in the studied environment.

Literature review

The use of solar energy is nothing new and has existed since the dawn of mankind. However, in recent years, the spotlight on energy use on a global scale has quickly fueled growth in the study and creation of "green" alternative fuel sources, such as solar, wind, hydro, wave, geothermal, hydrogen, and other types of energy. Today, because of this concentration, solar energy consumption is growing rapidly, especially given that sunshine is free, inexhaustible, easily accessible, clean, and reliable[5].

A solar energy generation system converts the sun's energy into a form that may be stored in a lead acid cell and used to power an electrical load or appliance[6].

Given that we are blessed or rich in sunlight—high temperatures—which is the primary factor that fuels a solar energy generation system for uses—in our region of the world, where the power supply is ineffective and inefficient, using a solar power supply is of immense value and advantage.

The use of generators that burn fuel or diesel (petroleum costs between N500 and N800 and diesel costs between N650 and N750 across Nigeria) combined with routine maintenance and service of the generator is really expensive when compared to solar energy generation systems, whose life span is better and more dependable when used under, within, or above the stipulated rating of the solar power device.

THE BASICS OF SOLAR ENERGY GENERATION SYSTEM

A typical solar power supply device comprises a solar panel, a charge controller, a power inverter with a monitoring system, and an electrical distribution system, as illustrated in Figure 1.

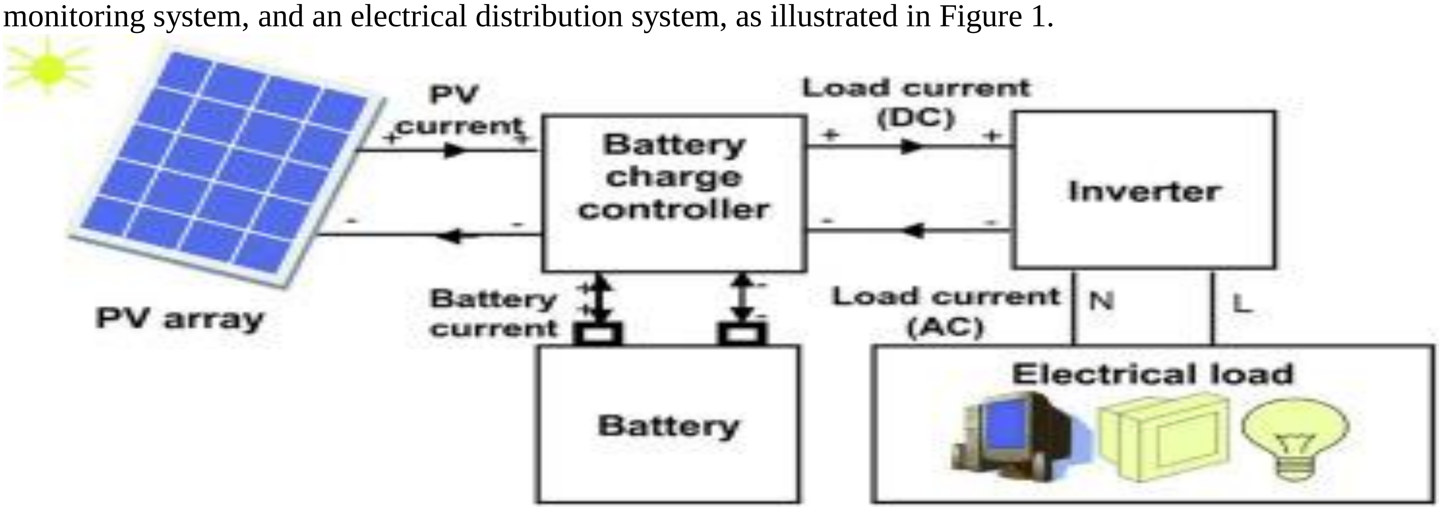

Fig. 1: Block diagram of the solar energy generation system [7].

SOLAR PV MODULE

A solar panel converts solar energy into DC electrical energy, while a photovoltaic panel, made of silicon crystals reacting with solar radiation, converts solar energy into electrical power. These panels can be used to charge batteries and appliances directly or via an inverter. More modules can produce more electricity, which can be stored in batteries for use in cloudy or wet weather [8]. Panels come in various sizes, voltages, and amps, and can be connected in series, parallel, or series and parallel

Estimating the solar panel output

The PV system's output fluctuated due to fluctuating sunshine levels, affecting the solar array surface [9]. Factors such as sunlight intensity and weather significantly impacted the system's output, requiring an understanding to predict system production and financial benefits under varying weather conditions.

