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# IMPACT OF DUST PARTICLES ON THE OUTPUT POWER OF PHOTOVOLTAIC MODULES IN CALABAR, CROSS RIVER STATE

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## ABSTRACT

During the dry season, dust particles on photovoltaic modules (PV modules) are a regular occurrence in Calabar, Cross River State. This dusty condition or environment is caused by the migration of dust particles from the Sahara region via the east-west wind. The concentration of dust on PV modules has an impact on the overall performance of solar energy systems. This research looks into the effect of dust particles on the output power of solar modules. This investigation was carried out by subjecting 80-watt monocrystalline PV modules to an outdoor experiment and analyzing the changes in current and voltage from the control and dusty PV modules with a digital multimeter. Other environmental factors such as relative humidity, ambient temperature, and solar radiation were also measured with a hygrometer, thermometer, and solar power meter respectively. Appropriate formulars were employed to calculate output power and efficiency. Dust particles on the surface of PV modules dramatically reduces the quantity of sunlight that penetrate the panel by 21.10%, resulting in a drop in the system's overall output power. The study emphasizes on the importance of frequent cleaning and maintenance of PV systems.

**Keywords:** Photovoltaic Modules, Output Power, Monocrystalline, 80W, Efficiency**.**

## INTRODUCTION

The demand for clean and sustainable energy sources has led to the rapid growth of solar photovoltaic (PV) installations worldwide. Nigeria, like many other countries, is embracing solar energy as a means to diversify its energy mix and reduce its reliance on fossil fuels. However, Nigeria's geographical location exposes solar panels to various environmental challenges, including high dust levels. Dust accumulation on the surface of solar panels reduces their efficiency by blocking sunlight and creating hotspots.

Photovoltaic modules (PV modules) are made up of multiple layers, including a protective cover, an anti-reflective coating, and a cell encapsulation layer, to protect the cells from environmental damage and ensure maximum energy production. The cells are usually made of silicon, and can be either monocrystalline, polycrystalline, or thin-film (Shanmugam *et al.,* 2020). Monocrystalline cells are made from a single crystal of silicon and are the most efficient, while polycrystalline cells are made from multiple silicon crystals and are less efficient. Thin-film cells, on the other hand, are made from layers of different materials and are less efficient than both monocrystalline and polycrystalline cells, but are more cost-effective. PV modules are used in a wide range of applications, from small portable devices to large-scale power plants. They are commonly used in residential, commercial, and industrial settings to generate electricity from sunlight, and are key component of renewable energy systems.

All inorganic PV cells have two layers of semi-conductors, one n-type and another p-type. When light shines on the semi-conductor, the electric field across the junction between these two layers causes electricity to flow, generating DC (direct current) (Yang, *et al*., 2021). A typical silicon photovoltaic cell produces less than 3 watts at 0.5 volts DC; therefore, cells must be connected in series or parallel configurations to form PV modules to produce enough power for high-power applications (Al-Showany *et al*., 2016). Modules have peak output powers varying from few watts to more than 350 watts, depending on the application. If the application requires output power to range from few hundred watts to megawatt range, modules are connected in series, parallel or series-parallel configurations to form PV arrays (Kouro *et al*., 2015).

Generally, PV systems are considered to be an expensive method of producing electricity. However, in remote locations PV system is very often the most economical solution to provide electricity. The growing PV market all over the world indicates that solar electricity has entered many areas in which its application is economically viable (Hoffmann, 2006). Additionally, the rapidly growing application of photovoltaic in utility grid-connected situations shows that photovoltaic are very attractive for a large number of people, companies and governments who want to contribute to the establishment of new and more environmentally friendly electricity supply systems. Also, many research and development centers are working towards reductions of cost envisaging mass production of photovoltaic systems, leading to further attractiveness of this technology and its extension to other fields of applications (Martins *et al*., 2008).

