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Investigating the Impact of Dust Accumulation on Photovoltaic Modules: Case of Buea Region

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Abstract—**Photovoltaic (PV) modules are rated such that they yield optimum output under Standard Test Conditions (STC). Due to environmental effects, the efficiency of the module is reduced gradually after installation. Airborne dust deposition on the surface of PV module influence the transmittance of solar radiations from the PV module's glazing surface. In this work, an indoor experimental setup was performed using a mono-crystalline solar kit to investigate the effect of dust on PV modules in Buea. It was noticed that the accumulation of dust had a strong impact on the performance of PV modules as it considerably reduced the power production capacity by up to 58% and efficiency by 58% as well, a situation which aggravates progressively with mass deposition density of the dust particles.**

Keywords—Photovoltaic; dust; accumulation; efficiency

I. INTRODUCTION

Besides the low conversion efficiency as a result of intrinsic properties of the semiconductor materials used in the technology, the PV module is exposed to environmental conditions that again further reduces its efficiency such as temperature, dust, humidity, shading, wind velocity, hail, snow, fog, etc. [1, 2] Amongst the aforementioned, **dust** is one of the most acknowledge environmental factors that affect PV modules' performance. Its settlement mainly relies on the dust properties as well as the environmental conditions. Dust deposition has a negative effect on the PV modules performance as it leads to an increase in cells' temperature due to its additional converting of light energy into heat that circulates on the PV surface, a situation undesired for optimum performance of the PV cells which has as property; negative temperature coefficient. [3]

A. Characterization of Dust

Dust refers to particles of matter. It occurs in the atmosphere from various sources such as dust lifted by the wind, pedestrian dust and vehicle movement, volcanic eruptions, and pollution. Most often, dust is referred to as minute pollens (fungi, bacterial, and vegetation) and microfibers (from fabrics such as clothes, carpets, linen, etc) that are omnipresent and easily scattered to the atmosphere and consequently settles as dust. It is commonly applied to minute solid particles with diameters less than 500 µm [4].

Studies related to dust accumulation is critical as a further decrease in the system efficiency will tend to make PV systems an unattractive alternative energy source. Current research into characterizing deposition of dust and their impact on PV system's performance is limited given the fact that dust deposition is a complex phenomenon and is influenced by diverse site-specific environmental and weather conditions. [5]

B. Report on Previous Findings

Solar PV technology will no doubt lose its attractiveness if its low conversion efficiency is further reduced by external environmental factors such as dust reason why this study is of paramount importance. Over the years, researchers across the globe have applied different techniques in appreciating this issue.

Kaleid Waleed et al. in [6] simulated the effect of dust using the Matlab Software and found out that, the performance of solar panels widely declines by changing the quantity of dust accumulation homogeneously on the surface of the PV modules and the ideality factor. Ahmed et al. in [7] compared the results of indoor and outdoor experiments on the effect of dust in the United Arab Emirates at different tilt angles and observed a linear relationship between the dust density and the normalized PV power with a drop of 1.7% per g/m^2. Likewise, Sanaz Ghazi et al, in [8] under Brighton's climatic condition carried out similar experiments and concluded that the effect of dust on the surface of PV modules has little effect in the case of the United Kingdom (UK) given the many rainy days that characterize UK environment. Ehsan [9] studied The effect of dust deposition on the front surface of the PV module by using two identical Photovoltaic cells which were mounted on an angular movable stand and control board and noted that, the reduction in voltage generation by unclean panel due to natural pollution deposition on the front of the panel for three months was about 3.8% compared with clean panel and 13.8% if it has been compared with voltage production by the panel when it has been cooled by water. In the same vein, Dayal Singh Rajput et al [10] quantified the effect and concluded that we get the maximum efficiency of 6.38%, a minimum of 2.29% without dust & a maximum efficiency of 0.64%, minimum of 0.33% with dust. Their results show that dust considerably reduces power production by 92.11% and efficiency by 89%. Likewise, *Ehsan Fadhil* [9]. N. N. Nipu et al. in [11] arrived at a similar conclusion by simulating the I-V characteristics of a solar panel under clean and dusty conditions through P-Spice software (taking the Irradiance and temperature profile as input model) within 2weeks and a month of exposure.

