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Design and Construction of An Arduino - Based Solar Power Parameter-Measuring System with Data Logger

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ABSTRACT

Precise monitoring and assessment of solar photovoltaic panel characteristics are crucial for analyzing solar power plant performance and projecting future energy production. Obtaining such data is often challenging due to the high costs associated with top-of-the-line equipment or reliable satellite weather data procurement. This research aimed to develop an affordable parameter-measuring system for solar photovoltaic panels utilizing an Arduino microprocessor board. The system measures five key parameters: voltage, current, light intensity, temperature, and pressure. A hardware circuit was designed to connect various sensors to the Arduino board, with the measured data subsequently recorded onto a computer for further analysis. The accuracy of the devised device was confirmed by comparing the measured parameters with those obtained from conventional standard measuring instruments, demonstrating satisfactory agreement. The findings suggest that solar irradiance and temperature significantly influence the output energy generation from solar photovoltaic panels.

INDEX TERMS: Solar power plant analysis, voltage, current, light intensity, temperature, pressure, Arduino based monitoring, Excel sheet analysis, Cost-effective.

I. Introduction

Escalating fossil fuel expenses, the specter of global warming, and increasingly extreme weather patterns have driven numerous countries to explore alternative energy options, aiming to diminish dependence on fossil fuels. Among these alternatives, solar energy stands out as one of the most promising renewable energy sources worldwide, catering to the escalating need for electrical power. Solar energy ranks as the second-fastest-growing renewable energy source for electricity production, following closely behind wind energy. This energy form entails converting solar radiation into either electrical or thermal energy. Sunlight is harnessed directly through photovoltaic cells or indirectly via concentrated solar power technologies.

The solar photovoltaic (PV) energy system operates by directly converting sunlight photons into electricity through solar cells. These cells, composed of light-sensitive semiconductors, utilize photon energy to displace electrons, thereby generating an electric current. Photovoltaic modules are broadly classified into two types: mono-crystalline and poly-crystalline. Poly-crystalline solar cells consist of multiple silicon crystals, whereas mono-crystalline solar cells are crafted from a single silicon crystal, typically boasting higher efficiency. The power output from a solar cell is predominantly influenced by weather conditions, particularly solar irradiance and ambient air temperature.

Recent developments in the energy sector highlight the rapid expansion of the solar-energy market globally. There is a growing demand for remote monitoring and control equipment for solar-energy applications.

The evolution of solar cell technology has resulted in the creation of smarter solar cells that are more efficient, flexible, and lightweight. Solar manufacturing companies now integrate electronics such as power optimizers, micro DC-to-DC converters, and condition monitoring devices into solar PV modules. Monitoring and measuring solar PV parameters and site conditions are crucial for evaluating existing solar installations, advanced system monitoring, and predicting future generation. These activities also support decision-making, product development, system maintenance, and various other applications.

Ensuring the efficiency of a solar PV energy system necessitates reliable data acquisition of both electrical and meteorological data for ongoing condition monitoring and performance evaluation. Traditionally, acquiring such data has been costly, especially when deploying cutting-edge equipment on-site, with concerns over the reliability of satellite data as a substitute for on-site data. This study focuses on creating a cost-effective solution: an Arduino-based system for measuring solar photovoltaic parameters and logging data. The developed system effectively measures crucial parameters like incident light intensity, voltage, current, and temperature associated with solar photovoltaic

Problem statement

Today, there's a wide array of alternative jackets in the market offering both cooling and heating functionalities alongside traditional insulation. Dealing with diverse climate extremes, from intense cold to extreme heat, poses health risks. In particular, the threat of hypothermia or excessive cooling in frigid conditions is a significant concern. Given the vital role of soldiers in defending our nation, especially in harsh cold climates, we've developed a specialized army jacket to support them. This smart safety jacket is engineered to monitor the soldier's well-being, internal temperature, and issue SMS alerts promptly in case of emergencies.

Objectives

The proposed system introduces a new, cost-effective, and efficient microcontroller-based Maximum Power Point Tracking (MPPT) system for solar photovoltaic setups, ensuring optimal operation despite changing environmental conditions. Employing the Perturb and Observe (P&O) MPPT algorithm, the system regulates the maximum power transferred from a PV panel. This algorithm is implemented by a PIC microcontroller, which utilizes data on PV voltage and current to adjust the duty cycle of a pulse width modulation signal applied to a DC/DC converter.

