Real-Time Monitoring And Diagnosis Of Organic Solar Cell Stability

Mekila Mbayam Olivier, Sam Kassegne, Mutuku Muvengei

Abstract: The still increasing high-level emissions of CO_2 around the world is underlining the importance of wider adoption of renewable energy. With the advancement of new technology and development of organic solar cell, the price of photovoltaic is going down and encouraging large implementation of photovoltaic system. Due to the implementation of solar panels in locations that are often remote, it is very difficult to monitor physically. The traditional method of monitoring solar panels using PLC or SCADA systems is not cost effective. Therefore, with the development of advanced technology, we developed a data acquisition system using Internet of Things (IoT) technology. It is a new cost effective technology used to monitor organic solar cell using open source tools such as Integrated development environment and Thinkspeak. Thinkspeak is an IoT platform incorporated in Matlab that provides an environment to monitor solar panels parameters. This paper proposes a system for real-time data acquisition and remote monitoring of organic solar cells (OSC) incorporated in buildings facades for stability analysis. The system consists of embedded systems and sensors to monitor organic solar cells parameters such as current and voltage and weather conditions such as humidity, temperature and irradiation. The result of the proposed system has shown an efficient method for monitoring solar panels with an ability to display and store data in cloud. Also, during four months of observation the result has shown some preliminary delamination in the organic solar cell with a decrease in output power.

Index Terms: Internet of Things (IoT), Data Acquisition, Organic Solar Cells (OSC), Thinskpeak, cloud system, stability.

1. INTRODUCTION

The ever-growing need for energy has further increased usage of fossils fuels and augmented the emissions of CO_2 about 78% of the total GHG emissions from 1970 to 2010 as shown in fig1 [1]. Therefore, to reduce CO_2 emission photovoltaic energy can be a compelling candidate. The potential of photovoltaic energy is estimated 6000 times larger than annual energy consumption of 13,000 million tons of oil equivalent. An estimation has shown that if 43,000 square miles' area is covered by solar panels even with moderate efficiencies achievable today, it can produce 17,4 TW power for the world consumption [2]. It shows clearly that 1.2% of Saharan desert in Africa is sufficient to provide energy to the world. Photovoltaics energy can tremendously contribute to energy generation in the world. Currently, the solar industry is dominated with conventional, un-organic silicon-based cells. Although it is an established technology have been conducted to enable data transfer and monitoring of photovoltaic systems using wireless monitoring systems. Kabalci et al. developed a real-time system to monitor solar panels and wind turbine using developed sensing circuits connected to 18F4450 microcontroller [4]. Adhya et al. proposed an IoT based on PIC18F46K22 microcontroller for data processing, MicroSD for storage, and GPRS module to send data remotely to the server [5]. Chooruang et al. designed a low-cost IoT to monitor billing system and energy management using ESP8266 Wi-Fi module and Wemos D1 microcontroller for data processing and remote control through the Internet [6]. Also, Zahran et al. designed a system using NI WSN 3202 and WSN-9791 and NI WAp3711 industrial access point to monitor a stand-alone photovoltaic. The system used LabVIEW to send data over the internet for the users [7]. Data visualization of the system is developed through the LabVIEW programming environment to control performance of the system in rural areas. Others researches have also reported for faults detection and anomalies in solar panels and batteries [8-9]. IoT technology has been mostly tested in inorganic solar cell. However, with the development of organic solar cell it is most convenient to test in OSC. The combination of OSC with IoT technology will enable vast implementation of IoT devices. Since IoT devices have low power consumption, the power output of organic solar cell will be adequate. This current research investigated the use of data acquisition system using IoT technology to monitor organic solar cells installed on building facades to enable real-time monitoring and data collection through an IoT platform called Thinkspeak. Also, stability analysis of organic solar cell during four months of monitoring is investigated.

2. METHODOLOGY

2.1 Model Design

The experiment is performed as described in figure 2. Organic photovoltaic is exposed to real conditions to determine the current and voltage. The system also records irradiance, temperature and humidity data that are monitored in real-time and sent to Thinkspeak cloud every 10 minutes. The model used various sensors to collect input data on temperature, humidity and irradiation as well as output data on current and voltage. A Wi-Fi module is used as a receiver to collect data from microcontroller Arduino and sent it to Thinkspeak cloud for monitoring and analysis. Figure 1 describes the block diagram for data acquisition.

