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Design and Implementation of a Photovoltaic Data Acquisition System for Some Meteorological Variables

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Abstract

In this paper we have developed a data logging and monitoring system, we validated the system by comparing the result from it with the existing one and found that the system performs slightly better than the existing work in the same area. This implies that the data logger and monitoring system is good and can be used to monitor solar energy variables even at the comfort of our homes. We fitted a model to the generated data and found that the meteorological variables considered accounted for 99.88% of the power output in the rainy seasons while 0.12% of the variation was not explained due to other factors. Solar panels inclined at an angle of 5^0 (Tilt) and facing South Pole perform optimally.

Keywords

Data Logging and Monitoring System, Circuit Design Development, Chip Programming and Software Development, Photovoltaic Cell, Meteorological Parameters

1. Introduction

Solar photovoltaic (PV) energy system is regarded as one of the reliable, accessible renewable energy sources. In several places where there is an abundant level of solar energy, a solar power plant is the best form of generating electricity. Hence, solar photovoltaic systems are being more and more utilized in solar home system (SHS), commercial industrial grid and there is a growing need to develop a real time monitoring system of data generated from PV systems to enable proper optimization of its overall performance. Therefore, A PV data logger and monitoring system is an electronic instrument that records digital, analog, frequency or smart protocol based measurements over time [1]. It is an all-purpose piece of measuring device that finds use in a variety of applications [2]. Solar PV data logging involves the collection or gathering of PV parameters data over a period of time. Solar PV data loggers measure, store, and analyze physical phenomena from the real world. Data logging integration for PV solar energy system is very vital for easy, reliable, robust and effective monitoring of PV system operations. Data logger enables the real time monitoring of the operation of a PV system by identifying any minor/major operational changes, malfunctions and breakdowns. Most solar data logger system integrates the basic PV system parameters with meteorological input parameters sensors in their designs and implementation; these sensors are integrated to the PV data logger circuit board. Hence, the real time value of PV panel voltage, current, power output, panel temperature, ambient temperature, solar irradiation, wind speed, relative humidity, atmospheric pressure, rain gauge can be data logged and analyzed. The low cost data logging designs should be simple, fast response and have large space memory. Data loggers are designed and developed for different monitoring purposes, for example, to monitor temperature and relative humidity [3]; to monitor PV systems [4]; to evaluate potential area of solar energy [5]; to evaluate the effect of dust on the performance of solar PV module [6]; to measure solar panel power characteristics [7]; to monitor temperature readings and solar voltage variations of a solar system [8]; to monitor the measurement of the voltage and current of the PV system and for weather monitoring and measurement [9]; to measure solar intensity [10] [11].

We developed a localized low cost data logger and monitoring system with internet connectivity where data can be collected on site and anywhere using the internet enabled devices. The developed system contains a set of distributed sources (PV Arrays), a smart RF interface for GSM communication for Things Web IoT service, USB/USART converter, 4 multicolor touchscreen TFT LCD, a remote dashboard (PC) and an Android smartphone. The solar PV prototype monitoring design will be based on power sensing (current, voltage) leveraging analog to digital converter (ADC) feature in the microcontroller. These will be developed using the C++ language on Arduino IDE for the firmware, Virtual Basic .NET for PC app and JAVA on Android Studio for the smart phone. For the meteorological factors (solar irradiation, temperature, humidity, and wind speed), a photodiode sensor for solar radiation, DHT11 module for ambient temperature, humidity sensor is used to measure the humidity of the environment, and the wind speed is measured by anemometer respectively. The sensor data is collected by the microcontroller. The sensor data is collected by the microcontroller every second and is displayed on the device screen. This data collected every second is averaged and stored in the SD card and cloud at 5 min intervals. The data could be viewed from the remote dashboard (PC or Smartphone) using IoT or by connecting a USB cable from the data logging system to the admin PC. In this regard, the prototype of the solar PV monitoring and data logging system for remote data acquisition and monitoring will be developed. System model for internal design and performance response with respect to fault tolerance of low voltage or high voltage via load balance service, virtual machine load scheduling will be accounted for in the design process. Functional algorithms for knowledge exploration of the acquired data from the solar PV monitoring and data acquisition system will be derived. The evaluation studies will be achieved via developed sophisticated web/android based services and MatLAB-Sim-event software. To this end, an analysis of the system performance on the basis of quality of service, throughput, services, availability, and delay/latency will be considered.

This work is also interested in designing a data monitoring device that senses temperature, relative humidity, and other characteristics such as voltage and pulse by combining analog and digital readings with programming methodology [12]. Transducers, computers, and sensors are used to monitor and log data in a solar PV system. The solar PV monitoring and data logging system could record real-time values for voltage, current, power, and energy associated with PV solar panels, as well as input from thermocouple temperature and humidity sensors and other sensors. The monitored data is subsequently stored and transmitted to the cloud database which is analyzed with software. Digital technologies, such as sophisticated microprocessors, solid-state sensors, and fully featured software, are used in solar PV monitoring and data logging system to increase accuracy. Solar PV data logging system can give improved accuracy over longer periods of time.

