Investigation of the Impact of Soot on the Efficiency of Solar Panels using a Smart Intelligent Monitoring System

Marian kingsley-Amaehule, Roland Uhunmwangho, Nkolika Nwazor, Ekene S. Mbonu, and Kenneth E.Okedu‡

*Department of Electrical and Electronic Engineering, University of Port Harcourt, 5325, Choba, Rivers State, Nigeria

** Department of Mechatronics Engineering, Federal University of Technology Owerri, P. M. B 1526, Imo State, Nigeria

***Department of Electrical and Electronic Engineering, Nisantasi University, Istanbul 25370, Turkey

(mkingsleyamaehule@gmail.com, roland.uhunmwangho@uniport.edu.ng, nkolika.nwazor@uniport.edu.ng, Ekene.Mbonu@futo.edu.ng, Kenneth.okedu@uniport.edu.ng)

‡ Corresponding Author; Kenneth E. Okedu, University of Port Harcourt Nigeria Kenneth.okedu@uniport.edu.ng

Received: 07.02.2023 Accepted: 10.03.2023

Abstract- Globally there has been an increase in the rate of acceptance of solar Photovoltaic (PV) systems because they are a source of green energy and contribute significantly to the reduction of global warming. Regardless, there are environmental factors that affect the efficiency of the solar PV systems in different parts of the world. Rivers state located in southern Nigeria is dealing with air pollution and a high level of soot production as a result of the proliferation of illegal refineries. The presence of soot has had a significant negative impact on the environment. The cost of maintaining solar PV systems has risen. This work focuses on determining the impact of soot on solar panels with the goal of increasing the efficiency of power generated in Rivers State Nigeria using smart intelligent monitoring system which involved using (Internet of Things) IOT edge to cloud analytics. The work consists of analysing data collected at the cloud level under two conditions: soot free and soot polluted condition to determine the effect of soot on the panel temperature of the solar photovoltaic system. A comparison of the two reveals that the temperature of the solar panel under sooty condition is higher than that under a soot free condition. The presence of soot reduces solar panel output 27.8%. as a result, PV systems installed in such environment will require more frequent maintenance than counterparts installed in non-sooty environments.

Keywords: Soot, Solar PV Systems, Temperature, Real-time Monitoring, Fog and cloud, algorithm

1. Introduction

The solar panel is the fundamental component and the beating heart of the solar PV system used to harness solar energy. A solar module is made up of linked cells mounted on a frame, whereas an array is made up of multiple modules linked together. It is the component responsible for capturing solar energy and converting it into an alternating current and voltage signal [1]. A photovoltaic system has a typical lifespan of 25 years [2]. However, the efficiency and lifespan of a solar panel can be affected by a variety of factors, including the module's quality, tilt-angle, fill factor, material deterioration, shading, soiling, parasitic resistances, and other significant parameters, to name a few [3]. Because efficiency levels vary depending on weather conditions, the location and surrounding areas can have a negative environmental impact on the solar panel [4]. Rivers State, for example, which accounts for roughly 60% of Nigeria's crude oil production output, has recently seen visible soot fallout. Soot is a dark, powdery substance composed primarily of amorphous carbon produced by the incomplete combustion of organic matter. This is due to the fact that artisanal refining of crude oil (small-scale, uncontrolled burning of hydrocarbons to produce petrol, diesel, and kerosene) has been shown to have negative environmental effects due to the emission of carbon dioxide, methane, and other gases, which results in soot [5]. The soot particle is 2.5 microns in size, according to experts, and can only be seen with a powerful microscopic lens. Enclosed spaces where these particles could enter through the air include homes, classrooms, places of worship, and workplaces. This soot cannot be easily washed away like regular dust. This has created an environmental challenge for Rivers State residents, and the efficiency of solar panels has suffered as a result.

Types of solar panels

There are various types of solar panels on the market today, each with its own design and efficiency. Solar cells are the building blocks of solar panels. One solar panel contains approximately 35 solar cells. The small amount of energy produced by each solar cell combined yields enough energy to charge a 12-volt battery. When comparing solar panels, the wattages of the output (determined by multiplying the total volts and amps of the solar module), power output, and total capacity must all be considered. The amount of output produced depends on where you live (number of sun hours), the ambient temperature, and the efficiency rating [6]. The wattage represents the panel's anticipated or expected power output under ideal sunlight and temperature conditions. Typical module power ratings range from 250 to 400 watts [6]. Higher wattages have a higher efficiency rating and require fewer modules to meet the ideal energy requirements. As a result, two factors must be considered when determining the efficiency of a solar panel. The first factor to consider is panel efficiency, which is determined by the design and silicon type, cell layout and configuration, and size of the solar panel. The maximum power rating under standard test conditions (STC) is divided by the total area of the panels to calculate cell efficiency (in meters). [6]

The three major types of solar panels that are widely available in the world are shown in Fig. 1 [7]. They are monocrystalline solar panels, polycrystalline solar panels, and thin-film solar panels.

Monocrystalline solar panels, also known as single-crystalline silicon panels, are created by growing a single crystal of silicon with a high purity rate, increasing their efficiency to 17-23%. They take up less space than polycrystalline and thin-film panels and can last up to 25 years due to the constant and inert nature of silicon. Monocrystalline solar panels are frequently recommended as the most efficient option and work best for larger energy systems in commercial and residential buildings. Despite this, because panel sizes vary, monocrystalline can be used in smaller systems. However, due to their intricate construction, their prices are significantly higher, and they are not suitable for regions with harsh winters because snowfall could damage the solar cells and cause system failure. Nonetheless, it works perfectly in Nigeria. [6]

Polycrystalline solar panels, on the other hand, are rectangular with no rounded edges and have a grainy, blue-coated appearance due to the imperfect crystal structure of their cells. As the name implies, they are made by melting many lower purity silicon crystals together, making them less efficient than monocrystalline cells with an efficiency rate of 13% to 17%, and they also take up more space to generate the same amount of power as monocrystalline cells. They are less expensive than monocrystalline panels, however, because the manufacturing process is simpler and produces less waste after the melting process, making them more environmentally friendly. Polycrystalline solar panels, like monocrystalline panels, are long-lasting and durable, making them an excellent choice for frugal homeowners. [6]

Thin-film solar panels are lightweight, portable, and have a low efficiency (between 7 and 13%), so they are only used in installations and appliances that do not require a lot of power. Their main advantages are portability and flexibility. They are also less expensive and simpler to manufacture. They are, however, a poor choice for rooftops because they require a large space to harness solar radiation and generate energy output. [6]. Amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIS/CIGS) are the three types.