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Using artificial dust (mud and talcum) under a constant irradiance conducted in an indoor laboratory Shaharin A. et al. [12] concluded that, the reduction in the peak power generated can be up to 18%. It was also shown that under greater irradiation, the effect of dust became slightly reduced but not negligible. In the study, it was further shown that the differences between the results obtained by using mud and talcum were generally small; that is about 6%. Different pollutant mass depositions were selected by Kaldellis and Kapsali [13] to simulate the effect of dust on PV module and the result proved that the worst deterioration is caused by the deposition of red soil, that is approximately 16 Wh energy decrease per hour, representing almost 19% of the respective energy produced by the clean pair panel. The effect is smaller for limestone and ash, that is approximately 10% and 6% reduction of the energy produced by the clean pair panel respectively, a conclusion that concurred with the findings of Hussein A Kazem et al. who added that larger reduction occurs when the PV module's temperature is increased and keeping the PV modules clean and cool results to efficient system performance [14]. J. Zorrilla-Casanova et al [15] studied, in general, the energy losses due to accumulated dust on the surface of photovoltaic modules using both ray-tracing technique and direct radiation on a simple model and concluded that the estimation of energy losses produced by the presence of dust has to be calculated differently for photovoltaic systems with fixed modules or with solar tracking. Muhammad Ali et al [16] investigated the effect of dust by using four commercially available photovoltaic modules of two different types (two mono-crystalline (c-Si) and two polycrystalline (p-Si) silicon modules). During the study, one module of each type was remained in the outdoor atmosphere for three months to accumulate dust naturally on the panel surface and concluded that the performance of PV modules decreased progressively with the amount of dust deposited on its surface with the monocrystalline incurring higher losses after 11weeks of environmental exposure. A.K. Tripathi et al [17] on their part carried out a study using an indoor solar panel set-up with the help of a solar simulator to determine the effect of dust shading, red soil was used in a string of PV modules. The soil of size less than 35µ was used for this purpose which proved that the power output of PV panel drops drastically with the shading of one solar cell in a string. Areej Ghazi and Falah Mustafa [18] studied dust characteristics using microscopy technics and its effect on PV modules in Baghdad-Iraq and found out that, the accumulation of dirt is not consistent with dust only but a chunk of dust, birth droppings, and many other components that stick on the panel surface and creat a hotspot in the panel leading to undesirable temperature rise. Aminul Islam et al [19] studied the effect of dust by exposing for a month, the solar panel on the natural environment in Bangladesh. Their conclusion led them to up to 35% decrement in power as a result.

II. METHODOLOGY

A. *Study Area*

The study area lies on the lower slopes of Mt. Cameroon, and Buea to be precise which is located within latitudes 4.000-4.130 N and longitudes 9.000-9.300 E. The climate of Mt. Cameroon is a humid tropical one, characterized by a pronounced dry season (mid-November to March) and wet season (mid-March to November) [20] with an average rainfall of 2559.12 mm/year recorded between 2011 and 2015. The combination of high relief (4095 m) and proximity to the sea leads to strong local climatic contrasts. Mean annual temperatures reported between 2008 till 2010 varied between 19.9ºC and 27.1ºC. Mt. Cameroon soils are formed from lavas, pyroclastic flows, and lahars transported as mudflows from the top of the volcano. [20] the organic matter of the topsoil is about 5% and decreases with depth. They are relatively rich in nutrients but are susceptible to wind erosion. [21]

B. *The Solar Kit*

For the experiment, a solar trainer was used which is made up of a solar cell unit consisting of a stand-alone housing with integrated transformer and inclination adjustable monocrystalline module containing four identical solar cells of 5 x 10 cm, off-load voltage approximately 0.5V, short-circuit current of approximately 1.5A (1.00 W/m^2). Coupled with the module amongst others are a miniature 5 x 20 mm fuse-link with a maximum current capacity of 1A, a mains connection (230Vac/50Hz), a 12V low voltage connection for the irradiation unit, a mains switch (position ―off counter-clockwise rotation stop) and brightness control (scale; 0 to 10), and a degree scale for solar module inclination and countermark of the degree wheel. A sensor is used to measure the irradiance in connection with a multi-meter in the measuring range of 2,000mV. The measurement of the irradiance is in W/m^2, where 1W/m^2 = 1mV. For measurement purposes, the device must be aligned with the sensor field towards the source of light so that the rays fall vertically on the round sensor field. The solar cell and the sensor field must not be shaded during the measurement.