- *Mekila Mbayam Olivier (corresponding author), Pan African University, Institute of Basic Science Technology and Innovation, Kenya, Tel: +254743607743. E-mail: mekiolivier@gmail.com*
- *Sam Kassegne, San-Diego University, USA, Tel: (619)594-1815, Email: Kassegne@sdsu.edu*
- *Mutuku Muvengei, Jomo Kenyatta University of Agriculture and Technoloy,Kenya, Tel: +254720642441, Email: mmuvengei@eng.jkuat.ac.ke*

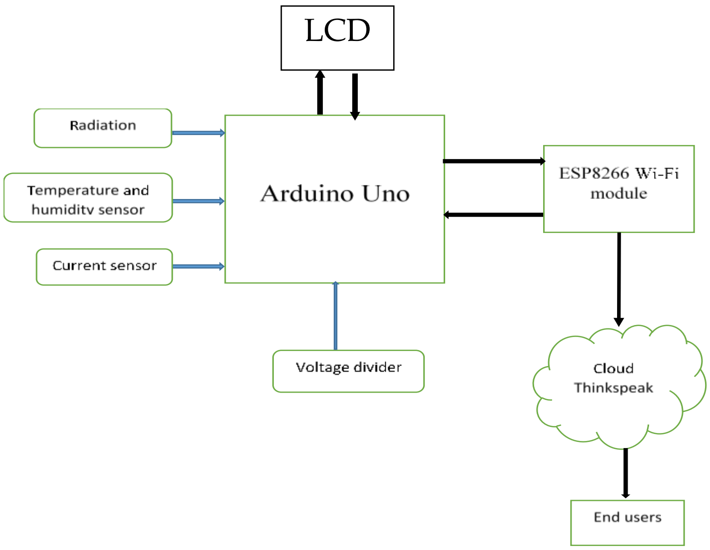

Fig 1: *Block diagram of model design*

The most critical part of the design is the connectivity to the internet and storage of data in the cloud for monitoring and analysis. Therefore, for an efficient and cost-effective monitoring system, an ESP8266 Wi-Fi module is considered for its simplicity and connectivity with TCP/IP. The device requires a 5V DC input, either from USB or external source. The ESP chip also operates on a low power mode making it efficient over a long duration. For visualization and data analysis, IoT platform Thinkspeak is used. The system used different sensors to measure voltage, current, humidity, temperature and irradiation. The voltage sensor used has a range of 0 to 5V, while the current sensor had a range of from 0 to 25A with an ability to measure DC/AC current. Humidity and temperature sensor (DHT22) 3 to 5 volts' power with 2.5ma maximum current from measured the ambient temperature and humidity received by the solar panels. Irradiation sensor (LDR) has a maximum voltage of 200volts, wavelength 600nm and maximum resistance of 4.5kΩ. It is used to measure the amount of light received by the solar panels. For data processing, a microcontroller Arduino Atmega 328P is used. It is an 8-bit microcontroller which can support up to 28 pins and more analog to digital converter channel (ADC) [8]. Light-emitting diodes (LED) are used to show the presence of Wi-Fi, connectivity to the Internet and data sent to cloud. Fig 2 shows the design of data acquisition and monitoring system. The working principle of data acquisition system is described in Fig 3.

