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ORIGINAL RESEARCH ARTICLE

DESIGN AND CONSTRUCTION OF AN ARDUINO - BASED SOLAR POWER PARAMETER-MEASURING SYSTEM WITH DATA LOGGER

Oladimeji I.[1*], Adediji Y. B.[1], Akintola J. B.[1], M. A. Afolayan[1], O. Ogunbiyi[2], Ibrahim S. M.[3], Olayinka S. Z.[1]

([1]Department of Electrical and Electronics Engineering, University of Ilorin, Nigeria

[2]Department of Electrical and Computer Engineering, Kwara State University, Nigeria

[3]Department of Electrical Engineering, Kano University of Science & Technology Wudil, Nigeria)

**Corresponding author's email address: reacholaibrahim@gmail.com*

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ABSTRACT

Accurate monitoring and measurement of solar photovoltaic panel parameters are important for solar power plant analysis to evaluate the performance and predict the future energy generation. There are always challenges of getting such data readily available due to huge amount of money to be spent on state of the art equipment or the purchase of reliable satellite weather data. This study aimed at the development of a cost-effective parameter-measuring system for a solar photovoltaic panel using Arduino microprocessor board. The systems measure five parameters, including voltage, current, light intensity, temperature, and pressure. The hardware circuit was designed to link different sensors with the Arduino board and the measured data were in turn were documented into a computer for further analysis. The accuracy of the constructed device was ascertained by comparing the measured parameters with that of conventional standard measuring instruments which shows good agreement. The measured parameters show that the output energy generation from solar photovoltaic panel largely depends on the solar irradiance and temperature.

1.0 Introduction

The rising costs of fossil fuels, global warming, and severe weather conditions have compelled many nations to look into alternative sources of energy to reduce reliance on fossil-based fuels. The solar energy is one of the most promising renewable sources of energy currently being used globally for meeting rising demands of electric power (Kannan and Vakeesan, 2016; Kabir et al., 2018). Solar energy is considered as fastest growing renewable energy source for electricity generation after the wind energy (Adib et al., 2015). It involves conversion of solar energy into electric and/or heat energies. The sunlight is collected either directly by using photovoltaics cells or indirectly using concentrated solar energy (Singh, 2013).

The solar photovoltaic (PV) energy system directly converts the sun photons energy to electricity through the solar cells. Solar cells are made from light sensitive semiconductors that use photon energy to dislodge electrons to drive an electric current. The two broad classifications of photovoltaic modules are the mono-crystalline and poly-crystalline. Polycrystalline solar cells are formed from multiple silicon crystals while mono-crystalline solar cells are made from a single silicon crystal and they usually have higher efficiency (Yamaguchi, 2003). The output of power generated from a solar cell largely depends on weather conditions most especially the solar irradiance and air temperature (Osueke et al., 2013; Ibrahim et al., 2015).

The recent development in energy sector have shown that solar-energy market is one of the most rapidly expanding renewable energy markets in the world (Adib et al., 2015). Presently there is significant increasing in demands for remote monitoring and control equipment for solar-energy applications.

The advancement in the solar cell technology has led to the development of a more efficient, flexible and lighter PV cells named smart solar cells (Luque and Hegedus, 2011; Battersby, 2019). Solar manufacturing company now embeds electronics such as power optimizers, micro DC-to-DC converters, and condition monitoring devices in the solar PV modules. The monitoring and measurement of solar PV parameters and site condition has some importance in evaluating the performance of existing solar installations, advanced system monitoring and the prediction of future generation (Diagne et al., 2013; Shamim et al., 2015; Verbois et al., 2018; Ghasempour et al., 2019). They also aid in decision making, product development, system maintenance, and many other applications.

A solar PV energy system requires reliable means of data acquisition of all the electrical and meteorological data for condition monitoring, and evaluation of the system performance. Acquiring such data has been capital intensive when state of the art equipment is to be installed at the site and there is a concern of reliability over the use of satellite data in place of site data. This study involves the development of low-cost Arduino-based solar photovoltaic parameter-measuring system with data logger. The developed system successfully measures the solar photovoltaic parameters such as incident light intensity, voltage, current, and temperature.

2. Materials and Methods

In this work, an Arduino-based solar parameter-measuring system was designed and constructed using Arduino Uno and multiple sensors. The system was found to be capable of measuring different solar PV parameters including the voltage, current, real time temperature, real time atmospheric pressure, and light intensity. The measured parameters were simultaneously logged into a personal computer (PC) for future analysis or references. Figure 1 shows the block diagram of an Arduino based solar PV parameter-measuring system having sensors interfaced between the solar panel and Arduino board.

The system comprised of both hardware circuit design and software programming for interfacing solar with the Arduino board. The hardware development involves the design of electronic components for the sensors interface between the solar panel to the Arduino UNO. The hardware unit comprised of the voltage sensor, current sensor, light dependent resistor (LDR) sensor, pressure-temperature sensor and the Arduino Uno. The acquired data from sensors are analogue, thus the conversion to digital equivalent was performed within the Arduino UNO analogue-to-digital converter module programmed in C- language.