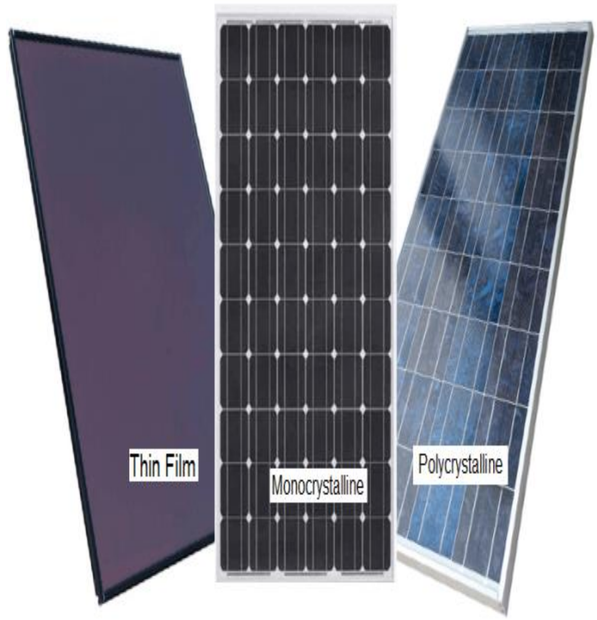


Fig. 1. Three Major Types of Solar Panel [8]

Some authors have studied the effect of environmental impact on the efficiency level of solar panels in the literature. [9] evaluated the effects of weather conditions, particularly solar radiation, and temperature on the outputs of photovoltaic cells installed at a university of technology east of Baghdad. As a result, a high intensity of solar radiation increases the amount of electricity generated but also raises the temperature, which reduces the panel's productivity. As a result, the author concluded that the temperature of the photovoltaic panels has a significant impact on the performance of PV systems, implying that a high temperature degrades the power output. Similarly, the authors [10] investigated the effect of photovoltaic panel temperature on this effective solar energy conversion power in real-world conditions relevant to the Sri Lankan context. Solar insolation, output current, output voltage, panel temperature, and photovoltaic panel efficiency are all shown to have a direct correlation in the data. The experimental results suggest that, in a steady-state regulated environment, the voltage level, current, and power of such a solar panel may decrease over time as its temperature rises. As a result, the solar module's efficiency will gradually decline.

[11]investigated empirically the effect of black soot on the performance of photovoltaic systems. Their experiment revealed that the accumulation of soot on the PV panels reduced the average PV efficiency by 12%. Another study [12]investigated the effect of dust accumulation on the performance efficiency of photovoltaic modules in Sokoto State, Nigeria's northern region. Two solar panels were tested, one in an outdoor environment to collect natural dust and the other in a dust-free environment.

The results show that dust accumulation on the solar panels reduces the overall performance of the solar module and increases energy loss, particularly in the high-rate dusty region with a low frequency of rain. To investigate the impact of dust accumulation on the performance of PV modules under Cairo climate conditions, the authors [13] installed five modules on the same mechanical structure and ran them simultaneously at the same operating condition with different cleaning scenarios for the months in the summer season. The results showed that the immediate power output of the modules decreased in direct proportion to the amount of dust collected. An examination of recent studies on the effect of operational and environmental parameters on solar energy performance. The paper [14] provided an analysis of recent studies discussing the impact of operational and environmental parameters on the performance of solar PV cells.

Temperature and humidity, as well as dust distribution and soiling effects, were discovered to have a significant impact on the performance of PV modules. [15]investigated the effects of changing solar radiation and rising temperatures on the overall performance of solar panels in their research. The experimental results demonstrated that temperature and solar radiation variations have a significant impact on how the characteristics of the PV panel react in real-world operating conditions as opposed to standard test conditions (STC). [16] conducted research on the effect of coal dust deposition on PV panel output response as part of their effort to aid in the efficient use of solar energy in mining industries. The obtained results revealed a significant loss in PV panel output power due to coal dust deposition on its surface. This research discovered a mathematical relationship between the mass of coal dust deposition and the output power of the panel. With a Pearson's correlation coefficient of -0.97712 and an excellent coefficient of correlation of 0.94974, the proposed model demonstrated a significant negative correlation.

After determining that the presence of dust and environmental pollution is a factor that influences the output performance of solar panels, the authors [17] worked on developing a method of protecting solar panels against dust pollution in northern parts of the Russian Far East that can also be applied to other parts of the world because increasing the energy efficiency of solar panels is a global concern. Their paper proposed a specific type of chemical material that shields the surface of solar panels from dust pollution, thereby improving the efficiency or performance of solar PV panels. [18] conducted research that resulted in the design and implementation of dust-cleaning equipment for solar panels in an effort to develop a cleaning solution that is critical to improving solar panel efficiency. The paper followed a logical flow, beginning with design specifications, progressing to significant design choices, and finally prototyping the proposed solution to the dust soiling problem, a combination of dry and wet brush-based cleaning strategies. The use of such a dust-cleaning system for solar panels improves panel performance, reduces maintenance costs, and eliminates the risks associated with manually cleaning solar panels.

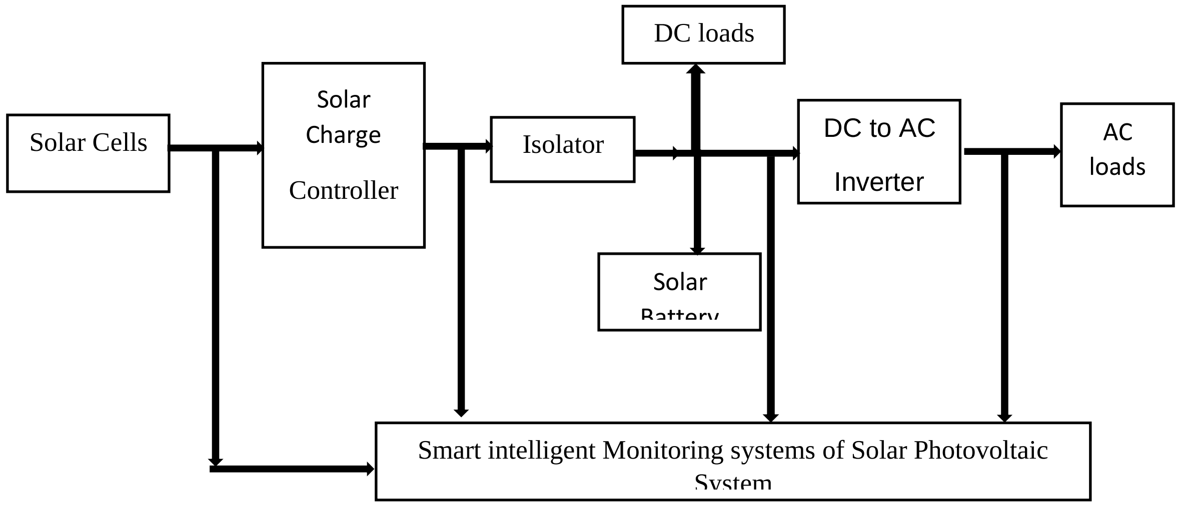
There may be other studies similar to this one being conducted elsewhere; however, they are focused on conditions in other countries rather than the weather in Port Harcourt, Rivers State, Nigeria. There are no previous local or international studies that the researchers are aware of that are comparable to this one. The level of soot in Port Harcourt, Rivers State [19] [20] is a global concern for environmental pollution. Because Port Harcourt is surrounded by cement ash plants, oil companies, refineries, oil servicing firms, and other chemical businesses and activities, its impact on PV modules cannot be overlooked.