The development of low cost data acquisition and monitoring system that explore wired/wireless sensor infrastructure to develop a compatible integration with respect to the Solar PV operation is novel. Therefore, this research seeks develop a solar PV data acquisition and monitoring system for improved solar PV panel performance. We will also adopt the approach by [13] to evaluate the performance of the system and compare the results.

Hypothesis

$H_0 : \beta_i = 0\,(P > 0.05)$ Vs $H_1 : \beta_i \neq 0\,(P < 0.05)$; Take $\alpha = 0.05$.

H_0: The parameters are not significant and on the other hand, H_1: the parameters are significant.

2. Literature Review

A PV data acquisition and monitoring system is an electronic device that automatically records, scans, and retrieve information at a high rate and with improved efficiency during a test or measurement at any location in an environment over time [14]. The user determines the type of data to be recorded, such as temperature, relative humidity, voltage, or pulse; as a result, it can automatically monitor electrical output from any sort of transducer and register the value. A PV monitoring and data logging system is a device that uses sensors to transform physical events and stimuli into electronic signals like voltage and current. These electronic impulses are then transformed to binary data, which can be easily evaluated by software and saved for further analysis. Digital processors are used in data loggers; it is an electronic device that uses a built-in instrument or sensor or external instruments and sensors to capture data over time in relation to position. The major and most important benefit of employing data loggers is that they can automatically gather data 24 hours a day, 7 days a week. Data acquisition, monitoring and control for solar home PV system can utilized the real-time LabVIEW interface based system, remote intelligent monitoring system, Arduino based system, ATmega based system and IoT based system. The authors [9] proposed that collecting sensor data from an isolated photovoltaic (PV) system requires both data recorders and web upload. The data comprises measurements of the PV system's voltage and current, as well as weather information for the area. Also [15] proposed "An IoT based smart solar photovoltaic remote monitoring and control unit". In this study, an IoT (internet of things) based network is deployed to remotely monitor and control the state of photovoltaic system. The developed data logging and remote monitoring unit comprises of sensing layer, network layer and application layer.

In a related work by [16] "Remote GSM module monitoring and photovoltaic system control", has proven that the remote monitoring and control of photovoltaic system using Zigbee technology is inefficient in vast distance range due to its limited wireless network range. The proposed data acquisition and transmission is a wired sensor network organized in the smart PV station of irradiance (LDR sensor), temperature (LM35 sensor), operating voltage (Voltage divider sensor), current (hall-effect sensor) and battery state (LM 3914 sensor). And [17] utilized the zigbee wireless communication protocol to manage, monitor and detect faults of domestic solar PV panels. In the proposed design, the data acquisition systems sensors used are a PDB-C139 photodiode to measure light irradiance, NTC Thermistor sensor for temperature, voltage divider circuit for cell voltage measurement, MOSFET to measure current. The authors [18] designed and developed a solar powered wireless monitoring system capable of monitoring methane from a safe distance. The solar powered wireless monitoring system consists of LM35DZ temperature sensor, MQ-2 methane and MQ-5 methane sensors. The wireless data acquisition system consists of AIR-BR500GHP model outdoor access point, omnidirectional antenna DI-720-EN model and WLAN network. A stand-alone PV power system consist of 75 W solar panel, 25 A/12V MPPT charge controller, 12 V/100Ah lead acid battery. The graphical user interface via LabVIEW consists of WinDaq Pro display software on LabVIEW 8.0 data logging platform. The set up results shows effective monitoring of temperature and gas concentration data in real time at a line of sight of distance of 160m between transmitting-receiving access points.

Furthermore [6] analyzed the dust deposition on the performance of PV module in desert area of Manipal University, Jaipur over a 55 days period. The hardware used are 2 units of polycrystalline solar panel of 51 Wp which is wired to LM35 (temperature sensor), ACS712 (current sensor) and DC voltage sensor. The outputs of the sensors are wired to DAQ 6009 data logger system. LABVIEW 2013 software version is used to run the program which is displayed on GUI interface. One of the panels was cleaned regularly while the other is left unclean and the results shows a 9% decrease in its power output. Also [19] demonstrated a LabVIEW simulation of real-time solar panel data gathering. Two Arduino were utilized in the creation of a prototype model. One is used to connect the solar panel to the PC for data collecting, while the other is utilized to control the servomotor. The servomotor is connected to the solar panel via a shaft and rotates in response to the LDR output. For tracing the sunlight, two LDRs are mounted on both sides of the solar panel. The entire simulation is run using the LINX firmware wizard, which can be found in LabVIEW Maker's Hub. Data were taken on various days and for varying periods of time. The behavior and voltage of the solar module were analyzed based on the acquired data. The design of a low-cost solar tracking and real-time data gathering system was very reliable and exhibited accurate performance. Data obtained from renewable energy sources are widely used in evaluation of system performance. But [20] developed a computer based system comprising of electrical and meteorological sensors routed to a precision electronic circuits interfaced to a PC via data acquisition card. LabVIEW program was used to further process, display and store the acquired data in the PC disk. The proposed system is suitable for the operation of renewable energy system, quick system improvement and changes. The technology of harvesting solar involves the capability of extracting solar energy from the environment; hence it should be efficiently integrated into an embedded system to convert that harvested energy into increased application performance and system lifetime.

