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ORIGINAL RESEARCH ARTICLE

PERFORMANCE EVALUATION OF SOILING MITIGATION TECHNIQUE FOR SOLAR PANELS

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ABSTRACT

Soiling is the accumulation of dust, leaves, and debris on the surface of photovoltaic modules which affects its overall conversion efficiency. Globally, several researches have indicated that with an increase in dust accumulation, the efficiency of the solar panels can drop by approximately 50%. This research aimed at increasing the efficiency of solar panels by mitigating the effects of soiling. The panel was incorporated with a dust sensor that senses increment in dust settlement and a DC Fan/blower which was placed in a position covering the surface of the panel. The speed of the installed fan can be varied using an L293D motor driver. It is actuated when the light intensity of the module falls below a set threshold. Solar energy parameters of the panel were measured and displayed on the constructed onboard controller. A comprehensive analysis was carried out on the design and the results show a 72% increase in efficiency after mitigation which reflects that controlled wind is an ideal technique in eliminating dust on solar panels.

1.0 Introduction

The use of a non-renewable source of energy such as fossil fuels is depreciating by the day, thereby giving prevalence to solar energy and other renewable sources of energy in the world. Solar energy has been discovered to be one of the most popular renewable energy sources on the earth (Zhao et al., 2014, Li et al., 2009). This is because it has a comparative advantage over other forms of non-renewable energy sources such as coal, petroleum, and fossil fuels, etc. and other renewable energy sources such as wind power, hydroelectricity, etc. Some of the merits of solar energy include reduction of electricity bills; it is clean, generates no noise, minimum maintenance cost, and environmentally friendly with no reported pollution emissions (Stigka et al., 2014, Tsoutsos et al., 2005).

Solar energy from the sun can be trapped by the use of solar panels. A solar panel is made up of semiconductor material and the most common semiconductor material used is silicon (Si). In daylight, the energy from the sun is absorbed by the semiconductor materials of PV modules to break the electrons loose allowing them to move freely thereby generating a flow of electrons within the cell (Armaroli et. al., 2016). Therefore, connecting external load such as a light bulb will generate the flow of electricity in the cell. It is clear that the efficiency of a solar panel depends on the intensity of sunlight that impacts on the surface of the panel. The use of solar panels is highly efficient in arid or desert regions because the intensity of the sun is high in these regions. However, the performance of a solar panel depends on several factors (one of which is the degree of freedom from the accumulation of dust on the surface of PV panels) to attain maximum performance. Other factors that reduce the efficiency of the solar panel are cracks on the surface of the panel, accumulation of snow, and soiling. (Akuru et al., 2017).

The term soiling is used to describe the accumulation of leaves, dust, dirt, snow on the PV module. Soiling is defined by Meija et al. (2014) as the accumulation of dust on the surface of solar panels (either fixed or concentrated) which ultimately leads to the low efficiency of the module. Soiling is not limited to dust accumulation but also combustion products, salt deposits from non-distilled water, soot, etc. Nummo and Seid (2010) defined dust as any particle matter less than 500µm in diameter which is 10 times the size of human hair. However, with advances in research, in 2011, Mani and Pillai defined dust as a term generally applied to minute solid particles with a diameter of less than 500mm. The composition of dust varies from region to region across the world. A comprehensive review of Mani and Pillai (2011) gives the factors that affect the accumulation of dust on solar panels as shown in Figure 1.

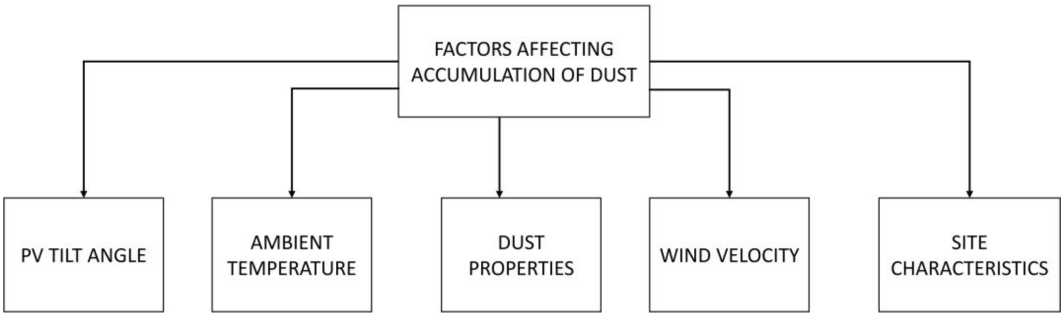

Figure 1: Factors affecting the accumulation of dust on solar panels (Mani and Pillai, 2011)

Another factor that affects the efficiency of the solar panel is the operating temperature caused by the absorption of solar radiation. Musthafa (2015) revealed that cooling solar cells by water during operation leads to a decrease in operating temperature by 40°C, consequently increasing the cell efficiency by 2.6%.

In 2016, Kadhum et al. (2016) observed the impact of dust on the current and voltage generated by the module under controlled conditions. When dust accumulates on the surface of PV panels, the transmittance of solar irradiance is reduced thereby causing a decrease in output voltage and output power of solar panel leading to corresponding decrease in the efficiency of the panel. Its effect on current was widely observed to be constant. Ibrahim (2010) showed that the accumulation of dust on silicon solar cells also decreases the short circuit current ISC by 2.78% and open-circuit voltage VOC by 0.83%.