The energy from the sun incident on the earth's surface in an hour is almost equal to the one-year total consumption on earth (Styszko *et al*., 2019). However, when solar radiation penetrates the atmosphere, a significant amount of its energy is lost due to the fact that sun radiation is absorbed by solid particles (dust particles) and droplets in the atmosphere and reflected by water vapor and air molecules (Styszko *et al*., 2019). The dust particles or solid particles that is also absorbed by solar radiation, decreases the direct solar radiation components and causing an increase of the diffused components. For this reason, the urban and polluted areas typically receive less of the total solar radiation in reference to the clean air of the country side or industry-free rural area (Darwish *et al*., 2018). The term dust is defined as any substance or particle of matter that exist in the atmosphere with less than 500µm diameter (10 times smaller than the diameter of human hair) but not limited to solid inorganic and organic particles such as soil particles, smoke (including factory smoke, vehicular smoke and firewood smoke) volcanic vapor, bacteria, pollen, fungi, microfibers and eroded limestone (Darwish *et al*., 2013). These particles exist in different sizes, volumes, chemical concentrations and shapes. In

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addition, the particle types vary with geographical locations and their local activities. The term soiling on the other hand refers to the process by which dirt, dust and contamination are deposited and accumulated on the surface of a solar PV module. Dust accumulation is considered the third most significant factor that can influence the performance of a solar PV module after solar radiation and temperature. It is difficult to generalize the loss level caused by soiling on a PV module because the severity of soiling varies with geographical location and seasonal climatic conditions (John *et al*., 2015). Most locations with high solar potential across the world are either arid or semi-arid, experiencing insufficient rain and pervasive dust which is considered one of the primary mechanisms that significantly affects the overall performance of PV devices (Al Shehri *et al*., 2016). Hence the formation of dust on the PV module degrades the overall performance and reduces maximum yield during its expected period of operation.

Studies in the past have shown that the accumulation of dust on the surface of PV modules can reduce their energy output up to 50% in some cases. The dust can also cause hot spots on the solar cells, which can lead to permanent damage and reduce the lifespan of the modules. (Said, *et al.,* 2018)

Chanchangi *et al*., (2020) examined the effects of dust accumulation on PV module performance. They found that energy lose in PV modules is due to the accumulation of dust on PV. However, their review presents a number of mitigation techniques which are available to maintain a certain level of performance. From their review, there is a need to further conduct comprehensive research on the effects of dust in all geopolitical regions in Nigeria to acquire data that can be used for designing the PV module system considering the most suitable technique in reducing or preventing the effects of soiling in each specific area.

Abdulkarim *et al.,* (2022) suggested that the impact of dust on the solar PV modules deserves more attention. According to them, North-eastern Nigeria has high potential of solar irradiance but it is pruned to dust accumulation. Their paper therefore, investigated the impact of dust on the performance of solar Photovoltaic modules in North-Eastern Nigeria. They carried out a field experiment in Maiduguri to assess the performance of the module based on continuous dust deposition for 14 days during dust accumulation period. Their results showed that more than 50% loss in power output was recorded under 14 days of continuous deposition. The efficiency of the module reduced from 17.1% on the first day to 7.2% on the fourteenth day of the experimentation. Their investigation also showed that at high humidity the PV performance reduces. Solar irradiance increases the performance. The deployment of solar PV energy supply system is recommended in spite of dust accumulation challenges. To maintain adequate performance of the system, a once-a-week cleaning is recommended during intense dust period

Amusan, and Muzan, (2020) *investigated the effect of dust on the output performance of a solar module. In their investigation they used a 250W monocrystalline modules (control and dust). The experiment was performed in the University of Port Harcourt, at the Basic Unit in Abuja Campus, Rivers State, Nigeria with longitude 4.903674˚N and latitude6.923759˚E. The amount of current and voltage generated by both panels, under solar radiation, were recorded using a digital multimeter at an interval of 15minutes between 7.00am and 4.00pm for a period of 7days. Measurement data and graphical analyses were used to evaluate the I-V characteristics of the control and dusty modules, and also the amount of output power generated by both modules. The minimum and maximum values of the cumulative average power output obtained for the control module were 2156.16W and 5790.655W respectively. While the minimum and maximum values of the cumulative average power output (watt) obtained for the dusty module were 1743.277W and 4714.068W respectively. The percentage reduction in output power for the solar module with dust typically ranged from 5.92% to 28.78%. Their results reveal that dust particle accumulation on the surface of solar module leads to a significant reduction in the current, voltage and amount of output power generated by a solar module which in turn abates its overall performance. Their investigation suggests regular cleaning of PV modules.*