3. Materials and Method

This research comprises two segments; the first section is the development of solar PV data logger and monitoring system while the second section is concerned with the modeling; analysis of the data obtained from the developed system and comparing the result with the data collected from Nigeria Environmental Climatic Observatory Project (NECOP), sees [13]. The study was conducted in Port Harcourt, Nigeria a metropolitan city which is densely populated. The city is situated in a low Latitude of 4.7974˚N, longitude 6.9803˚E and an elevation of 5 m. The city experience a wet season with heavy rains between April to September and light rains between October to December. The dry season is between January to late March. It also experiences a high average temperature of 32˚C between January to March and low average temperature of 21˚C in the month of July.

3.1. Circuit Design and Development

The proposed circuit was designed using KiCAD software. Its schematic was captured, exported to the Printed Circuit Board (PCB) section of the KiCAD. The generated Gerber file format of the PCB was used for PCB development and the components assembled on the printed circuit board (PCB). The Solar PV data logging and monitoring system starts with the solar PV modules which powers the overall system and its PV power generation is also being monitored. The sensing section at the bottom comprises ACS712 current sensors, voltage divider circuit, LM35 panel temperature sensor, ATMEGA2560 microcontroller, SIM800L GSM/GPRS module, DTH11 (digital humidity-temperature), miniature wind sensor, photodiode sensor, LDR/linear actuator for panel angle tilt, ultrasonic sensor for water level. The network and storage section is the region where data logging from the system for real-time processing is done which includes database for storage. An 8G SD memory card, alternatively, data is saved to the remote server/cloud and could be retrieved for visualization using the Things Web IoT service. The schematic circuit of solar PV data logging and monitoring system was presented in **Figure 1** and data logger board with inputs and outputs components was presented in **Figure 2**.

3.2. Implementation of Developed Solar PV Data Logging System

1) The installation of the experimental research is done at the same location housing the Nigerian Environmental Climatic Observatory Project (NECOP) station in Rivers State University, Nigeria; with coordinates 4.7974˚N (latitude) and 6.9803˚E (longitude).

2) The solar PV data logging and monitoring system comprises a 3 meter high galvanized frame 0˚ - 90˚ adjustable and rotatable for mounting the solarmodule, four (4) 10 watts solar modules of which a pair is mounted at a fixed position on one arm of the pole. The four solar PV panels were oriented facing the true south azimuth with the help of GPS, compass and digital inclinometer at a tilted angle of 5 degrees corresponding to the latitude of the location.

3) Similarly, the remaining pair is mounted similar to the first pair but with a linear actuator device attached underneath the solar modules which is configured to regulate the east to west azimuth movement automatically at every hour from 6 am to 6 pm daily. The panels tilt automatically to track the movement of the sun to get maximum possible irradiation output. The solar panels mounted are used to power the system and drive the overall system unit.

4) The Data logging and monitoring system has peripheral components and modules attached to it for sensing, storage, monitoring and control. And all these positioned strategically on a metal structure to shield it from weather changes and for effective measuring and control of the system parts. The current and voltage sensors are mounted on the circuit board. These sensors only require wires from the panels to be connected to the board. Using the ACS712 modules, the current is sensed, while a potential divider network is used to sense but the panel voltages and battery voltage. The panel temperature sensor consists of LM35 glued underneath each panel, to get the actual temperature of each