Standard test conditions

The solar power modules produced DC electricity, which was evaluated using standard test conditions (STC) in the production plant. The peak sunlight intensity was 1000 W/m2, equivalent to a clear summer's midday. The solar cell's temperature range is 25-49°C, with the panel used in this example having a nominal temperature of 47°C [10].

Temperature

The STC recommends a temperature reduction factor of 89% or 0.89 for crystalline modules, which can significantly increase the module output power. In full sunlight, a 300-watt module would operate at approximately 85 watts, with 4 300-watt modules, resulting in a total output of 1068 watts [11]. This is particularly important for the solar modules on roofs.

Solar Charge Controller

A charge controller is an electronic voltage regulator that regulates the speed at which the electric current is drawn into or discharged from the batteries. It stops the charge when the battery reaches its optimal charging point and turns it back on when it falls below a predetermined threshold [12]. The controller displays the battery condition, system operation parameters, and over-discharge prevention. It regulates the electricity used to charge the batteries and monitors the electricity generated by the solar panel. Proper charging is believed to prolong the battery life and performance by preventing damage. There are two main types of solar charge controllers: PWM (pulse-width modulation) and MPPT (maximum power point tracking) [13]. Each type has its own features and functionality.

INVERTER

The inverter converts the DC voltage generated by the solar panels into the A C voltage. It also draws power from the batteries. When available, the inverter can also charge the batteries using a different power source, such as the mains or a generator connected to the inverter [14]. For the components to work properly, selecting the appropriate inverter for the load demand and power requirements of the system was essential.

Inverter Sizing

An inverter converts a direct current (DC) power source into an alternating current (AC) supply, often at a voltage comparable to a standard mains power supply [15]. In other words, it made it possible for household appliances to run off a low-voltage DC supply, such as a solar battery, which served as the system's main power source [16]. Before getting the inverter, the inverter's size was considered and the continuous wattage output. The inverter was selected by observing the largest load to be operated at one time [17]. Therefore, a 5 KVA 24VDC was selected for this study.

DC to AC Conversion Losses

An inverter was used to transform the DC electricity produced by the solar module into standard household AC power [18]. The conversion procedure resulted in some power loss, and there were also losses in the wires running from the roof, from the panel to the inverter, and from there to the house cut-out. The manufacturer claims that the inverter used with PV power systems has a peak efficiency of 92%–94%; however, once again, these were studied in well-controlled environments [19].

As a sensible compromise, the actual field conditions typically led to an overall dc-to-ac conversion efficiency of roughly 88-92%.

SOLAR BATTERY

The study used a Tubular battery as a power source, connected in series to two 12v/220Ah solar batteries. The system was only powered during the sun's outage, and the power was cut off during cloudy periods. The load consumed 80% of the energy the solar battery held in reserve [20]. The system was offered in various voltages and amp-hour ratings to meet the system's needs.

Temperature effect on the battery

The temperature of the lead-acid battery affected the pace of the chemical process that was taking place inside it; the colder the temperature, the slower the reaction, and the warmer the temperature, the faster the reaction, and the quicker the battery could be charged [21]. A lead acid battery operates best at a temperature of about 77 °F [22]. Starting an automobile in the morning in a cold morning is an illustration of how temperature affects a battery since the engine just turns over more slowly.

Battery voltage

Voltage meters, which are affordable and simple to use, are used to show the battery's state of charge. In this PV system, charging, discharging, or doing both simultaneously was the norm [23].

A second light was lit to represent the battery's degree of discharge on the inverter display screen as the battery was charged and as it was being discharged.

Results

Generation of the Raw Data

A simplified block diagram of the installation connection flows of the 5 KVA solar energy generation system is presented in Fig. 1 [7]. Then, after connection, we check and test for final verification before commissioning the system. The sun irradiance meter was positioned to read the irradiance and temperature at an interval of 5 min alongside the AVO meter to take the reading of the voltage simultaneously the power, current, and voltage also was been monitored on the charger controller, all these processes of reading were done at the same time concurrently in every 5 min interval till all the data need were generated as shown in Table 4.1 and Table 4.2 shows the measurement we carried out on each solar panels (1,2,3 & 4) and measurement on string-1 (1&2), string-2 (3&4) and all strings connected in series, the result of the measurement was presented in table 4.2 and titled: Measured voltage compared with System rated voltage [24].