II. Literature review

This paper presents an enhanced Perturbation and Observation (P&O) algorithm designed to track the maximum power point (MPP) of a solar PV panel. Solar PV cells exhibit a non-linear V-I characteristic with a unique MPP influenced by environmental factors like temperature and irradiation. Maintaining operation at the MPP is crucial for consistently harvesting maximum power from the solar PV panel. The proposed P&O algorithm addresses common drawbacks associated with traditional P&O algorithms by incorporating the determination of short-circuit current before each perturbation and observation stage. Simulation results are compared with MPPs obtained using conventional P&O algorithms across various atmospheric conditions, demonstrating superior performance of the advanced P&O algorithm in tracking MPPs of solar PV panels. Moreover, it offers simplicity and ease of implementation in digital signal processors (DSPs). [1]

The study focuses on a PV battery charge regulator designed for advanced CdTe modules with output voltages significantly higher than the common values of around 12 or 24 V. While most PV autonomous installations typically operate at 12 or 24 V due to convenience, technical tradition, and battery characteristics, the high DC module voltage needs to be converted to a suitable lower value using a high-efficiency DC/DC inverter. The paper introduces a new 60/12 V charge controller solution developed in-house. This charge controller utilizes a "step-down" inverter equipped with modern Maximum Power Point Tracking (MPPT) technology. The selection and implementation of the MPPT algorithm using a microprocessor are explained and discussed, along with the final test and measurement outcomes. The results of the operational tests are highly satisfactory, indicating that the solution holds significant value for the emerging market of high voltage modules. [2]

This paper describes the development of a maximum power point tracking (MPPT) algorithm using an artificial neural network (ANN) for a solar power system. By employing a three-layer neural network with simple activation functions, efficient tracking of the maximum power point of a solar array is achieved. The tracking algorithm, integrated with a solar-powered battery charging system, is successfully implemented on a low-cost PIC16F876 RISC microcontroller without the need for an external sensor unit. Experimental results obtained with a commercial solar array demonstrate that the proposed algorithm surpasses conventional controllers in terms of tracking speed and stabilizing output power fluctuations during steady-state operation. The overall system efficiency exceeds 90%. [3]

This paper introduces a fully integrated solar charger controller with a wide input voltage range of approximately 10V to 28V for solar panels. The controller utilizes input loop regulation as a form of Maximum Power Point Tracking (MPPT) protection and supports various battery voltages ranging from 4V to 12V. Only one error amplifier is used in the controller system, eliminating the need for external compensation components. Additionally, the controller features 600 kHz PWM modulation and includes over-current and overvoltage protection functionalities. All necessary components, such as the bandgap, reference generator, saw-tooth generator, register controller, and driver circuits, are integrated into the circuit. The chip is fabricated using a 0.4-μm 5V/40V 2P4M process and has a power consumption of approximately 10mA. [4]

III. Proposed methodology

- **Block Diagram**

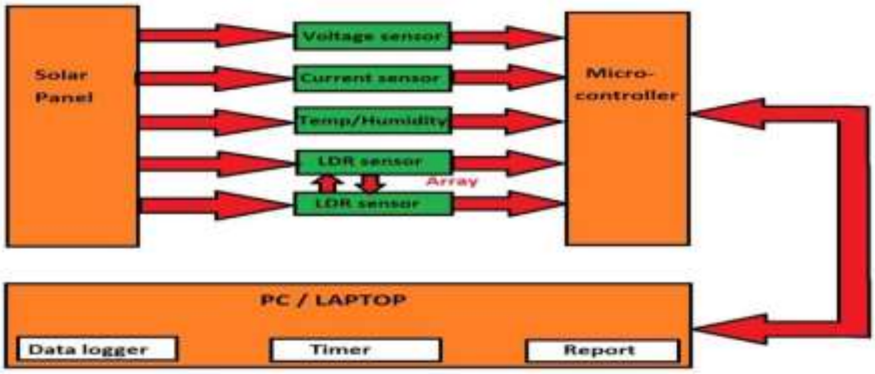

Figure 1 : Block Diagram

This study involved the creation of an Arduino-based system for measuring various solar PV parameters, utilizing an Arduino Uno and multiple sensors. The system demonstrated the capability to measure voltage, current, real-time temperature, atmospheric pressure, and light intensity. These parameters were logged simultaneously into a personal computer (PC) for future analysis or reference. A block diagram of the system, as depicted in Figure 1, illustrates the interface between the solar panel and the Arduino board through sensors.

The development of the system encompassed both hardware circuit design and software programming to interface solar parameters with the Arduino board. Hardware development involved designing electronic components for sensor interface between the solar panel and the Arduino Uno. The hardware unit included voltage, current, light-dependent resistor (LDR), and pressure-temperature sensors, along with the Arduino Uno. As the acquired sensor data were analog, conversion to digital equivalents was performed using the Arduino Uno's analog-to-digital converter module, programmed in C-language.

- **Software Programming**

This section describes the programming of the Arduino board and emphasizes the significance of software in the system's operation. Some sensors, such as the temperature and LDR sensor, produce analog outputs, which were converted to digital equivalents using the microcontroller's analog-to-digital converter (ADC) module. Programming for the Arduino UNO was carried out using the Code Blocks Arduino IDE, an open-source software tailored for Arduino development. The microcontroller was connected to a PC via a USB cable. The Arduino board's ADC monitored changes in analog input voltage and converted them into binary numbers ranging from 0 to 1023 bits. The "analogRead(pin no)" function returned a number between 0 and 1023, representing the voltage applied to the pin. The flowchart in Figure 2 illustrates the analog-to-digital conversion process and how the measured data were displayed on an LCD screen and logged onto the PC.