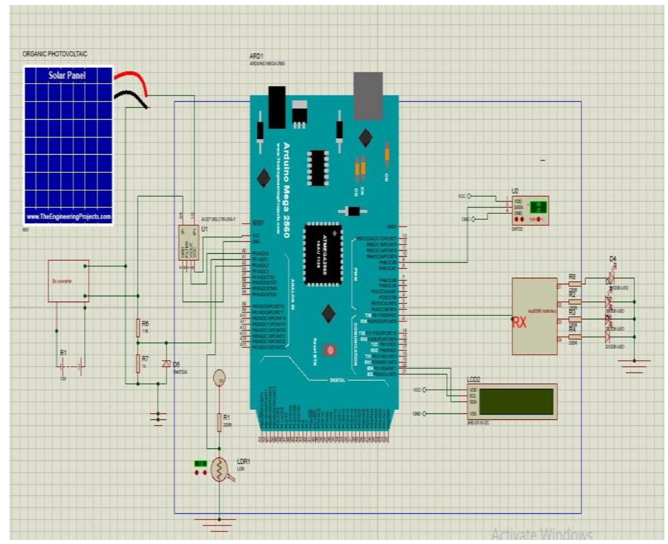

Fig. 2: *Schematic diagram of the data acquisition*

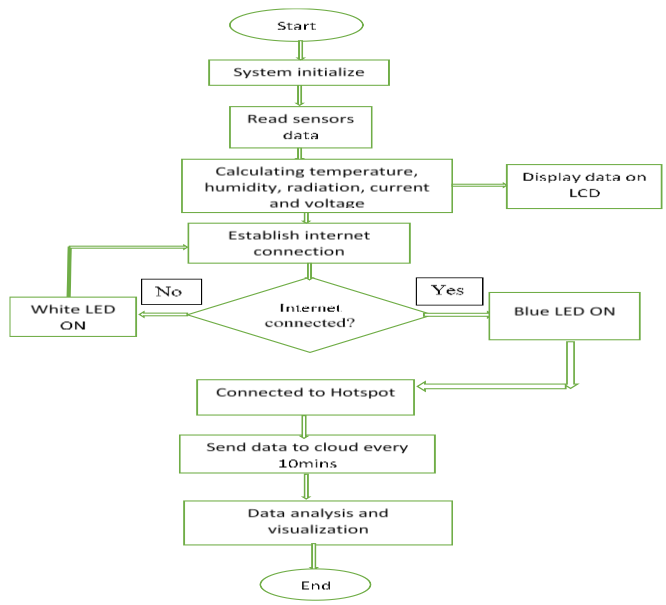

Fig. 3: *Flowchart of the system*

2.2 Sensors Calibration

The accuracy of organic solar cells electrical parameters and weather data is influenced by sensors calibration and coding. These data are measured using various sensors and stored in cloud for analysis and visualization. The environmental conditions considered are: humidity, irradiance and temperature, while the electrical parameters are current and voltage. The current sensor Acs712 is based on the principle of Hall-effect. Therefore, the current transported in a conductor is placed in a magnetic field, allowing the voltage to be across its edges in a perpendicular direction of the current and magnetic field [9]. Due to Lorentz force, the current distribution is non-uniform through the conductor and generates potential difference through the edges. In this, work, Vcc=5.0V is used as a voltage reference for analog-digital (A/D) since it is the voltage required for Arduino and Acs712 current sensor. Arduino is 10-bit (0-1023); hence, it converts the analog output of Acs712 to 512 counts when there is no current (zero reading). Therefore, to estimate the current in the photovoltaic module, the coding and calibration is described in equation 1. Current sensor is connected to the microcontroller using analog pin(A0).

$$sV = ((zr - rv(A0)))*(5000 \div 1023); \quad (1)$$

sV = Sensor Value
zr = Zero Reading
rv = read value
For acs712 20mA used for experiment the sensitivity is 100mV for 1A and offset is 2500ma at no current
Therefore, the current is determined using equation (2):

$$I = (ofst - sV) \div \text{sens}; \quad (2)$$

I = Current
$ofst$ = Offset
sV = Sensor Value
The voltage measurement used a voltage divider principle. In this case, the maximum voltage of the solar panels is 60volts. Therefore, since Arduino can only accept 5 volts, two resistors are used, R1=11k and R2=1K. The application of the voltage divider principle is given in equation (3).

$$V_{out} = V_{in} \times R_2 \div (R_1 + R_2); \quad (3)$$

V_{out} = Output Voltage
V_{in} = Input Voltage
R_2 = Resistance
R_1 = Resistance

Then, to read real voltage value from solar panels, it is given in equation (4).