As part of an ongoing research project, this paper investigated the effect of soot on solar PV systems in Rivers State, Nigeria, using Smart Intelligent Monitoring and Maintenance Management of Photovoltaic Systems (SIMMM-PVS), developed in [21]. The authors of [21] proposed a smart intelligent model (SIM) for monitoring and maintenance of stand-alone PV systems in their methodology. The following section provides a brief review of [21]

Review of Smart Intelligent Monitoring System for PVS

It would be necessary to review previous work published as ongoing PhD research in order to have a proper flow of understanding of this work. Fig. 2 depicts the SIMMM-PVS architecture, while Fig. 3 depicts the complete implementation diagram. The authors of [21] developed mathematical models that characterised the parameters of a typical PVS first, before developing the algorithms used to measure the parameters and transmit them to the Thingspeak server [22], while storing the transmitted results in a Google Excel sheet for further analysis.

Figure 5 depicts the experimental setup for data collection in [21] six sets of data were collected: the solar panel's temperature and voltage output, the charge controller's output and input voltage, and the inverter's battery voltage and frequency. The SIMMM-PVS response to solar panel temperature during the day is shown in Fig. 6, and the system response to solar panel temperature during the night is shown in Fig. 7. Fig. 8 depicts the inverter frequency response, while Fig. 9. depicts the response to both solar panel voltage and battery voltage. The primary goal of [21] is to design and validate a smart monitoring system capable of wirelessly measuring and transmitting PVS parameters to the cloud for further analysis. The authors accomplished their goal. They did not, however, use the developed system to investigate the effect of soot on the performance of PVS. Furthermore, the experiment was conducted in Anambra State, Nigeria, where there is no soot.



. Architecture for Smart Intelliegent Monitoring and Maintenance Management of Photo-Voltaic Systems (SIMMM-PVS) [21]

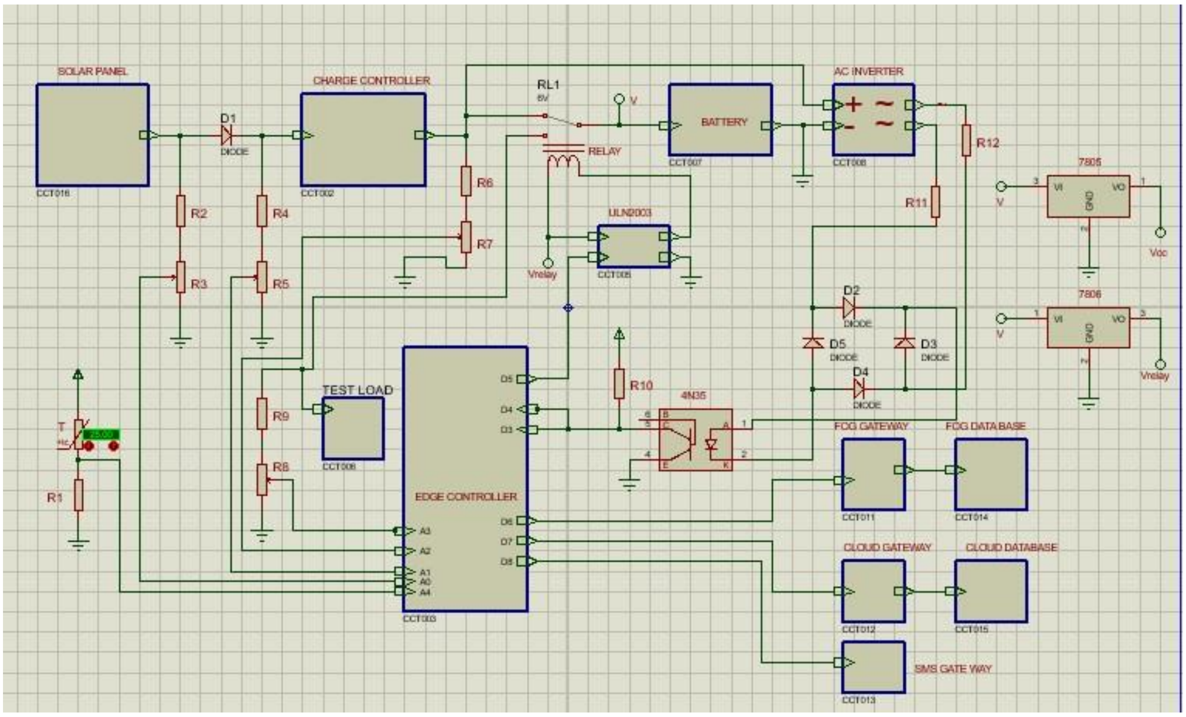


Fig. 3. System Design Diagram of SIMMM-PVS [21]

Fig. 4. Experimental setup for data collection using SIMMM-PVS **without soot** In Akwa, Anambra state.