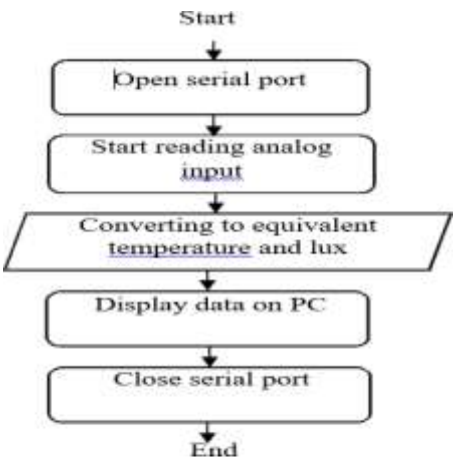

Figure 2. Flow Chart

Measurement data logging was facilitated using an add-on named PLX-DAQ (Parallax Data Acquisition). This Python-based user interface program enables communication between Microsoft Excel on a Windows computer and any device supporting serial port protocol. The Python Excel user interface, depicted in the figure, serves as an open-access tool. Initially developed to establish communication between an Arduino board and Microsoft Excel, it enables seamless data exchange between the two platforms.

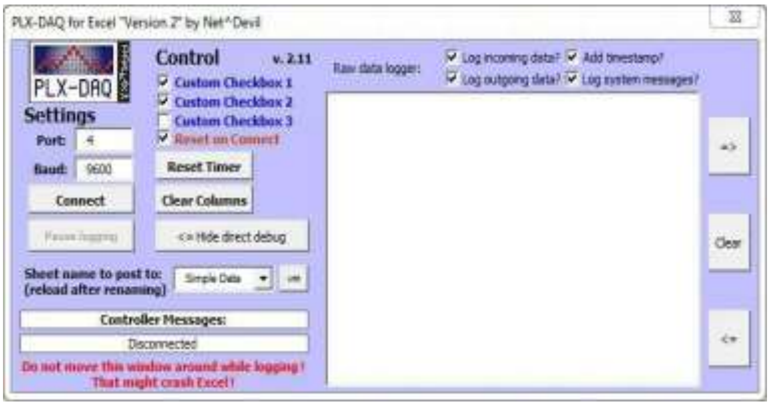

Figure 3. PLX- DAQ user interface

- **System Simulation**

The simulation involved optimizing the circuit parameters of the sensor interface for the solar PV parameter measuring system using PROTEUS ISIS. Each component was selected from the library's toolbar in PROTEUS schematic capture and component mode. The complete circuit schematic, displayed in Figure 4, illustrates all essential components arranged in the workspace before wiring the circuit.