Corresponding author's e-mail address: reacholaibrahim@gmail.com

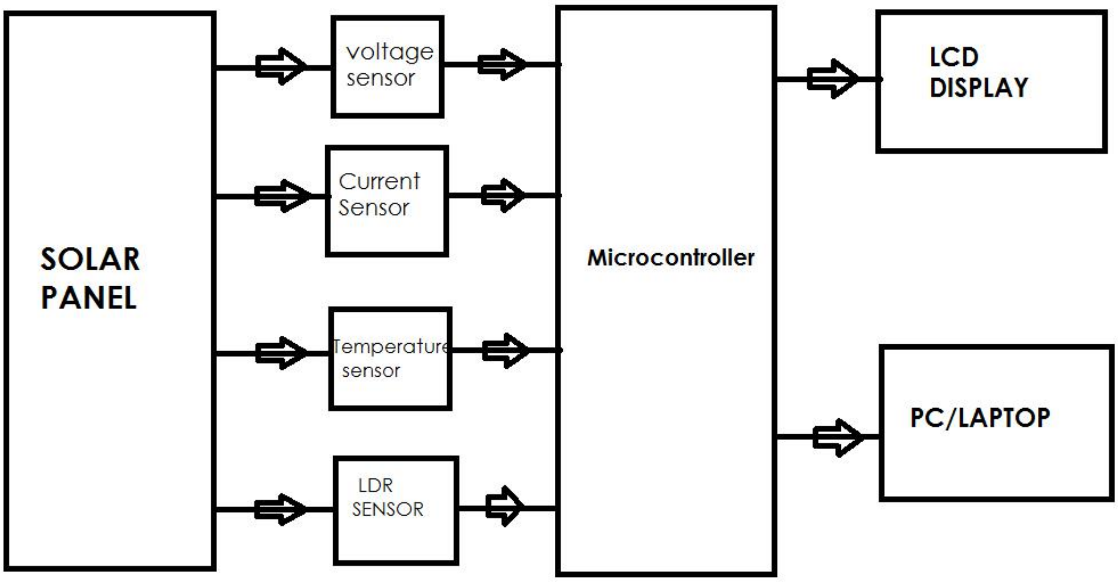

Figure 1: Solar PV parameter-measuring system

2.1 System Components

2.2.1 Solar panel

A solar photovoltaic panel converts sunlight (photons) into electrical energy through the influence of the photovoltaic effect. The photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies electric energy from solar energy in commercial quantities for community uses. The common types of photovoltaic modules are mono-crystalline, poly-crystalline, and thin film photovoltaic modules.

In this study, a 12V, 20W solar panel composed of mono-crystal solar cell with an efficiency of 17% was selected. The manufacturer's technical specifications of the 12V solar panel is presented in Table 1 (BlueSolar Datasheet).

Table 1: Manufacturer's description of the Mono-crystalline solar panel

Name: BlueSolar series 4a Solar Panel	
Dimensions (mm):	440 × 350 x 25mm
Net Weight (kg):	1.9
Nominal power (PMPP-W):	20
Max-Power Voltage (PMPP-V):	18.5
Max-Power Current (IMPP-A):	1.09
Open-Circuit Voltage (VOC-V):	22.6
Short-Circuit Current (IOC-A):	1.19

2.2.2 Arduino Microcontroller

Arduino is an open-source, prototyping platform that is widely used in digital world owing to simplicity and ease of configuration. The Arduino UNO R3 used in this project is a microcontroller board based on the ATmega328. The microcontroller is shown in Figure 2, it has 16 MHz crystal oscillator, 14 digital input/output pins of which 6 can be used as PWM outputs. It has 6 analog inputs, a USB connection function as power source and communication channel, a power jack, an ICSP header, and a reset button.

Corresponding author's e-mail address: reacholaibrahim@gmail.com

Figure 2: Arduino UNO R3 microprocessor

2.2.3 Light Dependent Resistor (LDR)

The Light Dependent Resistor (LDR) is a light-controlled variable resistor. Its resistance depends on the light impinging on it. The resistance offered by the LDR is inversely proportional to light strength. Light dependent resistors are useful especially in light/dark sensor circuits application. The symbol is shown in Figure 3, they usually have high resistance up to 1MΩ, but when they are illuminated with light, the resistance drops drastically.

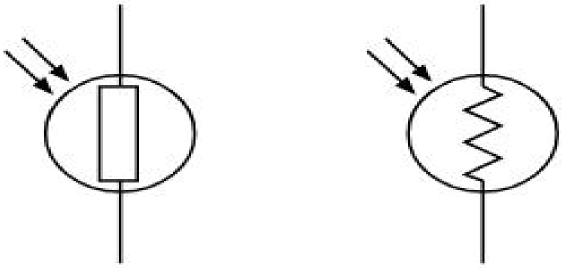

Figure 3: Light dependent resistor

In this work, the LDR sensor is used to monitor the light intensity incidence on the solar PV.The change in resistance can easily be measured by converting the resistance into voltage equivalent. The input of the LDR is connected to a 5V supply and in series with a 10KΩ resistor. The middle point is used as output connected to the Arduino board. When light falls on the LDR, the resistance of LDR decreases and the analog voltage changes. This voltage is applied to the analog input of the Arduino which is converted to digital equivalent corresponding to light intensity. For measuring the light intensity in degree lux, the LDR voltage (V_{LDR}) is converted using equation (1) (Ashishi, 2018).

$$Light\ Intensity = \frac{V_{LDR} \times 1023}{5} \qquad (1)$$

2.2.4 Temperature and Pressure Sensor

The temperature and barometric pressure were measured using BMP180 temperature-pressure sensor. The BMP180 sensor is an environmental sensor for different weather sensing and can be used with both I2C (inter-integrated circuit) and SPI (serial peripheral interface) communication protocol. This precision sensor from BOSCH company is a popular low-cost precision sensing solution for measuring barometric pressure with ±1 hPa absolute accuracy, and at temperature ±1.0°C accuracy. Figure 4 show the BMP180 sensor with the connection pins for interface with the Arduino board.