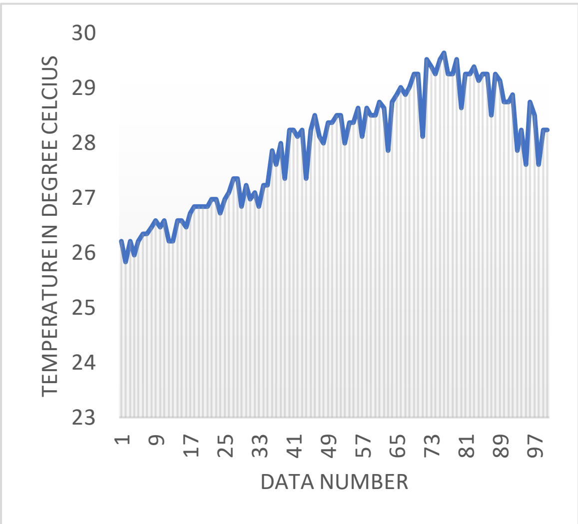


Fig. 5. SIMMM-PVS response to solar panel temperature during the day **[21]**

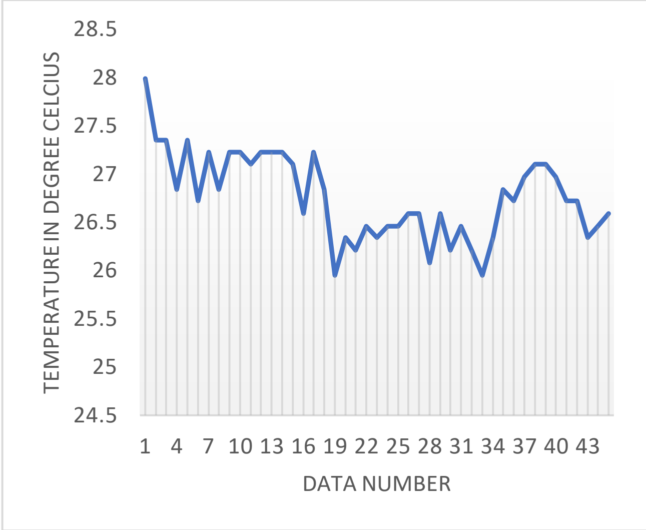


Fig. 6. SIMMM-PVS response to solar panel temperature during the night **[21]**

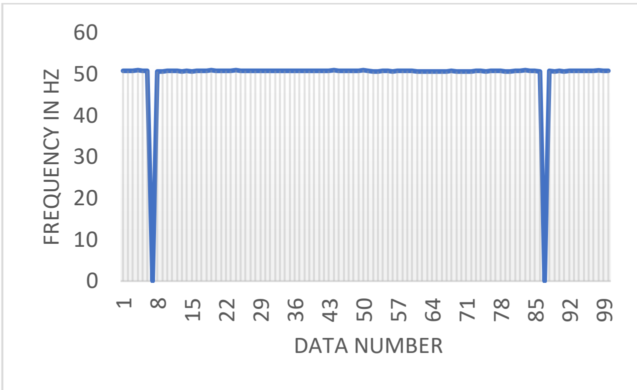


Fig. 7. SIMMM-PVS response the inverter frequency **[21]**

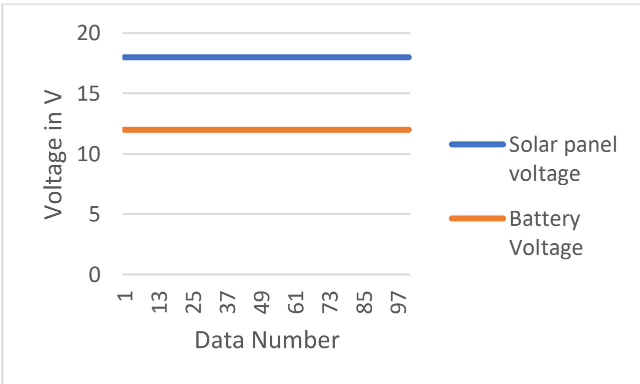


Fig. 8. SIMMM-PVS **r**esponse to both solar panel voltage and battery voltage

2. Methodology

SIMMM-PVS was used in this study to investigate the impact of soot on the efficiency of solar panels in Port Harcourt, Rivers State, Nigeria. To begin, the generic algorithms developed in [21] were given unique addresses and labels in order to upload data to a user-defined Google Sheet address. Following that, as shown in Fig. 10, a soot-affected solar panel was connected to the system, and PVS parameters were measured and sent to the Google data sheet for further analysis. Finally, data collected in Anambra State under soot-free conditions was compared to data collected in Rivers State, Nigeria, under sooty conditions, to determine the impact of soot on solar panel efficiency.

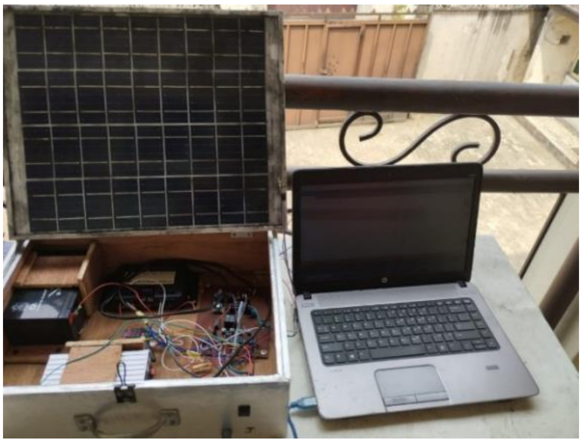


Fig. 10. Experimental setup of the Smart intelligent monitoring system **under soot condition** in Port Harcourt Rivers State, Nigeria

Characterisation of the Test Bed

Algorthm is used to characterised the testbed

Algorithm 1: The test bed Characterization and Setup Algorithm [21]

Input: *Testbed physical addresses, pin numbers, data range, and data type*

Output: *mode classification of Testbed physical addresses, pin numbers, range of data*

SoftwareSerial gprsSerial(physical address of GPRS_modem);

Datatype solar panel_route_address = address _number;

Datatype charge controller_route_address = address _number;

Data_type battery_route_address = address _number;

Data_type battery_route_address = address _number;

Datatype inverter_route_address = address _number;

Datatype GPRS_route_address = address _number.

Data_type solar _data label and range.

Datatype chargecontroller_data_labe and rangel.

Data_type battery_data_label and range;

Datatype inverter_data_label and range.

void setup ()

{gprsSerial.begin(data_baudrate).

pin Mode (solar_route_address, state_mode).

pin Mode (chargecontroller_route_address, state_mode).

pin Mode (battery_route_address, state_mode).

pin Mode (inverter_route_address state_mode).

}

Software Implementation of Algorithm 1.

ATMEG328 microcontroller was used to implement algorithm 1. Arduino integrated development environment (IDE) was used to develop the embedded c codes used in implementing the algorithm as shown below.

```
#include <SoftwareSerial.h>

Software Serial gprsSerial (9,10).

 #include <String.h>

String message.

const int Solar = A0;// Analogue input address of solar panel

const int Charge_controller_input = A1;// Analogue input address of charge controller

const int Charge_controller_output = A2;// Analogue input address of charge controller address

const int Battery = A3;// Analogue input address of battery

const int Panel_Temp = A4;// Analogue input address of temperature sensor mounted on solar panel
```

```
int frequency = 3;// pin address of inverter frequency

//variable declarations:

int n = 0.

 float s ;// solar input

 float c1; //charge controller input

 float c2; //charge controller output

 float b; //battery level

 float t ;// solar panel temperature

 float i;// inverter frequency

 int high time.

int low time.

float time_period.

float Inverter_frequency.

void setup ()

{gprsSerial.begin(9600); // the GPRS baud rate.

 Serial.begin(9600); // the microcontroller baud rate

pin Mode (frequency, INPUT).

}
```

Algorithm II: Sensor reading Algorithm [21]

Below is the universal sensor reading algorithm that was presented in [19]. It is used in this work to develop embedded c codes for sensor reading

Input: *Sensor Physical address*

Output: *sensor real data value*

For (sensor_address=0; sensor_address<4; sensor_address++)

{*Datatype sensor_value = analogRead(sensor_address****).***

Data_type sensor_real_value **=** ***(****sensor value* *******maximum ADC voltage****)****/adc_resolution****.***

sensor real data value **=** *map (sensor value, R1, R2, M1, M2);*

// M1 is the minimum rated value the sensor can read)

// M2 is the maximum rated value the sensor can read)

// R1 is the actual reading of the sensor in the absence of test signal)

// R2 is the actual reading of the sensor when subjected to the maximum concentration of the //test signal)

Measure frequency.