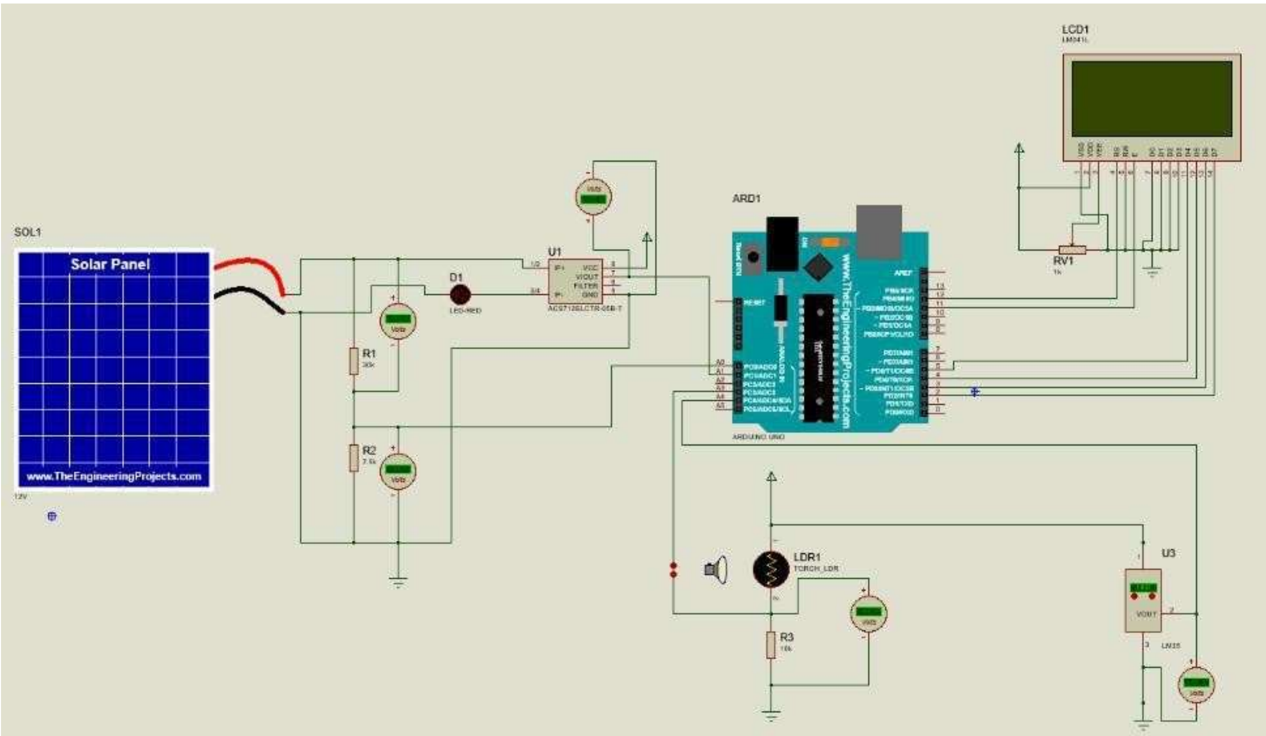

Figure 4: Simulated Solar PV parameter measuring system

The voltage sensor gauges the voltage produced by the solar panel in volts and transmits the analog input to the microcontroller. Similarly, the current sensor measures the load's current draw in amperes and sends the analog input to the microcontroller. Additionally, the BMP180 sensor detects pressure (Pa) and air temperature (°C), providing these values directly in digital output. This is achieved by linking the BMP180 output to the microcontroller's analog input. The LDR sensor is utilized to measure light intensity in lux. The output parameters from these sensors serve as input values to the Arduino, and the resulting output is showcased on the LCD screen. The Arduino Uno's ADC module is programmed to convert analog inputs from the sensors into digital output equivalents for display on the LCD screen and logging through PLX-DAQ data acquisition. The LCD screen exhibits the output values of voltage, current, temperature, pressure, and light intensity.

IV. Hardware implementation of proposed model

The process began with simulating the designed circuit parameters using PROTEUS ISIS software, which was then utilized to select components for constructing the Arduino-based solar PV parameter-measuring system. Construction involved mounting and soldering circuit elements onto a breadboard. Hardware assembly entailed connecting the physical components, including the voltage sensor unit, current sensor unit, temperature and pressure sensor unit, light intensity sensor unit, and the Arduino microcontroller unit. The construction stage, depicted in Figure 10, illustrates the assembly of component parts on the breadboard. The subsequent stage involved programming the Arduino in C-language to provide central control for system operation. The program used for system testing in PROTEUS ISIS software was downloaded to the board to finalize the circuit construction.

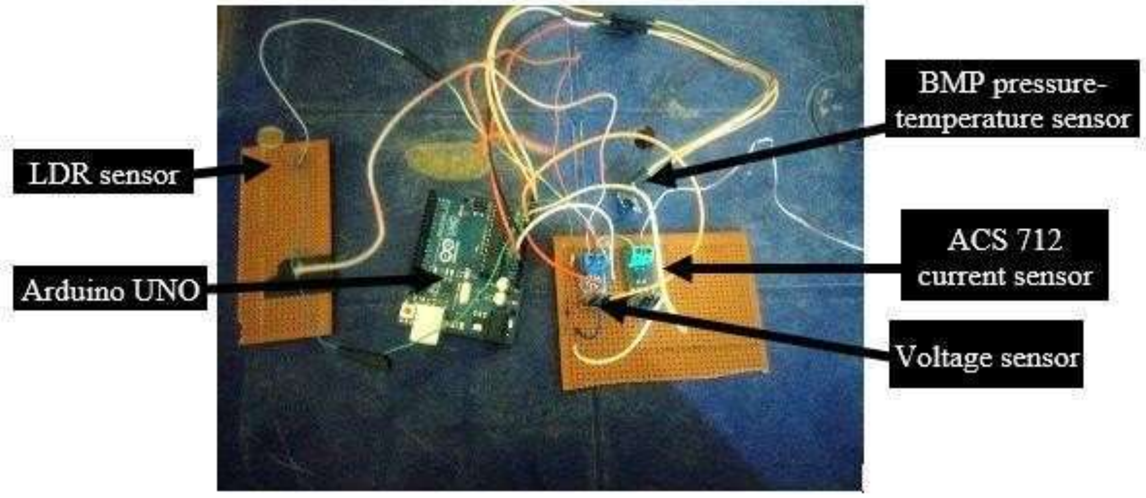

Fig. 5: Constructed solar PV parameter-measuring system

Following circuit construction, the measurement system underwent testing using a mono-crystalline 20W solar panel and a 10W DC bulb as the load. The outdoor test spanned several days, during which voltage, current, light intensity, temperature, and pressure values were logged onto a computer. To verify the accuracy of the constructed measuring device, comparative measurements were taken using a standard multimeter (ANENG AN8002) for current and voltage, and the multimeter's thermocouple probe for temperature. The measured values from both the constructed device and the standard instrument exhibited strong similarity.