Njoku *et al*., (2020) evaluated the thermal profiles and the electrical power outputs of PV modules in order to establish the impact of soiling under tropical field conditions. Two case-study PV installations in the University of Nigeria were considered. Assessments of the PV systems, undertaken both when soiled and after they had been cleaned, involved the measurement of electrical power outputs and the acquisition of infrared (IR) thermograms. They found that soiling had noticeable impacts on both module surface temperature distributions and their power outputs. The IR images, which showed spatial distributions of module surface temperatures, revealed the occurrence of hotspots on the modules when soiled. Furthermore, as a result of soiling, up to four-fold declines in module electrical efficiencies were observed. These declines were more significant in the ground-mounted PV system at the University Staff Primary School compared to the roof mounted system at the University Energy Research Centre. Simple cleaning of the modules led to the disappearance of hotspots and significant improvements in output, showing that it is an effective means of maintaining PV modules performance and recovering the performance potentials lost due to soiling.

Chukwuekum, and Oseme, (2020). Their study is based on the effects of dust particles accumulation on the performance of solar photovoltaic panels and also to remove dust particles accumulation on the surface of PV panel using mitigation method that require minimum amount of energy and less use of water. Their research was conducted to determine the influence of dust particle accumulation on solar panel with constant light source deliver by halogen lamp, to establish the output power generated and the efficiency. It was concluded from their study results that dust accumulation on the surface of PV panel can reduce solar panel system efficiency by up to 30-50%. It was notice that the output power of the solar panel after cleaning with pressurized water and soap is 2.31 W, water and surfactant is 2.295 W, while the output power for solar panel surface coated with thin glass nano-structure is 2.43 W. The results clearly show that coating the surface of PV panel with conducting material is the best method to mitigate dust accumulation. This method has good advantages since water is not require, which is rare and quite expensive in northern part of Nigeria.

Hussain *et al.,* (2017) experimental study on effect of dust on power loss in solar photovoltaic module shows how seven dust samples were carried out at three radiation levels of 650, 750 and 850 W/m$^2$ with different dust samples weights. Due to accumulation of dust particles on the surface of solar PV systems, and output power is reduced to a large extent. It is concluded that a small layer of dust itself reduces PV system efficiency to a large extent. The minimum power value of 3.88 W is obtained during the accumulation of rice husk on the solar PV module. From the SEM analysis and obtained

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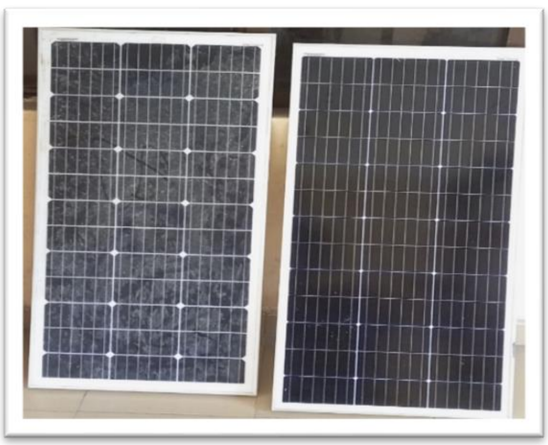
power values, it is confirmed that the smallest particle blocks more sunlight and thus reduces the efficiency of solar panels and modules. They concluded that in desert areas where probability of sunlight is maximum and where a solar array plan can be established, due to the accumulation of dust the efficiency of solar modules and panels in terms of power can be reduced up to 60%.
Diop *et al.,* (2021) evaluated the influence of dust deposition on the electrical performance of silicon-based photovoltaic cells by a model. They analyze the losses of electrical characteristics as a function of dust. This enables them to evaluate the losses of electrical characteristics such as production efficiency, power output, short-circuit current and fill factor of monocrystalline silicon based photovoltaic cells as a function of dust deposited on the surface of these solar modules in Dakar, Senegal.
Firstly, their work showed that the deposition of dust on PV cell surfaces does not significantly change open circuit voltage. However, short-circuit current affected by this dust deposit with loss of about 51% for a dust layer of 70µm (corresponding to dust deposit of 3.3 g/m$^2$) compared to clean cell current. Their main conclusion was that cleaning the cell should be considered in order to optimize it electrical performance from dust layer thickness of 70µm (corresponding to dust deposit of 3.3 g/m$^2$).