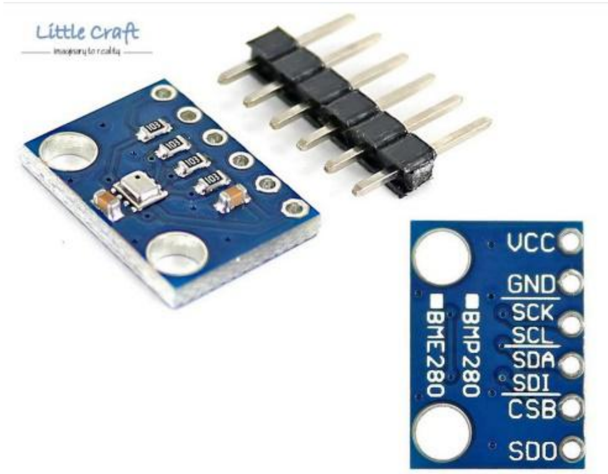

Figure 4: BMP 180 temperature-pressure sensor

2.2.5 Voltage Sensor Module

The voltage sensor as shown in Figure 5 is used to measure the voltage of the solar panel. The voltage module analog interface can detect input voltage up to 5V and a voltage greater than 5V will not be detected. The solar PV voltage was measured employing a voltage divider. The voltage sensor interface circuit comprised of two series resistors R1 and R2 obtained as 30kΩ and 7.5kΩ and resistance factor (Rf) obtained from equation (3) is responsible for converting the voltage back to the original solar panel value to be displayed on the PC. The measured solar panel output voltage is given by Eqn (2) (Ravi 2018).

Figure 5: Voltage sensor module

$$\text{Measured voltage} = \frac{\text{Voltage devider analogue value} \times \text{Reference voltage}}{\text{Resistance factor(Rf)}} \quad (2)$$

$$Rf = \frac{1023}{R_1/(R_1 + R_2)} \quad (3)$$

2.2.6 Current sensor (ACS712)

The ACS712 20A rating current sensor shown in Figure 6 was selected for measuring the current flowing into the system. The sensing terminal of the current module can measure load current on medium voltage system up to 230V AC mains while output sensed voltage is isolated from measuring part. In this application, the sensor was operated with 5V supply voltage and outputs analog voltage is proportional to current measurement on the sensing terminals. The microcontroller ADC converts the analogue value to digital current equivalent for displayed or storage in data logger. The measured solar panel current is given by Equation (4) and the power is computed from Equation (5) (Ravi 2018).

Figure 6: Current sensor module

$$Current\ measurement = \frac{(Analogue\ value \times Analogue\ \ factor)\text{-}ACoffset}{Sensitivity} \tag{4}$$

where:

$Analogue\ \ factor=5/1023,\ ACoffset=2500mA,\ and\ Sensitivity=100mV/A$

The power per square meter measurement for the solar panel was obtained using the relationship in equation (5)

$$Power = \frac{Voltage \times Current}{Area}\ \text{watts/m}^2 \tag{5}$$

2.2 Software Programming

This section presents the programming of the Arduino board and highlights the software relevance in the system operation. Some of the sensors such as temperature and LDR sensor output are in analog format which the conversion to digital equivalent was done using the analog-to-digital converter (ADC) module of the microcontroller. The Arduino UNO was programmed using the CodeBlocks Arduino IDE (integrated development environment) which is an open -source customized software for Arduino development. The microcontroller was interfaced to the PC with using universal serial bus (USB) cable. The Arduino board ADC monitors the analogue input voltage changes and converts it to a binary number between 0 to 1023 bit. In between, analog Read(pin no)returns a number between 0 and 1023 proportional to the amount of voltage being applied to the pin. The flow chart in Figure7 shows the analogue to digital conversion process and how the measured data were display on LCD screen and log to the PC.

Corresponding author's e-mail address: reacholaibrahim@gmail.com

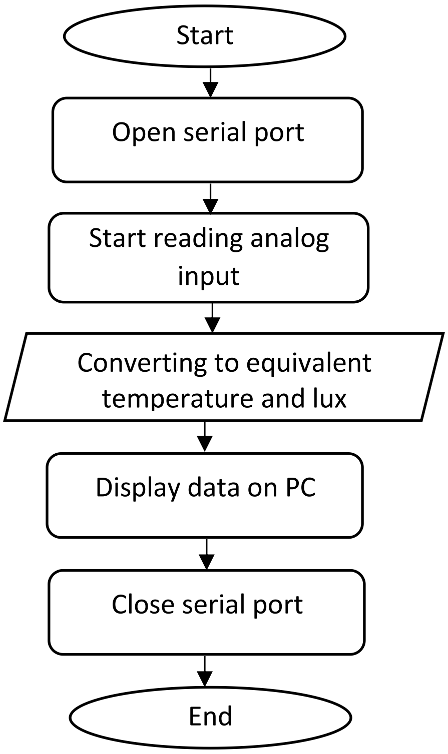

Figure 7: Arduino ADC conversion

The data logging of the measurement data was done using an add-on called PLX-DAQ (Parallax Data Acquisition). The PLX-DAQ is an open access program used to establish communication between Microsoft Excel on a Windows Computer and any device that support serial port protocol. The PLX- DAQ user interface is shown in Figure 8. It was originally written to allow communication between Arduino board and Microsoft Excel.