The field experimental setup, depicted in Figure 5 along with the PC for data logging, was situated at the University of Ilorin, Faculty of Engineering and Technology. Testing occurred from the 19th to the 21st of June 2019, with readings collected between 7:00am and 6:00pm each day.

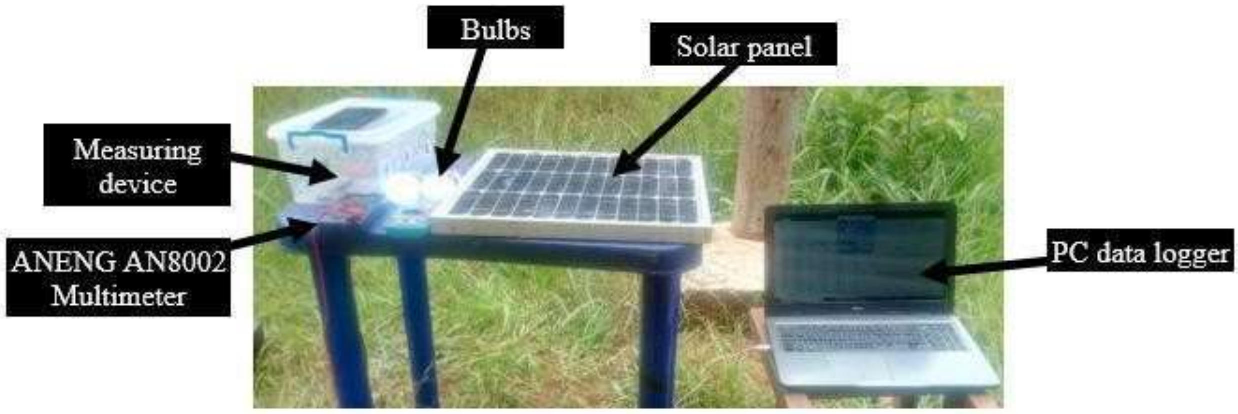

Figure 6: Field testing of measuring system

During the three-day testing period, the solar PV panel remained horizontally positioned to ensure consistent readings. Care was taken to prevent shading and maintain a clean surface on the panel to minimize errors in the measurements. Readings for voltage, current, light intensity, temperature, and pressure were logged onto a PC. Data collection occurred daily from the 19th to the 21st of June 2019, spanning from 7:00am to 6:00pm each day.

V. Results and discussion

- **Voltage and Light Intensity Measurement**

Figures 7, 8, and 9 depict the results of voltage and light intensity variation throughout the day for the solar PV panel. On the 19th of June 2019, the highest recorded voltage was 17.44V at 3:00pm, accompanied by a light intensity of 1014.5 lux, while the lowest voltage was 9.21V at 7:00am, with a light intensity of 990.5 lux. Similarly, on the 20th of June 2019, the highest voltage reached 13.79V at noon, coinciding with a light intensity of 1010.25 lux, while the lowest voltage was 9.28V at 7:00am, with a light intensity of 1000 lux. Lastly, on the 21st of June 2019, the highest voltage recorded was 18.54V at noon, with a light intensity of 1016 lux, and the lowest voltage was 10.16V at 7:00am, accompanied by a light intensity of 1000.5 lux. The graphs illustrate a direct correlation between light intensity and solar panel output voltage.

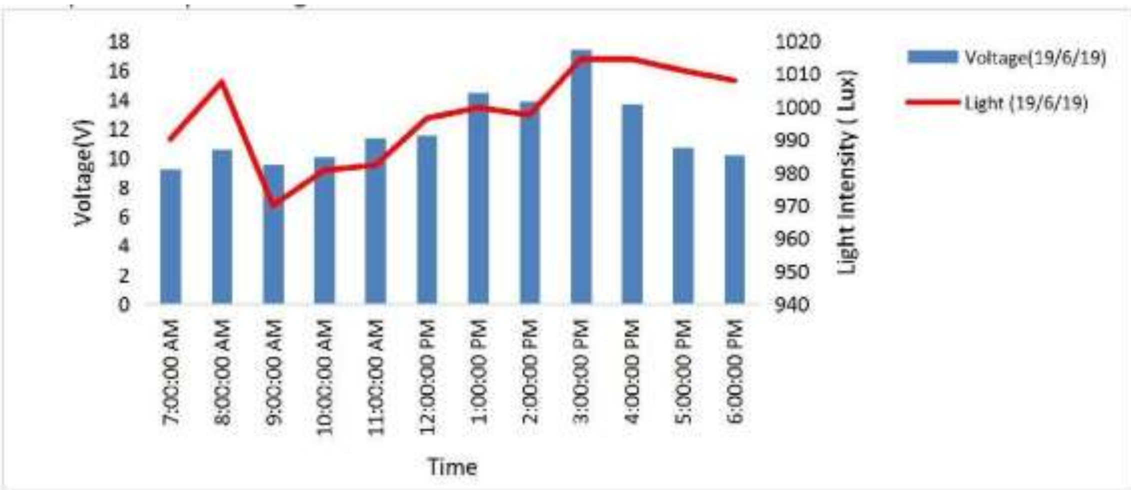

Figure 7: Graph of voltage and light intensity against time for day 1.