**MATERIALS AND METHODS**



a. 80watt monocrystalline solar

**Panel specification**
The manufacturer's technical specification given at standard test condition (STC) were given below as;

i. Temperature 25$^0$ C
ii. Solar radiation 1000W/m$^2$
iii. Air mass 1.5
iv. Peak output power 80W
v. Peak voltage power 17.5V
vi. Current at peak power 4.57A
vii. Open circuit voltage 22.05V
viii. Open circuit voltage 22.05V
ix. Open circuit current 5.12A
x. Surface area of panel 0.61m$^2$
xi. Module efficiency 13.11%

b. Thermo-hygrometer



C. Digital solar power meter


d. Fluke 117 digital multimeter

The solar panels were kept inclined at an angle that was varied with the horizontal. The length of the panels was aligned along the north-south direction. The experiment was carried out by having natural dusts deposited on one of the solar panels. Test was

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conducted also with the clean solar panel in order to quantify the effects of dust on the performance of the PV panel. Short circuit current (*Isc*) and open circuit voltage (*Voc*) were obtained using the fluke digital multimeter. This measurement was carried out in an interval of 30 minutes from 6.00am to 6.00pm daily. The ambient temperature was read directly from the digital thermometer and the solar panel temperature was determined using the sensing probe fixed to the panel. The relative humidity was also determined directly from the hand-held hygrometer and the time of the day recorded respectively.
From the data collected, the output power was obtained using the formula

$$P_{mea} = V_{mea} \text{ X } I_{mea} \ (V \text{ X } I) \quad (1)$$

Also, the module efficiency was calculated as,

$$\eta_{mod} = \frac{\text{Power of solar panel x 100\%}}{\text{Area of solar panel x 1000W/m}}2 \quad (2)$$

But the normalized efficiency was calculated as;

$$\eta_p = \frac{\text{Pmea}}{\text{Pmax}} \text{ X } 100 \quad (3)$$

From the above equations, $P_{mea}$, $V_{mea}$, $I_{mea}$, $P_{max}$ are the measured power, measured voltage measured current and maximum power respectively. Also, $\eta_{mod}$, $\eta_p$ is the module efficiency and normalized efficiency.

## RESULTS AND DISCUSSION

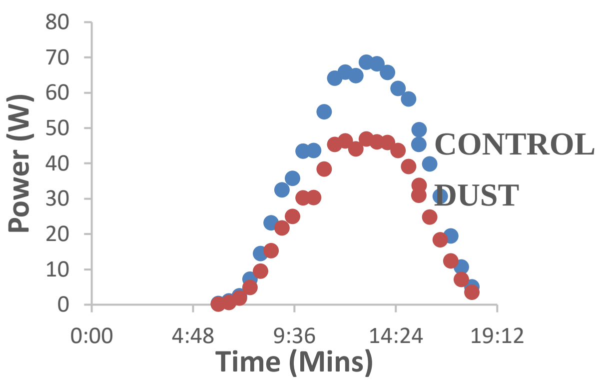


**Figure. 1.** Power (W) against Time (Mins)

Figure1 represents graph of output power against time. From the graph, the output power of PV modules dependent on time. The graph shows the best performing time of the PV module to be found around 1pm, although the dusty panel was seriously affected by the accumulated dust on it which led to the output power reduction. Again, from the graph we saw that output power started rising appreciably from 9am to it pick at 1pm and start falling from 3pm. Hence the output power of PV module depends heavily on the time of the day. This agrees with (Kazem *et al.,* 2019).