Table 4. 1: Raw Data generated

Time (Min)	Irradiance (w/m²)	PV input (v)	PV output (v)	MPPT/Battery Volt. (v)	Temperature °C	MPPT POWER OUTPUT (w)	CHARGING CURRENT (Amp)
1:15	226	96.2	95.5	25.5	32	122.8	
1:20	248	102.2	101.8	25.9	32.2	165.76	
1:25	309	106.4	105.7	26.3	33.7	201.2	
1:30	234	110.5	107.2	26.8	36.3	378.6	18.5
1:35	201	111	109.7	26.5	36.7	186.7	7
1:40	151	120.6	118.4	26	35.4	92.8	3.1
1:45	82	115.2	119.2	25.8	34.1	67.8	2
1:50	101	73	85.9	25.9	33.5	95.5	3.5
1:55	194	94	93.3	26	33.3	145.3	5.6
2:00	140	111.8	110.2	26.3	32.6	115.1	4.1

2:05	121	112	110.2	26.2	32.2	99.3	3.7
2:10	119	112.7	111.3	26.1	31.7	95.4	3.7

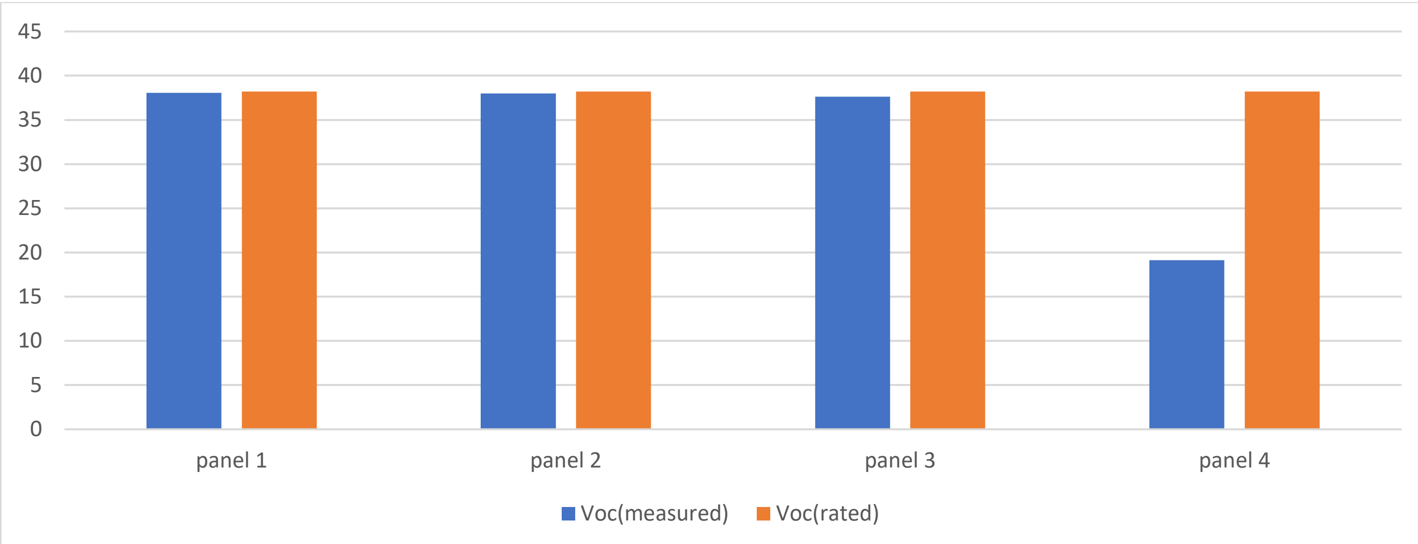

Fig. 4.1 Solar Panels Open Circuit Voltage Test Compared With Rated Voltage.

Figure 4.1 shows the open-circuit voltage test results of the four solar panels used in the research. The result of the test shows that panels 1, 2, 3, and 4 have an equal rated open-circuit voltage of 38.2 VDC, but after we conducted the open-circuit test on all these solar panels, we discovered that panels 1, 2, and 3 are 0.39%, 0.58%, and 1.49% less than their rated open-circuit voltage, while only solar panel 4 is 49.95% less than its rated open-circuit voltage, which shows that this solar panel in question has a manufacturer defect in some of its cells, which affected the open-circuit voltage when it was tested and this will affect the overall output voltage of the system if not replaced.