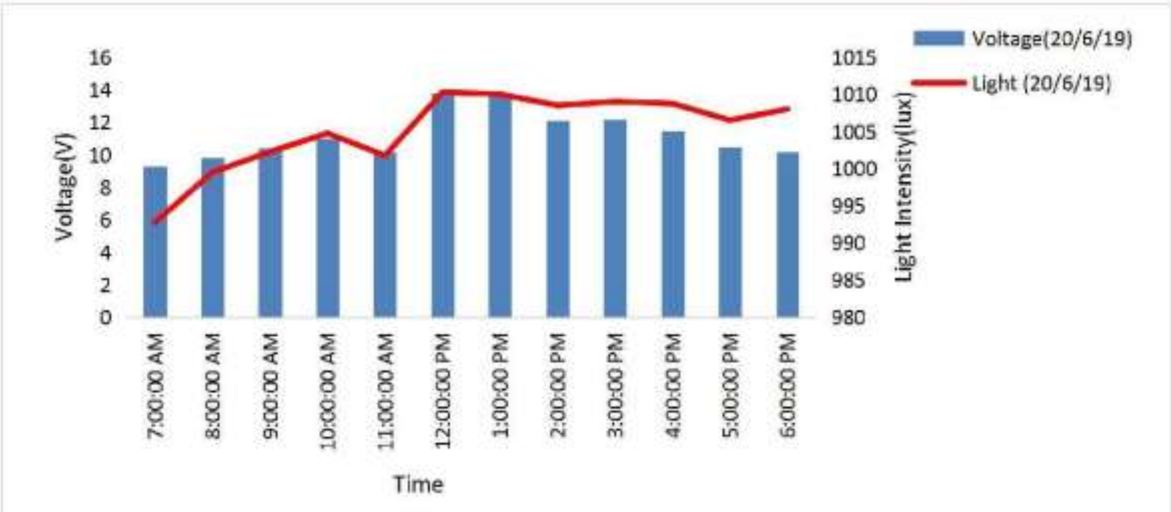

Figure 8: Graph of voltage and light intensity against time for day 2

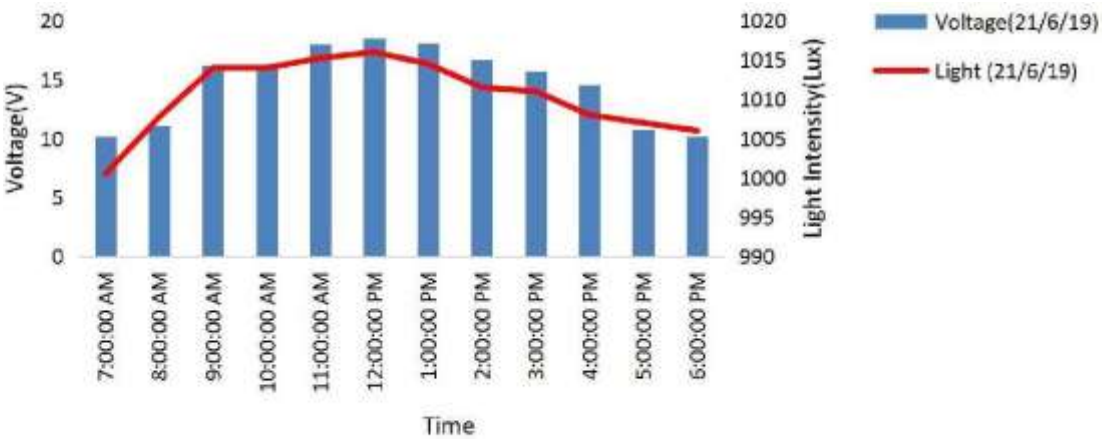

Figure 9: Graph of voltage and light intensity against time for day 3.

Figure 10 illustrates a comparison of light intensity across the three days. The bar chart indicates that the peak light intensity of 1016 lux was registered at noon on the 21st of June, while the lowest recorded light intensity was 960.75 lux at 10:00 am on the 19th of June 2019.