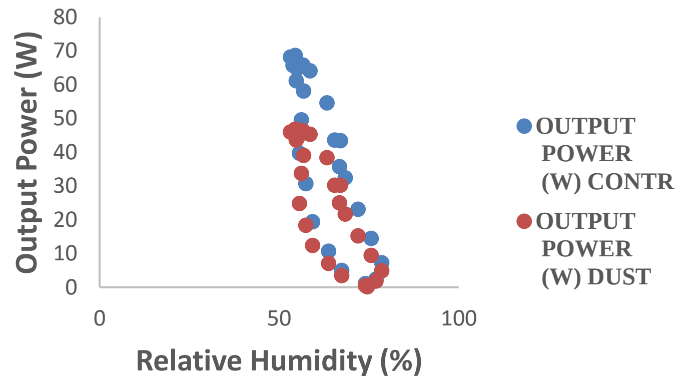


**Figure. 2.** Output power (W) against Relative Humidity (%)

Figure 2 is a graph of output power against relative humidity. It showed that decrease in relative humidity lead to increase in the output power of photovoltaic module and increase in relative humidity leads to decrease in the output power of photovoltaic module.

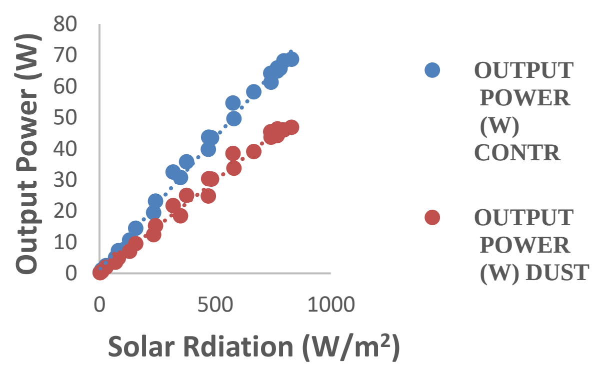


**Figure. 3.** Output Power (W) against Solar Radiation (W/m$^2$)

The performance of PV module is highly determined by solar radiation. The higher the solar radiation the better their performance. Again from the graph, the control panel has more output power than the dusty panel because of the accumulated dust on it. Hence high level of solar radiation leads to high power generation (Ettah *et al.*, 2011)

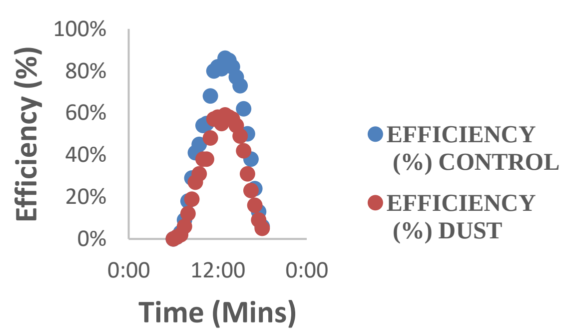


**Figure. 4.** Efficiency (%) against Time (Mins)

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Figure 4 is a graph of efficiency against time. From the graph, efficiency of PV modules dependent on time. The best performing time of the PV module from the graph is found to be around 1pm, although the dusty panel was affected by the accumulated dust on it which led to the gradual reduction in efficiency. Hence the efficiency of PV module depends heavily on the time of the day.