The System Behavior Graphic Result

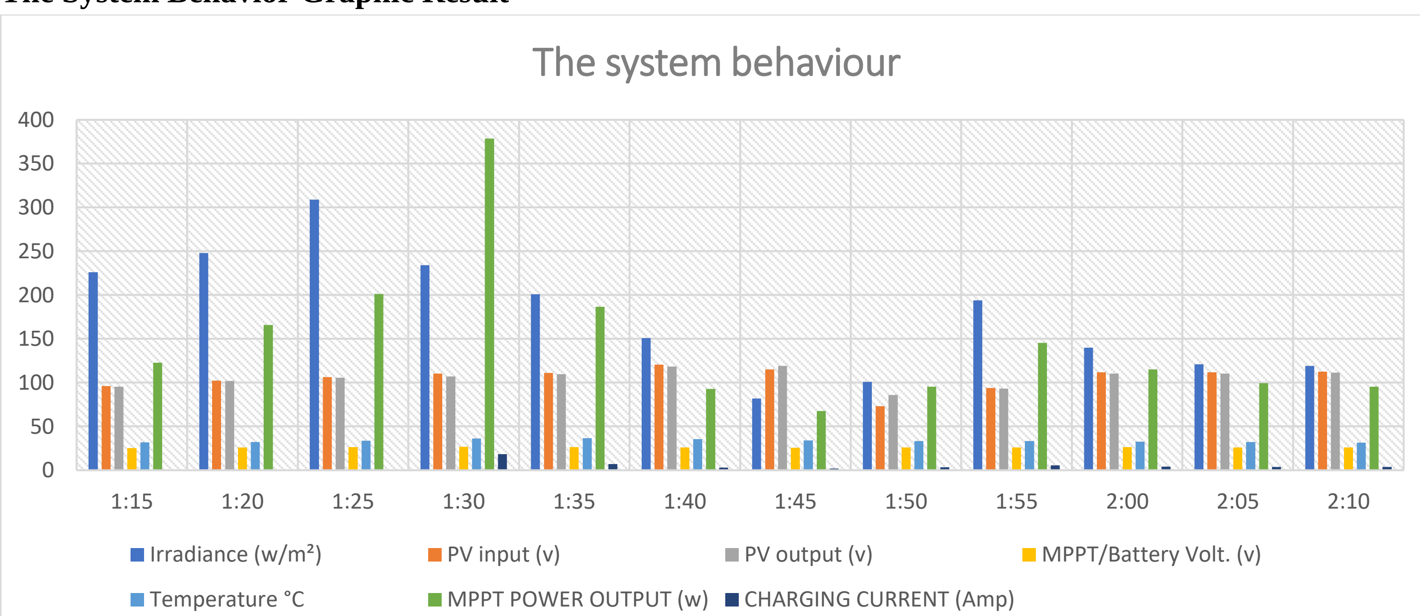

Fig. 4.2 Simulation Result of The System Modeling Concerning Time

The System Behavior Flowchart Result

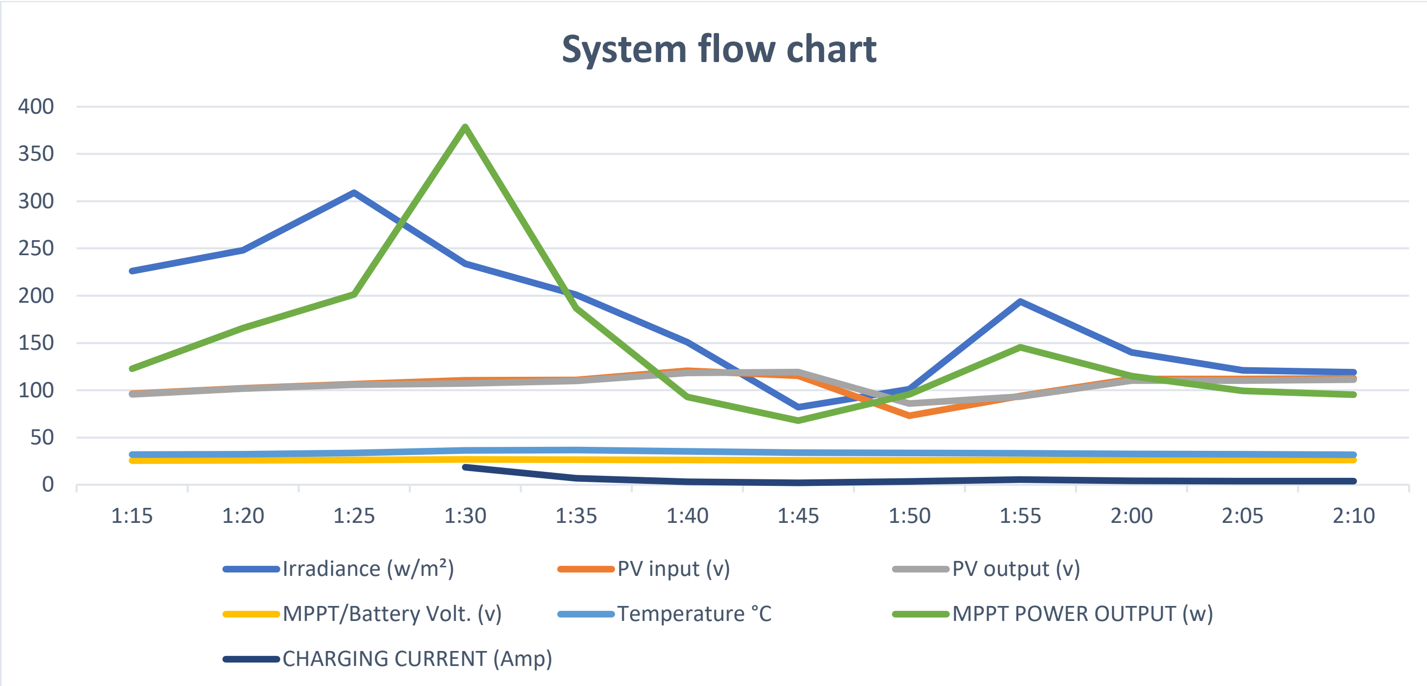

Fig. 4.3 The System Behavior Flowchart

Simulation result of the system showing the flow of the temperature, sun irradiance, output