An irradiation unit is used to irradiate the solar cells unit with artificial light incorporating a 12V/50W Halogen lamp. This was chosen with the assumption that, at a distance of approximately 10-15cm from the halogen lamp, the same value is achieved as that which is achieved during the measurement of the irradiance of the sun on a clear day. A variable resistor is used as the load to the solar cells with the resistance being varied and measuring the voltage and the current produced by the solar cells unit. The load resistance characteristic values are 100 ohms and 2W maximum. The complete setup of the solar kit used in this experiment is shown in fig. 1

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Fig. 1. Solar Kit Used for Experiment

C. Dust Samples Collection

To study the effect of dust, topsoils developed on basaltic rocks representing different stages of soil development were sampled from four sites which are Buea town, Molyko, University of Buea campus, and Muea. These soil samples were collected from the soil horizons up to a depth of 50cm. The samples were air-dried for over 3 days and stored in plastic bags. Roots and litter were removed and samples lightly crushed with fingers to loosen soil aggregates and remove rocks. The samples were air-dried and sieved through a 2mm sieve. The samples were then weighed and adequately mixed. On Thursday, July 13, 2017, the soil was poured into two liters of water in a container and left for four days for the soil to soften up to have a finer quality, where it was then filtered. Clear polyvinyl chloride (PVC) transparent papers of thickness 0.15mm and A4 size were used to simulate the effect of dust. After haven treated the sheets with alcohol to free them from oil and to enable them to better attract the soil, they were immersed one after the other and left for 10 minutes inside the solution while gently stirring it to have a homogenous mixture in the process. The soil-coated sheets were then removed and air-dried in the lab to dehydrate. A total of 5 sheets were used to appreciate the effect of dust at different degrees of deposition.

Fig. 2. Dust Samples

D. Experimental Setup

The experiment was set up indoors in the Postgraduate laboratory of the Faculty of Engineering and Technology in the University of Buea as shown in fig. 3. The cells were connected in parallel to put the module to full capacity. To eliminate the effect of ambient light as it is not very stable and has an impact on the module, a black box was made to contain the panel and the light source while the multi-meters and 0-to-100 ohms variable resistors were placed out of the box. A multimeter was connected as a voltmeter, with the range selector switch set to position DC V 20. Another multi-meter was connected as an ammeter with its range selection switch at DC A 10. The lamp arm was put in the south position with the solar cells in position 90 degrees and the brightness controller fixed to its maximum (level 10) which gave an irradiance of 170 W/m^2.

Firstly, the measurement of the current through and the voltage across the resistor varying its resistance from maximum to a minimum was recorded. The process was then repeated under the same setup with clean and dusty sheets placed on the surface of the module cumulatively. The clean sheets stocked normally on the module while the dusty sheets stocked with the help of a cello tape at the edges of the module.

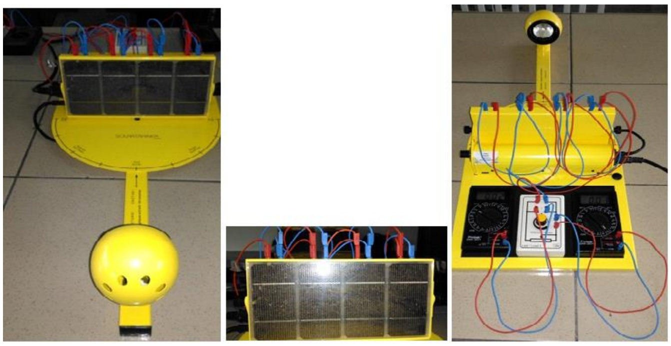

Fig. 3. Experimental Setup

III. RESULTS AND DISCUSSION

Here, the results obtained in the experiments carried out as described above are presented and discussed.

The voltmeter reading using the solar pyranometer was 170mV corresponding to an irradiance of 170W/m^2. With the module's cells occupied area (A_C) of 0.02 m^2, the input power is calculated as;

$$P_{in} = \frac{170W}{m^2} * 0.02m^2 = 3.4W$$

This power is the same throughout this experiment since the cell's area and the irradiance are kept constant.

A. Analyses of plan module without sheets

Here the module is characterized under the particular conditions that follow through the experiments. The current and voltage data obtained gave the curve shown in fig. 4 below.