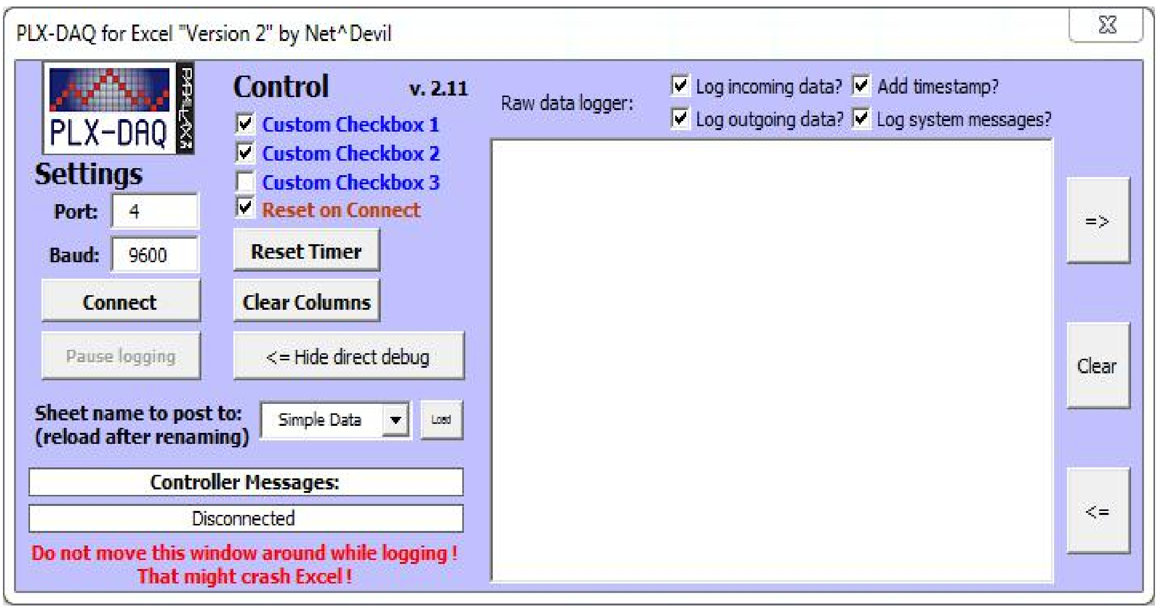

Figure 8. PLX- DAQ user interface

2.3 System Simulation

After designing the sensor interface circuit for the solar PV parameter measuring system, a simulation was carried out in PROTEUS ISIS to optimize the circuit parameters prior to practical construction of the designed system. Each component was picked by selecting the PROTEUS schematic capture and component mode from the library's toolbar. The complete circuit schematic is presented in Figure 9 showing all essential components placed in the workspace before the circuit was wired up.

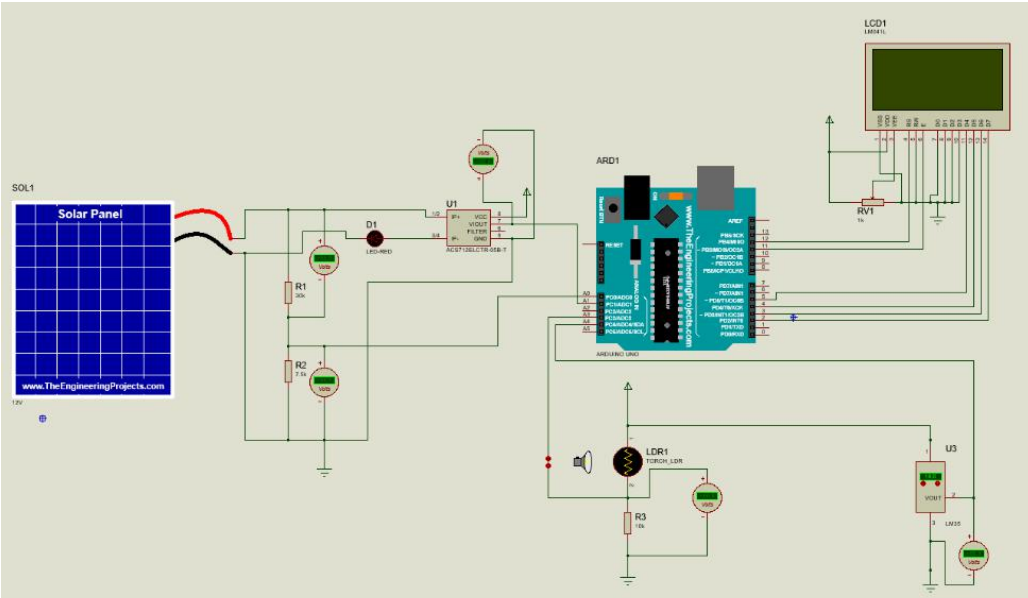

Figure 9: Simulated Solar PV parameter measuring system

The voltage sensor measures the voltage generated by the solar panel in volts and sends the analog input to the microcontroller. The current sensor measures the current drawn by the load in ampere and sends the analog input to the microcontroller. Also, the BMP180 sensor senses the pressure (Pa) and air temperature (°C) but provides the values directly in digital output. This is done by interfacing the output of the BMP180 to the analog input of the microcontroller. The LDR sensor was used to measure the light intensity in lux. These sensors output parameters provide the input value to the Arduino and the output is displayed on the LCD screen. The Arduino Uno ADC module was programmed to convert the analog input from the sensors to digital output equivalent for display via LCD screen and logged in the PLX- DAQ data acquisition. The LCD screen displays output of the voltage, current, temperature, pressure, and light intensity values.

2.4 Circuit Construction and Testing

The designed circuit parameters were first simulated on PROTEUS ISIS software which was in turn was used to select components for the construction of the Arduino-based solar PV parameter-measuring system. The system construction encompasses mounting and soldering of the circuit elements on the breadboard. The hardware construction involves the coupling of physical part of the system which is made up of circuit units and interface between the voltage sensor unit, current sensor unit, temperature and pressure sensor unit, light intensity sensor unit and the Arduino microcontroller unit. The constructional stage of the system is presented in Figure 10 showing the assemblage of the components parts on the breadboard. The second stage involves programming of the Arduino in C-language which provides central control for the system operation. The program used for the system testing on the PROTEUS ISIS software was downloaded to the board to complete the circuit construction.