power PV input voltage, current flow, and battery voltage concerning the time of reading

Temperature vs. Output Voltage Result

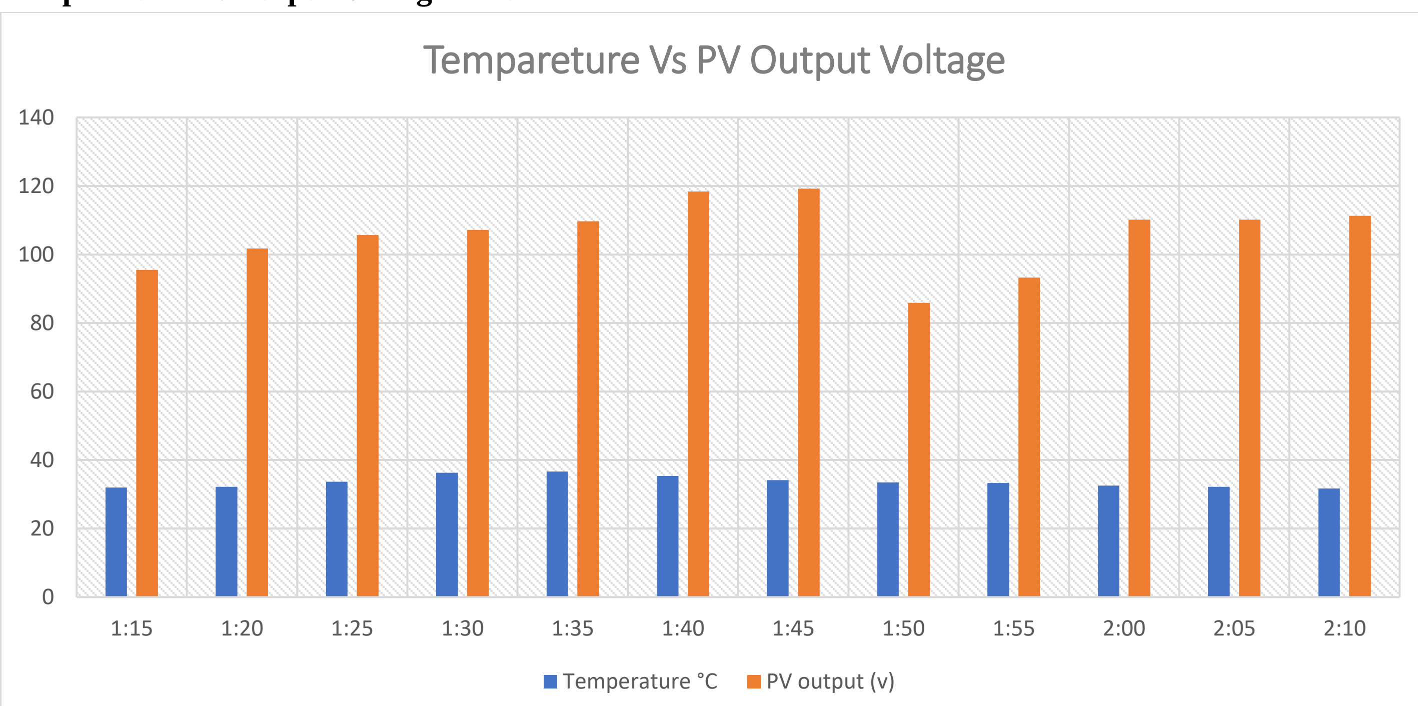

Fig. 4.4 Temperature vs. output voltage graph

Graphic expression of the simulation result showing the effect of temperature on the PV output voltage at different time intervals