Complete cleaning of PV modules is essential to ensure peak efficiency. Several techniques can be used to eliminate dust from the surface of solar panels. Einhorn et al. (2018) recommended that a successful mitigation technique can lead to significant energy gain and reduce the maintenance cost of PV modules. Several natural methods have been proposed for cleaning solar panels. In most cases, the user of the PV module climbs to the top of the building to clean the module which poses a great risk to the life of the user since panels are usually installed at high altitudes. Another widely known method is to have a company clean the panel at least once a week, however, these two methods greatly increase the cost of maintenance of PV systems especially the latter approach.

Water cleaning as an alternative to rainfall involves the use of a huge amount of water for the cleaning process. It is expensive and inefficient in areas where there is the unavailability of water. Analysis carried out by Al Dowsari et al. (2014) showed that dry cleaning is a preferred technique used in arid regions to minimize wet cleaning. It is reported that cleaning of unsoiled panels and non-cleaning of over soiled panels can lead to increase in the cost of maintenance and significant losses respectively (Deceglie et al., 2017, Micheli et al., 2017). An automated system of cleaning solar panels is necessary to eliminate the risk of damage to the panel and high cost of maintenance. However, it involves using a microcontroller to send actuating signals to the mechanical parts such as motor, roller, brushes, wiper, etc. to remove dust from the surface of the panel for better improvement in conversion efficiency (Meija et al., 2014). Saraf

(2015) stated that this actuating signals should however not be based on voltage drop sensed by a voltage sensor only since at high temperature, the voltage value drops. Instead, a dust sensor can be used to initiate the actuating signal in order to achieve a better performance.

Saini et al. (2017) designed a portable automatic cleaning system made up of an AT89S52 microcontroller, two DC motors, a dust sensor, a nickel-metal hydride battery, brushes, and a threaded rod. The AT89S52 microcontroller relies on the signal from initiating devices such as a dust sensor to determine whether to activate the two DC motors. The two DC motors perform similar functions, as one rotates the rod, the other rotates the brushes used to clean the surface of PV panels. Although this system requires low production cost and consumes low power, it involves high operational cost due to changing of belts and pulley system used to drive the DC motors and the rod. Consequently, it cannot be used in situations where the PV panel has to be tilted at an angle or in concentrated solar panels which involve the use of solar tracker.

Ganesh et al. (2011) recommended the use of coating agents with water repellant properties such as TiO_2 or ZnO in making the cleansing process more efficient and effective. The property of TiO_2 allows rain that falls on the slides of the concentrated panels to wash the dust off. Hee et al. (2012) suggested coating the surface of the module with a 60mm thickness of TiO_2.

Das et al. (2015) proposed the use of titanium oxide PV systems to increase the solar panel output power. The design was based on a single-axis solar tracking system equipped with a unique water cooling system to mitigate the effect of dust and high temperature on solar panels. The water is sprinkled on the surface of the module when the temperature is high as sensed by the thermostat. The sprinkler is gravity controlled with little wastage since the water is recycled. This design was based on a solar panel that has an efficiency of 34% which is almost double the value of commercially available PV modules. Another limitation of this design is that lumps of clay will be produced on the surface of the module as a result of the water being sprinkled.

Aly et al. (2015) proposed the use of a DC fan which produces an air drag that rises up and is discharged at the exhaust assembly via the outlets made available. This method does not only remove the dust; it also cools the PV module. Solar panels designed with this dust mitigation technique have been found to have an efficiency of 24.1%. The effectiveness of this method is dependent on the diameter of DC fans used. A positive can be drawn from this method of controlled airflow as a dust mitigation techniquewhich also cools the panel.

2.0 Materials and Method

The system is divided into two parts; the hardware and software parts. The hardware components consist of Arduino Uno (based on Atmega 328) MCU, Two light-dependent resistors (LDRs), Quadruple Half-H Drivers (L293D), Liquid crystal display (LM044L LCD), one BLDC blower, resistors among others. The pictorial view of the experimental setup is shown in Figure 2.

Figure 2: Experimental setup of the onboard controller and solar panel

The block diagram that describes the relationship between the physical components and the microcontroller unit is as shown in Figure 3. The solar panel supplies the components of the automatic cleaning system the power required for its operation. The panel charges a 12V 4.5Ah battery, in-between this interval, a charge controller was placed in order to protect the battery from overcharge and dissipating the excess charge as heat. The charged battery powers the solar measurement circuit which comprises a voltage sensor, current sensor, and light intensity sensor. The voltage sensor senses the voltage from the solar panel and sends a signal to the microcontroller in the Arduino board. The microcontroller unit (MCU) receives a signal from the input components (the LDRs and current sensor), monitors the integrity of their operation, and controls the output components (motor drivers and LCD) based on the input signal received. The output components operate based on the signal received from the MCU. The parameters are then displayed on the LCD screen. The light intensity sensor used in this design is a light-dependent resistor (LDR) whose maximum solar intensity recorded at any instance is 1000LUX.