}

Software Implementation of Algorithm 2.

```
//get input variables

//measure solar voltage

  float Solar Value = analogRead (Solar).

  float RealSolarValue = (Solar Value*5)/1024;//scale down to 5v

  s = map (RealSolarValue, 0, 2.50, 0, 18.00); //Map it to the right scale

 float C_ControllerInputValue= analog Read (Charge_controller_input).

  float RealC_ControllerInputValue = (C_ControllerInputValue*5)/1024.

  c1 = map (RealC_ControllerInputValue, 0, 2.50, 0, 18.00); //Map it to the right scale

   float C_ControllerOutputValue = analog Read (Charge_controller_output).

  float RealC_ControllerOutputValue = (C_ControllerOutputValue*5)/1024.

  c2 = map(RealC_ControllerOutputValue, 0, 2.50, 0, 18.00); //Map it to the right scale

 float Battery Value = analogRead (Battery).

  float RealBatteryValue = (Battery Value*5)/1024.

  b = map(RealBatteryValue, 0, 2.50, 0, 13.00); //Map it to the right scale

float TempLevel = analog Read(Panel_Temp); //Read in temperature level

// Measure Frequency

high time=pulse in (frequency, HIGH).

low time=pulse in (frequency, LOW).

time_period=high_time+low_time.
```

time_period=time_period/1000.

Inverter_frequency =1000/time_period;}

Algorithm III: *Data transmission to Remote Server Algorithm* [21]

Input: *AT command of GPRS modem, APN, and API address* of the remote server

Output: concatenated data comprising solar (temperature and voltage), charge controller, battery, and frequency levels

gprsSerial.println("set of AT_Commands for GPRS configuration");

gprsSerial.println("AT+CSTT=\"APN_address of GPRS modem\"");

gprsSerial.println("AT+CIPSTART=\"TCP\",\" APN_address of remote server\",\"port_number of the server\"");

String str="GET https://api.thingspeak.com/update?api_key=API_address_of_the_server&field1=" + String(solar_level) +"&field2="+String (charge controller level) +"&field3="+String(battery level) +"&field4="+String(frequency_level);

Serial.println(str).

gprsSerial.println(str).

Implementation of Algorithm III

The C codes listed below were used to implement algorithm III. The API address of the online server is CN8J0L0CV9PESFNI.

gprsSerial.println("AT+CSTT=\"airtelgprs.com\"") ;//start task and setting the APN,

gprsSerial.println("AT+CIICR") ;//bring up wireless connection.

gprsSerial.println("AT+CIFSR") ;//get local IP address.

gprsSerial.println("AT+CIPSPRT=0").

gprsSerial.println("AT+CIPSTART=\"TCP\",\"api.thingspeak.com\",\"80\"");//start up the connection

gprsSerial.println("AT+CIPSEND");//begin send data to remote server

String str="GET https://api.thingspeak.com/update?api_key=CN8J0L0CV9PESFNI&field1=" + String(s) +"&field2="+String(c1) +"&field3="+String(c2) +"&field4="+String(b)+"&field5="+String(t)+"&field6="+String(i);

gprsSerial.println(str);//begin send data to remote server

gprsSerial.println((char)26) ;//sending data.

gprsSerial.println("AT+CIPSHUT") ;//close the connection.

}

3. Results

Table 1 displays cloud data collected in Port Harcourt, Rivers State, Nigeria, during sooty conditions. A total of 45 samples were collected from six distinct data sets, including solar panel voltage (field 1), charge controller input voltage (field 2), charge controller output voltage (field 3), battery voltage (field 4), solar panel temperature (field 5), and inverter frequency (field 6). Table 1 also includes the time stamps of the data as recorded by the cloud server. Figure 11 is the graph of the six data collected under soot condition. Table 2 shows the SIMMM-PVS data collected in Anambra State under normal conditions. Same 45 samples were collected from six distinct data sets.

Table 1. Cloud data collected during soot polluted weather condition in Port Harcourt, Rivers State Nigeria

Created at	**Data_id**	**field1 (Panel Voltage)**	**field2 (CC input)**	**field3 (CC output)**	**field4 (Battery Voltage)**	**field5 (Panel Temp)**	**field6 (Inverter Frequency)**
2022-03-21T12:12:59+00:00	1	13	13	13	12	30.79	50.86
2022-03-21T12:15:14+00:00	2	13	13	13	12	31.42	50.86
2022-03-21T12:17:30+00:00	3	13	13	13	12	31.17	50.92
2022-03-21T12:22:01+00:00	4	13	13	13	12	31.81	50.93
2022-03-21T12:24:17+00:00	5	13	13	13	12	31.68	50.97
2022-03-21T12:28:57+00:00	6	13	13	13	12	31.93	51.03
2022-03-21T12:33:28+00:00	7	13	13	13	12	32.06	50.95
2022-03-21T12:35:52+00:00	8	13	13	13	12	32.06	51.03
2022-03-21T12:38:16+00:00	9	13	13	13	12	32.19	51.02
2022-03-21T12:40:31+00:00	10	13	13	13	12	32.19	50.95
2022-03-21T12:42:55+00:00	11	13	13	13	12	32.06	51.09
2022-03-21T12:45:11+00:00	12	13	13	13	12	31.93	51
2022-03-21T12:47:35+00:00	13	13	13	13	12	32.19	51.05
2022-03-21T12:49:59+00:00	14	13	13	13	12	32.19	51.06
2022-03-21T12:52:22+00:00	15	13	13	13	12	32.32	51.02
2022-03-21T12:54:46+00:00	16	13	13	13	12	32.44	51.03
2022-03-21T12:57:10+00:00	17	13	13	13	12	32.44	51.03
2022-03-21T12:59:34+00:00	18	13	13	13	12	32.19	51.03
2022-03-21T13:01:58+00:00	19	13	13	13	12	32.44	51.09
2022-03-21T13:04:22+00:00	20	13	13	13	12	32.57	51.14
2022-03-21T13:09:09+00:00	21	13	13	13	12	32.7	51.16
2022-03-21T13:18:45+00:00	22	13	13	13	12	32.95	51.05
2022-03-21T13:22:10+00:00	23	13	13	13	12	33.08	50.09
2022-03-21T13:24:26+00:00	24	13	13	13	12	32.82	50.1
2022-03-21T13:26:41+00:00	25	13	13	13	12	32.82	50.11
2022-03-21T13:28:57+00:00	26	13	13	13	12	32.7	50.14
2022-03-21T13:31:13+00:00	27	13	13	13	12	32.95	50.12
2022-03-21T13:33:29+00:00	28	13	13	13	12	32.57	50.22
2022-03-21T13:35:45+00:00	29	13	13	13	12	32.7	50.26
2022-03-21T13:42:31+00:00	30	13	13	13	12	33.08	50.17
2022-03-21T13:49:18+00:00	31	13	13	13	12	32.7	50.15
2022-03-21T13:51:34+00:00	32	13	13	13	12	33.08	50.21
2022-03-21T13:58:21+00:00	33	13	13	13	12	32.95	50.23
2022-03-21T14:00:37+00:00	34	13	13	13	12	32.82	50.12
2022-03-21T14:02:52+00:00	35	13	13	13	12	33.08	50.17
2022-03-21T14:05:08+00:00	36	13	13	13	12	33.21	50.2
2022-03-21T14:14:10+00:00	37	13	13	13	12	33.08	50.33
2022-03-21T14:16:26+00:00	38	13	13	13	12	33.59	50.15
2022-03-21T14:18:42+00:00	39	13	13	13	12	33.59	50.16
2022-03-21T14:23:13+00:00	40	13	13	13	12	33.72	50.16
2022-03-21T14:25:29+00:00	41	13	13	13	12	33.46	50.19
2022-03-21T14:27:45+00:00	42	13	13	13	12	33.33	50.13
2022-03-21T14:30:01+00:00	43	13	13	13	12	33.33	50.25
2022-03-21T14:32:16+00:00	44	13	13	13	12	33.08	50.23
2022-03-21T14:34:32+00:00	45	13	13	13	12	32.95	50.12