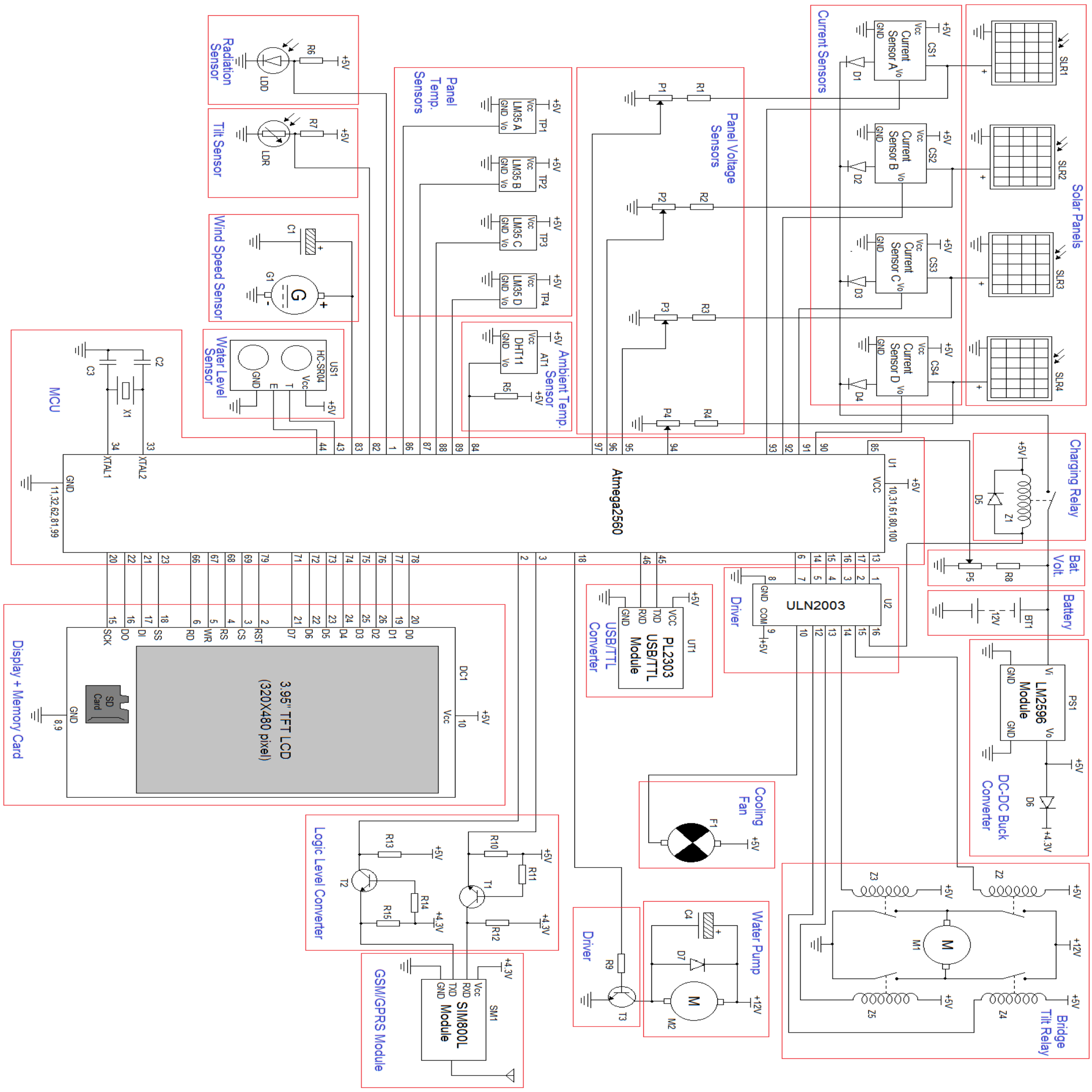

Figure 1. Schematic circuit of solar PV data logging and monitoring system.

panel. These sensors here stated, help get the parameters of the panel. The atmospheric parameters are gotten using the DHT11 for humidity and temperature, photodiode sensor for sunlight intensity, wind turbine for wind speed. The DHT11 and photodiode are placed inside a box, with the DHT11 facing down, to eliminate the possibility of being touched by rain water and the enclosure having vents, to stabilize the temperature and humidity of the space within the enclosure with the surrounding environment. The photodiode sensor is fixed through a 5 mm hole so that it is directly exposed to sunlight. The whole enclosure having the DHT11 and photodiode sensor is glued to the automatic moving