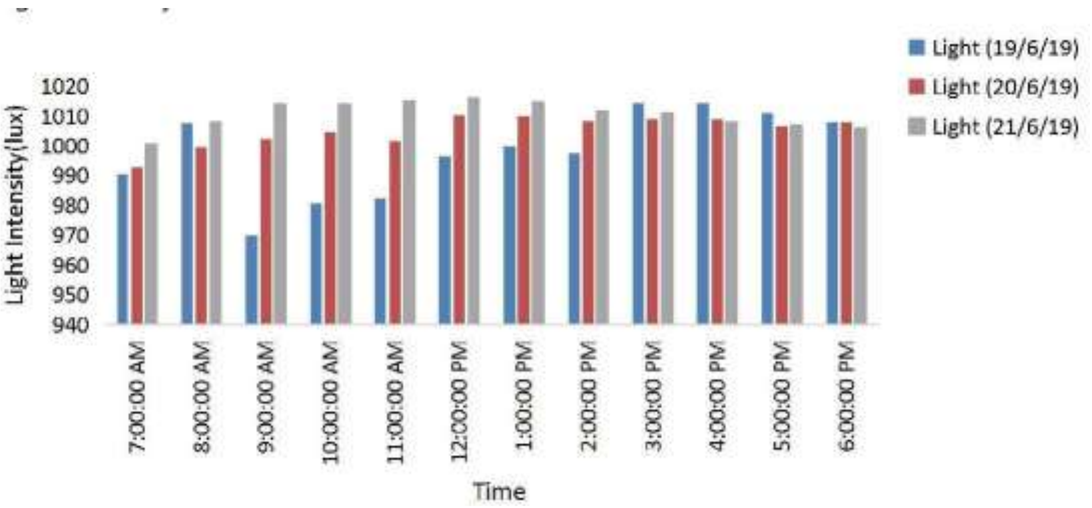

Figure 10: Graph of light intensity against time

- **Temperature and Pressure Measurement**

Figures 11, 12, and 13 display the ambient temperature and pressure readings around the solar PV panel for the three days. On the 19th of June 2019, the highest recorded pressure and temperature were 976.09 Pa and 32.71°C, respectively, at 3:00pm, while the lowest pressure and temperature were 971.35 Pa and 23.89°C, respectively, at 7:00am. Similarly, on the 20th of June 2019, the highest pressure and temperature reached 976.96 Pa and 30.91°C, respectively, at 1:00pm, while the lowest pressure and temperature were 971.37 Pa and 24.19°C, respectively, at 6:00pm. Lastly, on the 21st of June 2019, the highest pressure and temperature recorded were 975.97 Pa and 33.41°C, respectively, at 11:00am.