Table 2. Cloud data collected during normal weather condition at Awka, Anambra State, Nigeria

Created at	**Data_id**	**field1 (Panel Voltage)**	**field2 (CC input)**	**field3 (CC output)**	**field4 (Battery Voltage)**	**field5 (Panel Temp)**	**field6 (Inverter Frequency)**
2021-12-21T08:58:24+00:00	1	18	18	18	12	26.21	50.85
2021-12-21T09:02:55+00:00	2	18	18	18	12	25.83	50.83
2021-12-21T09:06:43+00:00	3	18	18	18	12	26.21	50.79
2021-12-21T09:08:59+00:00	4	18	18	18	12	25.95	50.9
2021-12-21T09:11:14+00:00	5	18	18	18	12	26.21	50.83
2021-12-21T09:13:27+00:00	6	18	18	18	12	26.34	50.88
2021-12-21T09:15:52+00:00	7	18	18	18	12	26.34	INF
2021-12-21T09:18:08+00:00	8	18	18	18	12	26.46	50.72
2021-12-21T09:20:23+00:00	9	18	18	18	12	26.59	50.72
2021-12-21T09:22:39+00:00	10	18	18	18	12	26.46	50.73
2021-12-21T09:24:55+00:00	11	18	18	18	12	26.59	50.88
2021-12-21T09:27:10+00:00	12	18	18	18	12	26.21	50.73
2021-12-21T09:29:26+00:00	13	18	18	18	12	26.21	50.68
2021-12-21T09:31:42+00:00	14	18	18	18	12	26.59	50.73
2021-12-21T09:33:57+00:00	15	18	18	18	12	26.59	50.67
2021-12-21T09:38:29+00:00	16	18	18	18	12	26.46	50.87
2021-12-21T09:40:44+00:00	17	18	18	18	12	26.72	50.83
2021-12-21T09:47:31+00:00	18	18	18	18	12	26.84	50.84
2021-12-21T09:49:47+00:00	19	18	18	18	12	26.84	50.89
2021-12-21T09:52:03+00:00	20	18	18	18	12	26.84	50.84
2021-12-21T09:54:18+00:00	21	18	18	18	12	26.84	50.83
2021-12-21T09:56:34+00:00	22	18	18	18	12	26.97	50.85
2021-12-21T09:58:50+00:00	23	18	18	18	12	26.97	50.84
2021-12-21T10:01:05+00:00	24	18	18	18	12	26.72	50.89
2021-12-21T10:03:21+00:00	25	18	18	18	12	26.97	50.88
2021-12-21T10:05:37+00:00	26	18	18	18	12	27.1	50.84
2021-12-21T10:07:53+00:00	27	18	18	18	12	27.35	50.86
2021-12-21T10:10:08+00:00	28	18	18	18	12	27.35	50.87
2021-12-21T10:12:24+00:00	29	18	18	18	12	26.84	50.85
2021-12-21T10:15:58+00:00	30	18	18	18	12	27.23	50.84
2021-12-21T10:18:13+00:00	31	18	18	18	12	26.97	50.88
2021-12-21T10:20:29+00:00	32	18	18	18	12	27.1	50.84
2021-12-21T10:22:45+00:00	33	18	18	18	12	26.84	50.83
2021-12-21T10:25:00+00:00	34	18	18	18	12	27.23	50.83
2021-12-21T10:27:17+00:00	35	18	18	18	12	27.23	50.88
2021-12-21T10:29:32+00:00	36	18	18	18	12	27.86	50.85
2021-12-21T10:31:47+00:00	37	18	18	18	12	27.61	50.88
2021-12-21T10:34:03+00:00	38	18	18	18	12	27.99	50.83
2021-12-21T10:36:19+00:00	39	18	18	18	12	27.35	50.84
2021-12-21T10:38:34+00:00	40	18	18	18	12	28.24	50.84
2021-12-21T10:40:50+00:00	41	18	18	18	12	28.24	50.85
2021-12-21T10:43:06+00:00	42	18	18	18	12	28.12	50.88
2021-12-21T10:45:22+00:00	43	18	18	18	12	28.24	50.83
2021-12-21T10:49:53+00:00	44	18	18	18	12	27.35	50.89
2021-12-21T10:52:09+00:00	45	18	18	18	12	28.24	50.85

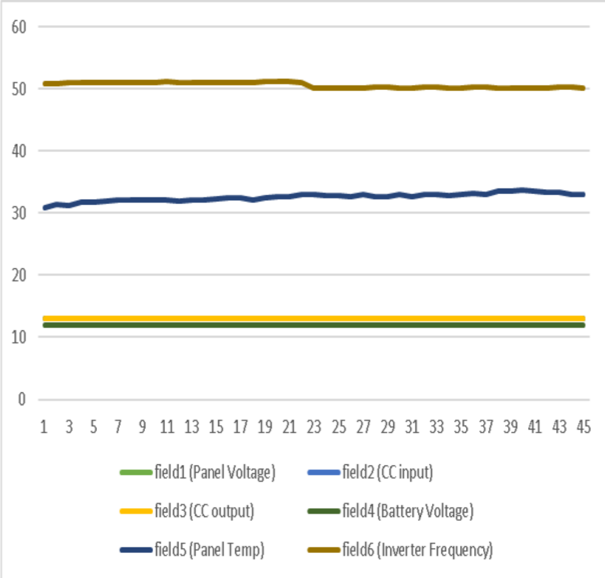


Fig. 11. Cloud Data Collected During Soot Polluted Weather Condition in Port Harcourt, Rivers State Nigeria