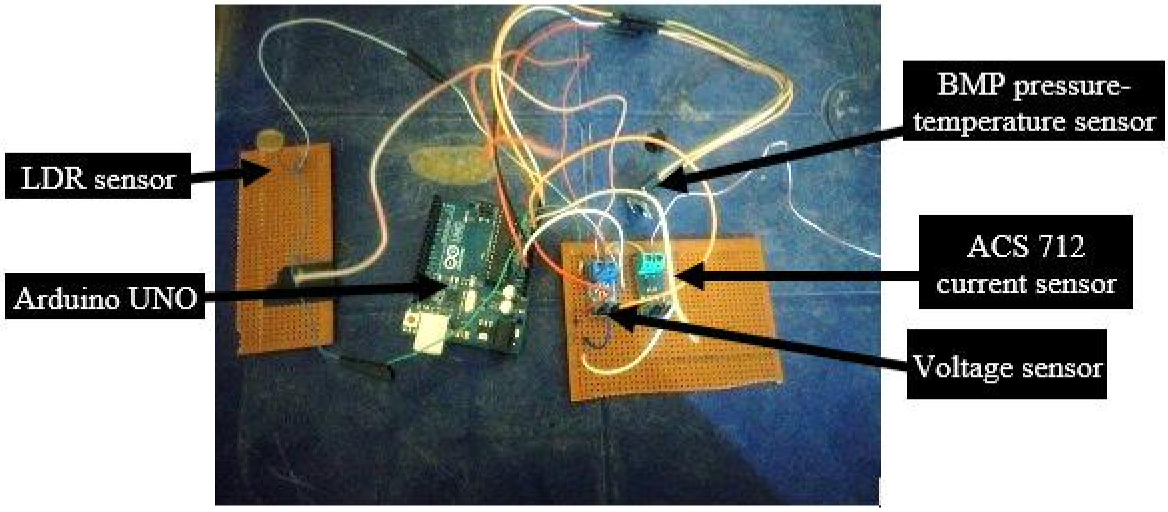

Fig. 10: Constructed solar PV parameter-measuring system

After the circuit construction, the measuring system was tested with a mono-crystalline 20W solar panel and 10W DC bulb as load. The test was conducted outdoor for few days and the values of the voltage, current, light intensity, temperature and pressure were all logged into a computer. To confirm the accuracy of the constructed measuring device, a comparative measurement was also taken by using standard multimeter (ANENG AN8002) for current and voltage measurement and also the temperature measurement using the multimeter since it has thermocouple probe. The constructed measurement values and that of the standard instrument shows good similarity. The field experimental setup is shown in Figure 11 together with the PC for data logging.

The testing was conducted on the 19th, 20th, 21st of June 2019 at University of Ilorin, Faculty of Engineering and Technology. The readings were taken from 7:00am to 6:00pm daily for each of the testing days.

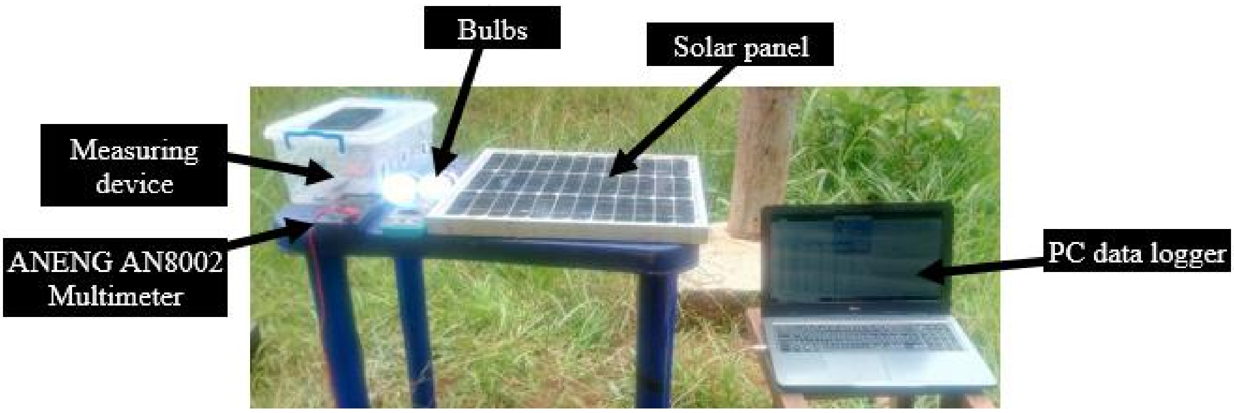

Figure 11: Field testing of measuring system

The solar PV panel was placed in horizontal positions throughout the three days test period in which the readings were logged to PC. It was well positioned to ensure that the solar panel was not affected by shading and surface was kept clean at all times to avoid errors in the readings. The results for voltage, current, light intensity, temperate and pressure were presented. The results were recorded on the 19th, 20th and 21st of June, 2019 between 7:00am to 6:00pm daily.

3.0 Results and Discussion

3.1 Voltage and Light Intensity Measurement

The results of voltage and light intensity against the hours of the day for the solar PV panel are presented in Figures 12, 13 and 14, respectively. The highest voltage for 19th of June, 2019 was 17.44V at 3.00pm with light intensity of 1014.5lux and the lowest voltage was 9.21V at 7.00am with light intensity of 990.5lux. The highest voltage for 20th of June, 2019 was 13.79V at 12.00 noon with light intensity 1010.25lux and the lowest voltage was 9.28V at 7.00am with light intensity 1000lux. The highest voltage for 21st of June,2019 was 18.54V at 12.00pm with light intensity 1016lux and the lowest voltage was 10.16V at 7.00am with light intensity of 1000.5lux. As observed from the graphs, there is direct relationship between the light intensity and the solar panel output voltage.