$$V = (rd(A1) \div 1023) \times V\max; \quad (4)$$

V = voltage
$V\max$ = maximum voltage
rd = Read Voltage

Max voltage= 60 volts. It is the maximum voltage of OSC.
Environmental conditions are critical to analyze the stability of organic solar cells and determine their effects for long-term performance. To record data about humidity and temperature, DHT22 is used. It is a sensor measuring temperature range from -40 to 80°C with an accuracy of +-0.5°C. humidity range is 0 to 100% with an accuracy of +-5%. The sampling rate is one reading every second operating with 3 to 5 volts, while the maximum current is 2.5mA [10]. Temperature is measured using NTC thermocouple, which is a variable resistor and changes according to ambient temperature. Calibration is carried out by the manufacturer using data from local weather station. It is connected to digital pin of the microcontroller (D9).
Measurement of irradiance is through an LDR sensor. It works with the principle of photoconductivity. When there is a light falls on its surface it makes electrons in the valence band of the resistors to move to conduction band[11]. Calibration is done using a solar power meter, to measure different values of irradiance and compare with LDR data. After, many data collected and plotted against each other, statistical analysis of regression helps to determine intercept which the value is 1224.74 and a gradient of -0.2748. Accuracy, is confirmed when solar power meter oriented in the same direction as LDR give same value. Coding of LDR sensor is described in equation (5).

$$H = pow(((rd(A2)) \div x), (1 \div (y))); \quad (5)$$

H = Humidity
pow = power value
rd = read value
x = gradient
y =intercept
const float gradient = -0.2598;
const float intercept = 1224.740433;

2.3 Implementation
The pilot system of organic solar cells was installed in Jomo Kenyatta University of Agriculture and Technology on a building facade facing south in the Architecture laboratory. The system consists of organic solar cells, esp8266 Wi-Fi module, Arduino Uno microcontroller connected to radiation sensors, current sensor Acs712 20ma, temperature, and humidity sensor DHT11, display system LCD16*2, and light-emitting diode (LED). OSC are manufactured by infinity PV using the roll-to-roll ambient and coating printing techniques. The data acquisition and real-time monitoring system is shown in fig. 4, and OSC were installed in the building facades as shown in fig. 5.

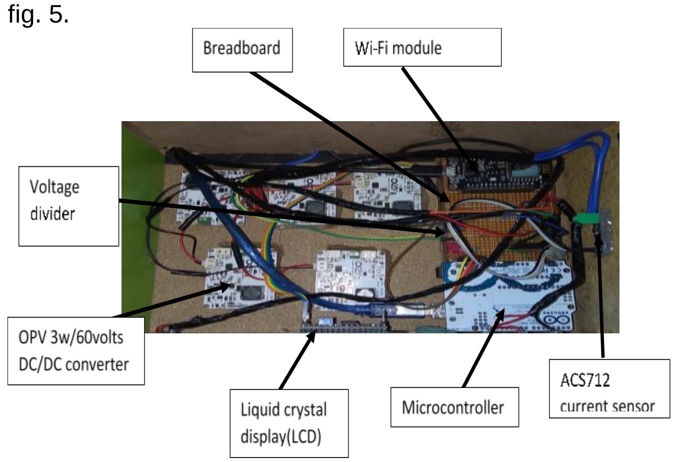

Fig. 4: *Practical implementation of data acquisition system*

Fig. 5: *Organic solar cell installed in building façade*

The installation consists of 10 numbers of organic solar cell connected in parallel. Each solar panel has a maximum output power of 60volts and 20ma.

2.4 Data Collection and Analysis
Arduino Software (IDE) was used for coding in this work. It is

an open-source software used in windows and mac OS. It is used for programming microcontroller devices using C and C++ language for coding and also provides the library with standard inputs and outputs procedures[12].
ThinkSpeak is used in data acquisition and real-time monitoring of organic solar cell. It is an IoT platform integrated into MATLAB from MathWorks to collect and visualize data from sensors connected to sense solar parameters and weather variations. It is used to store and retrieve data using HTTP protocol via the internet or using the local network area(LAN) or Wireless fidelity(Wi-Fi). Finally, to access data displayed in Thinkspeak cloud it required to use a username and password for login.
The model design was connected to ThinkSpeak cloud using the following steps:

1. Create channel number and API keys.
2. Connect the Wi-Fi module to Thinkspeak using channel number and API keys
3. Send the Data to Thinkspeak cloud for analysis and visualization.