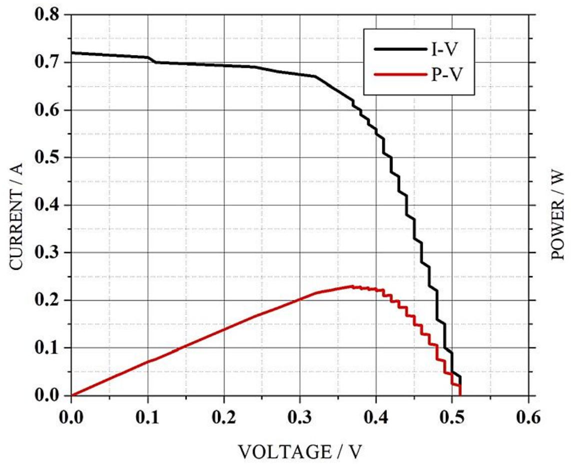

Fig. 4. Current-Voltage Characteristics of the plain module without dust

The maximum parameters (current, voltage, and power) measured are shown in table 1.

Table 1. Observations for plain module

Imax (A)	Vmax (V)	Pmax (W)	Isc (A)	Vsc (V)
0.62	0.37	0.2294	0.72	0.51

With the maximum power (P_{max}) as depicted above, the efficiency of the solar module is calculated as;

$$\eta = 0.2294/3.4 * 100 = 6.7\%$$

This is far below close to 25 percent efficiency expected from the monocrystalline PV module reason being that the irradiance is far below the standard test irradiance of 1000 W/m^2.

B. Study of the influence of a clean sheet on the module

This was done following the same procedure as was done with the plain Module. Analyzing the data obtained from the experiment gave the fig. 5 below.

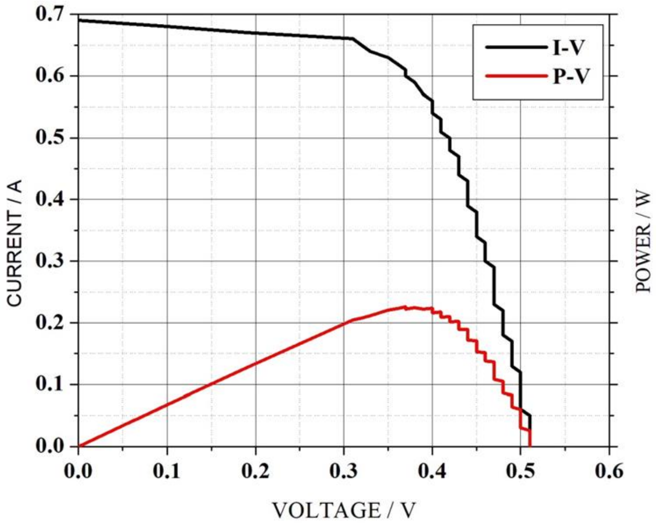

Fig. 5. The outcome with a single clean sheet on the module

Table 2. Observations of a single clean sheet

Imax (A)	Vmax (V)	Pmax (W)	Isc (A)	Vsc (V)
0.61	0.37	0.2257	0.69	0.51

Here, the efficiency drops slightly as calculated below due to the influence of the sheet on the surface of the panel

$$\eta = 0.2257/3.4 * 100 = 6.6\%$$

Comparing the two outcomes makes it clear that, the clean sheet on the module has little effect on the module's efficiency as the difference between the efficiencies without and with the sheet is 0.1%. Hence the sheet has minimal impact on the module's operation.

Below is the observation on the influence of dust considering different mass deposition of dust on the module in terms of the number of sheets.

C. Analyses of Dust Effect Using Single Sheet

The plot of the result using a single sheet in both dusty and clean conditions are displayed below with figs. 6(a) and (b) representing the behavior of the dusty and clean sheets on the module respectively.

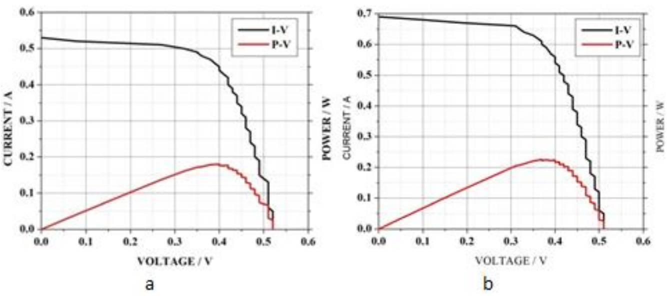

Fig. 6. Effect using Single sheet. a) Dusty sheet; b) Clean sheet

Table 3. Observations in the case of a single sheet

Dusty Module					
Imax (A)	Vmax (V)	Isc (A)	Voc (V)	Pmax (W)	$\eta_{d\ cell}$ (%)
0.45	0.40	0.53	0.52	0.180	5.3
Clean Module					
Imax (A)	Vmax (V)	Isc (A)	Voc (V)	Pmax (W)	$\eta_{c\ cell}$ (%)
0.61	0.37	0.69	0.51	0.2257	6.6