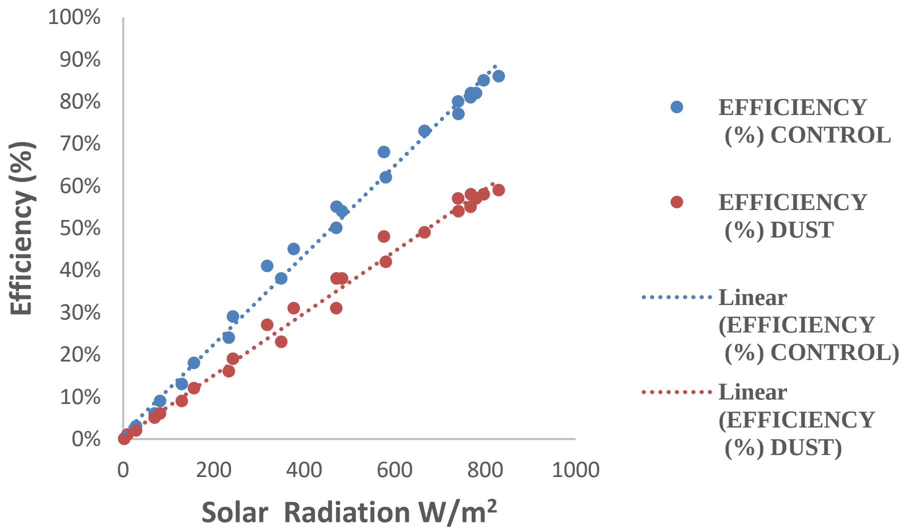


**Figure. 5.** Efficiency (%) agaist Solar Radiation (W/m$^2$)

Again from figure 5, increase in solar radiation favours increase in efficiency as seen in figure 5 above which inturns favours the over all output of PV module. The control panel has it all time efficiency to be 86% against 59% for the dusty panel.

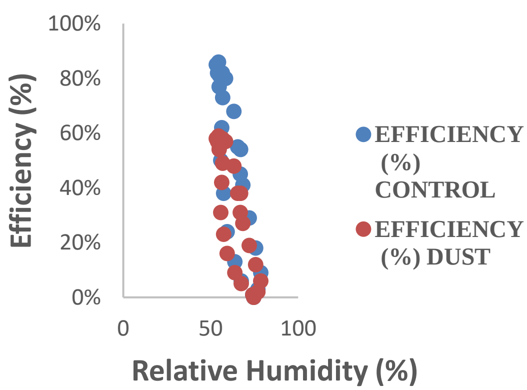


**Figure. 6.** Efficiency (%) against Relative Humidity (%)

Figure 6 a graph of efficiency against relative humidity. From the graph, continious increase in relative humidity leads to a decrease in efficiency and vise versa. (Ettah *et al*., 2011)

**Conclussion**

The performance of photovoltaic modules is affected by the presence of dust particles on their surface. This study investigated the impact of dust particles on the output power of photovoltaic modules. Two 80W monocrystalline commercial sunshine photovoltaic modules with other equipment were employed in this study. The study was carried out by exposing the photovoltaic modules to an outdoor environment and measurement was taken for voltage, current, panel temperature respectively. Other environmental parameters like relative humidity, ambient temperature and solar radiation were also determine using hygrometer, thermometer and solar power meter for an interval of 30minutes from 6.00am to 6.00pm every day for two months. From the results, output power and efficiency were calculated. The findings revealed that the output power of photovoltaic modules decreases with increasing dust concentration on the PV modules which in turn affects the efficiency of the PV modules. The study provides insight into the impact of dust on solar energy systems and highlights the need for effective cleaning to maintain the performance of photovoltaic modules.

**Recommendations**

Based on the findings of this study, it is recommended that;

**1.** Effective cleaning techniques be developed to maintain the performance of photovoltaic modules in areas with high dust concentration.

**2.** The use of automated cleaning systems, such as robots or waterless cleaning methods, should be explored as a potential solution to reduce maintenance costs and improve the efficiency of solar energy systems.

**3.** Further research is needed at different locations of the state to quantify the effect of dust on solar panels

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