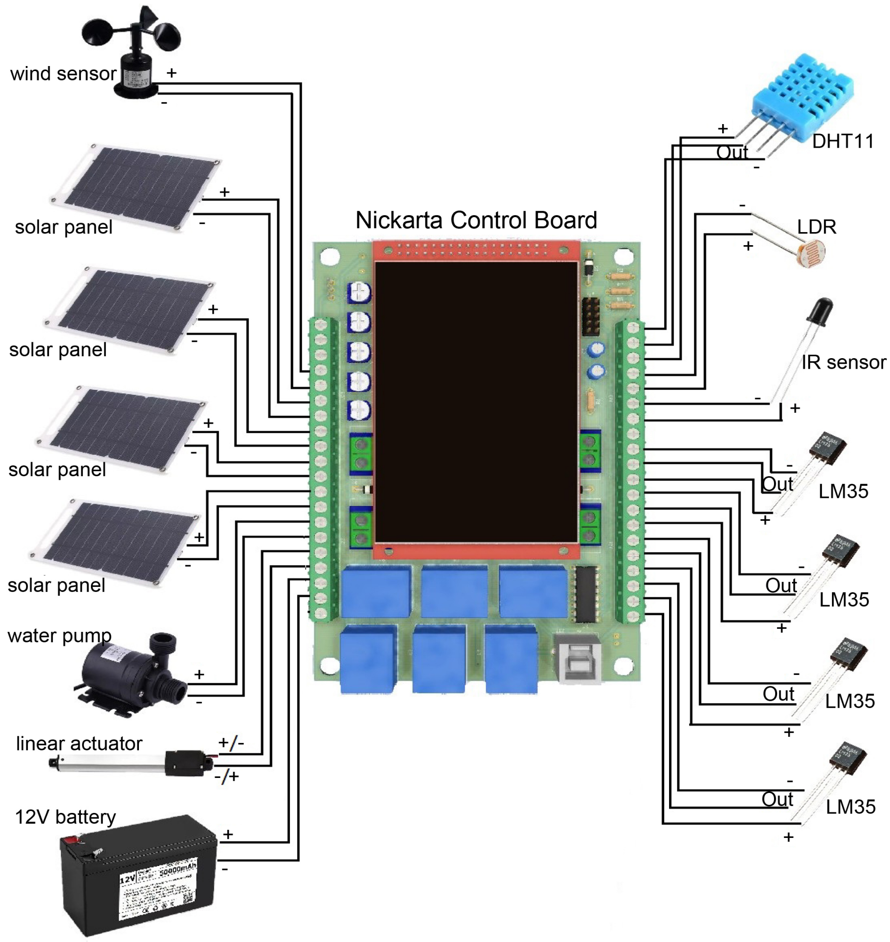

Figure 2. Data logger board with inputs and outputs components.

solar panel pair, so that it is constantly facing the sun directly as the panel moves. The DHT11 gives out a digital output serially while the photodiode sensor network gives out varying voltages depending on the intensity of the rays hitting it. The photodiode sensor output is fed to the ADC pin of the microcontroller, and its maximum possible voltage variation is 5 V. The wind speed is sensed using a miniature wind turbine, placed high above the panel so as not to have any wind obstruction from any direction, and it's spaced away from the panels so as not to cast its shadow on the panel. The wind turbine generates direct current that is proportional to the wind speed. This current being equal to or less than 5 V is fed directly to the ADC of the microcontroller, since the maximum ADC voltage is already being set at the AVCC (anolog voltage supply) pin to be 5 V maximum. Thus, a varying wind speed, results in varying ADC values. The embedded program uses that to calculate the actual wind speed based on turbine parameters as stated by the manufacturer.

5) Regular cleaning the solar PV panel is achieved using a 12 V pump. This pumps water though a hose, from a reservoir placed on a stool. The water flows to a plastic pipe with slits along its length, through which the water gushes out to spray the solar panels. The pipe is placed at the high side of the panel that is ele-

vated north-south; this helps the water rush down from North to South, thereby cleaning the automated side of the solar panel configured to clean the panel every 2 days interval. In accordance with manufacturer's specification, the water level is constantly checked to avoid the pump switching on without water in the bucket. The level sensing is achieved using an ultrasonic level sensor. The operator receives in-app and SMS notifications on water levels. In the manual mode the operator does the checking and pumps switching, from an Android phone or windows PC.

6) Details of the system sensor reading and status is stored to the memory card every 5 minutes and to the cloud at 30 minutes interval, while the system continuously gets reading and averages the readings every 200 ms. The system conserves battery power by putting the GSM/GPRS module in sleep mode, only to wake up every 1 minute to get updates of time, date and network signal strength, also send status information every 5 minutes. It wakes up too once it receives data from the cloud, initiated on a mobile device or PC. The saved data could be retrieved using the USB cable or via the Internet. The read data and state is displayed on the screen and the on-screen information is updated every 10 seconds.

7) The PC and Android app detect the connected data logging system and then send a string character to the data logger. The data logger senses an active connection to it, prompting the screen to display the USB icon to the operator (for USB connection mode). The operator can read and save data and can then export to spreadsheet for further analysis.

3.3. Source of Data

Data collected for this research work is primary type data collected between April to June, 2022 from latitude (4.7974˚N) NECOP Station, Rivers State University Port Harcourt. The meteorological parameters considered in this work are: solar irradiation, ambient temperature, relative humidity and wind speed. These variables are called the independent variables, while the dependent variable is the power produced by the solar panels. These variables determined the daily average solar current (A), voltage (V), and power (W). Subsequently, the electrical and meteorological parameters were recorded experimentally by the developed solar PV data logging system installed at the NEPCOP station.

3.4. Sample Size

A sample of eight-one (81) data points from April to June, 2022 was obtained from the developed data logger system. These are daily data covering the three months and are for the study.