4.5 Temperature vs. output voltage flow chart

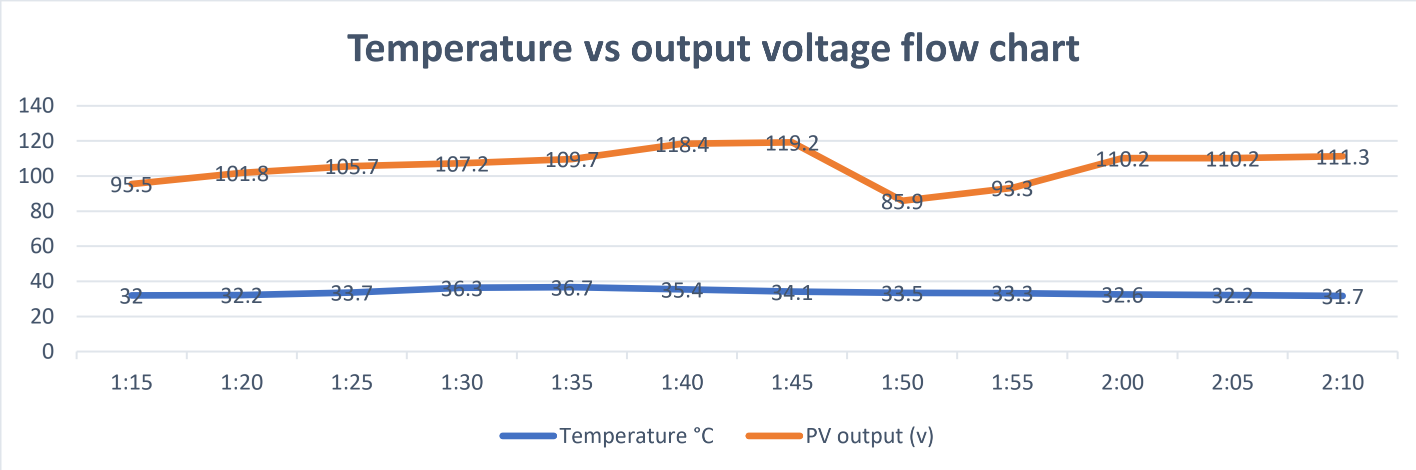

Fig. 4.5. Temperature vs. output voltage flowchart

Flowchart result of a simulation showing the level of temperature effect on the PV output voltage at different time intervals

4.6 Temperature and Voltage Output Analysis

In general, the voltage output of a solar panel decreases with increasing temperature. At 1:45, the PV produces the largest of 119.2v at 34.1°C, as shown in Fig. 4.4. This is due to the semiconductor materials used in the solar cells. As the temperature rises, the electrons in the semiconductor material gain more energy and move more freely but due to the weather during the process of taking the readings, the voltage dropped is not much because the temperature is still less than the rated temperature of the solar PV module 47±2°C compared with the highest temperature of 36.7°C 109.7v at 1:35 as shown in fig. 4.4. leading to an increase in the leakage current. As a result, the voltage across the terminals of the solar panel decreases by 9.7 V.

4.7 Temperature, Voltage, and Power Analysis

The power output of a solar panel is the product of its voltage and current (P = V x I). Since the voltage decreases with increasing temperature, the power output may decrease as well as at 1:50 the temperature is 33.5°C we got the lower output voltage of 85.9v shown in Fig. 4.4 and Fig. 4.5. However, the current (I) generated by the solar pane at this same time is 3.5 Amp, as shown in Fig 4.1 and Table 4.1, respectively, which is on the slight increase with temperature, due to the increase in the number of charge carriers (electrons) in the semiconductor material. This increase in current partially compensates for the decrease in voltage, leading to a moderate decrease in the overall power output when the temperature starts increasing.