An increase in dust settlement on the surface of the panel leads to a decrease in light intensity sensed by the light intensity sensor. A 12V 1.04A dc fan is placed at the top of the panel which serves as the dust mitigation technique employed in this design. The microcontroller unit activates the L293D motor driver initiating the operation of the dc fan. The activation was set by choosing threshold value such that when the light intensity sensed by the solar panel drops below this value, the fans speed up and will remain in this state until the light intensity rises above this value. The experiment was carried out from 6th June 2019 to 16th July 2019. Because the values were closely related, the values taken on 16th June 2019 were used for analysis. Average values were obtained every hour from the pool of available data.

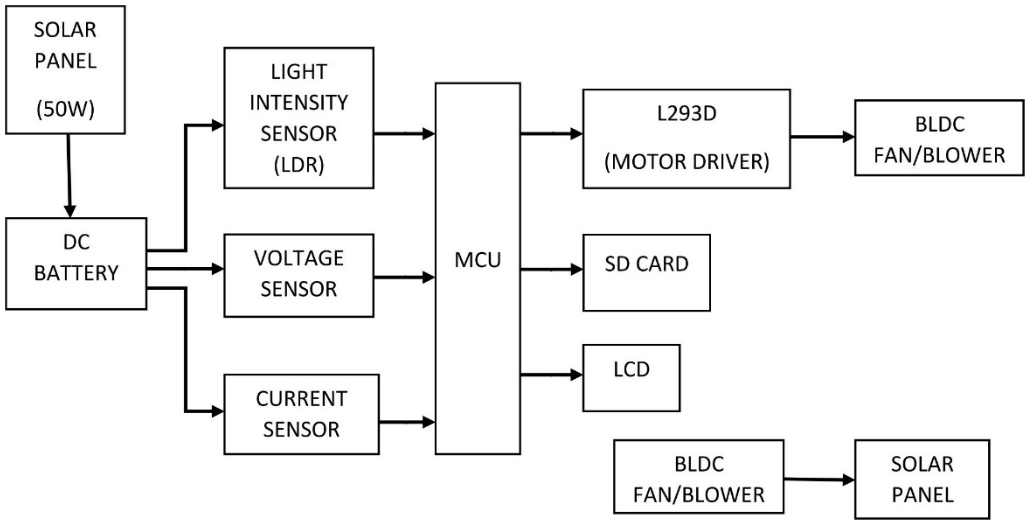

Figure 3: Block diagram of the PV system incorporated with a soiling mitigation technique

The circuit diagram of this design is shown in Figure 4.

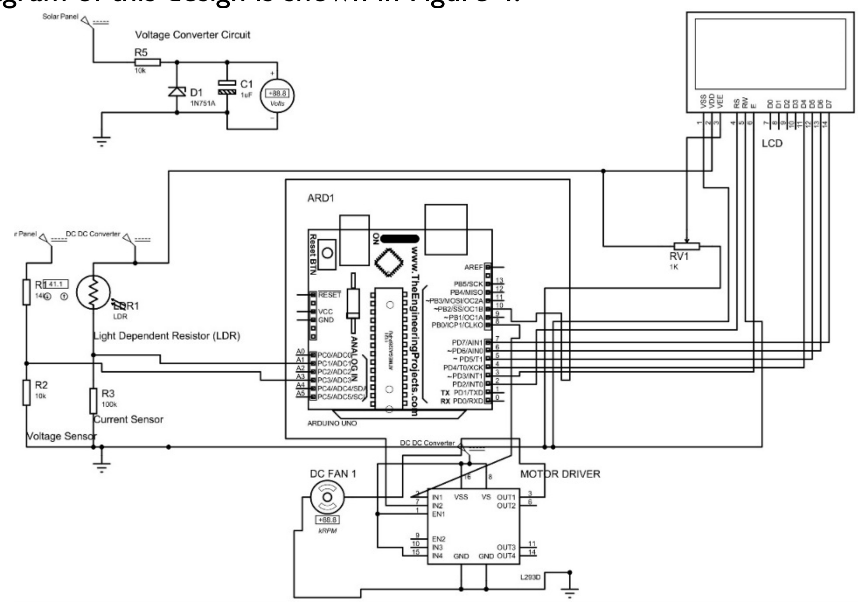

Figure 4: System circuit diagram designed using proteus

The specification of the panel used in the design is shown in Table 1.

Table 1: Solar panel specification

Part	Specification
Maximum Power PMAX	50W
Operating Temperature TC	25°C
Solar Irradiance G	1000W/m^2
Output Tolerance	3%
Current at Pmax IMAX	2.94A
Voltage at Pmax VMAX	17V
Short Circuit Current ISC	3.19A
Open Circuit Voltage VOC	22V
Charging Current	0.75A
Air Mass A.M	1.5

This study involves the implementation of the cleaning mechanism constructed and mounted on a 50W solar panel under different atmospheric and load conditions. Dust was allowed to settle on the surface of the PV module naturally. Voltage, current, and light intensity readings were taken as the measured values while power, panel efficiency, irradiance, irradiation, conversion efficiency and fill factor were calculated from the measured values. The solar panel was fixed at the top of a building during the experiment. The solar energy measurements are recorded on a per-minute basis and data collected are stored in a memory device which can be retrieved for analysis. Solar Irradiance, irradiation, fill factor, and conversion efficiency of each of the solar panel was calculated using the following equations.