3.5. Method of Data Collection

The developed solar PV data logger experimental system was used with occasional visits to the location and downloading the recorded data to a computer via

IoT connection. Real-time average daily measurement was obtained for ambient temperature, relative humidity, wind speed, irradiation, voltage, current and power of the panels. The eighty-one (81) data set used for the analysis was from April to June 2022. The data was presented in Table 1 under data presentation. The data sets will be used to develop a model for the study.

3.6. Method of Data Analysis

The model for this study was the multiple linear regression (meteorological) model adapted from [13], since our interest was to compare the performance of the developed system with the already existing work. Hence, the model for the study is

$$Y_i = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} + \hat{\beta}_2 X_{2i} + \hat{\beta}_3 X_{3i} + \hat{\beta}_4 X_{4i} \tag{3.1}$$

where: $i = 1, \cdots, 81$; Y_i = Power (W) (5^0Tilt), X_1 = average irradiation (MJ/m^2 day), X_2 = average temperature (˚C), X_3 = wind speed (m/s), X_4 = Humidity (%). Hence, the meteorological model is given in Equation (3.1).

For us to implement the developed model, we used Minitab 16.0 version of software to fit trend line to the model in Equation (3.1), see Equation (4.1) for the fitted trend lines.

4. Data Presentation and Analysis of Results

4.1. Data Presentation

We present meteorological data obtained from the developed data logger system for the second quarter (April - June, 2022) in Table 1. Figures 3-5 are for the test of Normality, one of the most important conditions for the use of multiple linear regression.

4.2. Data Analysis

$$Y_i = -2.31108 + 0.971258 X_1 + 1.09866 X_2 + 1.04342 X_3 + 0.999255 X_4 \tag{4.1}$$

Table 2 present the T-test analysis which can be used to make inference about the data if we are interested in the meteorological variables as a multivariate data set. Table 3 present the analysis of variance (ANOVA) which was used to make inference about the study.

4.3. Summary of Model

S = 0.383322, R-Sq = 99.88%, R-Sq(adj) = 99.87%.

PRESS = 14.3686, R-Sq(pred) = 99.84%.

4.3.1. Interpretation of Results

From the analysis in Table 3, we observe that the fit was very much adequate and a little better than the corresponding fit in work of [13]. This is attributed to precision due to the developed data logger system. The reason is that the meteorological parameters considered in this study, Irradiation (X_1), Temperature

Table 1. Meteorological data on irradiation, temperature, wind speed and humidity (April - June, 2022).

Day	Power (W) (5^0 Tilt)	Ave. irradiation (MJ/m^2 days)	Average Temp. (˚C)	Wind speed (m/s)	Humidity (%)
1	77.88	26.78	30.51	1.77	18.82
2	79.07	22.98	30.83	1.96	23.30
3	67.92	19.52	30	1.7	16.70
4	75.23	18.66	30.28	1.83	24.46
5	66.69	16.85	27.2	1.68	20.96
6	83.51	31.19	30.8	1.82	19.70
7	64.03	14.08	27.1	2	20.85
8	91.44	35.68	31.7	2.11	21.95
9	77.05	20.71	32.7	2.06	21.58
10	79.79	28.17	30.8	2.76	18.06
11	87.52	31.97	31.1	2.57	21.88
12	79.63	29.29	29.7	1.32	19.32
13	69.98	18.84	30.3	1.2	19.64
14	85.20	28.94	32.13	3.35	20.78
15	89.53	30.59	32.45	1.55	24.94
16	91.39	29.81	31.58	4.32	25.68
17	81.44	30.41	32.07	1.25	17.71
18	74.71	23.24	29.81	1.18	20.48
19	72.84	22.46	27.35	3.32	19.71
20	79.38	22.03	30.28	4.12	22.95
21	71.03	26	32.36	2.1	10.57
22	81.56	27.3	30.43	1.55	22.28
23	66.19	17.45	28.34	1.4	19.00
24	83.52	22.72	30.37	6.79	23.64
25	85.90	29.72	30.28	1.69	24.21
26	56.94	15.21	27.52	1.86	12.35
27	92.80	35.16	31.15	1.74	24.75
28	92.68	35.68	31.44	2.06	23.50
29	61.98	14.34	24.12	1.36	22.16
30	84.85	30.59	31.36	2.07	20.83
31	64.50	11.92	26.15	0.91	25.52
32	86.60	28.68	31.18	1.95	24.79
33	73.77	21.95	30.23	2.66	18.93
34	93.13	33.44	31.66	1.75	26.28