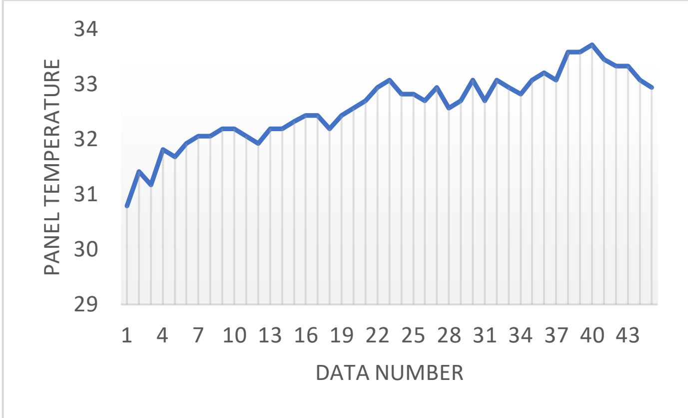


Fig. 13. Temperature Response of the Solar Panel during the day in Port Harcourt Rivers state

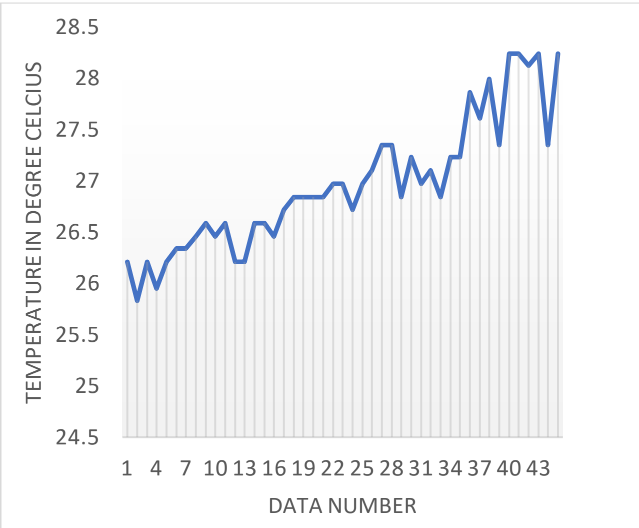


Fig. 12. Temperature Response of the Solar Panel During the Day in Akwa, Anambra State [21, 22].

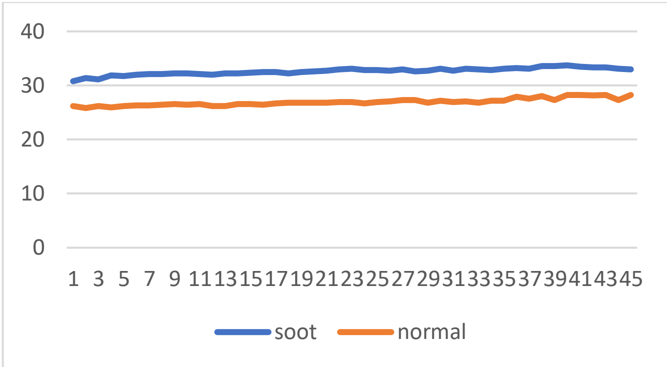


Fig. 14. Comparison of Panel Temperatures under Soot and Normal conditions

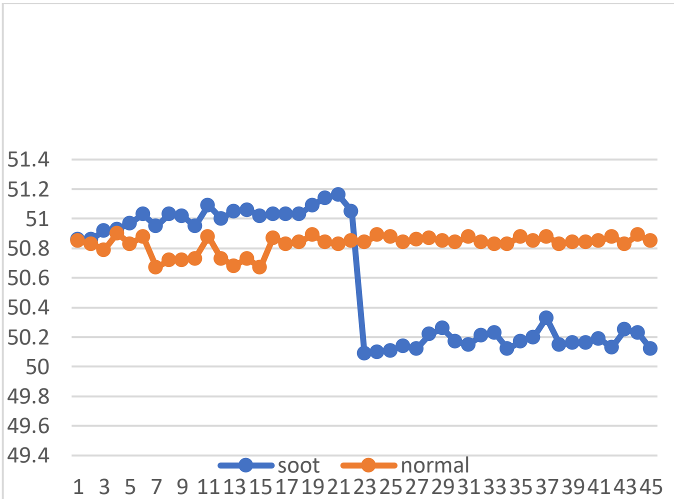


Fig.15. Comparison of Inverter's Frequency under Soot and Normal conditions

4. Discussions

Figure 12 is an excerpt from feedback data logged at the online server during the day in Akwa, Anambra State, under non-polluted atmospheric conditions, whereas Fig. 13 is an excerpt from feedback data logged at the online server via cloud in Port Harcourt, Rivers State, during the soot environment.

The 45-sample data for Fig. 12 were collected between 9 a.m. and 11 a.m., and the cloud feedback system's response to the data collected in Awka, Anambra State, was extracted and recorded. The panel output voltage was 18 volts, the charge controller input and output voltages were also 18 volts, the battery was 12 volts, the panel temperature averaged 26.96 °C, and the inverter frequency averaged 50.83 Hz. The parameters extracted indicated that the solar photovoltaic system is performing optimally, as the efficiency of the solar panel has a direct relationship with the solar voltage and temperature, as established in [t]. The panel output voltage was 18 volts, the charge controller input and output voltages were both 18 volts, the battery was 12 volts, the panel temperature was 26.96°C on average, and the inverter frequency was 50.83 Hz on average. According to the parameters mined, the solar photovoltaic system is performing optimally because the efficiency of the solar panel has a direct relationship with solar voltage and temperature, as established in [21].

Similarly, the same equipment was mounted in Port Harcourt, Rivers State, and exposed to soot-polluted atmospheric conditions for approximately 90 days, and the same smart intelligent monitoring system was linked to mine data for analysis, as shown in Fig 13. The panel voltage fell to 13 volts, causing the charge controller's input and output voltages to fall to 13 volts as well; the battery voltage remained at 12 volts; the panel temperature was found to be high, with an average of 32.59 °C; and the inverter frequency was 50.58 Hz.

The experimental results show that the voltage level, current, and power of such a solar panel may decrease over time as the temperature rises in a soot-polluted environment. As a result, the solar module's efficiency would gradually decline, and the panel's lifespan would be reduced.