TABLE 4.4 SUN IRRADIANCE VS POWER OUTPUT RESULT

Time (Min)	Irradiance (w/m²)	MPPT POWER OUTPUT (w)
1:15	226	122.8
1:20	248	165.76
1:25	309	201.2
1:30	234	378.6
1:35	201	186.7
1:40	151	92.8
1:45	82	67.8
1:50	101	95.5
1:55	194	145.3
2:00	140	115.1
2:05	121	99.3
2:10	119	95.4

4.8 Irradiance Vs Power Output Analysis

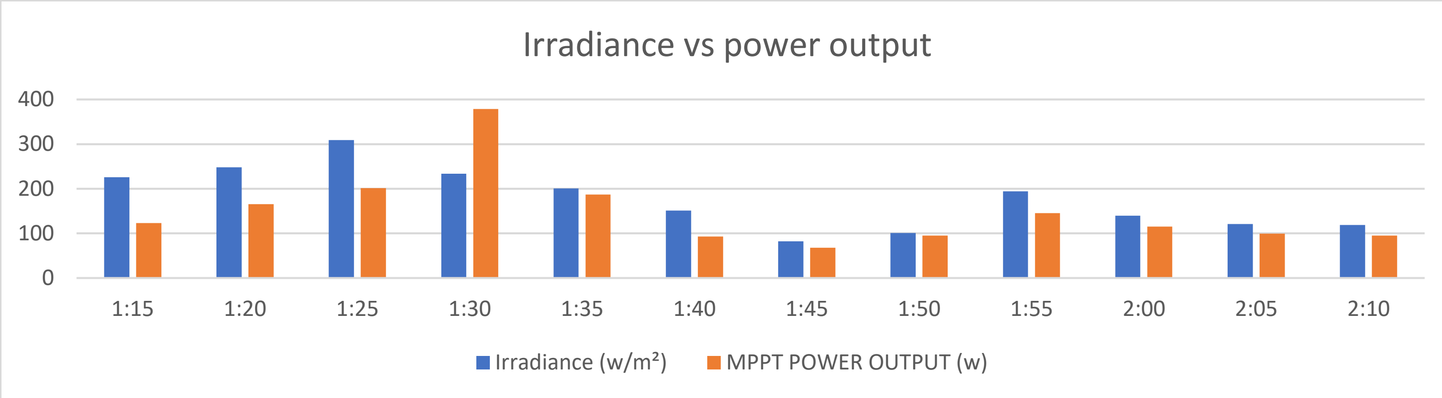

Fig. 4.6 Irradiance Vs Power Output Graphic Analysis

Graphic expression of the simulation result showing the effect of the sun irradiance on the solar energy generation system output power (watt) at different time intervals

4.9 Irradiance vs. power output flowchart

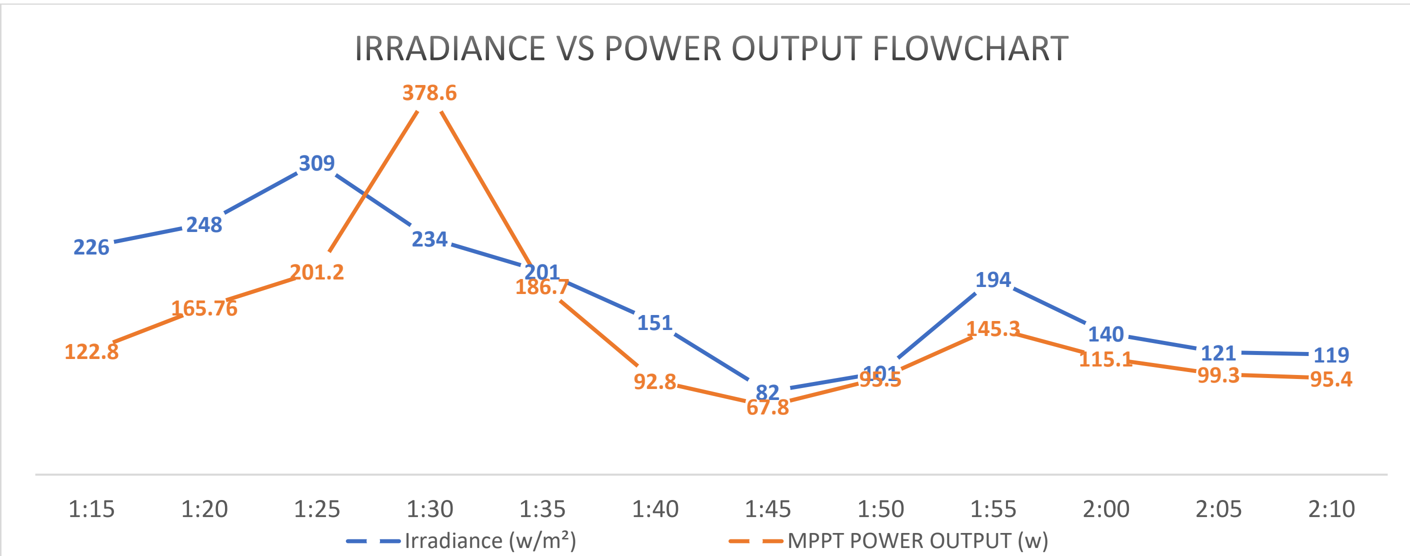

Fig. 4.7 Irradiance vs. power output flowchart

Flowchart showing the effect of sun irradiance on the power output of the solar generation system at different time intervals according to the variations of the weather