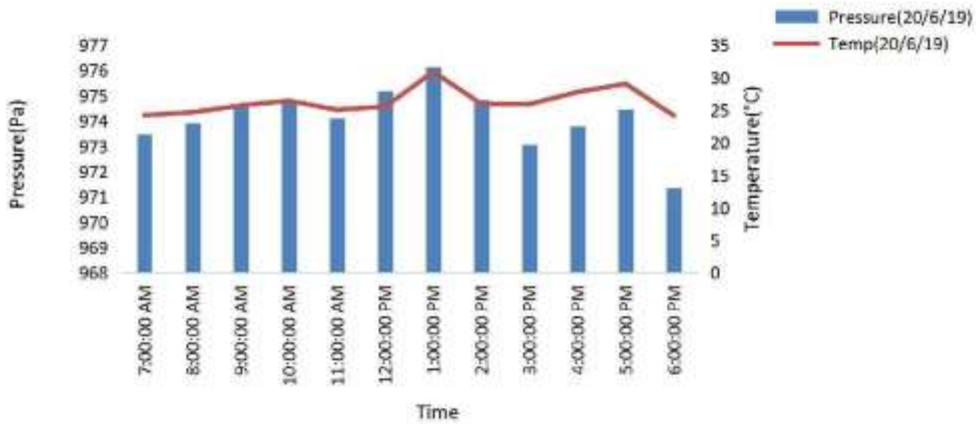

Figure 11: Pressure and temperature against time day 1

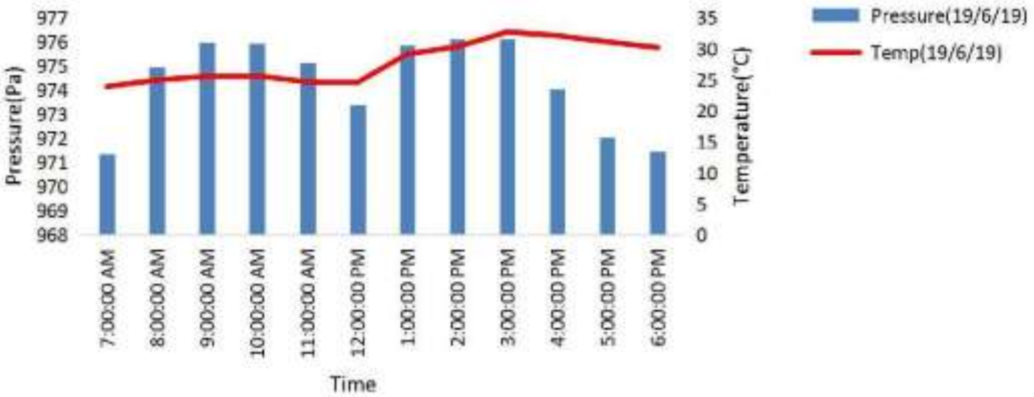

Figure 12: Pressure and temperature against time day 2

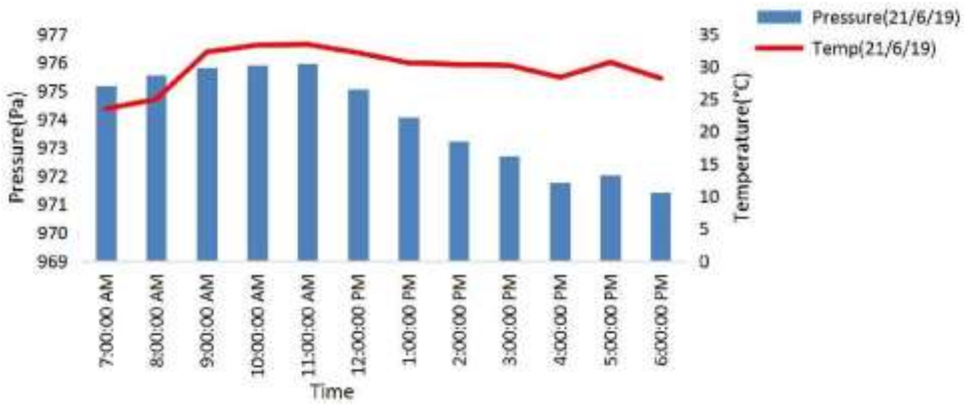

Figure 13: Pressure and temperature against time for day 3

- **Solar PV Panel Output Power**

Figure 14 illustrates the power generated by the solar panel. The data indicates that the output power is directly influenced by the solar panel voltage, light intensity, and temperature. The highest power output of 7.5W was observed on the 21st of June, coinciding with the brightest part of the day and a moderately low temperature of 33.31°C at 11:00am. Conversely, the lowest power output of 0.48W was recorded at 7:00am on the 19th of June 2019..

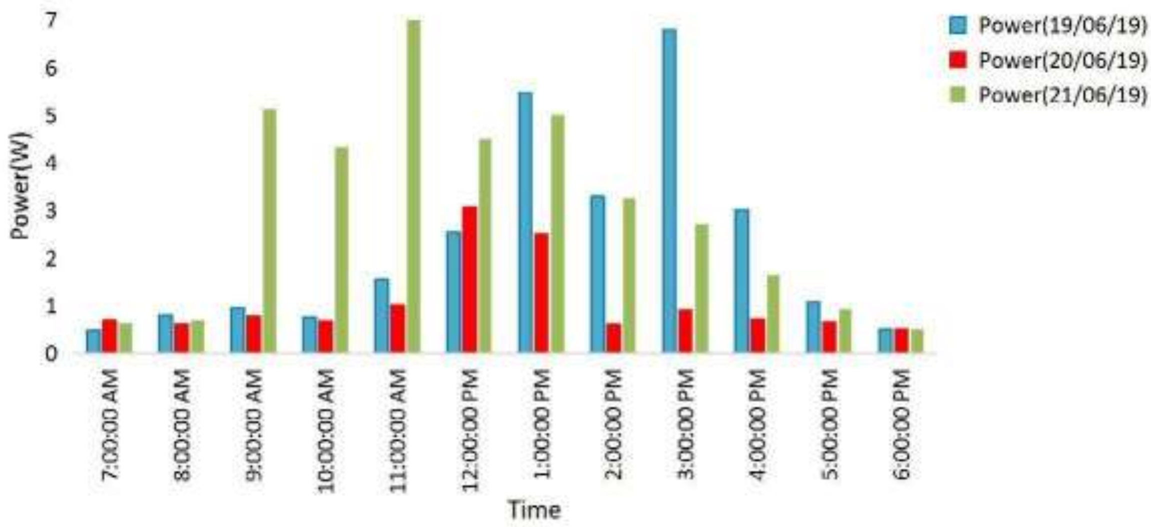

Fig. 14: Solar panel output power against time.

VI. Conclusion

An Arduino-based solar power parameter-measuring system was developed and built using optimized parameters simulated in Proteus ISIS. This device was utilized to gather data on solar PV current, voltage, power, temperature, pressure, and light intensity.

The system enables measurement of solar panel data for assessing solar energy performance and predicting future energy generation. Analysis of the measurement data revealed that solar PV energy generation is directly influenced by solar irradiance, temperature, and air pressure.

VII. References

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