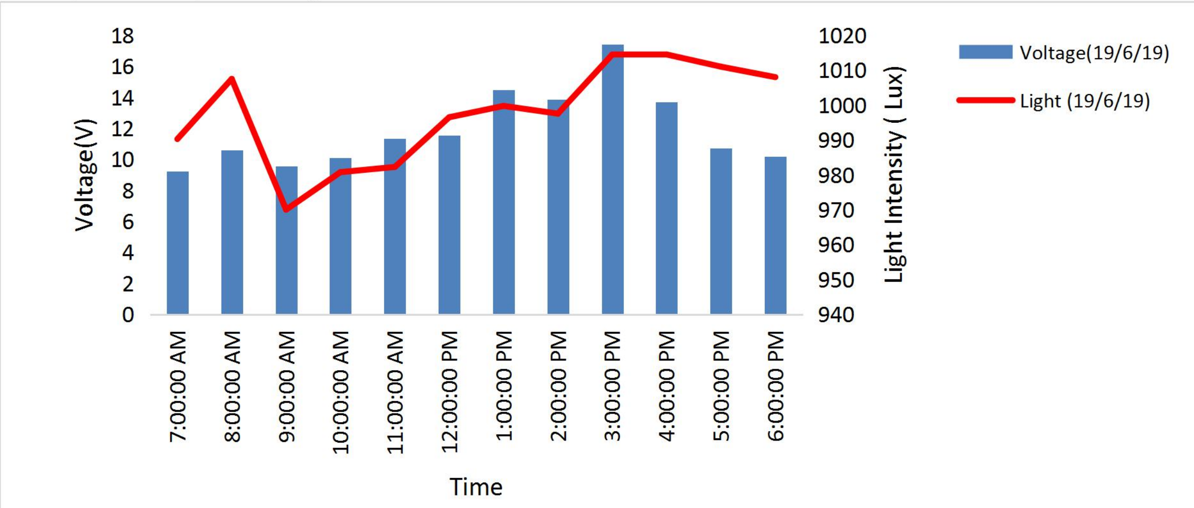

Figure 12: Graph of voltage and light intensity against time for day 1.

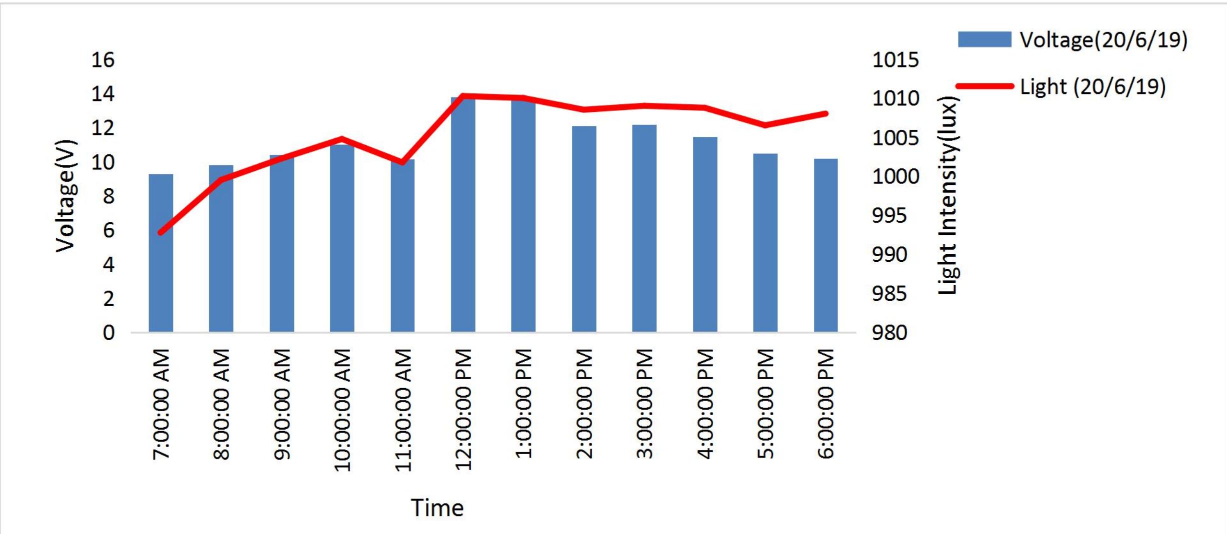

Figure 13: Graph of voltage and light intensity against time for day 2.

Corresponding author's e-mail address: reacholaibrahim@gmail.com

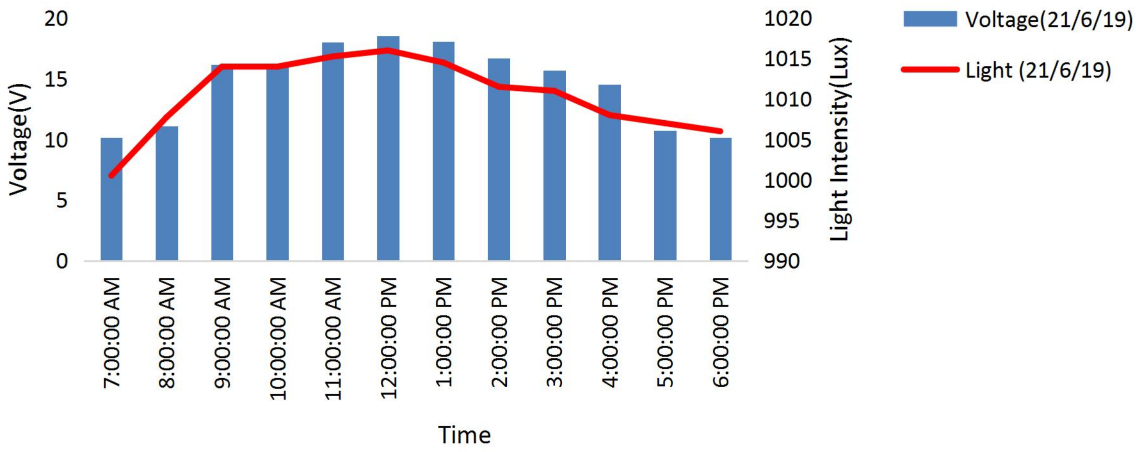

Figure 14: Graph of voltage and light intensity against time for day 3.

Figure 15 presented a comparison of light intensity for the three days, from the bar chart shows that highest light intensity of 1016lux was recorded at 12.00 pm on the 21st of June while the lowest light intensity was 960.75 lux at 10am on the 19th of June 2019.