4.10 Analysis of The System Efficiency

Efficiency: The solar panel efficiency, which is the ratio of the electrical power output to the incident sunlight power, is also affected by the temperature at 1:25. We have the highest sun irradiance of 309 w/m^2 and 201.2-watt power output, which is not the highest power at 1:30 pm when the irradiance is 234 watt/m^2. We got the highest power of 378.6 watt as shown in fig. 4.6 and fig. 4.7. The drop in the voltage output caused by higher temperatures can lower the overall efficiency of the solar panels. Modern solar panels, on the other hand, are made to reduce some of these losses by the use of technologies like bypass and block diodes, as shown in Fig. 3.3, and better materials, which reduce the effect of temperature on efficiency.

The solar PV module used for this practical exercise is rated at 47±2°C nominal temperature this implies that any time the sun temperature rises above the rated nominal temperature, the voltage will start dropping, which also leads to a drop in the current. Throughout the practical exercise, the sun temperature never rose above the rated temperature of the PV module

Conclusion

A thorough knowledge of the effectiveness, dependability, and financial sustainability of solar energy-producing systems is possible through the rigorous modeling of their performance under various scenarios. The best technology and system configuration may be chosen using this procedure, which also makes it easier to make educated decisions on sustainable energy projects and backup plans for times when there is little or no sunshine, especially during the rainy season. In general, it is demonstrated that an effective solar energy generation system is viable, trustworthy, efficient, affordable, and environmentally friendly for home and commercial use as well as to contribute to the reduction of global warming and promote sustainable energy, concerning the results generated and analyzed from modeling and simulation.

Recommendation

i) Consider site selection, advanced technology integration, predictive modeling, operational strategies, maintenance, climate-responsive policies, education, training, cooperative research, data sharing, and continual improvement of the existing system.

ii) Establish routine maintenance schedules and monitor system health to prevent performance degradation.

iii) Encourage collaboration among researchers, industry stakeholders, and policymakers to drive innovation in materials, technologies, and system designs.

Contribution to Knowledge

This study significantly contributes to renewable energy and has practical implications for designing, operating, and enhancing the efficiency of solar power systems.

Understanding sun irradiance and temperature variations in solar panel performance can provide accurate models for energy production estimation and improve system design and optimization, ensuring system resilience and performance based on regional conditions.

Understanding sun irradiance, temperature, and energy yield is crucial for assessing solar projects' long-term performance and economic viability, aiding in site selection, and considering local climate conditions.

Research in this area aids in developing new materials and technologies to improve solar cell efficiency, including cooling technologies, improved thermal characteristics, and adaptive control systems.

Understanding temperature and irradiance variation aids in developing operational strategies such as real-time monitoring and adaptive control systems, while environmental factors influence system degradation, extending the lifespan of the solar installation.

Policymakers can utilize this knowledge to create regulations and incentives for solar energy adoption, while planners can make informed decisions about integrating solar power into the energy mix.

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Authors Biography

Folorunso Augustine Olugbenga, holds a National Diploma and Higher National Diploma in Electrical / Electronic Engineering from The Polytechnic, a Postgraduate Diploma from Lautech Ogbomosho Oyo State, a Bachelor of Electrical Engineering from Mewar University, and a Master of Engineering from Bells University of Technology. He is a registered practicing Electrical Engineer with the Council for the Regulation of Engineering in Nigeria (COREN) and is a corporate member of the Nigerian Society of Engineers.

Olusanya Olamide Omolara, Associate Professor, Deputy Dean, College of Engineering at Bells University of Technology, Ota, Ogun State.

Fasipe Oladimeji Ola-Oluwa Fasipe, is a Nigerian professional with a background in electrical and electronics engineering. He was a pioneer Engineer in Mega Screen Limited, a multimedia company specializing in crowd control technology. After a decade with the company, he resigned to oversee his private companies Moladol Technologies and Willares Engineering.