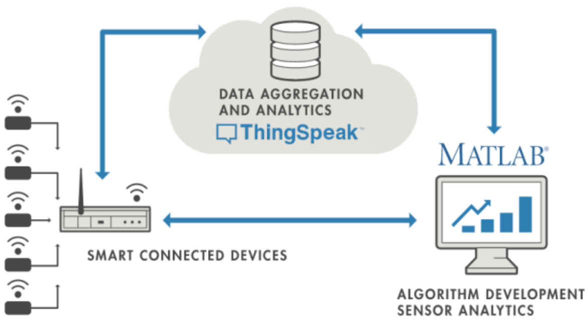

***Fig 6:** data acquisition and analysis in think speak[13]*

Data are stored in three formats JSON, XML, and CSV in Thinkspeak cloud.
In this research, we considered data from 6.00am to 6.00 pm coherently related to sunrise and sunset for data analysis. Therefore, statistical analysis is used to determine the mean, maximum, minimum and standard variation for the data collected during the month of August and September.
The standard variation is used to measure how spread out is the distribution of data is deviates or different from the mean. It is given by equation (6):

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})^2} \qquad (6)$$

σ : The population variance

X_i : The i element from the population

n : The number of elements in the population

$\bar{X}$: The population mean

The mean is used to calculate average data received in order to make a comparison for the two months' data collected. It is given by equation (7)

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad (7)$$

$\bar{X}$: The population mean
n : The number of observations

X_i : The i element from the population

3 RESULTS AND DISCUSSIONS

3.1 Preliminary Result of Data Collected

In this section, the results obtained from the experimental work are presented and discussed. The result presented here, describes three months of data collected to analyze the stability of organic solar cell in tropical environment. In the fig. 7 data collected to analyze the effect of ambient temperature on the organic solar cell stability during the month of August, September and October 2019 are described. During the three months of observation the average maximum temperature is 23.12℃ for the month of August with a minimum of 22.70℃ in October. The result showed that , there is a variation of temperature during the months of observation.Also, a decrease of temperature in October which is attributed to the period when the atmosphere is cloud with a highest humidity. In addition, we observed from September to october that the solar output decreases with the increases of temperature which shows cleary the effect of tempearture on the organic solar stability. Adeeb et al. have also confirmed this result when conducting their research on the effect of temperature on performance of solar cell technologies [14]. Therefore, this result can be used as preliminary design steps in developping organic solar cell to be installed in tropical area.

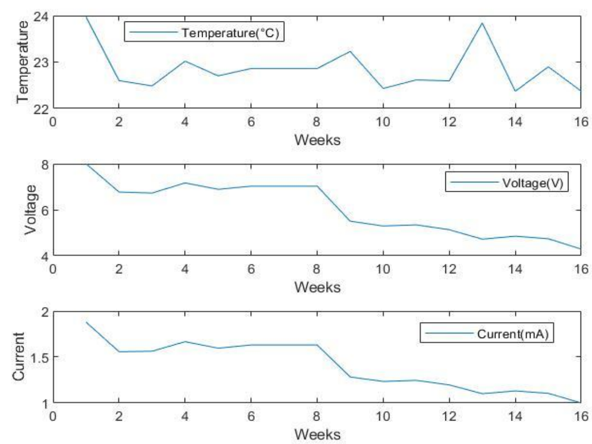

***Fig. 7:** Daily Average Temperature vs Voltage and current*

In the result Fig 8 data about irradiance is collected to analyze its effect on organic solar cell stability. The result has shown that the highest irradiance was in the month of August as shown in the graph. According to our observation irradiance increased proportionally with the voltage and current which shows the relationship between irradiance, current and voltage. The output power of organic solar cell increases proportionally to the irradiance. In conclusion, during the three months of observation there is no negative impact of irradiance on the performance of organic solar cell.