Applying the equations (1) and (2) below, we get a percentage reduction in PV power output of 20.2% and a percentage reduction in PV cells efficiency of 19.7%.

$$\%P_R = \frac{P_{clean} - P_{dirty}}{P_{clean}} \times 100 \qquad (1)$$

Where P_R is the reduction in power production, P_{clean} is the output power of the clean PV module, and P_{dirty} is the output power of the dirty module.

$$\%\,\eta_R = \frac{\eta_{clean} - \eta_{dirty}}{\eta_{clean}} \times 100 \qquad (2)$$

Where η_R is the reduction in the PV cell efficiency, η_{clean} is the efficiency of the clean PV module, η_{dirty} is the efficiency of the dirty PV modules.

D. Analyses of dust effect using five sheet

The plot of the result using five sheets in both dusty and clean conditions is displayed below with fig. 7 representing the behavior of the dusty and clean sheets on the module respectively.

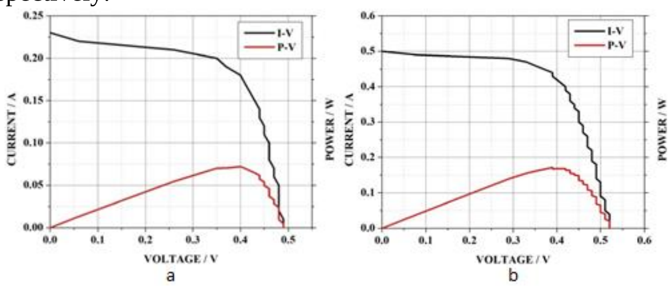

Fig. 7. Effect using five sheets. a) Dusty sheet; b) Clean sheet

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Table 4. Observations in the case of five sheet

Dusty Module					
Imax (A)	Vmax (V)	Isc (A)	Voc(V)	Pmax (W)	$\eta_{dcell\ (\%)}$
0.18	0.40	0.23	0.49	0.072	2.1
Clean Module					
Imax (A)	Vmax (V)	Isc (A)	Voc(V)	Pmax (W)	$\eta_{c\ cell\ (\%)}$
0.44	0.39	0.5	0.52	0.1714	5.0

Again, applying the equations (1) and (2) below, we get a percentage reduction in PV power output of 58% and a percentage reduction in PV cells efficiency of 58%

The output power of the module decreased continuously as dust accumulation increased. As the dust layer on the surface of the module was made thicker, the loss of module output power and efficiency increased. Fig. 8 and 9 show the efficiency and power variations respectively with dust accumulation in order of the number of dusty sheets.

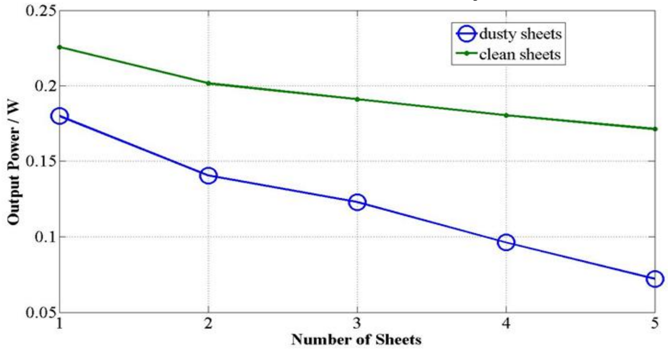

Fig. 8. Module's Power of Clean and Dusty Module against Number of Sheets

It was seen that the difference in module efficiency between plain module and module whose surface is covered with a clean sheet is 0.1% which is very small to influence the performance of the module. The efficiency and output power of the module showed a progressive increase in percentage reduction as dust accumulation increased, taking five different mass depositions. This could be a result of the fact that dust particles on the surface of the module scatter the rays of light that were supposed to be absorbed by the PV cells. Also, dust trapped on the surface of the PV module converts the light energy it absorbs into heat energy which radiates on the surface of the module thereby increasing its temperature above the standard room temperature desired by the PV module.