Continued

35	58.40	16.07	26.2	1.11	15.02
36	89.06	35.33	31.52	1.44	20.77
37	96.19	32.75	32.04	2.15	29.25
38	85.03	29.81	30.92	2.58	21.72
39	91.23	33.18	31.91	1.73	24.41
40	67.99	15.81	26.7	1.44	24.04
41	93.71	41.39	32.41	1.48	18.43
42	91.50	29.72	31.23	1.99	28.56
43	87.30	33.87	30.58	1.81	21.04
44	62.52	16.24	24.74	5.39	16.15
45	95.69	39.14	32.03	1.53	22.99
46	70.00	17.71	29.13	1.94	21.22
47	69.64	25.66	25.97	1.6	16.41
48	58.43	12.36	25.81	1.64	18.62
49	83.77	28.08	28.54	1.2	25.95
50	80.98	24.28	29.58	1.08	26.04
51	76.30	17.71	23.37	4.95	30.27
52	84.35	34.91	30.86	1.85	16.73
53	52.77	9.94	25.31	1.21	16.31
54	81.92	27.65	28.65	1.57	24.05
55	80.49	31.45	29.18	1.29	21.57
56	81.86	26.18	29.15	4.04	22.49
57	75.96	27.13	29.32	3.48	16.03
58	80.30	26.87	30.52	2.01	20.90
59	83.31	25.57	28.86	5.64	23.24
60	62.30	15.9	25.88	2.49	18.03
61	66.73	16.42	27.62	1.64	21.05
62	75.88	20.91	28.17	4.75	22.05
63	79.13	26.52	25.06	1.55	26.00
64	79.14	25.4	28.17	1.46	24.11
65	62.06	14.95	23.74	5.76	17.61
66	72.48	22.03	27.12	3.79	19.54
67	84.63	28.25	28.92	2.11	25.35
68	71.66	17.11	27.23	3.35	23.97
69	70.68	24.26	20.25	1.44	27.03
70	70.70	14.86	25.12	1.5	29.22
71	74.44	21.77	27.75	1.73	23.19

Continued

72	81.96	25.49	28.57	5.68	22.22
73	62.43	10.71	24.65	5.54	21.53
74	83.60	27.48	28.75	2.24	25.13
75	73.79	16.85	27.04	5.43	24.47
76	68.78	18.4	27.8	1.73	20.85
77	63.86	18.14	27.12	1.85	16.75
78	68.34	16.33	27.78	2.36	21.87
79	79.16	23.07	28.35	1.99	25.75
80	57.47	17.02	27.56	1.94	10.95
81	54.35	9.85	24.78	4.08	15.64

Source: Data from solar PV data logging system, rivers state university, Port Harcourt.

Table 2. Coefficients.

Term	Coef	SE Coef	T	P
Constant	−2.31108	0.661381	−3.494	0.001
X_1	0.97126	0.008847	109.779	0.000
X_2	1.09866	0.024489	44.864	0.000
X_3	1.04342	0.032242	32.132	0.000
X_4	0.99925	0.011376	87.842	0.000

Table 3. Analysis of variance.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	9129.83	9129.83	2282.46	15533.46	0.0001
X_1	1	7697.64	1770.77	1770.77	12051.3	0.0021
X_2	1	102.09	295.75	295.75	2012.8	0.0003
X_3	1	196.32	151.71	151.71	1032.5	0.0031
X_4	1	1133.78	1133.78	1133.78	7716.2	0.0011
Error	76	11.17	11.17	0.15		
Total	809141.00	9141.00				

(X_2), Wind speed (X_3) and Humidity (X_4), were able to explain that 99.88% of the solar power output was attributed to these variables while 0.12% of the variation was not explained. The unexplained variables could be due to other environmental conditions not considered here, but the meteorological variables considered in this research were up to 99.88% responsible for solar power production.

From the Analysis of Variance presented in Table 3, we observed that all the parameters such as; Irradiation (X_1), Temperature (X_2), Wind speed (X_3) and Humidity (X_4) were significant in solar power output in this quarter, this also

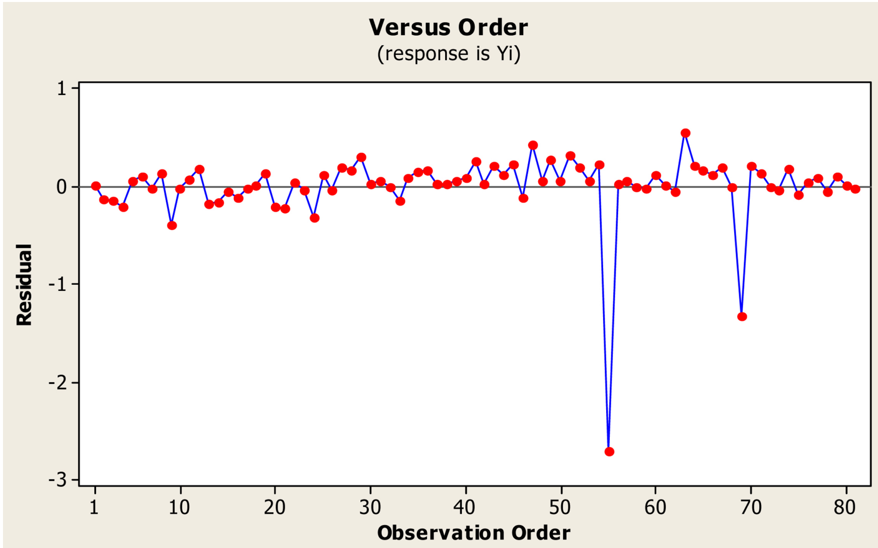

Figure 3. Residuals vs order for Y_i.