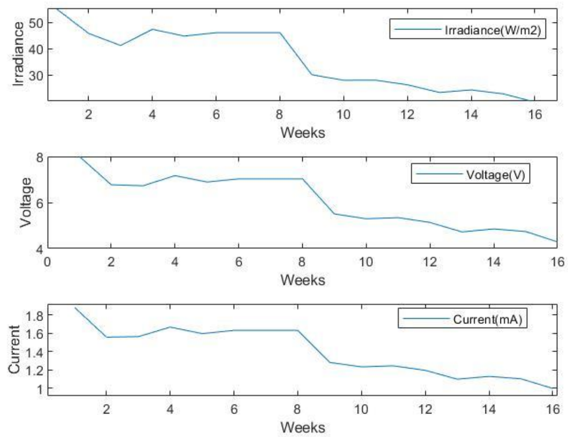

Fig. 8: *Daily average irradiance vs voltage and current*

Data collected in fig. 9 showed the analysis of humidity on the performance of organic solar cell. The result of the experiment has shown that, when humidity increased, it decreases significantly the current and voltage of organic solar cell. The highest humidity was observed during the month of October with an impact on the output power of organic solar cell which lead to a drop on the voltage and current. Since, current and voltage are the main parameters to analyze the stability of organic solar cell. The trend of the result has shown clearly that humidity has a great impact on the OSC performance. This result is approved by Tariq et al. who have also conducted review on the effect of the humidity on photovoltaic technology, and their findings demonstrated that high humidity causes a significant reduction in solar cell performance[15].

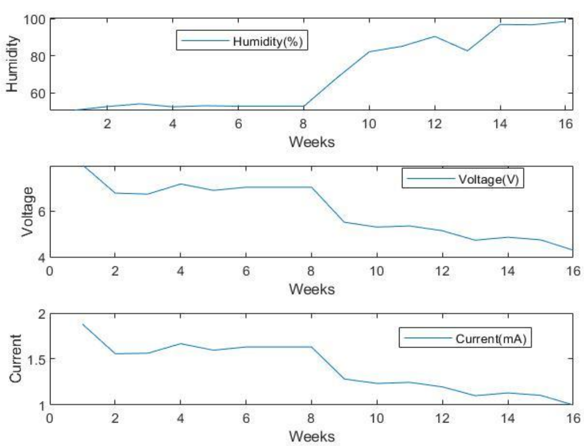

Fig. 9: *Daily Average Humidity vs voltage and current*

The result of the statistical analysis for the month of August, September and October are described in table 1.

Table 1: *Statistical Analysis*

August				
	Max	Min	Mean	STDV
Temperature(℃)	25.6	19	23.12	1.545
Humidity (%)	77.1	41.2	54.86	10.004
Irradiance (W/m^2)	68.2	17.9	43.526	12.55
Voltage(V)	9.7	3.9	6.983	1.315
Current(mA)	2.37	0.9	1.63	0.319
September				
Temperature(℃)	26.25	18.79	23.28	1.754
Humidity (%)	80.53	38.46	60.33	10.43
Irradiance (W/m^2)	42.59	20.22	31.69	5.571
Voltage(V)	7.32	3.84	5.82	0.713
Current(mA)	5.97	0.89	1.50	0.846
October				
Temperature(℃)	26.28	20.08	22.70	1.430
Humidity (%)	99.9	52.73	82.34	14.04
Irradiance (W/m^2)	35.70	18.79	27.89	4.013
Voltage(V)	6.44	4.036	5.29	0.544
Current(mA)	1.50	0.94	1.234	0.126
November				
Temperature(℃)	24.69	22.89	20.82	0.92
Humidity (%)	99.9	90.78	77.42	6.79
Irradiance (W/m^2)	29.48	21.67	13.59	3.67
Voltage(V)	5.60	4.48	3.27	0.58
Current(mA)	1.30	1.04	0.76	0.13

The overall result of the statistical analysis for the three months of observation indicate that data are more consistent around the mean about temperature, voltage and current. but we observed significant variations for humidity and irradiance. This result is relatively due to variation in weather conditions. The statistical analysis has shown that humidity is high in the month of October with a decreases in voltage, current, temperature and irradiance. Also, there is no significant differences on the data collected about the mean and standard variation about irradiance, voltage, current and temperature is observed during the three months of monitoring.

3.2 Data stored in Think view

Data shown in fig. 11 are real-time data collected though Internet and displayed in ThinkSpeak Cloud.