A = Light Intensity (Lux)
B = Irradiance (W/m^2)
C = Irradiation (MJ/m^2)
D = Irradiation(kWh/m^2)
E = Maximum Power (W)
K = Conversion Efficiency
F = Open Circuit Voltage (V)
G = Short Circuit Current (A)
H = Fill Factor
I = Solar Irradiance (W/m^2)
J = Total Area (m^2)

$$B = A * 0.0079 \quad (1)$$

$$C = B * 11.6 \quad (2)$$

$$D = \frac{C}{3.6} \quad (3)$$

$$H = \frac{E}{F * G} \quad (4)$$

$$K = \frac{E}{I * J} * 100 \quad (5)$$

Assuming all the solar irradiance on a solar panel is converted to power for a cross-sectional area of 1m^2, this implies that the conversion efficiency is 100%. However, typical solar panels have conversion efficiency between 15-18%. In order to calculate the total area of the solar panel, a conversion efficiency of 18% is taken as the minimum efficiency required. Hence,

$$E = I * J * K \quad (6)$$

$$J = \frac{E}{I * K} \quad (7)$$

$$J = \frac{50}{1000 * 18} = 0.2778m2 \quad (8)$$

$$H = \frac{50}{22 * 3.19} = 71.25\% \quad (9)$$

$$K = \frac{50}{1000 * 0.2778} * 100 = 18\% \quad (10)$$

The dimension of the panel was measured using a meter rule; the length and width were measured to be 65.7cm and 42.6cm respectively. The cross-sectional area of the panel is 0.2799m^2. This validates the assumption used in calculating the area of the panel. The calculated conversion efficiency using the measured area is 17.86%. Generally, the fill factor of PV modules is greater than 70%. It should be noted that the wattage of the panel is exceedingly high which could damage the solar energy measurement circuit, hence a charge controller circuit was designed as a supplement to this circuit such that the excessive inflow of current supplied by the panel is converted and dissipated as heat through a heat sink so as not to damage the circuit.

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3.0 Results and Discussion

The current, voltage, and light intensity were measured while the power, solar irradiance, efficiency at every instance (per hour), conversion efficiency and fill factor were calculated as shown in Tables 2, 3, 4 and 5 respectively for both conditions (before and after mitigation).

Table 2: Measured and calculated results of the panel obtained at high altitude before mitigation

Time (Hours)	Voltage (V)	Current (A)	Power (W)	Efficiency (%)	Conversion Efficiency (%)
1	8.04	0.85	6.85	2.46	17.86
2	8.04	0.78	6.25	2.24	17.86
3	8.04	0.78	6.25	2.24	17.86
4	8.04	0.78	6.25	2.24	17.86
5	8.06	0.63	5.08	1.82	17.86
6	8.06	0.78	6.27	2.25	17.86
7	8.06	0.78	6.27	2.25	17.86

Table 3: Measured and calculated results of the panel obtained at high altitude before mitigation

Time (Hours)	Light Intensity (Lux)	Irradiance (W/m^2)	Irradiation (MJ/m^2)	Irradiation (kWh/m^2)	Fill Factor (%)
1	666.00	5.26	61.03	16.95	71.25
2	699.00	5.52	64.05	17.79	71.25
3	696.00	5.49	63.78	17.71	71.25
4	693.00	5.47	63.50	17.64	71.25
5	693.00	5.47	63.50	17.64	71.25
6	697.00	5.50	63.87	17.74	71.25
7	607.00	4.79	55.62	15.45	71.25

Table 4: Measured and calculated results of the panel obtained at high altitude after mitigation

Time (Hours)	Voltage (V)	Current (A)	Power (W)	Efficiency (%)	Conversion Efficiency (%)
1	12.67	1.63	20.60	7.42	17.86
2	12.63	1.70	21.44	7.72	17.86
3	12.60	1.78	22.37	8.05	17.86
4	12.56	1.75	22.02	7.93	17.86
5	12.55	1.71	21.43	7.71	17.86
6	12.51	1.72	21.57	7.76	17.86
7	12.44	1.78	22.17	7.98	17.86

Table 5: Table showing measured and calculated results of the panel obtained at high altitude after mitigation

Time (Hours)	Light Intensity (Lux)	Irradiance (W/m^2)	Irradiation (MJ/m^2)	Irradiation (KWh/m^2)	Fill Factor (%)
1	926.45	7.32	84.90	23.58	71.25
2	934.77	7.38	85.66	23.79	71.25
3	943.88	7.46	86.50	24.03	71.25
4	896.47	7.08	82.15	22.82	71.25
5	889.17	7.02	81.48	22.63	71.25
6	894.27	7.06	81.95	22.76	71.25
7	929.02	7.34	85.14	23.65	71.25

The readings of the panel under these two conditions are compared with each other. The state of each parameter before mitigation is compared with its equivalent output parameter after mitigation.

Figure 5 shows the comparison of the voltage of the panel before and after mitigation was achieved. It was discovered that there was a 35% increment in the voltage level after the panel had been cleaned due to reduction in dust particles that led to an increase in the transmissivity of the solar panel.