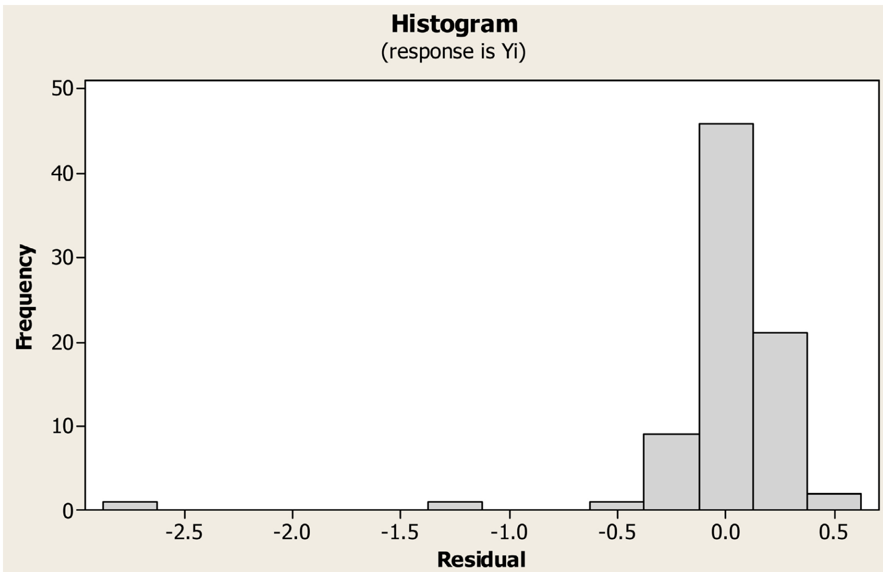

Figure 4. Residual histogram for Y_i.

correspond to the work of [13]. In this case, we accept the alternative hypothesis (H_1:) and conclude that these parameters (Irradiation, Temperature, Wind speed and Humidity) contributed significantly to the solar power output. This model can be used for forecasting the solar power output at any given time provided the values of the independent variables are known.

4.3.2. Comparative Analysis of Solar Power Output between the Existing System and Data Logger System

We compare the result in rainy season from [13] and with that obtained from data logger. We observed that all the four meteorological parameters were significant, this means that rain does not have negative effect on solar power output; rather, it enhances solar power production. We also observed that the

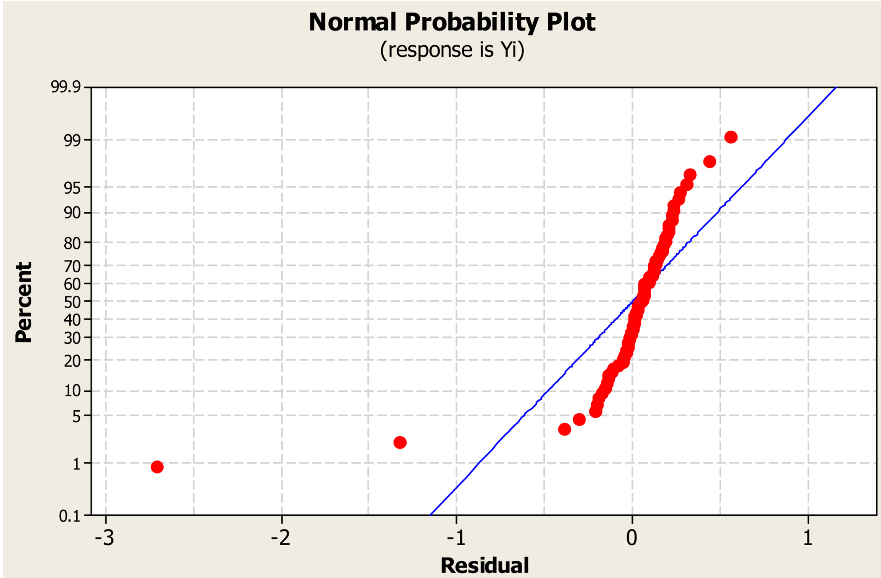

Figure 5. Normplot of residuals for Y_i.

independent variables explain the model better when the data from the developed data logger model was used.

5. Conclusion

We have developed a data logger and monitoring system. We compared the functionality of the developed system with the work of [13] and found that the model performs equally well with the already existing work in all respect but slightly better than the existing work. This implies that the data logger and monitoring system is good and can be used for solar energy production. From the fitted model, we observed that the meteorological variables accounted for nearly 100% of the power output. We observed that the solar panel performs well in the rainy seasons.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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