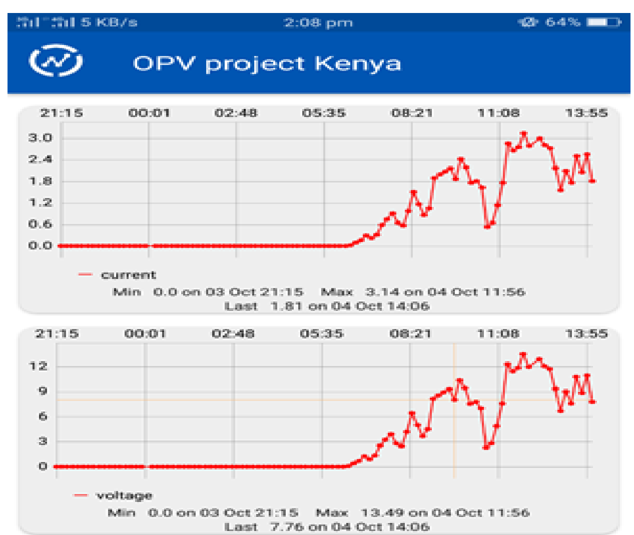

Fig. 10: *Data Displayed in ThinkView*

The real time data is collected from organic solar cell. Figure 4 has shown the data recorded and displayed on ThinkView through the Internet Once ThinkView is installed, the data was accessible on smartphone and on a computer. Data is stored and analyzed using Thinkspeak cloud. Some Researchers have also developed a prototype to implement an IoT based technology to monitor silicon photovoltaic plant using Arduino and results are displayed on Thinkspeak which shows an agreement with our result [16] .

3.3 Bleaching on Organic Solar Cell

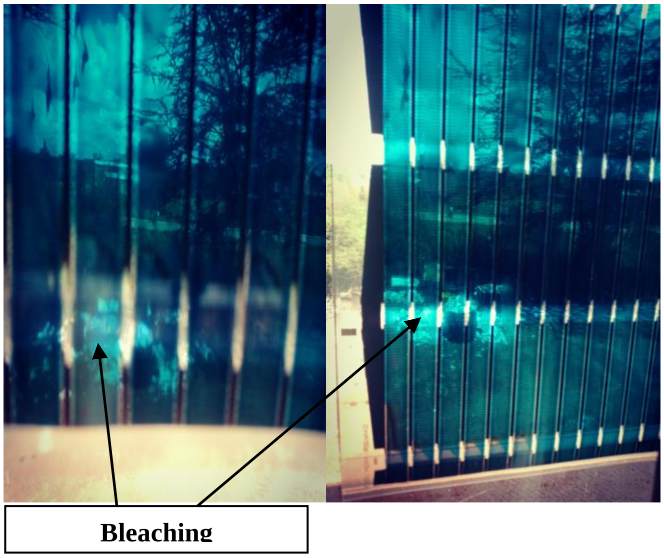

Fig. 11: *Organic Solar Exposed To Real-Condition*

The result of the experiment in Fig.11 show a photograph of the organic solar cell after three months of observation. It shows clearly some bleaching in the modules as a result of three-month exposure in real condition in Kenya. This trial experiment shows that bleaching or delamination is a significant cause of degradation of the modules and it is the cause of its instability. This may result in higher humidity or mechanical stress during transport and installation. In addition, the exposure of the modules in real condition allow the ingress of water, air and dirt into the modules and accelerate the delamination of modules.

4. CONCLUSION

In this research paper, we have demonstrated the efficiency of real-time monitoring system to collect data from organic solar cell, which is usually done manually and requires a lot of manpower. For this purpose, we used IoT technology that consists of a Wi-Fi module connected to a microcontroller with sensors to monitor solar panels parameters and others parameters related to weather. Our low cost monitoring system has a lot of purpose; it has solved the maintenance issue, which is a key role in photovoltaic system. In addition, it has allowed and efficient method for data collection using IoT platform called Thinkspeak. İn addition, this research investigated the stability of organic solar cell in tropical environment. So, the result has shown clearly different weather condition affecting organic solar cell stability and give a preliminary result of different factors to be considered for future development of the product. Therefore, for online monitoring the IoT technology has some disadvantages such as loss of privacy since it is an open source platform. However, this technology aids in data collection and very useful for remote locations. In future works, some features such as shutdown alert, remote management can be incorporated in the real-time monitoring system.

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