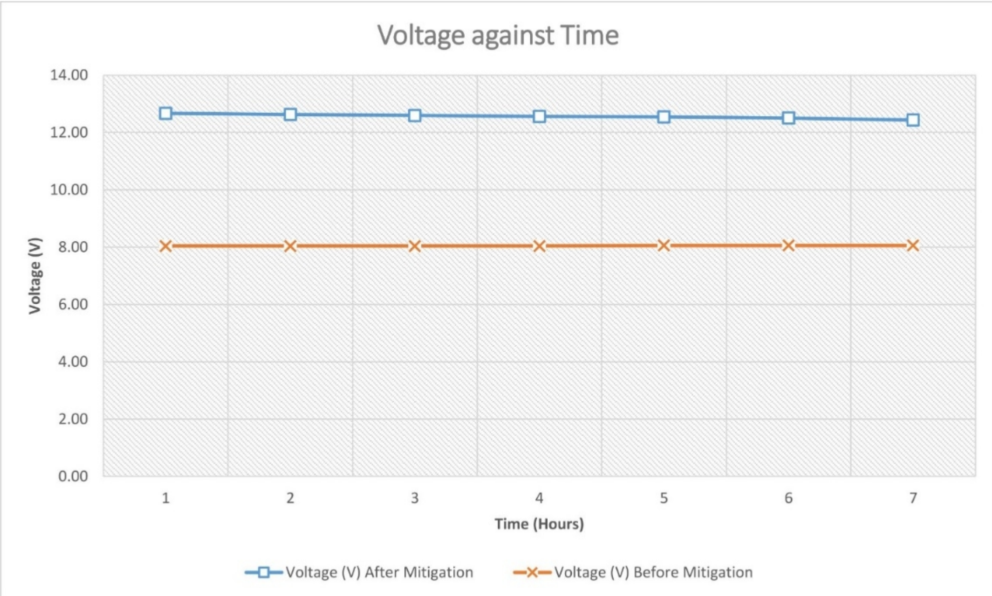

Figure 5: Voltage against Time

Figure 6 shows the comparison between the current generated by the panel before and after mitigation was achieved. The current value increased by 55% after mitigation.

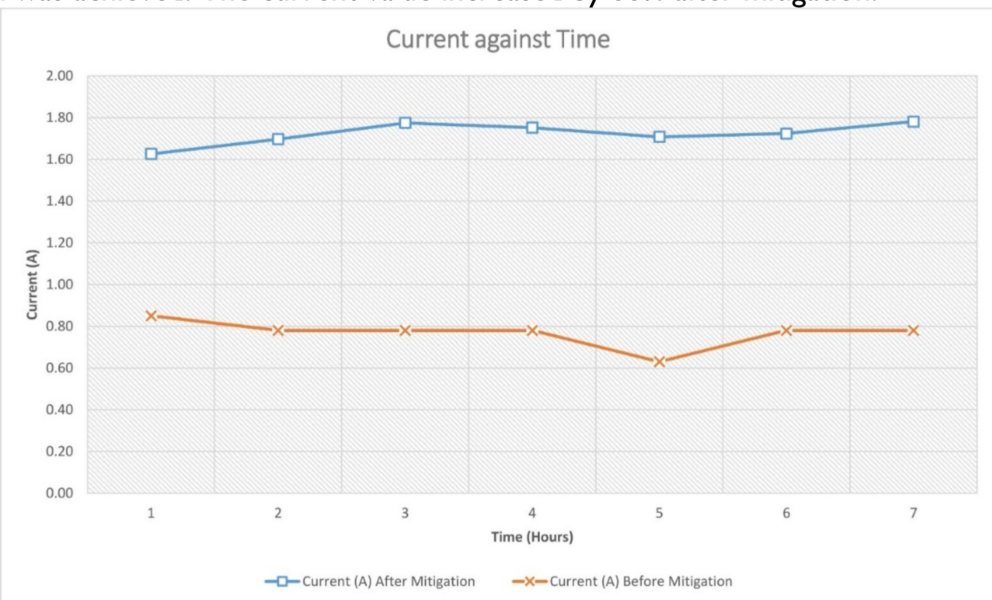

Figure 6: Current against Time

Figure 7 shows the comparison of the power generated by the panel before and after mitigation was achieved against time. The power output depends on the current and voltage of the panel. As the current on individual cells increases, the power generated by the panel also increases vice-versa. The rate at which the power increased after cleaning is 71%. Also, the power produced is proportional to the efficiency.