The temperature of the solar panel under soot and normal conditions is shown in Fig. 14. The average temperature in normal conditions is 26.97 °C, while in sooty conditions it is 32.59 °C. This difference has significant implications not only for the efficiency of the solar panel, but also for its life span, because an increase in temperature increases heat trapping within the cells of the solar panel, reducing its expected life span. Finally, Fig. 15 compares inverter frequency under soot and normal conditions, implying that other parameters are affected. This difference is significant, but it is insignificant if it is within ±1 standard deviation.

5. Conclusion and Recommendation for Further Study

The current study discusses the effect of soot on the efficiency of solar panels using smart, intelligent monitoring systems. To obtain the results, two experimental setups were created: one of a smart intelligent monitoring system without soot in Awka, Anambra State Fig. 4 and one of a smart intelligent monitoring system with soot in Port Harcourt, Rivers State Fig. 10.

Two sets of data from different locations for about 45 samples were collected and recorded, with special attention paid to the temperature of the solar panel. The experimental study compares the two conditions and finds that the soot condition reduced solar panel output by 27.8%, implying that increasing the operating temperature had a negative effect on overall photovoltaic panel performance. The temperature of the solar panel rises because of the soot impact.

The charge controller voltage drops by approximately 27.8% as the temperature rises, significantly reducing output power and degrading electrical efficiency. Solar PV systems installed in such an environment will require more frequent maintenance than those installed in non-sooty environments. Self-cleaning automatic PV systems are recommended to save money on panel washing and reduce energy loss from soot particles. It is also recommended that the panels be installed at a distance from the roof or any other foundation to allow for air circulation, which may aid in cooling them and, as a result, lowering their temperature, increasing their efficiency, and, eventually, extending their lifespan. Furthermore, it is critical that this research be expanded in the near future to account for the impact of additional meteorological variables such as wind speed, relative humidity, and solar panel placement.

References

[1] R. Vijaya, R. N. Ganapathi and M. Amhed, "IOT based solar energy prophecy using RNN architecture,," in *E35 web of Conference*, India, 2020.

[2] J. Klaus, I. Olindo, A. H. Smets, R. A. v. Swaaij and Z. Miro, Solar Energy: Fundamentals, Technology, and Systems, Netherland: Delft University of Technology, 2014.

[3] W. A. Nsasak, R. Uhunmwangho, E. Omorogiuwa and A. B. Alabo, "Evaluation of Solar Panel for Improved Performances," *Indian Journal Of Engineering,* vol. 18, no. 49, pp. 222-231, 2021.

[4] R. Uhunmwangho, Leesi, B. Victor and A. Big-Alabo, "Application of Generic Algorithn to solar panel Efficiency; A case Study of Port-Harcourt Metropolis," *International Journal of Engineering Technologies-IJET,* pp. 61-69, 2018.

[5] M. Whyte, N. a. K. Tamuno-Wari and Sam, "Residents Perception of the Effect of Soot pollution in Rivers State, Nigeria," *African Journal Of Environmental Science and Technology,* pp. 35-46, 2020.

[6] B. B. Zito and L. Pelchen, "The Most Efficient Types Of Solar Panels Of 2022," 13 july 2022. [Online]. Available: https://www.forbes.com/advisor/home-improvement/most-efficient-solar-panels/.

[7] NREL, "NREL's PV Watt Calculator," 16 june 2021. [Online]. Available: https://pvwatts.nrel.gov. [Accessed 10 july 2021].

[8] HavenHillsSynergy, "Three Major Types of Solar Panels," 20 may 2021. [Online]. Available: http://havenhillsynergy.com.

[9] K. I. Abass, "Effect of temperature on PV Performance Based on Experimental Stusy," *International Journal of Trend in Research and Development,* vol. 7, no. 1, pp. 56-61, 2020.

[10] D. S. Raveen and F. Sachintha, "Effect of Temperature on Solar Cell Performance in a Sri Lanken Context," *Science Open Preprints,* pp. 1-7, 1 july 2022.

[11] E. C. Obuah and A. T.-o. Joyce, "Effect of Black Soot on the Performance of Photovoltaic Systems in Port Harcourt," *Ironic Research and Engineering Journals,* vol. 2, no. 6, pp. 63-68, 2018.

[12] S. Muhammad, Y. Tanimun and M. Abdulmumin, "Effect of Dust Accumulation on the Performance of Photovoltaic Module," *International Journal of Advances in Engineering and Management,* vol. 4, no. 2, pp. 957-964, 2022.

[13] T. E. El Shenawy and H. E. E. Ghetany, "Effect of Dust Accumulation on the Performance of PV Modules under Cairo Climate Conditions," *International Journal of Renewable Energy Research-IJRER,* vol. 11, no. 3, pp. 1313-1321, 2021.

[14] K. Hasan, S. B. Yousuf, M. Tushar, K. D. Barun and I. M. Saiful, "Wilwy Online Libray," *Effects of Different Environmental and operational Factors on the PV Perfoemance: A comprehensive Review,* vol. 10, no. 2, pp. 656-675, 2021.

[15] K. A.-G. Moafaq, R. T. ahmed and T. C. Miqdam, "The Influence of Temperature and Irradiance on Performance of the Photovoltaic Panel in the Middle Of Iraq," *International Journal of Renewable Energy Development (IJRED),* vol. 11, no. 2, pp. 501-513, 2022.

[16] K. T. Abhishek, P. Sandeep and S. Ray, "Laboratory Investigation on the Impact of Coal Dust Deposition on PV Panel Performance," in *IOP Conference Series: Materials Science and Engineering,* Kancheepuram, India, 2020.

[17] M. Nikolay, V. Pavel and A. Alzakkar, "Development of Method of Protection of Solar Panels Against Dust Pollution in the Northern Part of the Russian Far East," in *International Ural Conference on Electrical Power Engineering (UralCon),* Magnitogorsk, Russian Federation, 2021.

[18] W.-i. Issahaku, I. Stewarts and B. Heather, "Design of a Dust Cleaning Machine to Reduce Dust Solining on Solar PV Panels in Ghana," in *IEEE Global Humanitarian Technology Conference,* Santa Clara, CA, USA, 2022.

[19] "This Day live- Menance of soot in Rivers State," *This day live Newspaper,* 24 January 2022.

[20] V. Alikor, "The disturbing impact of soot on public health and economy of Port Harcourt," *BusinessDay Newspaper,* 6 January 2022.

[21] M. Kingsley-Amaehule, R. Uhunmwangho, N. Nwazor, Okedu and K. E, "Smart Intelliegent Monitoring and Maintenance Management of Photo-Voltaic Systems," *International Journal of Smart Grid,* vol. 6, no. 4, pp. 110-122, 2022.

[22] https://thingspeak.com/, "IoT Analytics - ThingSpeak Internet of Things," 04 October 2021. [Online]. Available: https://thingspeak.com/.