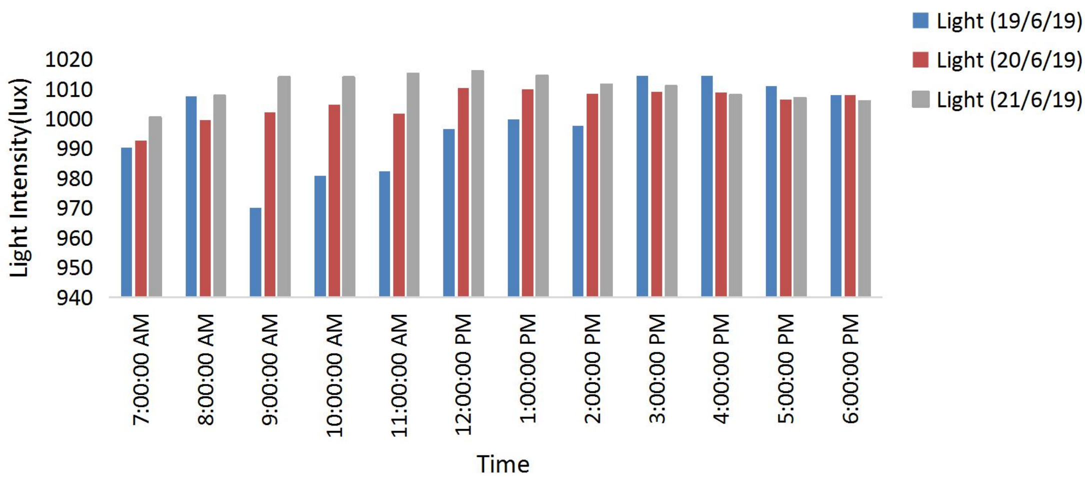

Figure 15: Graph of light intensity against time

3.2 Temperature and Pressure Measurement

The three days result of the ambient temperature and pressure around the solar PV panel are presented in Figures 16, 17 and 18. The highest pressure and temperature recorded for 19th of June, 2019 were 976.09Pa and 32.71°C respectively at 3.00pm and the lowest pressure and temperature were 971.35 Pa and 23.89°C at 7.00am. The highest pressure and temperature for 20th of June, 2019 were 976.96Pa, 30.91°C respectively at 1.00pm and lowest pressure and temperature were 971.37 Pa and 24.19°C at 6.00pm. The highest pressure and temperature for 21st of June, 2019 were 975.97Pa, 33.41°C at11.00am. The lowest recorded pressure and temperature for the day were 971.35 Pa and 23.9°C t at 7am. It can be seen from the pressure-temperature graphs that the air pressure is directly proportional to the air temperature.