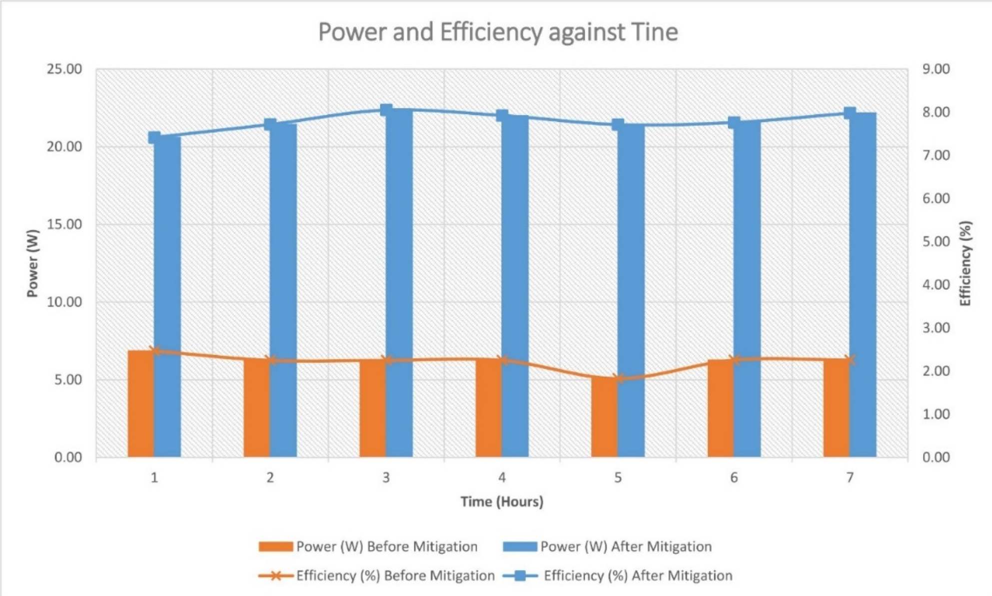

Figure 7: Power and Efficiency against Time

Figure 8 shows the comparison of the light intensity falling on the panel before and after mitigation against time. As the incident light that strikes the panel surface increased, the current also increased showing a direct relationship. Also from panel specifications, the short-circuit current is a function of solar intensity.

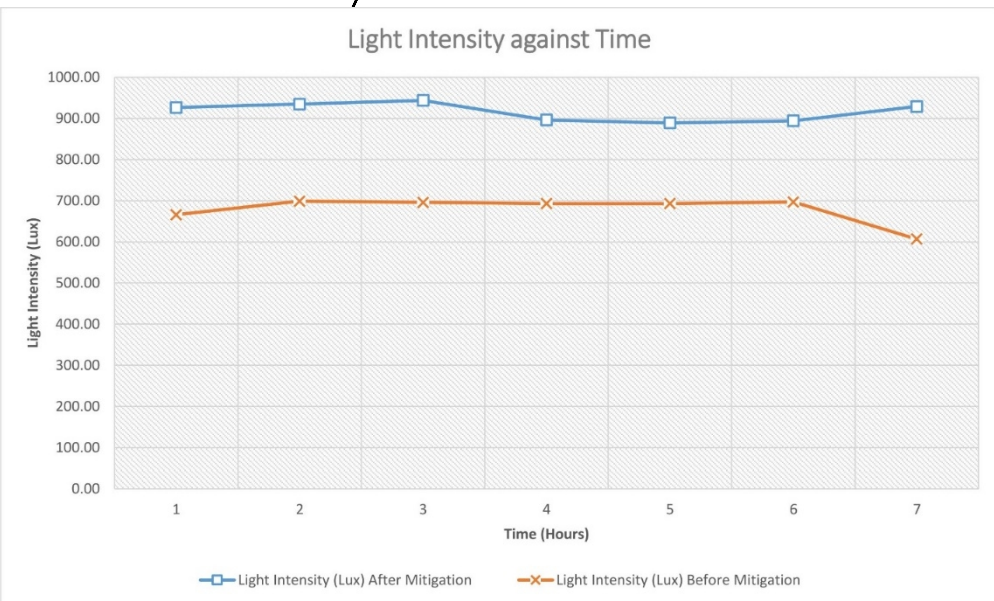

Figure 8: Light Intensity against Time

Figure 9 shows the comparison between the efficiency of the solar panel before and after removing the dust from the panel's surface against time.

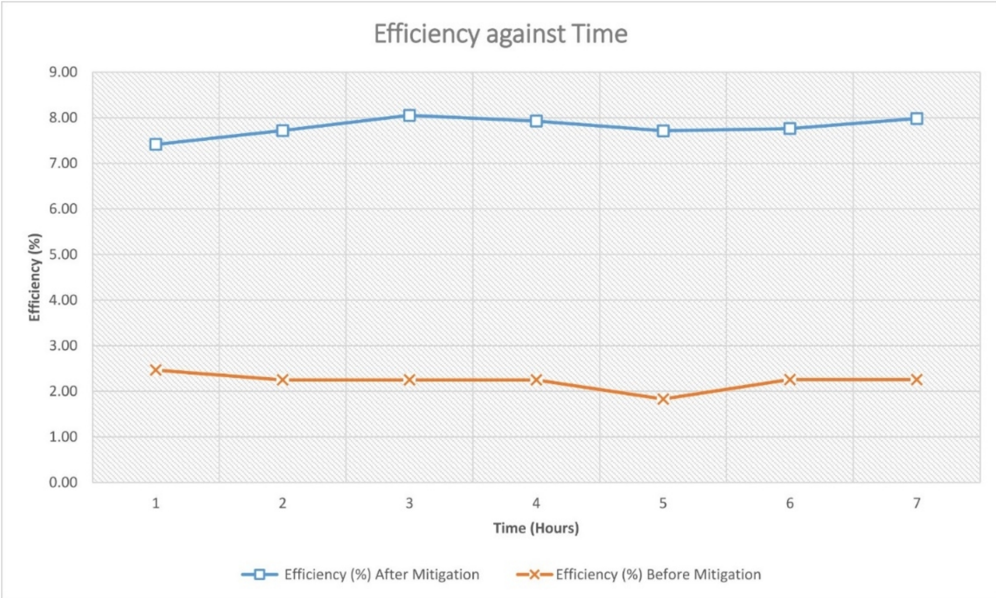

Figure 9: Efficiency against Time

Figure 10 shows a comparison between the irradiance of the solar panel before and after removing the dust from the panel's surface against time.