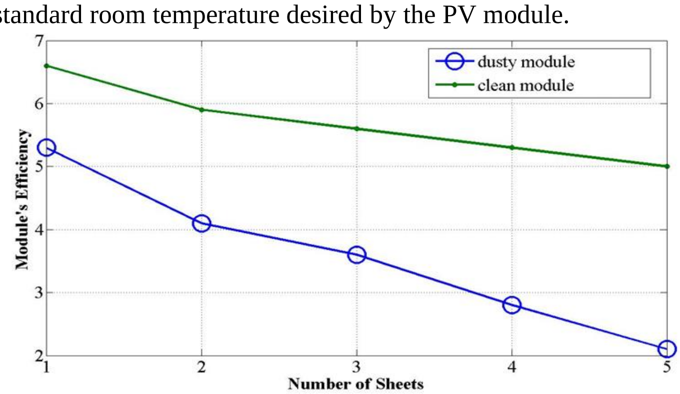

Fig. 9. Module's Efficiency of clean and dusty module against number of Sheets

Initially, one sheet was used in both clean and dusty conditions, and comparing the results gave a 20.2% and 19.7% reduction in power and efficiency of the module respectively. Cumulatively increasing the number of sheets (both clean and dusty) separately led to a progressive increase in percentage reduction of the module's power and efficiency respectively up to 58% each for five accumulated sheets. These outcomes are depicted in figs. 10 and 11 below.

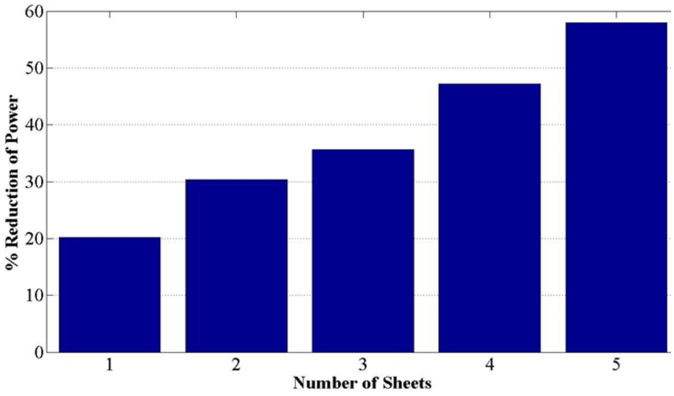

Fig. 10. Percentage Reduction of Power of Dusty Module Compared to the Clean Module

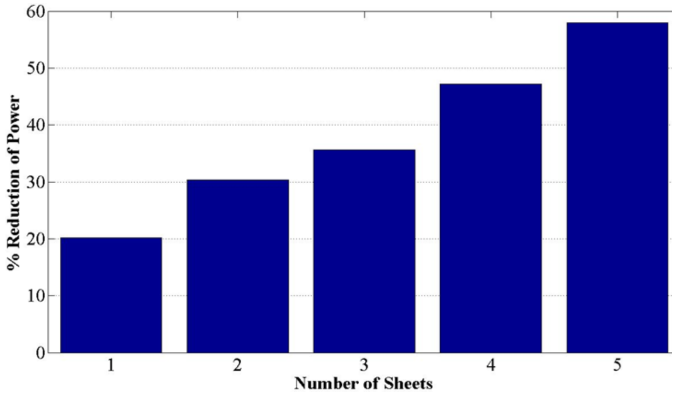

Fig. 11. Percentage Reduction of Efficiency of Dusty Module Compared to the Clean Module

IV. CONCLUSION

The effect of dust on the performance of a PV module was investigated in an indoors experimental set up at different mass deposition using transparent sheets. The output power, hence efficiency of the module was significantly affected by the dust deposition density on the module surface. The clear sheet was found to have little effect on the module's performance. We got the maximum efficiency 6.6%, minimum 5% without dust & maximum efficiency 5.3%, minimum 2.1% with dust. The result shows that dust considerably reduces the power production by 58 % and efficiency by 58%. It is recommended that, for proper sizing of solar PV systems, consideration on the influence of dust on the output should be taken into account in the given locality, given the fact backed up by our literature review that, different dust types, hence profile affect panels differently. By so doing, it is advised to add a factor to cater for this at the design stage, program preventive maintenance to ensure continuous optimum output or both of them.

Although this work has met its immediate objectives, research in the following areas will be needed in the future to improve on the quality of the work as well as serve as areas for further research.

- The experiment should span a year in other to see real life environmental effects like dust settlement temperature and moisture on the PV module in sub-Saharan Africa (Buea).
- The experiment should be done using the various commercially available PV modules of the Crystalline and Thin film family to decide on the one that best suit the study area.
- Span the work to cover the Northern and Center regions of Cameroon where the temperature, soil and weather are quite different from that of Buea.
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