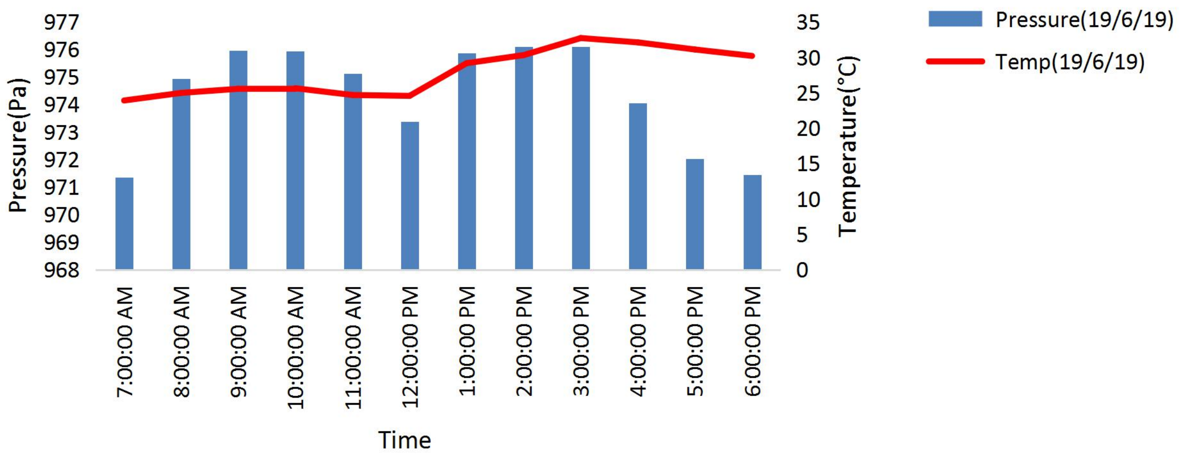

Figure 16: Pressure and temperature against time day 1

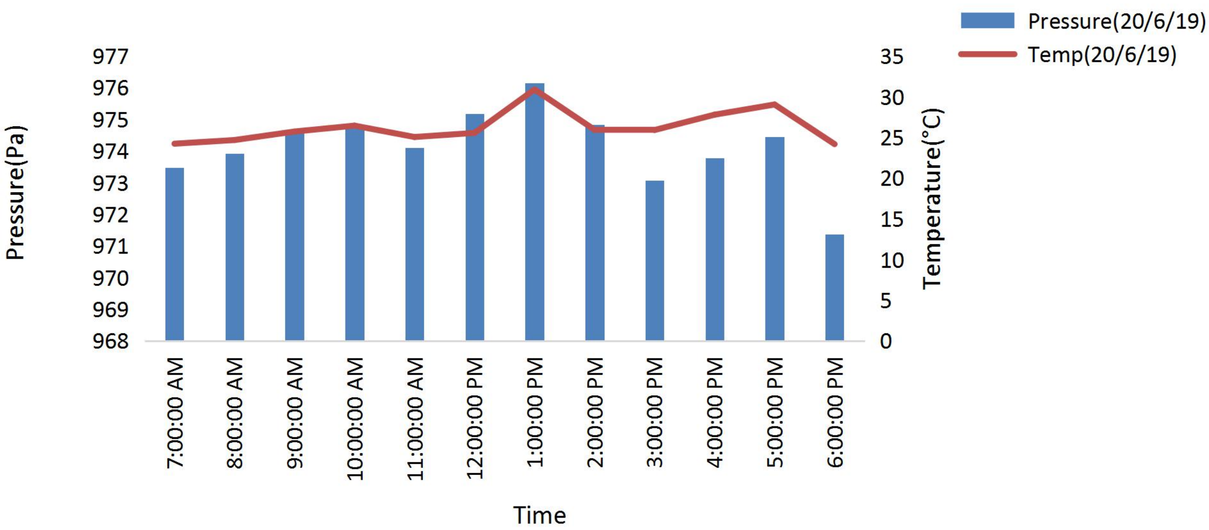

Figure 17: Pressure and temperature against time day 2

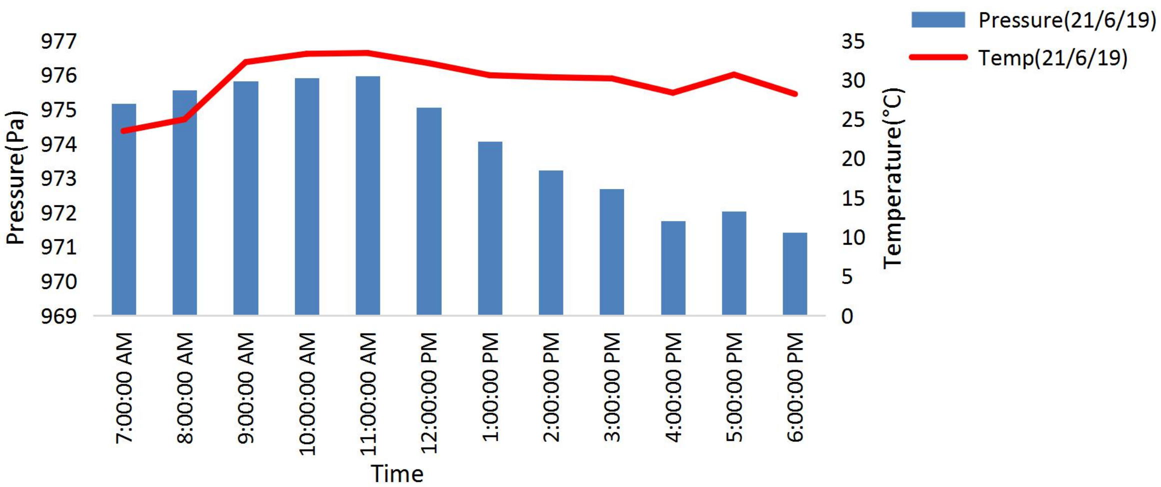

Figure 18: Pressure and temperature against time for day 3

3.3 Solar PV Panel Output Power

The result of the power generated by the solar panel is shown in Figure 19. The result pattern shows that the output power depends directly on the solar panel voltage, light intensity and the temperature. The solar panel highest power of 7.5W was recorded on the 21st of June when the day was brightest with moderately low temperature of 33.31°C at 11.00pm while the lowest power was 0.48W at 7.00am on the 19th of June 2019.

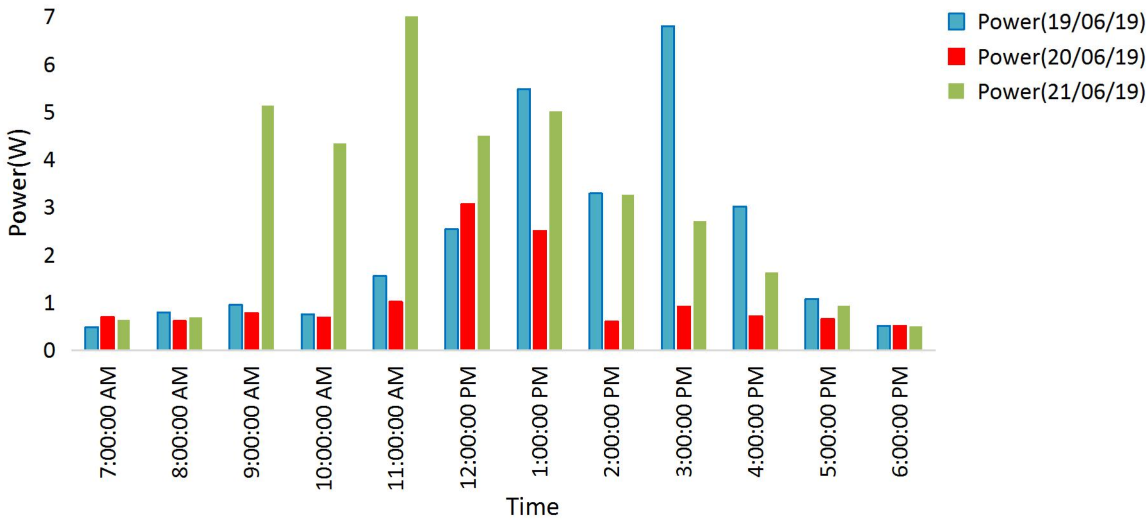

Fig. 19: Solar panel output power against time.

4.0 Conclusion

An Arduino based solar power parameter-measuring system has been designed and constructed using the optimized simulated parameter from Proteus ISIS. This device was then used to acquire solar PV current, voltage, power, temperature, pressure and light intensity. The system can measure data from solar panel that can be used to evaluate the performance of solar energy generated for future energy generation prediction. Based on the measurement data, it was observed that the solar PV energy generation directly depends on the solar irradiance, temperature and air pressure.

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Corresponding author's e-mail address: reacholaibrahim@gmail.com