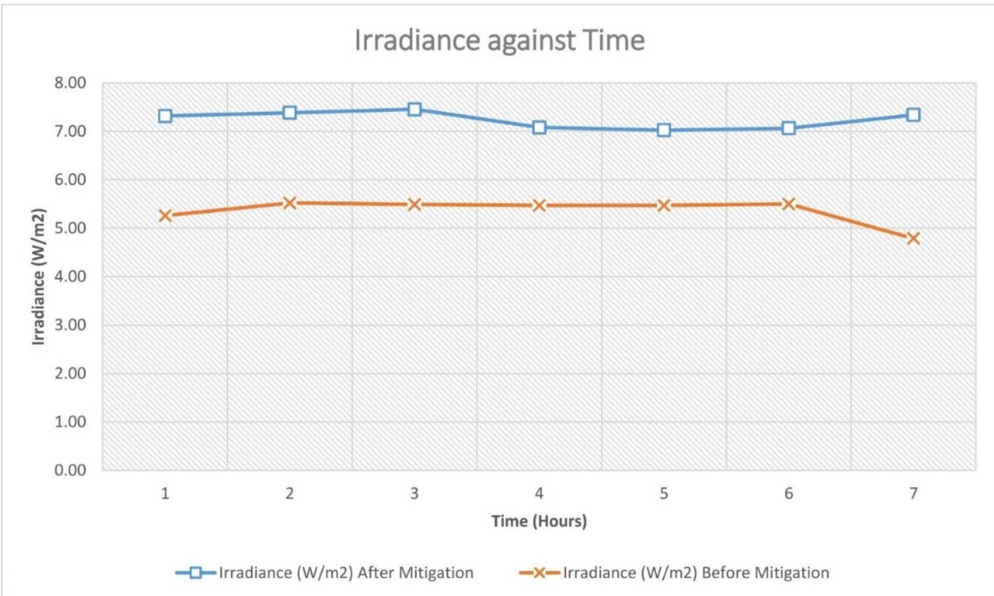

Figure 10: Irradiance against Time

Figure 11 shows the comparison between the light intensity and the voltage of the panel against time before and after mitigation was achieved.

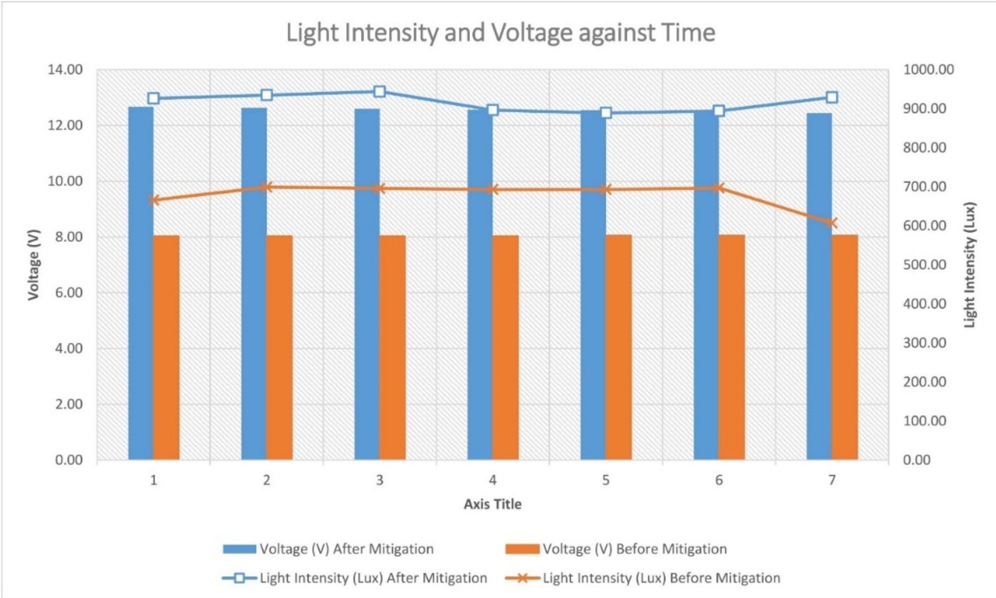

Figure 11: Light Intensity and Voltage against Time

Figure 12 shows the comparison between the light intensity and the current generated by the panel against time before and after mitigation was achieved.

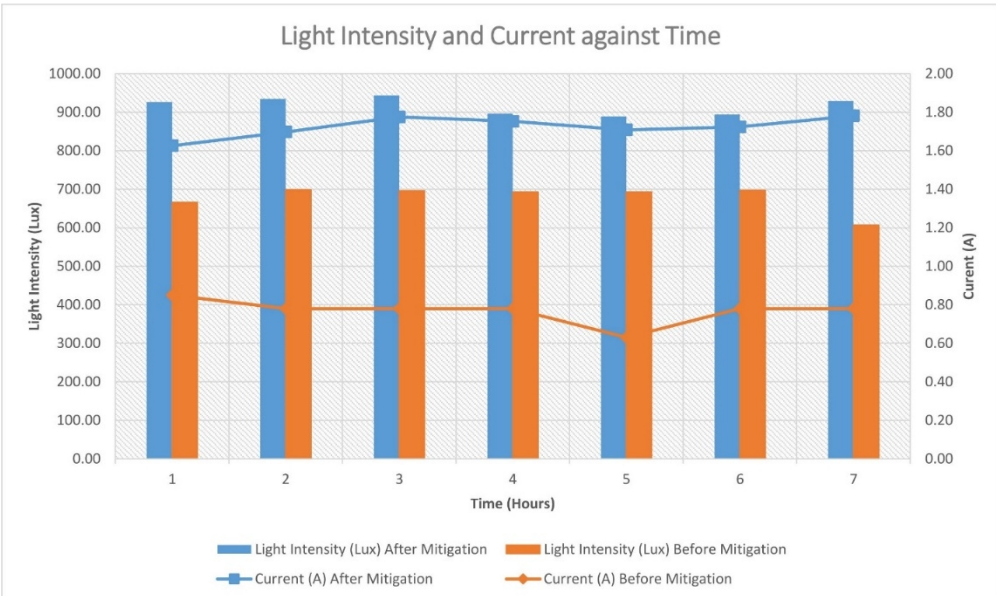

Figure 12: Light Intensity and Current against Time

Figure 13 shows the comparison between the power produced by the panel and the efficiency of the panel against time before and after mitigation was achieved.

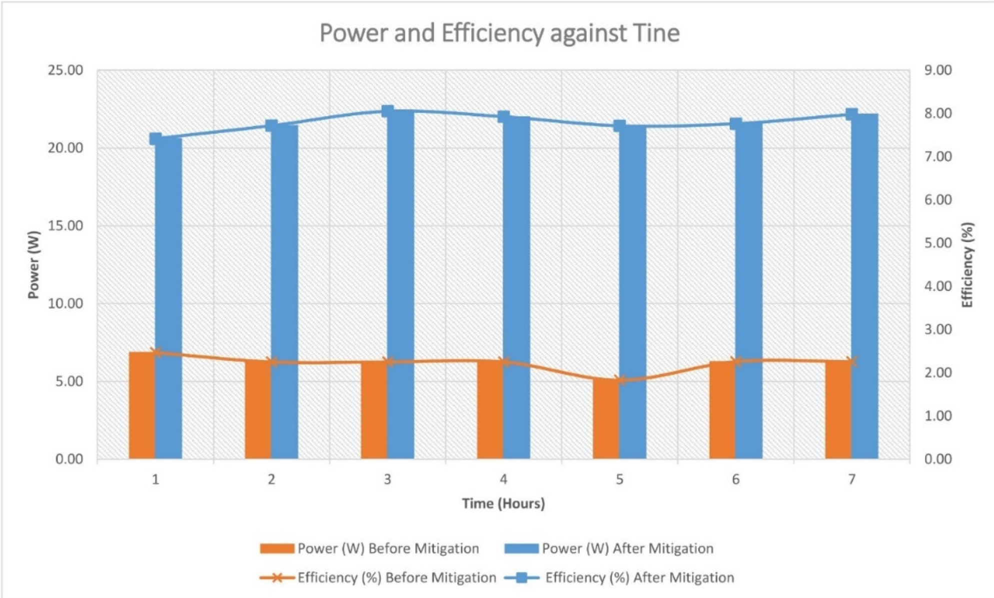

Figure 13: Power and Efficiency against Time

Figure 13 shows the graphical representation between the power and efficiency of the solar panel under both condition.

It was observed that the accumulation of dust on the surface of the panel drops the efficiency of the solar panel to approximately 2.5%. Similarly, the maximum intensity of the sun striking the surface of the panel led to a corresponding decrease in output power with maximum values of 699 lux and 6.85W respectively.

After the soiling mitigation technique was applied, the output parameters of the solar panels greatly increased. The light intensity improved by a third of previously set maximum values. Likewise, the efficiency quadrupled to 8.05% resulting in corresponding increase in maximum output power of 22.37W.In order to prove the effectiveness of this method, taking the averages of the output parameters before and after mitigation respectively, the percentage increase in the parameter output of the panel is calculated using equation 11.

$$Percentage\ Increase\ in\ Output(\%) = \frac{(Output\ of\ the\ panel\ after\ mitigation - Output\ of\ the\ panel\ before\ mitigation)}{Output\ of\ the\ panel\ after\ mitigation} \qquad (11)$$

Table 6: Percentage Increase in the Output of the Panel

Parameter	After Mitigation	Before Mitigation	Percentage Increase
Voltage (V)	12.57	8.05	35.95
Current (A)	1.72	0.77	55.40
Power (W)	21.66	6.17	71.49
Light Intensity (Lux)	916.29	678.71	25.93
Irradiance (W/m^2)	7.24	5.36	25.99
Irradiation (kWh/m^2)	23.32	17.28	25.93
Efficiency (%)	7.80	2.22	71.49

Table 6 shows that the efficiency of the solar panel increased by 71.49% due to the application of the soiling mitigation technique. Similarly, the output current and power also increased by 55.40% and 71.49% respectively. This confirms that increase in power leads to corresponding increase in efficiency.

4.0 Conclusion

Soiled part of solar cells acts as a resistance to the current produced by the cell and as such reduces the energy generated by the panel as well as the overall efficiency. It was noted that efficiency and other output parameters of solar panels are greatly affected by the accumulation of dust on the panel's surface. With the introduction of an automatic cleaning mechanism to mitigate the effect of soiling, the percentage increase in efficiency was 71.49% which confirms that controlled wind can be the perfect mitigation technique for solar panels. Another benefit of this design is that cost of maintenance is minimized, it is compact and can be incorporated with new and existing solar panels with ease.

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